LAND PREPARATION, MULCH APPLICATION AND IRRIGATION EFFECTS ON SELECTED SOIL PROPERTIES AND OKRA [*Abelmoschus esculentus* (L.) Moench] YIELD ON AN ULTISOL

BY

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ABSTRACT

Decline in soil physical and chemical properties, and scarcity of water are major constraints to dry season okra cultivation. Appropriate land preparation and mulch application under irrigation water management could enhance soil properties and moisture availability for optimum crop yield. However, there is a dearth of information on the effects of land preparation and mulch application on soil properties and okra yield under dry season irrigation conditions. This study was therefore conducted to determine the combined effects of land preparation, mulch application and irrigation rates on soil properties and okra yield on an ultisol.

In a screenhouse experiment, two okra varieties (UI4-30 and NH47-4) were grown in drainage lysimeters containing 14 kg soil. Irrigation water was applied based on three reference evapotranspiration (ET_o) rates: ET_o from the Nigerian Meteorological Agency (ET_o-N), ET_o from the International Institute of Tropical Agriculture (ET_o-I), and the mean of ET_o-N and ET_o-I (ET_o-M). The experiment was laid in a completely randomised design with three replicates. Okra evapotranspiration-ET_c (mm day^{-1}) was determined using standard procedure across 10 weeks after sowing, while Okra Pod Yield-OPY (g plant^{-1}) was estimated over the harvesting period. On the field, effects of three each of land preparation types (Raised Bed-RB, Ridge and Flat) mulch types (*Gliricidia sepium* Mulch-GsM, *Pennisetum purpureum* Mulch-PpM and Zero Mulch-ZM) and irrigation rates (100% ET_c, 75% ET_c and CROPWAT rate-CRW) were investigated. Treatments were laid as a 3 × 3 × 3 factorial in a randomised complete block design with three replicates. Okra variety UI4-30 was planted at a spacing of 30 × 45 cm. Water Stable Aggregates-WSA (%) and Soil Organic Carbon-SOC (g kg^{-1}) were determined using standard procedures, while Number of Pods per Plant (NPP) and OPY were estimated over the harvesting period. Data were analysed using descriptive statistics, t-test and ANOVA at $\alpha_{0.05}$.

The ET_c for UI4-30 (2.46±0.21) and NH47-4 (2.39±0.18) were not significantly different and ranged from 1.00±0.10 (ET_o-I) to 3.97±0.78 (ET_o-N) and 1.04±0.08 (ET_o-M) to 3.62±0.94 (ET_o-N), respectively. Across varieties, okra ET_c differed significantly and were in the order: 2.89±0.24 (ET_o-N) > 2.33±0.19 (ET_o-M) >

2.04±0.16 (ET$_o$-I). Across ET$_o$ rates, OPY of UI4-30 (10.14±1.17) was significantly higher than that of NH47-4 (8.97±1.28). Plants under ET$_o$-N had the highest OPY (10.67±0.33), followed by ET$_o$-M (9.63±0.80) and ET$_o$-I (8.37±0.84). On the field, WSA differed significantly among the treatments and was highest under RB+GsM+CRW (62.29±1.26) and lowest under RB+ZM+CRW (51.22±0.20). However, WSA under RB+GsM+CRW (62.29±1.26) and RB+GsM+75% ET$_c$ (55.60±0.31) were similar. There was no significant difference in SOC among the treatments. The SOC ranged from 13.1±0.19 (Flat+ZM+75% ET$_c$) to 24.45±1.11 (Ridge+GsM+CRW). The NPP and OPY were significantly different among the treatments. The NPP ranged from 3.1±0.10 (Ridge+ZM+CRW) to 11.6±2.60 (RB+GsM+75% ET$_c$), while OPY ranged from 8.32±1.17 (Ridge+ZM+CRW) to 57.17±12.04 (RB+GsM+75% ET$_c$).

Raised beds, mulch application using *Gliricidia sepium* and irrigation rate at 75% okra evapotranspiration rate enhanced water stable aggregates, soil organic carbon and okra pod yield on an ultisol.

Keywords: Irrigation water management, Water stable aggregates, Soil organic carbon, Okra evapotranspiration rate, Okra pod yield

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CERTIFICATION

We certify that this work was carried out by Mr. O. Aliku in the Department of Agronomy, University of Ibadan, Ibadan, Nigeria.

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DEDICATION

I dedicate this work to God Almighty, the wise and merciful God who is awesome in every way. You are my help in ages past, my present help in times of need, and my hope for years to come. You are more than enough for me. You are better than the best friend!

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CHAPTER 1

INTRODUCTION

Soil and water resources are important components of agricultural production. They are essential for food and fibre production which are indices of a nation's development. However, the quest for a sustainable agricultural production system, which has birthed increased intensification of crop cultivation, has often resulted to soil degradation through mining of soil finite resources. Carey and Oettli (2006) reported a reduction in world's arable land due to soil degradation processes. This is because intensification of crop production by farmers predisposes soils to degradation (Sanchez *et al*., 1997). Uwah *et al*. (2012) explained that one of the major limitations to agricultural production in Nigeria is low soil fertility. In addition, continuous use of ammonia-based inorganic fertilisers to enhance soil fertility has often resulted to high soil acidity and reduced crop yield (Mbah and Mbagwu, 2006). Hence, land preparation which include the sole use or combinations of different tillage, seedbeds and/or mulch are usually carried out to create favourable conditions for crop growth.

Land preparation is an important practice that affects soil physical properties and crop yield by positively influencing sustainable use of soil resources (Keshavarzpour and Rashidi, 2008). Lal (1993) explained that land preparation methods involving tillage and/or seedbed types affect the use of soil resources via their effects on soil properties. He explained that adequate land preparation can ameliorate soil related constraints, while inadequate land preparation can lead to undesirable processes such as depletion of organic matter, destruction of soil structure, accelerated erosion, disruption in water, organic carbon and plant nutrients cycles, and reduction in soil fertility. On the contrary, mulch application has been consistently shown as a management practice for enhancing soil properties and improving crop yield (Sarkar and Singh, 2007). It controls weeds and increases crop water use efficiency (Uwah and Iwo, 2011). Mulch increases soil porosity and water infiltration rate, and also controls runoff and erosion; thus; it provides a better soil environment for crop growth (Anikwe *et al*., 2007). Moreover, upon decomposition, organic mulches provide additional benefits like increasing organic matter and cation exchange capacity, enhancing biological activities, increasing plant nutrients, improving soil structure and maintaining high crop yield (Lal, 1995; Khurshid *et al*., 2006; Essien *et al*., 2009). They explained that this could be a good substitute for nitrogen fertilisers, thus reducing the possibility of nitrate contamination of ground water. The use of organic mulch materials on good land preparation type has earlier been demonstrated to successfully improve soil properties and crop yield via reduction of water loss by evaporation (Okunade *et al*., 2009). While several studies have demonstrated the combine effects of land preparation and mulch application on soil properties and crop yield (Lal, 1993; Rashidi and Keshavarzpour, 2008; Okunade *et al*., 2009), there is still paucity of information on land preparation and mulch effects on soil properties and crop yield under dry season irrigation conditions.

On the other hand, variations and reductions in rainfall amount brought about by climate change results to a significant doubt and restriction to farming by reason of the effects of low rainfall amount on surface and ground water sources for irrigation (Li *et al*., 2001). In Nigeria, less than 50% of about 71.2 million hectares of cultivable land is being farmed because of water constraints (Aremu and Ogunwale, 1994). Li *et al*. (2001) demonstrated that water constraints result to frequent drought occurrences (during dry seasons) and this could affect crop yield when the water requirement during drought periods amounts to 60% of water requirement of the crop for growth and yield production. Hence, there is need for improvement in the management of available water in order to ensure adequate use and distribution for dry season crop production. Bos *et al*. (2009) stated that irrigation water can be adequately managed through good planning and supply of right amount of water to crops. In Nigeria, irrigation water delivery includes both traditional (shadoof and bucket methods) and modern (border strip, furrow and sprinkler) irrigation technologies. The major limitations of these methods are water shortage and low water use efficiency caused by excess irrigation and deep percolation of the irrigation water during critical periods of crop growth. It has been reported that only a small fraction of the water applied via these irrigation systems is actually used by the crop (OECD, 2006). Currently, drip irrigation has been demonstrated as an efficient irrigation system for water distribution when compared to furrow and sprinkler irrigation (Boesen *et al*., 2009). Nevertheless, the sole use of drip irrigation cannot guarantee efficient management of scarce water resource in terms of accurate distribution with respect to specific crop water requirement per time. Hence, there is scope for improvement in water management via application of crop evapotranspiration (ET_c) under an integrated soil and water management approach.

The determination of crop evapotranspiration is a vital component of water management under any irrigation system (Aiyelaagbe and Ogbonnaya, 1996). They explained that excess or sub-optimum irrigation can be detrimental to crop growth and yield. Several methods based on estimated crop evapotranspiration rate (Jaikumaran and Nandini, 2001), ratio of irrigation water to cumulative pan evaporation (Aiyelaagbe and Ogbonnaya, 1996; Batra *et al*., 2000), open pan evaporation rate (Singh, 1987; Manjunath *et al*., 1994) and soil moisture depletion (Home *et al*., 2000) have been widely used in irrigation water management studies. However, most of these methods are laborious, expensive and time consuming. Difficulty in the assessment of soil water characteristics and the measurement of soil moisture under cropped surfaces have often led to the adoption of models for soil-water-plant relationship studies (Van Genuchten and Leij, 1992). Models that incorporate the use of water balance techniques in combination with the analysis of historical climate data have been recommended for irrigation water management (Phene *et al*., 1990). The use of computer models is an emerging trend in agricultural water management (Nazeer, 2009). Saxton *et al*. (2006) reported successful application of models to a wide variety of agricultural hydrology and water management studies. Bryant *et al*. (1993) explained that models can be used to optimize the allocation of irrigation water between different crops, and also facilitate the distribution of water during crop growth. CROPWAT model has been extensively used in the management of water for irrigation purposes (Nazeer, 2009). This is because it facilitates the estimation of crop evapotranspiration, irrigation schedule, and agricultural water requirements under different cropping patterns (Nazeer, 2009). However, there is limited information on the response of crops to simulated water requirements and irrigation schedules using CROPWAT model.

Okra (*Abelmoschus esculentus*) is an important fruit vegetable that is widely grown in the tropics. Although, an annual crop that requires warm growing conditions, changes in weather do affect the growth and productivity of okra (Alfredo and Arturo, 1999). Its world production as fruit vegetable was estimated at 6,000,000 tonnes per year (Iyagba *et al*., 2012), and in West Africa, it was estimated at 500,000 to 600,000 tonnes per year (Burkill, 1997). Iremiren and Okiy (1999) reported that okra is one of the foremost vegetable crops in terms of its consumption and production area in Nigeria. It is used for medicinal purpose such as reducing gastro-intestinal ulcers by neutralizing the digestive acids due to its alkaline pH (Wammanda, 2007). Okra production and marketing provide means of livelihood to farmers and many produce sellers. Hence, its economic importance lies in its internal trade (Sanni and Eleduma, 2014). In Nigeria, the production and economic importance of okra have increased in recent years (Jamala *et al*., 2011), with this increase being attributed to the use of different varieties by farmers in order to meet the demands of consumers (Jamala *et al*., 2011).

Despite the foregoing, okra cultivation is carried out predominantly by peasant farmers under rain-fed conditions. This is caused by water constraints during the dry season (Iyagba *et al*., 2012). This results to its seasonal supply which affects the quantity consumed all-year-round (Jamala *et al*., 2011). Therefore, the need for good irrigation water management for successful dry season okra production is imperative. The use of appropriate land preparation methods in combination with organic mulch under crop evapotranspiration irrigation rates could be a good soil and water management strategy for dry season okra cultivation. This could solve the problem of okra scarcity during the dry season (Chowdhury *et al*., 2014). It could also improve the economic status of farmers as okra commands higher price during the dry season when its supply is limited (Sanni and Eleduma, 2014). Although, considerable amount of research has been done on the effects of land preparation on soil properties and crop yield, response of okra to land preparation, organic mulch application and irrigation application rates during dry season conditions have not been so adequately explored in Ibadan, Nigeria. Hence, this study was conducted to assess the combine effects of land preparation, mulch application and irrigation rates on some soil properties and okra yield under dry season conditions.

The objectives of this study were to:

a) determine the crop evapotranspiration of okra using drainage lysimeters;
b) assess the effects of land preparation and mulch application on soil physical and chemical properties, and okra growth and yield;
c) assess the effects of irrigation rates on soil physical and chemical properties, and okra growth and yield and;

d) assess the combine effects of land preparation, mulch application and irrigation rates on soil physical and chemical properties, and okra growth and yield.

CHAPTER 2

LITERATURE REVIEW

2.1 Land preparation

Land preparation for crop production is the physical manipulation of the land which often involves tillage with various frequencies (Jijo, 2005). According to Oshunsanya (2013), land preparation involves ways of manipulating land surfaces for specific purposes. He explained further that land surfaces are sometimes left flat or tilled by traditional African farmers. It also involves incorporation of residues into the soil (Mazuchowski and Derpsch, 1984). This is done to eliminate weeds, attain emergence and good development of plants, preserve soil organic matter and avoid erosion, and eliminate hardpans or compacted layers to increase water infiltration (Jijo, 2005).

2.1.1 Land preparation methods for okra production

Land preparation greatly influence soil properties and crop yield. On large farms, land preparation is usually done by tractor-drawn implements where ploughing is followed by one or two harrowing prior to the onset of the rain (Raemaekers, 2001). Raemaekers (2001) further reported that this practice is changing due to the high cost of operating machinery. The adoption of a land preparation method depends on the vegetation cover and the manner in which the soil surface is to be exposed for sowing of seeds. In a study on okra growth and yield under mulching and land preparation, Aiyelari *et al*. (2011) reported that flat, beds, heaps and ridges with mulch are more adapted to tropical conditions.

2.1.2 Effects of land preparation on soil physical properties

Jijo (2005) demonstrated that land preparation methods had no effect on the textural composition of surface soil. However, conventional tillage influences soil porosity, bulk density, penetration resistance and moisture content (Khurshid *et al*., 2006). Rashidi *et al*. (2008) demonstrated that annual disturbance and pulverization of soil through ploughing and harrowing produced a finer and loose soil structure than conservation or no-tillage methods which leave soil intact. They explained that repeated tillage breaks soil aggregates into finer sizes and results to loss of organic matter, while Havlin *et al*. (1990) reported that as the loss of organic matter exacerbates aggregate stability, reduced tillage increases stability.

However, the use of tractors tends to compact the soil and increase penetration resistance and bulk density (Unger and Kaspar, 1994). Penetration resistance over 1000 kPa usually decreases yield (Khalilian *et al*., 1991) and induces root growth reduction (Ishaq *et al*., 2001). Soil compaction may result to a significant reduction in the productivity of soils by decreasing soil aeration, water storage and crop water use efficiency while greater soil penetration, bulk density and lesser total porosity is found on no tillage than tilled soils during crop growth (Cassel *et al*., 1995). Pikul and Asae (1995) reported that the zone of the highest soil bulk density roughly corresponds to the depth of tillage.

Conversely, conservation tillage influences soil bulk density, infiltration and water retention. No tillage reduces water loss from soil and improves soil moisture regimes than plough and harrow (Azooz *et al*., 1996). This is because no-tillage maintains surface residues, minimizes soil disturbance, encourages build-up of organic matter, preserves the soil structure, and conserves soil water. According to Jijo (2005), organic materials tend to enhance aggregate stability and increase water holding capacity of soils.

2.1.3 Effects of land preparation on soil chemical properties

Several studies have shown varying effects of land preparation on soil chemical properties. The effects of land preparation on soil chemical characteristics varies with soil type (Jijo, 2005). For instance, Jijo (2005) reported that land preparation affects soil pH through its effects on the distribution of nutrients and organic matter, with high pH values recorded for raised bed and flat in the top and lower layers of soil, respectively. Zero-tillage and stubble mulch resulted to lower surface soil pH than ploughed treatments (Follett and Peterson, 1988). Minimum tillage decreases the level of soil mixing, which also leads to concentration of immobile nutrients such as phosphorus and potassium in the upper soil layers (Follett and Peterson, 1988; Robbins and Voss, 1991). Flat and green manure increased the amount of soil organic carbon in the upper soil horizons (Jijo, 2005). However, Jijo (2005) reported that the use of raised bed, ridge and flat seedbeds did not significantly affect soil cation exchange capacity (CEC).

The effects of land preparation on soil mixing, soil porosity, soil water content and organic matter breakdown influence the distribution of the mobile nutrients such as nitrogen (Doran and Smith, 1987). They reported higher concentration of NO_3^- under conventional tillage than under zero tillage, with NO_3^- uniformly distributed through the surface 15 cm depth under conventional tillage in silty clay soils, while there was higher concentration in the surface 7.5 cm under zero tillage. Grant and Bailey (1995) reported higher concentration of nitrate under zero tillage than under conventional tillage in the surface 7.5 cm of fine sandy soils, presumably due to nitrogen mineralization of organic residues or residual nitrogen build-up. Jijo (2005) observed high available phosphorus in surface soil layer under raised bed and ridge seedbed types. Similarly, high phosphorus concentration in the surface 15 cm depth, with a peak occurring at the depth of fertilizer placement under both conventional and zero tillage was reported (Grant and Bailey, 1995).

2.1.4 Effects of land preparation on crop growth

According to Jijo (2005), the effects of land preparation on crop growth parameters are crop type dependent. Jijo (2005) reported that raised bed resulted in the lowest plant height of lentils as opposed to ridge, which resulted in the highest plant height. He also reported that ridge had the highest plant height of wheat, and noted that the treatments did not significantly affect the height of teff plant. The effect of tillage on maize growth is significant with leaf area per plant and leaf area index being lesser under no tillage as compared to conventional tillage (Karunatilake and Schindelbeck, 2000).

Aiyelari *et al*. (2011) reported highest values for okra height and stem girth under heap, followed by raised bed, while the lowest values were recorded under flat seedbed. They also reported lowest number of okra leaves under flat seedbed, with heap also recording the highest number of leaves. Crop root penetration is greater in conventionally tilled soil than under no-till condition (Nitant and Singh, 1995). Moreover, continuous ploughing results in plough pan that restricts the movement of nutrients and root penetration (Unger and Kaspar, 1994).

2.1.5 Land preparation effects on crop yield

Several authors have reported increase in yields of some crops grown under raised bed relative to flat seedbeds (Astatke *et al*., 1995; Astatke and Saleem, 1996). Conventional and conservation tillage methods influence crop yields significantly with conventional tillage method recording significantly higher yield compared to no tillage (Rashidi *et al.*, 2010). Gul *et al.* (2009) reported the effect of tillage practices on biological yield of maize to be significant, with conventional tillage producing higher biological yield than no-tillage.

Land preparation has earlier been shown to significantly affect the mean grain yield and straw yield of wheat and lentil (Jijo, 2005). Jijo (2005) however stated that land preparation did not significantly affect teff, thus showing the insensitivity of teff to physical manipulation of the land. Moreover, Getachew (2001) showed that raised bed significantly increased the grain yield of lentils by 59% compared with the control. Jijo (2005) reported highest mean grain and straw yield of wheat under reduced tillage (10% higher than the control), while grain yield of wheat grown on raised bed was significantly reduced by 35% relative to the control. The addition of green manure did not significantly enhance the grain yield of wheat relative to the control (Jijo, 2005). However, Efrem (2001) earlier reported that raised bed increased wheat grain and straw yields as against flat beds.

According to Aiyelari *et al*. (2011), heap and bed tillage have been reported to produce more okra pod yield than flat tillage. They also reported that okra grown on heaps produced higher number of pods and weight of pods respectively, when compared to raised beds and flat seedbed types. Although, they reported that flat seedbed produced the lowest number of pods and weight of pods, raised beds and heaps were not statistically different with regards to the number of pods, fresh weight and dry weight of pods produced. Aiyelari *et al*. (2011) also reported that the combination of tillage and mulch did not significantly affect okra pod yield, although it increased the green pod yield of okra.

2.2 Mulch

Mulch is any material used as a protective cover or placed on the soil surface (Crutchfield *et al*., 1986). Norman (1992) stated that mulching is the application of materials on the soil surface. Dalorima *et al*. (2014) also defined mulching as the process of covering the soil to provide more favorable conditions for plant growth, development and efficient crop production.

Thus, mulch is any material that is placed on the surface of the soil to protect the soil and plant roots from direct effects of raindrops and sunshine during the critical periods of plant establishment and growth. Several types of materials such as crop residues, grasses, perennial shrubs, farmyard manure, compost, inorganic materials and synthetic products can be used as mulch (Lal, 1990). Lal (2000) stated that mulch application rate of 4 to 6 t ha^{-1} is needed for an effective soil and water conservation. According to Dalorima *et al*. (2014), natural mulches such as leaf, straw, dead leaves and compost have been used for centuries, while in the last 60 years the advent of synthetic materials has altered the methods and benefits of mulching.

2.2.1 Effects of mulch on soil properties

Mulch application is one of the most widespread physical and biological methods developed by humans to improve soil properties (Wades and Sanchez, 1983). According to Sinkevičienė *et al*. (2009), the application of organic mulches as a soil cover is effective in improving the quality of soil and increasing crop yield. Organic mulch improves soil properties through the effects as tiny barriers that obstruct runoff, and thus increase infiltration (Adams, 1966). However, Toutain and de Wespelaere (1977) demonstrated that it is the accumulation of wind and/or water transported sediment on mulched soil that is responsible for improving soil conditions.

2.2.2 Physical properties

Mulch application is of benefit to crop yield by improving soil physical conditions, including improved stability in the topsoil (De Silva and Cook, 2003). Mulches reduce water evaporation from soil and help maintain stable soil temperature (Lal, 1974; Ji and Unger, 2001; Kar and Kumar, 2007). Straw mulch applied at 4 to 6 t ha^{-1} was effective in improving soil physical conditions in tropical environments including protection of the topsoil (Lal, 1976). Mulching can reduce excessive temperature of topsoil for more optimal germination and root development (Cook *et al*., 2006). Cooler day temperature may also be maintained below mulch (Riddle *et al*., 1996), due to the low thermal conductivity of the mulch materials.

Cook *et al.* (2006) stated that topsoil incorporation and mulching with municipal waste compost increases soil water content, thereby increasing crop water uptake. This is as a result of reduced soil surface evaporation which depends on whether the mulch material is incorporated or placed on the surface (Uson and Cook, 1995). Movahedi Naeini and Cook (2000) reported an improvement in soil temperature regime and conservation of soil water under mulched soil surface. Greater number of macropores (86±20) have been reported in mulched (woody material + straw) plots as compared to bare plots. According to Mando (1997), mulch types have significant effects on saturated hydraulic conductivity due to increased number of macropores. Soil resistance to cone penetration has also been reported to be greater in unmulched plots than mulched plots which had lower bulk density and higher porosity values, respectively (Mando, 1997).

2.2.3 Chemical properties

The favourable effects of organic mulches on increasing the available plant nutrient content in soils are well documented. It has been noted that the release of nutrients from decomposing mulches (rapidly and slowly decomposing) might have a positive effect on soils (Tukey and Schoff, 1963). A boost in maize yield was reported due to improvement in soil nitrogen and potassium in soils mulched with municipal waste compost (Movahedi Naeini and Cook, 2000). Tukey and Schoff (1963) reported increased amounts of available soil phosphorus and potassium under mulches. Application of straw mulch (Sønsteby *et al.*, 2004) and grass mulch (Cadavid *et al.*, 1998), significantly increased the available phosphorus and potassium in the soil. According to Saroa and Lal (2004), mulch application increased the total phosphorus content in soils from 601 – 658 mg kg^{-1} after four years of mulching and from 491 – 694 mg kg^{-1} after eleven years of mulching.

2.3 Crop response to mulch types

According to Wooldridge and Harris (1991), mulching results in improved crop performance. However, studies have shown the varying responses of crops to different mulch materials. Johnson *et al.* (2004) and Sønsteby *et al.* (2004) stated that some mulches (straw, peat, sawdust) may negatively affect crops by drying up soil nitrogen due to a wide C:N ratio. According to Gruber *et al.* (2008), there was no effect of mulching with wood chips on crop yield. Tolk *et al.* (1998) reported that mulch had no significant effect on crop yield in the first year (1994) of application but significantly increased yield in the second year (1995). Kar and Kumar (2007) reported higher potato yield and better crop growth in plots with straw mulch. Johnson *et al*. (2004) reported that potato yields were similar in mulched and unmulched plots, but watermelon yield was higher in plots with straw mulch. Döring *et al*. (2005) reported no positive effect of straw mulch on potato yield due to the relatively low amounts of straw applied.

Batra *et al*. (1985) found the yield of okra grown with polyethylene mulch to be higher than those grown on bare soil. Brown and Lewis (1986) and Vethamoni and Balakrishnan (1990) recorded higher yield in okra grown on black mulch. They attributed their results to plastic mulch's ability to reduce weeds and reduce leaching of fertilizers. Simone *et al*. (2002) reported that different varieties of okra had significantly higher yields when grown on plastic mulch rather than bare soil. The use of plastic mulch created significantly higher yields of okra compared to bare soil due to improved moisture retention in the soil (Lourduraj *et al*., 1997; Saikia *et al*., 1997; Tiwari *et al*., 1998). Aiyelari *et al*. (2011) reported higher okra pod fresh weight under 10 t ha^{-1} organic mulch than those of lower rates of mulch application.

2.3.1 Effects of organic mulch on crop growth parameters

Thakur *et al.* (2000) reported higher number of branches under grass mulch plots relative to unmulched control plots. Iftikhar *et al.* (2011) also observed that chilli plants grown under rice straw mulch produced the highest number of leaves followed by wheat straw mulch and sugarcane bagasse mulch. Grass mulched plots had higher stem diameter of sweet corn than control plots (Norman *et al.*, 2002). According to Abd El-Kader *et al*. (2010), number of branches and number of leaves per plant were significantly higher under mulched treatments compared to the control. Norman *et al*. (2011) reported that mulched plots produced higher number of okra branches and leaves than unmulched control. Sønsteby *et al*. (2004) reported increased amounts of phosphorus and potassium levels in crop leaves in plots mulched with wood chips.

2.3.2 Effects of organic mulch on crop yield

The influence of organic mulch materials on the yield parameters of crops have been reported in literature. According to Dauda (2012), the length of pepper fruit under grass mulch was similar to the control, while pepper yield was higher in mulched plots than unmulched control plots (Dauda, 2012). Nasir *et al*. (2011) reported that the average cucumber and bitter gourd yield was higher under mulch conditions compared to the control. The application of *Gliricidia* loppings as mulch was reported to significantly enhance the dry fruit yield of chilli as compared to no unmulched treatment (Venkanna, 2008). Gollifer (1993) attributed increase in chilli dry fruits yield to organic mulch application relative to the control, while Venkanna (2008) reported that the number of chilli fruit yield was significantly higher under mulched plots relative to unmulched plots. The highest number of fruits per plant was recorded in sugarcane bagasse mulch followed by rice straw mulch and wheat straw mulch, while no mulch recorded the lowest number of fruits per plant (Iftikhar *et al*., 2011). Cocoa husk mulch increased tomato fruits weight per plant compared to the control (Ojeniyi *et al*., 2007).

In okra production, significant increase in pod yield was observed for straw mulch and sawdust mulch over control (Batra *et al.,* 1985). Tomato and okra yield were observed to increase after the application of straw mulch when compared with the control (Gupta and Gupta, 1987). Okra fruit diameter and length were not significantly influenced by mulch application (Norman *et al*., 2011). Furthermore, higher total okra fruit yield was observed in plants under grass mulch treatment than those under the control (Norman *et al*., 2011). Okra plants mulched with plant residues and chicken manure had the highest green fruit yield compared to the control (Abd El-Kader *et al*., 2010). Higher number of okra fruits per plant was recorded in plants under grass mulch than those under the control (Norman *et al*., 2011). Norman *et al*. (2011) further reported that dry grass mulch produced higher fruits weight of okra per plant than the control. In Venkanna (2008), the application of *Gliricidia* mulch resulted to higher dry matter production as compared to no mulch, while Norman *et al.* (2011) reported maximum dry upper plant biomass of okra plants under dry grass mulch when compared to the plants under the control treatment.

2.4 Evapotranspiration concepts

Some of the evapotranspiration characteristics relevant to irrigation water application for crop production are reviewed as follows:

2.4.1 Reference evapotranspiration

The reference evapotranspiration is the evapotranspiration from a reference surface that is not deficient in water and it is symbolised by ET_o (FAO, 1998). The reference surface is a hypothetical grass reference crop with specific characteristics.

The reference evapotranspiration shows the evaporative demand of the atmosphere at a specific location and time of the year and does not consider crop and soil factors (FAO, 1998). The concept of ET_o was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development stage and management practices. Hence, only climatic parameters affect ET_o (FAO, 1998). As a result, ET_o can be estimated using meteorological data. According to Savva and Frenken (2002), the FAO Penman-Monteith method as described in eq. 1 by Allen (1998), is the standard method for defining and computing ET_o.

$$ET_o = \frac{0.408\Delta\,(R_n - G) + \gamma\,[900/\,(T + 273)]\,u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34u_2)} \qquad (1)$$

Where:

ET_o = Reference evapotranspiration (mm/day)

R_n = Net radiation at the crop surface ($MJ/m^2/day$)

G = Soil heat flux density ($MJ/m^2/day$)

T = Mean daily air temperature at 2 m height (°C)

u_2 = Wind speed at 2 m height (m/sec)

e_s = Saturation vapour pressure (kPa)

e_a = Actual vapour pressure (kPa)

$e_s - e_a$ = Saturation vapour pressure deficit (kPa)

Δ = Rate of change of saturation specific humidity with air temperature (kPa)

γ = Psychrometric constant (γ = 66 kPa).

2.4.2 Crop coefficient (K_c)

Allen *et al.* (1998) defined crop coefficients as properties of plants used in predicting evapotranspiration (ET). The most basic crop coefficient, K_c, is simply the ratio of ET observed for the crop studied over that observed for the well calibrated reference crop under the same conditions. The K_c integrates the characteristics of the crop that distinguish it from the reference crop (usually a short green well-watered crop that completely shades the ground) used to estimate reference ET (ET_o). Crop coefficients may be presented as a percentage of elapsed time from planting to full cover for the first part of the growing season, and days after full cover for the last part of the growing season (Allen *et al.*, 1998). Daily K_c values are determined as the ratio:

$$K_c = ET_c/ET_o \quad (2)$$

Where:

K_c = Crop coefficient

ET_c = Crop evapotranspiration (mm/day)

ET_o = Reference evapotranspiration (mm/day)

2.4.3 Crop evapotranspiration (ET_c)

Crop evapotranspiration (ET_c) is defined as the evapotranspiration from disease-free, well-fertilized crops, grown in fields under optimum soil water conditions and achieving full production under the given climatic conditions (FAO, 1998). The values of ET_c and crop water requirements (CWR) are identical. Aliku and Oshunsanya (2016) explained that while ET_c is the amount of water lost through evapotranspiration, CWR refers to the amount of water that is needed to compensate for that loss. Allen *et al*. (1998) showed that ET_c can be determined either empirically by adopting various standard methods with the help of crop-coefficient (K_c) values, or by measuring using lysimeter and/or soil water balance.

Crop water requirement refers to the amount of water needed to raise a successful crop in a given period. It includes the water lost as evaporation from crop field and water transpired and metabolically used by crop plants. FAO (1984) defined crop water requirements as the depth of water needed to meet the water loss through evapotranspiration of a crop, being disease-free, growing in large fields under non-restricting soil conditions, including soil water and fertility, and achieving full production potential under the given growing environment. Crop evapotranspiration is mathematically expressed as:

$$ET_c = ET_o \times K_c \quad (3)$$

Where:

ET_c = Crop evapotranspiration (mm/day)

ET_o = Reference evapotranspiration (mm/day)

K_c = Crop coefficient

2.4.4 Factors affecting crop evapotranspiration

The main factors affecting crop evapotranspiration are environmental factors which include climate and weather, crop characteristics and management practices (Savva and Frenken, 2002). They stated that the amount of water required for productive plant growth is influenced by temperature, wind speed, solar radiation and relative humidity. The crop type, variety and development stages affect evapotranspiration as differences in crop resistance to transpiration, crop height, crop roughness, reflection, canopy cover and crop rooting characteristics result in different evapotranspiration levels in different types of crops under identical environmental conditions (FAO, 1998).

2.5 Estimation of crop evapotranspiration

Plants use water for cooling and this process is regulated by the prevailing weather conditions. Different crops have different water use requirements under the same weather conditions. Estimation of crop water requirements is one of the main components used in irrigation planning, design and operation (Rowshon *et al.*, 2013). This involves the estimation of the reference crop evapotranspiration. A good estimate of crop evapotranspiration plays an important role in accurately determining the crop water requirements for appropriate scheduling. Rowshon *et al.* (2006) stated that the estimation of ET_c is an important factor in irrigation management for efficient water use.

According to Broner and Schneekloth (2003), water requirements of crops depend mainly on environmental conditions. In Taiwan, Kuo *et al.* (2001) measured crop evapotranspiration both in the field and lysimeters. They also estimated the crop water requirement in single and double rice cropping pattern using the CROPWAT4W model. Adeniran *et al.* (2010) explained that the interrelationships of the ET, soil type, bulk density of the soil, field capacity and permanent wilting point of the soil, and the effective root zone of the plant are important for determining crop water requirement.

2.5.1 Methods of estimating crop water requirement

Several methods can be employed in estimating ET_c which is an essential component in crop water use (Attarod *et al.*, 2005). Pereira *et al.* (1999) stated that a good estimated ET_c provides basic tool for determining water balance, water availability and crop water requirements. Although, some of these methods may involve the use of empirical equations, the FAO Penman-Monteith method is generally considered to be the best approach for estimating ET_o and determining K_c because of its good approximation to accurate lysimeter observations (Maina *et al*., 2012).

2.5.2 Lysimetry

Lysimeters are a direct and more accurate method of measuring crop evapotranspiration (Maina *et al.,* 2014). This method of measuring crop evapotranspiration could either involve assessing the change in soil water by using soil water sensors (Sumner, 2000; Evett *et al*., 2006), mass balance technique (Gao *et al*., 2007; McCabe and Markstrom, 2007; Dingman, 2008) or soil water balance approach. According to Allen *et al*. (2011), lysimeters can be grouped into three categories: (1) non-weighing, constant water-table types that provide reliable data for weekly or longer time periods in areas where a high water table normally exists and where the water table level is maintained essentially at the same level inside as outside the lysimeter; (2) non-weighing, percolation types, in which changes in water stored in the soil are determined by sampling or neutron methods or by precision measurement of inputs, and the rainfall and percolate are measured (these types are often used in areas of high precipitation); and (3) weighing types, in which changes in soil water are determined either by weighing the entire unit with a mechanical scale, counter-balanced scale and load cell, directly suspended by load cells, or by supporting the lysimeter hydraulically. Liu *et al*. (1998) stated that when lysimeter facilities are appropriate, results from drainage or percolation lysimeters can be accurate if there is accuracy in observing changes in soil water content.

2.5.3 Applications of lysimeters in crop growth studies

Although lysimeter measurements of ET are extremely sensitive to environmental factors, lysimeter studies are generally the reference to which modelled ET is compared. According to Jensen *et al*. (1990), lysimeters have been used extensively to provide baseline information for development, calibration, and validation of ET methods. Mutziger *et al*. (2005) reported that an evaluation of the ability of the FAO-56 Penman-Monteith equation to predict evaporation from bare soil used recorded lysimeter data to compare evaporation from different soil types. Ventura *et al*. (1999) reported that comparisons of ET models rely on lysimeter data as a benchmark. Cuenca (1989) reviewed the improvement of the Blaney-Criddle method of ET estimation and reported that its accuracy in estimating ET was improved by using measured crop water use from lysimeter studies.

2.5.4 Agrometeorological models

Agrometeorological models employ weather data in evaluating responses of agricultural crops, pests, diseases, and livestock to atmospheric and soil environment. Van Genuchten and Leij (1992) reported that the use of models in agrometeorological studies often emanates from the difficulty in describing the mechanical behaviour and water characteristics of soils. They explained that models aid agrometeorologists, agronomists and irrigation engineers in carrying out standard calculations for evapotranspiration and crop water use studies, and more specifically the design and management of irrigation schemes. According to Bryant *et al.* (1993), models can be used to optimize the allocation of irrigation water between different crops and/or the distribution of water during the crop season. Arora and Gajri (2000) reported that the model simulated biomass and grain yield of maize were close to the measured data in medium-water retentive sandy loam.

2.5.5 CROPWAT model

CROPWAT model is a computer program developed by the Land and Water Development Division of FAO for irrigation planning and management (FAO, 1992). It includes a simple water balance model that allows the simulation of crop water stress conditions and estimations of yield reductions based on well-established methodologies for determination of crop evapotranspiration (FAO, 1998), and yield responses to water (FAO, 1979). Through a daily water balance, the user can simulate various water supply conditions and estimate yield reductions and irrigation and rainfall efficiencies (FAO, 1998). Typical applications of the water balance include the development of irrigation schedules for various crops and various irrigation methods, the evaluation of irrigation practices, as well as rainfed production and drought effects. Figure 2.1 shows the flow chart of a CROPWAT model. Its main functions are to calculate reference evapotranspiration, crop water requirements, and crop irrigation requirements; to develop irrigation schedules under various management conditions, water supply scheme; to evaluate rainfed production and drought effects and efficiency of irrigation practices (FAO, 1992).

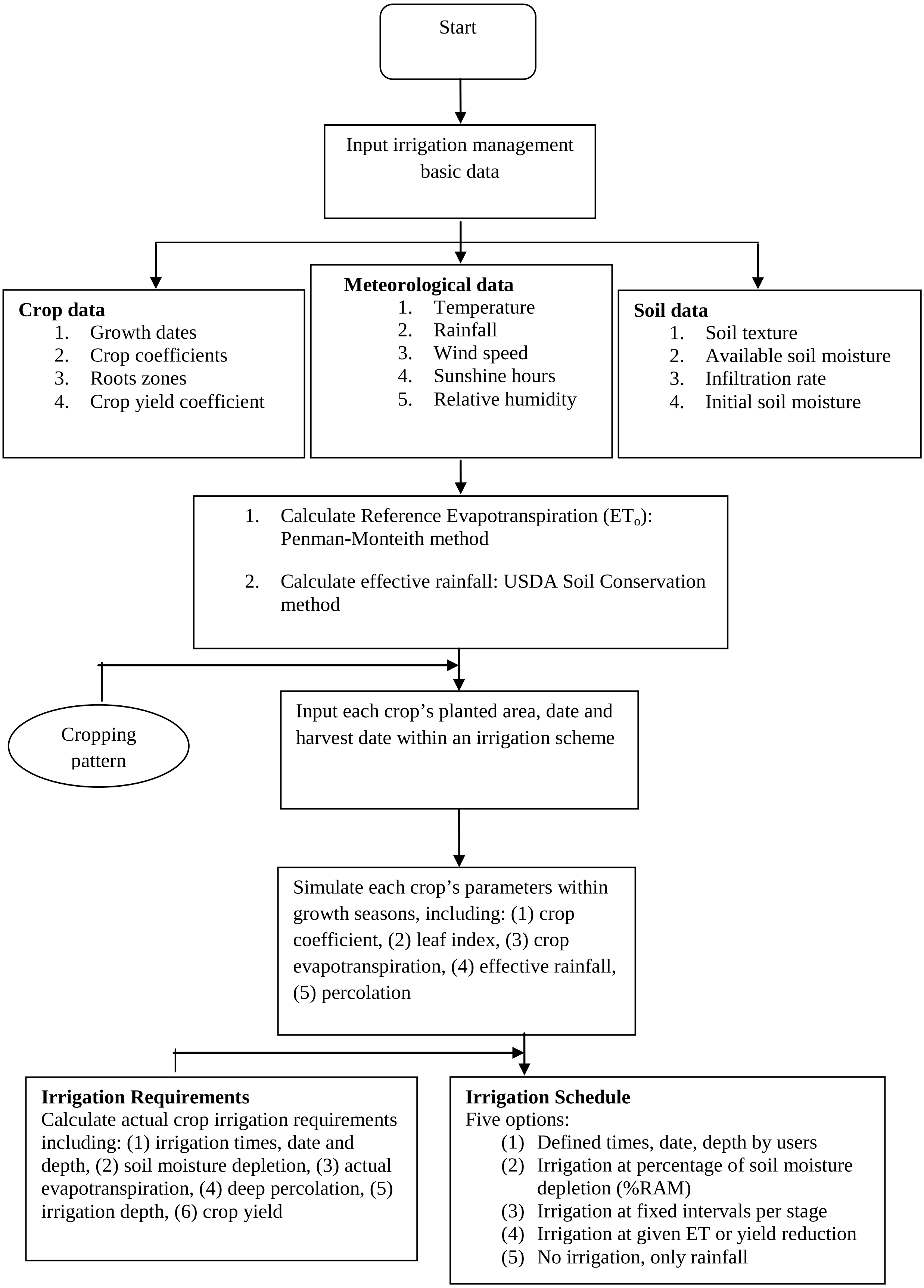

Figure 2.1: Flow chart of the CROPWAT model (FAO, 1998)

2.5.6 Applications of CROPWAT model for crop production

Studies by Itier and Brunet (1996) and Craciun and Craciun (1999) on CROPWAT simulation for maize crop, revealed that when the maize water requirements exceed the water supply, by applying adequate irrigation scheduling, the yield losses are significantly reduced. According to Nazeer (2009), CROPWAT can estimate the yield reduction resulting from water stress conditions and climate impacts, thus, making it a good tool for irrigation planning and management in maize production. Anaç *et al*. (1999) reported that the use of CROPWAT model with the adoption of climatic and ET_o data from the CLIMWAT database, showed good correlation with measured crop water use. They further reported that the seasonal and cumulative yield reductions calculated by CROPWAT were comparable with measured yield reductions in actual field scenario. CROPWAT simulated rooting depth and depletion level also corresponded to standard values expected for potato, while yield response factors corresponded well with previously reported values (FAO, 1979). However, Iqbal *et al*. (1999) reported yield reductions for potato to appear less consistent, with larger deviations from CROPWAT's, while reductions in sugar beet yield estimated under CROPWAT were similar to measured reductions, with the simulated values slightly higher than the measured values (Bazza, 1999). Crop coefficient (K_c) values for cotton were below expected standards (FAO, 1998), while the K_c values obtained for cotton in CROPWAT were comparable with standard measured values. According to FAO (1998), K_c values under optimum CROPWAT irrigation schedule much lower than the standard values for sugar beet and potato, while field determined crop water use efficiency (1756 m^3 ha^{-1}) was less than the amount computed by CROPWAT (6070 m^3 ha^{-1} and 5363 m^3 ha^{-1}) in 2003 and 2004, respectively.

2.6 Irrigation water quality

Water is a medium through which solutes are transported along a landscape. The presence of solutes, especially salts could reduce the quality of irrigation water. However, the use of low quality water for irrigation could be a good measure to conserve water, even though the cost of such water conservation measure may be deterioration of soil quality and crop yield quality (Halliwell *et al.*, 2001; Surapaneni and Olsson, 2002). Therefore, it is important to carry out water quality assessment to assess the characteristics and suitability of water for irrigation purpose. An outline of relevant parameters and their acceptable limits for irrigation water quality assessment (FAO, 1979), are presented in Tables 2.1 and 2.2, respectively.

2.6.1 Management problems associated with irrigation water

Some of the soil management problems associated with irrigation water quality are reviewed as follows:

a) Salinity

This is the presence of salt in the soil solution. The relationship between soil salinity and its flocculating effects, and soil exchangeable sodium percentage (ESP) and its dispersive effects, determine whether a soil will remain aggregated or become dispersed under various salinity and sodicity combinations. According to USDA, Natural Resources Conservation Service, (2002), while increasing salinity of the soil solution has a positive effect on enhancing or stabilizing soil aggregation, at high levels, salinity has a negative and potentially lethal effect on plants. On the other hand, contrary to enhancing flocculation, sodium saturation may cause dispersion. Bauder and Brock (2001), reported that soil dispersion is the primary physical process associated with high sodium concentrations. Thus, salinity resulting from high concentrations of sodium in which the cation exchange capacity of soils irrigated with saline water is dominated by sodium, has a direct adverse effect on soil structure (Bauder and Brock, 2001).

b) Sodium Adsorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP)

The common “bases” such as calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) generally make up almost all of the exchangeable cations in soils. The cation exchange site for most tropical soils has been reported to be dominated by calcium with lesser amount of magnesium and potassium and little or no sodium (Nwilo and Badejo, 2005). This composition ensures the availability of plant macro-nutrients and good soil structural stability, which are essential features of a productive soil. However, irrigating soils with sodium-contaminated wastewaters may cause structural problems (Menneer *et al.*, 2001). The capacity of irrigation water to change a non-sodic soil into a sodic soil depends on the soil type, management practice, water quality and time. The most important factor in water quality is its total salinity, of

Table 2.1: Quality parameters and acceptable limits for evaluating irrigation water

Laboratory determination	Reporting symbol	Reporting units	Equivalent weight
Electrical conductivity	ECw	mmhos cm^{-1}	-
Calcium	Ca	meq L^{-1}	20.0
Magnesium	Mg	meq L^{-1}	12.2
Sodium	Na	meq L^{-1}	23.0
Carbonate	CO_3	meq L^{-1}	30.0
Bi-carbonate	HCO_3	meq L^{-1}	61.0
Chloride	Cl	meq L^{-1}	35.4
Sulphate	SO_4	meq L^{-1}	48.0
Boron	B	mg L^{-1}	-
Nitrate-Nitrogen	NO_3-N	mg L^{-1}	14.0
Acidity-alkalinity	pH	pH	-
Adjusted Sodium Adsorption Ratio	Adj SAR	-	-
Potassium	K	meq L^{-1}	39.1
Lithium	Li	mg L^{-1}	7.0
Iron	Fe	mg L^{-1}	-
Aluminium-nitrogen	NH_4-N	mg L^{-1}	14.0
Phosphate-phosphorus	PO_4-P	mg L^{-1}	31.0

Source: FAO (1979)

Table 2.2: Guidelines for irrigation water quality interpretation

Irrigation problem	Units	Degree of problem		
		No problem	Increasing problem	Severe problem
SALINITY (affects crop water availability) Ecw	mmhos cm^{-1}	< 0.7	0.7 – 3.0	> 3.0
PERMEABILITY (affects infiltration rate) Ecw	mmhos cm^{-1}	> 0.5	0.5 – 2.0	< 0.2
adj. SAR				
Montmorillonite (2:1 crystal lattice)		< 6	6 – 9	> 9
Illite – vermiculite (2:1 crystal lattice)		< 8	8 – 16	> 16
Kaolinite – sesquioxides (1:1 crystal lattice)		< 16	16 – 24	> 24
SPECIFIC ION TOXICITY (affects sensitive crops)				
Sodium (Na)	Adj. SAR	< 3	3 – 9	> 9
Chloride (Cl)	meq L^{-1}	< 4	4 – 10	> 10
Boron (B)	mg L^{-1}	< 0.7	0.7 – 2.0	> 2.0
MISCELLANEOUS EFFECTS (affects susceptible crops)				
Nitrogen (NO_3-N or NH_4-N)	mg L^{-1}	< 5	5 – 30	> 30
Bi-carbonate (HNO_3) [overhead sprinkling]	mg L^{-1}	< 1.5	1.5 – 8.0	> 8.5
pH		[Normal Range: 6.5 – 8.4]		

Source: FAO (1979)

which two criteria are currently recognized in scientific literature as its indices (Rollins, 2007). These are the sodium adsorption ratio (SAR) with a reported threshold of 12 (cmol kg^{-1}) and the exchangeable sodium percentage (ESP) with a reported threshold of 15%. Mathematically, they are expressed in eqs. 4 and 5 as described by Chi and Wang (2011).

$$SAR = Na^{+} / \surd\ (Ca^{2+} + Mg^{2+}) / 2 \tag{4}$$

Where:
SAR = Sodium adsorption ratio, (cmol kg^{-1})
Na^{+}, Ca^{2+}, Mg^{2+} = Measured exchangeable sodium, calcium and magnesium in cmol kg^{-1}, respectively.

$$ESP = (Na^{+} / CEC) \times 100 \tag{5}$$

Where:
ESP = Exchangeable sodium percentage, %
Na = Measured exchangeable sodium, cmol kg^{-1}
CEC = Cation exchange capacity, cmol kg^{-1}

c) Carbonate and bicarbonate

Carbonate and bicarbonate always occur together in equilibrium in solution (Murray and Grant, 2007). They stated that at low concentrations in irrigation water, there are generally no problems but at higher concentrations, evident from elevated pH, carbonate becomes problematic. This is because, although all bicarbonates are soluble, calcium carbonate is relatively insoluble so that irrigation with this water tends to enhance the SAR of the soil water by removing calcium from solution so that sodium and magnesium dominate. Below the soil surface where the respiration of organisms is at work, concentrations of carbon dioxide in the soil atmosphere may be 100 times higher than in the greater atmosphere; this lowers the concentration of carbonate in favour of bicarbonate (Murray and Grant, 2007). However, near the soil surface, carbonate concentration is higher and may become even more elevated as transpiration and evaporation of water occurs. In extreme cases where pH and the concentration of carbonate in irrigation water are high, the soil will progressively become alkaline as well as sodic so that nutrient availability is also impaired (Murray and Grant, 2007).

2.7 Water and crop production

Water is an important component in agricultural production. It is crucial for optimum crop yield and quality. Malik and Luhach (2002) reported that the available water for irrigation purpose has been diminishing even in India blessed with abundant water resources. They reported further that in rainfed and irrigated agriculture, there is need to device water conservation strategies, defining water conservation as "measures planned to encourage efficient use of water and to eradicate wastage of water."

2.7.1 Rainfed agriculture

Although the importance of rainfed agriculture varies regionally, it is the primary form of crop cultivation for most poor communities in developing countries. In sub-Saharan Africa, more than 95% of farmed lands are under rainfed, while the corresponding figure for Latin America is almost 90%; South Asia, about 60%; East Asia, 65% and the Near East and North Africa 75% (FAOSTAT, 2005). Most countries in the world depend primarily on rainfed agriculture for their crops. Despite large strides made in improving productivity and environmental conditions in many developing countries, a great number of poor families in Africa and Asia still face poverty, hunger, food insecurity and malnutrition where rainfed agriculture is the main agricultural activity (Rockstrom *et al*., 2007).

2.7.2 Rainfed agriculture and water stress

Although the rate of water scarcity is rarely the major problem for rainfed agriculture, water scarcity is a key reason responsible for low agricultural productivity (Falkenmark, 1986). To identify management options for upgrading rainfed agriculture, it is essential to assess different types of water stress in food production. Especially important is distinguishing between climate- and human-induced water stresses and between droughts and dry spells. In semi-arid and dry sub-humid agro-ecosystems rainfall variability can generate dry spells (short periods of water stress during critical growth stages) even during the rainy season. However, when rainfall is scarce, supplemental irrigation can increase yields significantly, and in arid regions, this increase can be substantial (Rockstrom *et al*., 2007).

2.7.3 Irrigation

Hillel (2004) considered irrigation as the practice of supplying water artificially to permit farming in arid regions and to offset drought in semi-arid or semi-humid regions. As such, it can play a key role in feeding an expanding population. Even in areas with large amount of rainfall, it may be unevenly distributed during the year so that only with irrigation is stable multiple cropping possible.

2.8 Soil data relevant to irrigation

Some of the soil parameters relevant to irrigation studies are discussed as follows:

2.8.1 Physical characteristics

Some soil physical characteristics considered in irrigation studies include:

(a) Texture

Arens and Sivarajasingham (1979) considered this characteristic a relatively stable or a permanent soil condition that can easily be determined in the laboratory. They believed that field descriptions of texture by surveyors could give better insight into the nature of the soil if texture determination by feel-method is done properly. Sys (1985) reported that soils of all textural classes, with the possible exception of very coarse sand, could be successfully irrigated if the proper irrigation method is used. It is also known to influence other important soil properties relevant to irrigation such as permeability, soil water availability, drainage, tillage conditions and capacity to retain nutrients.

(b) Permeability (Hydraulic conductivity)

Scherer *et al*. (2013) defined permeability as the measure of the ability of air and water to move through soil. When defined quantitatively, the term hydraulic conductivity is used. The average hydraulic conductivity of a soil profile is used to determine subsurface drainage. According to FAO (1979), no universally accepted minimum value of hydraulic conductivity has been established for irrigation, although, it is influenced by the size, shape and continuity of the pore spaces, which in turn are dependent on the soil bulk density, structure and texture (Scherer *et al*., 2013).

(c) Soil water availability

Soil available water has customarily been regarded as the amount of water [between field capacity (FC) and permanent wilting point (PWP), in mm/m soil depth] stored in the root zone of plants (FAO, 1979). There have been differences in opinion as to the availability of water between FC and PWP. Viehmeyer (1972) proposed the theory of “equal availability” and stated that crops could extract water with ease between the zone of FC and PWP. FAO (1979), however, concluded that in practice, irrigation is applied well before wilting point is reached and practices differ with respect to differences in crops, soils and water control.

2.8.2 Chemical characteristics

(a) Soil pH

This is the negative logarithm of the hydrogen ion concentration. Soil pH measurement chiefly serves the purposes of irrigation scheduling by providing a general indication of soil reaction i.e. whether the soil is acidic, alkaline or sodic. In certain cases where empirical relationships can be established, soil pH measurements are used to appraise correctable soil deficiencies relating to economic correlation, such as needs for soil amendments (e.g. lime for acid soils and gypsum or sulphur for sodic soils) and optimum land management including cropping practices. In other cases, the relationship between soil pH measurements and other factors permit rapid screening of soil samples and soil tests in field and laboratory (FAO, 1979). Soil pH values approaching the extremes of the pH range give warning of soil characteristics likely to prove unfavourable to irrigated agriculture.

(b) Exchangeable Sodium Percentage (ESP)

This is the degree of saturation of the soil exchange complex with sodium ion and it is a good indicator of the structural stability of the soil and the physical response that may be anticipated when water is applied (FAO, 1979). At ≥ ESP of 15% or more, it is believed that most soils, especially those with expanding clay minerals in their exchange complex, exhibit unfavourable physical properties. There are however, some exceptions to this as was found by Robinson (1971), who reported a range of ESP between 6 and 15 as being optimum for the cultivation of cotton. Lunt (1963) reported a reduction in crop production due to the influence of high ESP. FAO (1979) observed that the ESP level after the introduction of irrigation water is of more practical significance to irrigation practice than the one prior to irrigation. They, therefore, concluded that it was possible to predict the approximate level of ESP, given the sodium adsorption ratio of irrigation water, in a well-drained soil.

(c) Salinity

A saline soil is a non-sodic soil containing soluble salts in such quantities that they interfere with the growth of most crop plants. It is usually characterised by an exchangeable sodium percentage (ESP) of less than 15%, pH value that is less than 8.5 and an electrical conductivity of the soil saturation extract that is more than 4 mmhos/cm. Salinity affects irrigation in terms of leaching requirement hence it is an important component of the gross water requirement of an irrigation project. The deleterious effect of excessive salinity is that the plant can be starved of water even though the soil is moist (FAO, 1979). This happens due to the concentration in the soil solution being higher than that in the plant thus leading to a reversed flow by osmosis. Thus, the amount of water extractable by plants is determined by soil salinity level (Sys, 1985).

2.9 Origin and geographic distribution of okra

Okra is said to have originated from somewhere around Ethiopia before spreading to the Middle East and North Africa (Lamont, 1999). The plant is now grown in many parts of the world, especially in tropical and subtropical countries (Arapitsas, 2008; Saiffullah and Rabbani, 2009). According to Qhureshi (2007), the introduction of okra to Africa and America has led to the spread of other species. Some of the countries where okra crop is being grown commercially include: India, Japan, Turkey, Iran, Nigeria, Yugoslavia, Bangladesh, Afghanistan, Pakistan, Myanmar, Malaysia, Thailand, Brazil, Ethiopia, Cyprus and in the Southern United States (Dalorima *et al*., 2014).

2.10 Ecology and seasonal growth of okra

Dalorima *et al*. (2014) reported that *Abelmoschus* species is a short-day plant but its wide geographical distribution shows that cultivars vary in photoperiod sensitivity. Okra requires a temperature higher than 20°C for normal growth and development (Lamont, 1999; Abd El-Kader *et al*., 2010). According to Akande *et al*. (2003), the optimum temperature range of 30°C to 35°C is adequate for high germination percentage and emergence rate. An increase in temperature beyond this range has been reported to delay flower initiation and flowering (Lamont, 1999; Abd El-Kader *et al*., 2010). Flowering is hardly affected by day length in popular subtropical cultivars, while most tropical cultivars show quantitative short-day responses, with qualitative responses also occurring. Dalorima *et al*. (2014) reported that okra tolerated poor soil, but preferred well-drained sandy loam soil with high organic matter content. They also noted that the plant required well distributed moderate rainfall of 80 to 100 mm year^{-1} to produce its young edible fruits.

CHAPTER 3

MATERIALS AND METHODS

3.1 Description of the study area

The study was conducted at the University of Ibadan, Ibadan, Nigeria. Ibadan lies within latitudes 07° 25′ N and 07° 37′ N, and longitudes 03° 51′ E and 03° 56′ E (Oshunsanya *et al*., 2016). It is about 190 m to 273 m above sea level. It is situated within the derived savannah agro-ecological zone of Southwest Nigeria.

3.2 The Study sites

Two sites within the University of Ibadan were used for this study, namely: the Screenhouse in the Department of Agronomy, University of Ibadan and the Teaching and Research Farm, Parry Road, University of Ibadan.

3.2.1 The Screenhouse

The screenhouse is situated behind the Department of Agronomy Building, it lies within latitude 07° 27′ 06.4″ N and longitude 03° 53′ 46.1″ E, and has an elevation of 200 m above sea level.

3.2.2 Teaching and Research Farm

The area lies between latitudes 07° 27′ 7.52″ N and 07° 27′ 8.04″ N, and longitudes 03° 53′ 27.77″ E and 03° 53′ 29.48″ E, with an elevation of 198 m above the sea level (Figure 3.1). It is within the humid tropical climate with a lengthy wet season and relatively constant temperature throughout the course of the year (Emielu, 1987). The wet season is bimodal and runs from March through October, August sees somewhat of a lull in precipitation. The two peaks for rainfall are in June and September. November to February forms the city's dry season, during which Ibadan experiences the typical West African harmattan, brought by the northeast trade wind. The long-term mean total rainfall for Ibadan is about 1200 mm (Emielu, 1987).

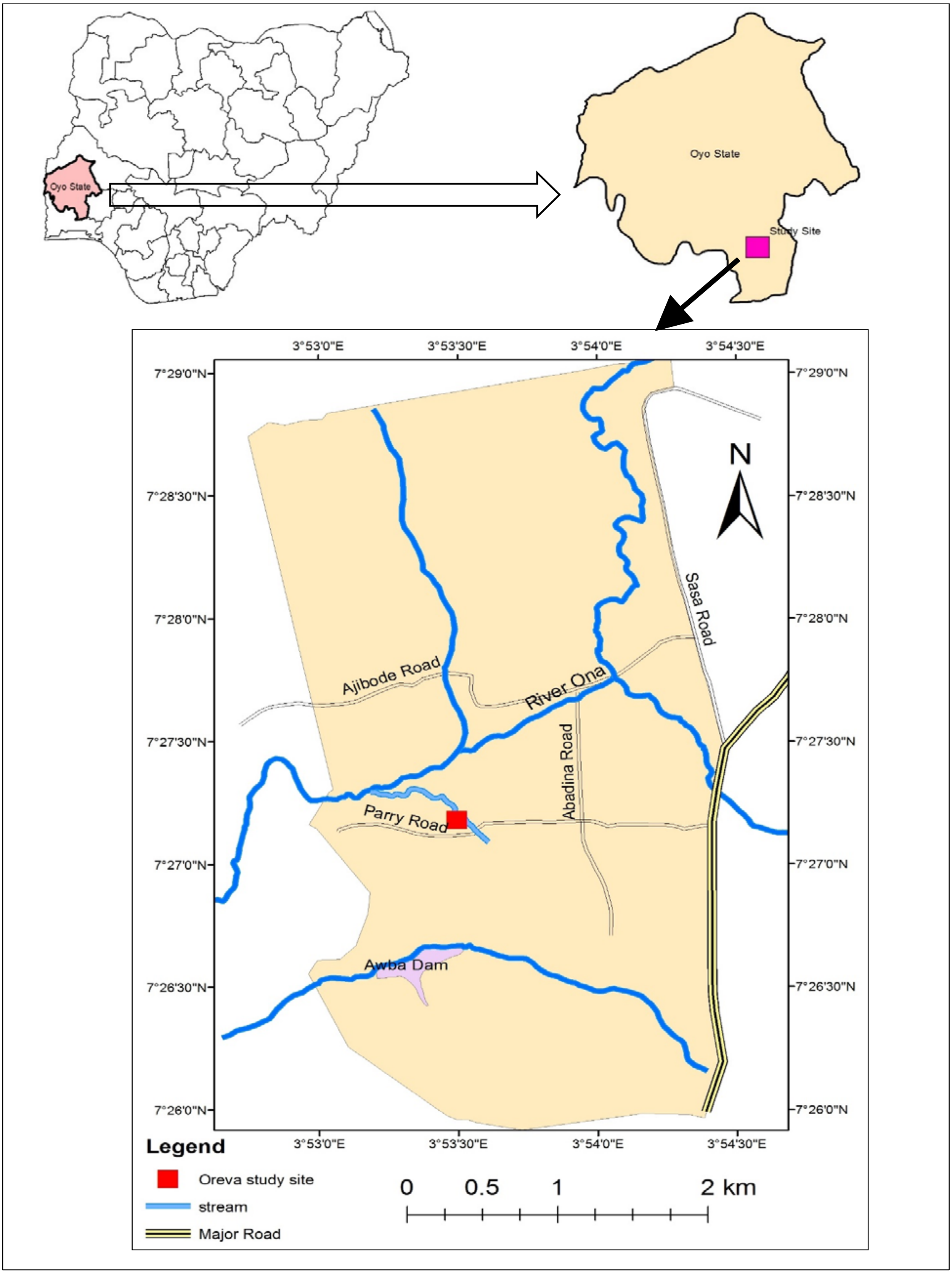

Figure 3.1: Map of the University of Ibadan showing the study site

The mean maximum temperature is 26.5°C, while minimum temperature is 21.4°C and the relative humidity is 76% (Ojo and Sadiq, 2010). The vegetation is a mixture of derived savannah and rain forest. The savannah is predominantly a mixed formation of grasses and shrubs that have been reduced as a result of farming activities. *Gliricidia sepium* and *Pennisetum purpureum* are among the common shrubs and grasses.

3.2.2.1 Geology and physiography of the study area

The study area is underlain by granite gneiss as described by Akeju (2010). Smyth and Montgomery (1962) described granite gneiss as a parent rock that is resistant to weathering. Frequently, outcrops are on the surface and this gives rise to relatively shallow soils, which are found in the Iwo Association. The soil is an ultisol and its catena in Iwo Association is clearly expressed in landforms of steep sided rock hills separated by a fairly level pediment (Akeju, 2010).

3.2.2.2 Cropping history of the site

The experimental site had been cultivated with okra since 2009 when a residual study on applied fertilizer treatments was carried out (Raheem, 2009). Okra was also grown under different irrigation treatment types between 2011 and 2013 (Aliku, 2011; Odekanye, 2013). The site was then left to fallow, up till in August, 2015 when the land was planted to okra for seed multiplication under different land preparation types in a rainfed condition, prior to the start of the study in December, 2015.

3.3 EXPERIMENT 1: Determination of crop evapotranspiration (ET_c) of okra in a screenhouse

This experiment consisted of two trials conducted between December, 2013 – February, 2014; and March, 2014 – May, 2014 in the screenhouse of the Department of Agronomy, University of Ibadan.

3.3.1 Objectives: the experiment was conducted to:

(i) determine crop evapotranspiration of okra under different rates of ET_o

(ii) assess okra growth and yield under different rates of ET_o

3.3.2 Materials

Seeds of okra varieties (UI4-30 and NH47-4) were obtained from the Department of Agronomy, University of Ibadan and the National Horticultural Research Institute (NIHORT) also in Ibadan, respectively. Daily weather data consisting of rainfall amount, relative humidity, sunshine hours, minimum and maximum temperatures for 20 years (1994 to 2013) were obtained from the Nigerian Meteorological Agency (NIMET) and International Institute of Tropical Agriculture (IITA). The daily weather parameters were used to compute the mean daily reference evapotranspiration (ET_o) per week using the FAO Penman-Monteith equation as described in eq. 1 (Page 14). The monthly mean daily ET_o for 20 years (1994 to 2013) is presented in Table 3.1.

3.3.3 Lysimetry procedure

Drainage lysimeters were installed for direct measurement of crop water requirement. The lysimeters were made using twenty-litre capacity buckets with a dimension of 30 × 27 × 38 cm (top diameter × bottom diameter × height). The drainage lysimeters were installed by adding 8 kg and 5 kg of granite and sharp sand, respectively, to serve for drainage purpose. The mixture of granite and sharp sand was topped with 14 kg of soil for planting. The soil used for planting was obtained from the trial plot at the Teaching and Research Farm, Parry Road, University of Ibadan. The soil was watered to field capacity and left for a week to regain normal density as a monolith. The drainage lysimeters used for the experiment are shown in Plate 3.1.

3.3.4 Experimental design

The experiment was laid out as a 2 × 3 factorial experiment in a completely randomised design. The factors were: two varieties of okra (UI4-30 and NH47-4) and three levels of ET_o (ET_o-N: derived from NIMET weather data, ET_o-I: derived from IITA weather data, and ET_o-M: derived as mean values of NIMET and IITA). Two seeds of okra were sown per lysimeter before thinning to one at two weeks after sowing. The treatment combinations were replicated three times, giving a total of 18 experimental units.

Table 3.1: Estimated monthly mean daily reference evapotranspiration for 20 years (1994 to 2013), at two locations in Ibadan

Month	NIMET	IITA
	mm day^{-1}	
January	6.12	3.89
February	5.57	4.73
March	5.41	4.59
April	5.13	4.22
May	4.47	3.77
June	3.92	3.33
July	3.13	2.46
August	3.00	2.05
September	3.33	2.45
October	3.99	2.81
November	4.44	3.58
December	4.72	3.92

NIMET: Nigerian Meteorological Agency, IITA: International Institute of Tropical Agriculture

Plate 3.1: Lysimeters and drainage collection facilities (a), and okra plant in a lysimeter at 5 WAS (b)

3.3.5 Water sampling

Water samples were collected in three sampling bottles from the irrigation water source (well) prior to use for the Screenhouse study. The samples were homogenised and replicated thrice for routine analyses of the chemical constituents described below.

3.3.6 Water analysis

The water samples were taken to the laboratory for chemical analyses. The parameters analysed are described as follows:

3.3.6.1 pH

This was determined using a Glass-electrode pH meter. The pH metre was inserted into the water samples with sufficient contact between the electrode and the liquid before the pH value was recorded (Mclean, 1982; Udo and Ogunwale, 1986).

3.3.6.2 Electrical conductivity

This was determined using the Wheatstone bridge arrangement. The electrode was inserted into the water samples with sufficient contact between the electrode and the liquid before the electrical conductivity value was recorded (Mclean, 1982; Udo and Ogunwale, 1986).

3.3.6.3 Sulphate

Turbidimetric determination of sulphate in the irrigation water was carried out by pipetting 10 mL of the sample aliquot into a 25 mL volumetric flask. One millilitre of gelatin-$BaCl_2$ reagent was added. This was made up to volume with distilled water. The content was mixed thoroughly and left to stand for 30 minutes. The %T and O.D. was determined at 420 nm on an electrocolorimeter by pouring the mixture into the photo-test tube (Udo and Ogunwale, 1986).

3.3.6.4 Carbonate and Bicarbonate (alkalinity)

These were determined by titration with 0.025M H_2SO_4 using phenolphthalein and methyl red indicators. Three drops of 0.25% phenolphthalein were added to 50 mL of the water samples in a 150 mL beaker. Due to lack of change in colour, two drops of 0.1% methyl orange were added, and titration was done to determine the titre value, while the final reading was noted. Blank determination was run with the reagents and distilled water (Udo and Ogunwale, 1986).

3.3.6.5 Chlorides

Following carbonate and bicarbonate titration, 1 mL of potassium chromate indicator was added to the solution obtained from the carbonate and bicarbonate procedure before titrating with 0.05M silver nitrate solution, using potassium chromate as the indicator (Udo and Ogunwale, 1986).

3.3.6.6 Calcium and Magnesium

These were determined with the aid of a flame photometer as described by Udo and Ogunwale (1986).

3.3.6.7 Nitrate

This was determined using the Brucine colorimetric method. A 10 mL aliquot of the water extract was transferred into a 25ml volumetric flask. Two millilitres of brucine reagent were added before rapidly adding 10mL of concentrated H_2SO_4. The mixture was mixed for 30 seconds and allowed to stand for 5 minutes. This was later made up to the 100 mL mark and absorbance was measured at 470 nm (Bremmer and Mulvaney, 1982; Udo and Ogunwale, 1986).

3.3.6.8 Boron

This was determined by azomethine-H colorimetric procedure (Udo and Ogunwale, 1986).

3.3.7 Data collection

Data on plant growth parameters such as number of leaves, plant height and stem diameter were taken on weekly basis at 2 to 10 weeks after sowing (WAS). The crop evapotranspiration (ET_c) values of the okra varieties were also determined at 2 to 10 WAS using the soil water balance approach as described by Hillel (1998) in eq. 6, while crop coefficient (K_c) was determined as described in eq. 2 above. Data on yield (number of pods per plant, fresh pod weight, fresh pod length, fresh pod diameter, dry pod weight and weight of 100 seeds) and shoot weight were taken after harvest. Dry shoot weight was determined by weighing after oven-drying at 75°C to constant weight.

$$ET_c = I + P + RO - DP + CR - \Delta SF - \Delta SW \quad (6)$$

Where I is irrigation water supplied (mm), P is the rainfall, RO is surface runoff, DP is deep percolation which recharges water table, CR is capillary rise, the ΔSF is subsurface flow in (SF_{in}) or out flow (SF_{out}) of the root zone, and ΔSW is change in the soil water content.

Due to the absence of P, RO, CR and ΔSF (assumed to be zero), eq. 6 was further simplified to:

$$ET_c = I - DP - \Delta SW \quad (7)$$

According to Hillel (2004), ΔSW was estimated as:

$$\Delta SW = Q_i - Q_o \quad (8)$$

Where Q_i is the quantity of water added, and Q_o is the quantity of water lost via drainage.

Irrigation water use efficiency for shoot ($IWUE_{shoot}$) and yield ($IWUE_{yield}$) production were estimated as described by Singh *et al*. (2007) in eqs. 9 and 10.

$$IWUE_{shoot} = \frac{\text{total fresh shoot weight}}{\text{Unit of water used over the entire season yield}} \quad (9)$$

$$IWUE_{yield} = \frac{\text{total fresh pod weight}}{\text{Unit of water used over the entire season yield}} \quad (10)$$

3.3.8 Statistical analysis

Data analysis was carried out using GenStat statistical package (8th Edition). Data collected were subjected to analysis of variance (ANOVA) procedure while significantly different means were separated using Duncan Multiple Range Test at 5% probability level.

3.4 EXPERIMENT 2: Preliminary study on land preparation effects on growth and yield of okra under rainfed conditions

3.4.1 Objectives: The experiment was conducted to:

i. evaluate the effects of land preparation on the growth and yield potential of okra under rainfed conditions;
ii. multiply seeds for dry season trials, and;
iii. generate crop and soil data for calibration of CROPWAT for scheduling irrigation.

3.4.2 Field preparation

The experimental field was ploughed and harrowed using the Massey Ferguson 435 tractor, while grasses were removed from the field by hand. Raised beds and Ridges were done with the aid of a traditional hoe.

3.4.3 Experimental design

The experiment was laid in a randomized complete block design. Land preparation types consisted of Raised bed, Ridge and Flat types. The field was split into three blocks and the treatments were replicated nine times per block, with each replicate measuring 4.2 m^2 (1.4 m × 3 m). A spacing of 0.5 m was used as border between each replicate, while 1.5 m spacing was used as border between blocks. In total, the experimental field had a dimension of 42 m × 17.6 m, giving a total land area of 739.2 m^2.

3.4.4 Land preparation and sowing of okra seeds

Raised beds and Ridges were made with the aid of local hoe, while the Flat was left unperturbed. Okra seeds (UI4-30) were sown at 2 seeds per hole, in three rows with 30 cm × 45 cm spacing. This summed up to ten plant stands per row, and a total of 30 plants per replicate after thinning to one plant at 2 WAS. Crop growth and yield data were obtained from four plants in the centre of the middle row of each replicate.

3.4.5 Soil sampling

Disturbed soil samples were randomly collected in polythene bags from twenty spots at 0 – 30 cm depth with the aid of an auger and bulked to form a composite sample before extracting triplicate subsamples for laboratory analysis of the chemical constituents of the soil. In addition, undisturbed soil samples were obtained from one spot per replicate per block at 0 – 15 and 15 – 30 cm depth using core samplers of 5 cm diameter and 5 cm height, for laboratory analysis of soil physical properties.

3.4.6 Soil analysis

This was air-dried at room temperature, crushed with a mortar and pestle before sieving through 2 mm and 0.5 mm mechanical sieves. The soil physical and chemical properties analysed were as follows:

3.4.6.1 Soil pH

This was determined in a 1:1 ratio mixture of soil and distilled water (Mclean, 1982). Ten grams of 2 mm sieved air-dried soil was weighed into a 50 ml beaker. Ten millilitres of distilled water was added and the mixture was stirred with a glass rod for 5 minutes. A glass-electrode pH meter was inserted into the suspension to measure the pH.

3.4.6.2 Organic carbon

The soil organic carbon was determined using the Walkley-Black wet-oxidation method (Nelson and Sommers, 1982). A half gram of 0.5 mm sieved air-dried soil was weighed into a 250 mL conical flask and 10 mL of 1N $K_2Cr_2O_7$ was added to it. The mixture was swirled to mix. Twenty millilitres of concentrated H_2SO_4 was added rapidly and the mixture was left to cool. One hundred millilitres of distilled water was prepared without soil. Three drops of ferroin indicator was added to blank and sample, respectively before titrating with 0.5 N ferrous sulphate until it changed to a wine colour. The value for organic carbon was calculated and expressed in percentage using the formula below:

$$\%\ \text{Org C} = \frac{(B-T) \times N \times 1.33 \times 0.003 \times 100}{W} \qquad (11)$$

Where B = Blank titre value

T = Titre value of sample

N = Normality of ferrous sulphate

W = Weight of sample

$$\% \text{ organic matter} = \% \text{ Org C} \times 1.724$$

3.4.6.3 Total nitrogen

Total nitrogen was determined using the micro-kjeldahl digestion-distillation apparatus (Bremmer and Mulvaney, 1982). Half gram of 0.5 mm sieved soil was weighed into a 250 mL conical flask. Five millilitres of concentrated sulphuric acid was added before swirling for 5 minutes and allowed to stand. One tablet of selenium was added as the catalyst. This was digested until a clear substance was attained. The clear substance in the beaker was rinsed and 5 mL of distilled water was added. This was left to settle before pouring into the micro-kjedhal apparatus. It was distilled by adding 5 mL of boric acid and NaOH, respectively into the Erlenmeyer flask of the distillation apparatus. The nitrogen content in the distillate was determined by titrating with 0.01 M standard HCl until the colour changed at the end-point from green to pink.

3.4.6.4 Available phosphorus

Colorimetric determination of phosphorus in water and soil extracts as described by Olsen and Sommers (1982) was done by weighing 2 g of soil into a reaction cup. Five millilitres of Melich 3 was added before extracting through Whatman filter paper. Five millilitres of Murphy and Riley colour reagent was added before the addition of 15 mL of distilled water. Phosphorus absorbance was read using the spectrophotometer.

3.4.6.5 Exchangeable acidity

This was determined using the KCl extraction method. Two grams of air-dry soil was weighed into a 150 mL plastic bottle. Twenty millilitres of 1 N KCl was added and shaken for an hour. This was later filtered through the Whatman filter paper into a conical flask. Three drops of phenolphthalein indicator were added and it was titrated against 0.01 N NaOH until the colourless solution turned pink.

3.4.6.6 Exchangeable bases

The exchangeable bases were determined from 5 g of air-dried soil using 100 mL neutral ammonium acetate as the extractant (Rhodes, 1982). Five grams of air-dried soil was weighed into a plastic bottle and 100 mL of neutral 1 M ammonium acetate was added. The mixture was mechanically shaken for 10 minutes and filtered through Whatman filter paper into a 100 mL volumetric flask. This was later made up to mark with acetate. Calcium and magnesium were determined from the extract by 0.01 M EDTA titration method, while sodium and potassium were determined using the flame photometer (Jackson, 1970).

3.4.6.7 Micronutrient extraction

The soil Fe, Cu, Mn, and Zn contents were determined using the hydrochloric acid procedure (Rhodes, 1982). Ten grams of soil was measured into a plastic bottle and 100 mL of 0.1 M HCl was added before a stopper was inserted. This was shaken for 10 minutes before filtering through Whatman filter paper No. 42. The nutrients were determined using the atomic absorption spectrometer (Adams *et al*., 1980).

3.4.6.8 Particle size distribution

The Bouyoucos hydrometer method was used to carry out the particle size analysis on the soil samples (Bouyoucos, 1951; Gee and Bauder, 1986). Fifty grams of air-dried soil was weighed into a dispersion cup. Twenty millilitres of 25% sodium hexametaphosphate (calgon) was added as the dispersant. Two hundred and fifty millilitres of water was added and the mixture was subjected to the mechanical stirrer for 10 minutes. After stirring, the suspension was decanted into a sedimentation cylinder through a 210-micron sieve. The coarse fraction collected in the sieve was oven-dried in a moisture can at 105°C and weighed. The suspension in the sedimentation cylinder was topped to the 1 L mark by adding distilled water. The temperature and density of the suspension were taken with the aid of a thermometer and the Bouyoucos hydrometer, respectively at 1 minute (silt and clay concentration) and 2 hours (clay concentration).

3.4.6.9 Soil moisture characteristics

Soil moisture retention within 0 – 15 cm and 15 – 30 cm depth was determined in the laboratory using tension table assembly (Topp and Zebchuk, 1979) for lower suctions (0 – 6 kPa) and pressure plate apparatus for higher matric suctions (10, 50, 100, 500, and 1,500 kPa), following Dane and Hopmans (2002) procedure. Soil available water (SAW) was estimated as the difference between field capacity (FC) obtained at 10 kPa (–100 cm water) and permanent wilting point (PWP) at 1500 kPa (–15,000 cm water) following eq. (12):

$$SAW = (\Theta_{FC} - \Theta_{PWP})/\rho_b \qquad (12)$$

where Θ is the gravimetric moisture content, (%) and ρ_b is the bulk density at the required depth in Mg m^{-3}.

3.4.6.10 Bulk density

After obtaining the constant weight of the soil samples by oven-drying at 105°C, bulk density was calculated using eq. (13) below:

$$\rho_b = \frac{Ms}{V_b} \qquad (13)$$

Where ρ_b is bulk density, M_s is mass of oven-dry soil and V_b is soil bulk volume.

3.4.6.11 Total porosity

This was computed from the measured bulk density (ρ_b) values as follows:

$$\text{Total porosity } (P_T) = (1 - \rho_b/\rho_s)\ 100 \qquad (14)$$

Where particle density (ρ_s) = 2.65 Mg m^{-3}

Other porosity characteristics were estimated as described by Mbagwu (1991) below:

$$\text{Macro porosity } (P_{ma}) = P_T - FC \qquad (15)$$

Where FC is volumetric moisture content at field capacity

$$\text{Micro porosity } (P_{mi}) = P_T - P_{ma} \qquad (16)$$

3.4.6.12 Saturated hydraulic conductivity (K_{sat})

Soil samples taken with cylindrical metal cores of 5 cm diameter and 5 cm height were used to determine the soil saturated hydraulic conductivity (K_{sat}) using the constant head permeameter (Reynolds *et al.*, 2002). Saturated hydraulic conductivity was calculated using eq. (17) as described by Hillel (2004).

$$K_{sat} = \frac{QL}{At\Delta H} \qquad (17)$$

where: Q is volume of the water that flows through the soil column (cm^3); A is the cross-sectional area of flow (soil core) through the soil column (cm^2); t is time interval (h); L is the length of soil column (cm); ΔH is hydraulic head drop (cm), equals the sum of the pressure head and gravitational head drops.

3.4.6.13 Soil penetration resistance

This was measured using an Eijkelkamp penetrologger (model 6.05), with a standard cone type of 1.0 cm^2, 60° and a penetration speed of 2 cm s^{-1}. Three replicate penetrations were made per treatment combination per block. The penetrologger used for the study is shown in Plate 3.2.

3.4.7 Crop parameters evaluated

In addition to the crop growth and yield parameters measured in Experiment 1, other parameters measured in this experiment are described as follows:

3.4.7.1 Shoot weight

This was measured on fresh and dry weight basis using a sensitive scale. The fresh weight was obtained by weighing the fresh shoot per plant, while the dry weight was measured by weighing after oven-drying to constant weight at 75°C.

3.4.8 Statistical analysis

Data analysis was carried out using GenStat statistical package (8th Edition). Data collected were subjected to analysis of variance (ANOVA) procedure while significantly different means were separated using Duncan Multiple Range Test at 5% probability level.

Plate 3.2: An Eijkelkamp penetrologger for determining soil penetration resistance

3.5 EXPERIMENT 3: Effects of land preparation, mulch and irrigation rates on soil properties, and okra growth and yield

This experiment consisted of two trials conducted between November, 2015 – February, 2016; and November, 2016 – February, 2017 at the Teaching and Research Farm of the Department of Agronomy, University of Ibadan.

3.5.1 Objectives: The objectives of the experiment were to:

i. evaluate the effects of land preparation and mulch types on selected soil properties and okra yield under dry season irrigation conditions;
ii. evaluate the effects of irrigation rates on some soil physical and chemical properties;
iii. assess the combined effects of land preparation, mulch and irrigation rates on soil properties and okra yield.

3.5.2 Field preparation

The experimental field was cleared with the aid of machete and hoe before the commencement of the experiment. Grasses were removed from the field by hand.

3.5.3 Experimental design

A 3 × 3 × 3 factorial experiment was conducted at the Teaching and Research Farm of the University of Ibadan during the off-set of the rainy season. The experiment was laid out in a randomized complete block design, having three land preparation types (Raised bed, Ridge and Flat), three mulch types [*Gliricidia sepium* Mulch (GsM), *Pennisetum purpureum* Mulch (PpM) and control (Zero mulch - ZM)], and three rates of irrigation water application (daily application of 100% ET_c, daily application of 75% ET_c and CROPWAT irrigation rate). Each treatment combination was replicated three times, giving a total of 81 experimental units, with each replicate measuring 3 m × 1.4 m. A spacing of 0.5 m was used to separate each replicate, while 1.5 m spacing was used between the irrigation treatments. The total land area of the experimental field was 739.2 m^2.

3.5.4 Land preparation

Raised beds and Ridges were done with the aid of a traditional hoe, while the Flat type was left undisturbed after clearing the field.

3.5.5 Irrigation treatments

The irrigation treatments adopted for this study included the:

a. daily application of 100% ET_c of the ET_o treatment that produced the best okra yield and water use efficiency in Experiment 1.
b. daily application of 75% ET_c of (a).
c. CROPWAT irrigation schedule

3.5.5.1 CROPWAT irrigation schedule

CROPWAT model 8.0 was used to schedule irrigation water for dry season okra production. Data inputted into the climate/ET_o, crop and soil modules are as follows:

(1) Climate module: Mean daily climate data that spanned from 1994 to 2013 for the best ET_o treatment of the Screenhouse study was inputted into this module. The climate parameters included minimum and maximum temperature, relative humidity, wind speed and solar radiation. Appendix 1 presents the weekly mean daily CROPWAT irrigation schedule used for the dry season field study. The effective rainfall was determined from the rainfall data using the United States Department of Agriculture, Soil Conservation Service (USDA-SCS) procedure as described by Sheng-Feng *et al*. (2006) below:

$$P_{eff} = \frac{P_{tot} \times 125 - 0.2P_{tot}}{125} \tag{18}$$

$$P_{eff} = (125 + 0.1 \times P_{tot}) \tag{19}$$

Where P_{eff} = effective rainfall (mm) and P_{tot} = total rainfall (mm). Equation (18) is valid for a rainfall of $P_{tot} \leq 250$ mm, while eq. (19) is valid for rainfall of $P_{tot} \geq 250$ mm.

(2) Crop module: The crop coefficient values of the variety and 100% ET_c used for this study was adopted. The rooting depth adopted for this study was derived as a mean of the okra taproot length obtained from the land preparation types in the preliminary study, while the maximum plant height adopted for this study was the highest plant height value recorded across the land preparation types.

(3) Soil module: Soil parameters such as the total available moisture was derived from soil moisture retention at field capacity and permanent wilting point obtained as mean values of data recorded under the three land preparation types in the preliminary study. The maximum rooting depth was determined by finding the mean of the maximum depth of root occurrence of the four sides of a 1.2 m mini-pit that was dug in the field trial plot (Plate 3.3).

3.5.6 Method of irrigation

Drip irrigation was adopted for this study. Eolos garden drip kits (Control number: 1331796) made by Eurodrip, United Kingdom were obtained from Kenya Agricultural Research Institute (KARI), Nairobi, Kenya. The driplines had a wall thickness of 15 mil (1 mil = 0.0254 mm), while its laterals had automatic emitters with a flow rate of 0.8 L hr^{-1}, spaced at an interval of 30 cm. Plate 3.4 shows drip irrigation installed on the field.

3.5.7 Source of water for irrigation

The water used for irrigation during the study was obtained from the stream that flows from the Faculty of Education, University of Ibadan, through the Research Farm at Parry Road, University of Ibadan. The distance between the closest point of the stream to the experimental field was 15.3 m, while the stream flows at 1.2 m below the surface soil of the experimental field. A Mitsubishi N25P–3 3.5ps gasoline engine water-pump was used to pump water from the stream to a 1,700 Litre tank which served as the primary reservoir from which water was measured and applied to each irrigation treatment as applicable.

3.5.8 Mulch application

Fresh *Gliricidia sepium* and *Pennisetum purpureum* leaves (Plate 3.5) were randomly collected within the study area. *Pennisetum purpureum* leaves were chopped to ≈10 cm before application, while *Gliricidia sepium* leaves were applied unaltered.

Plate 3.3: A mini-pit for determining the effective soil depth of the soil

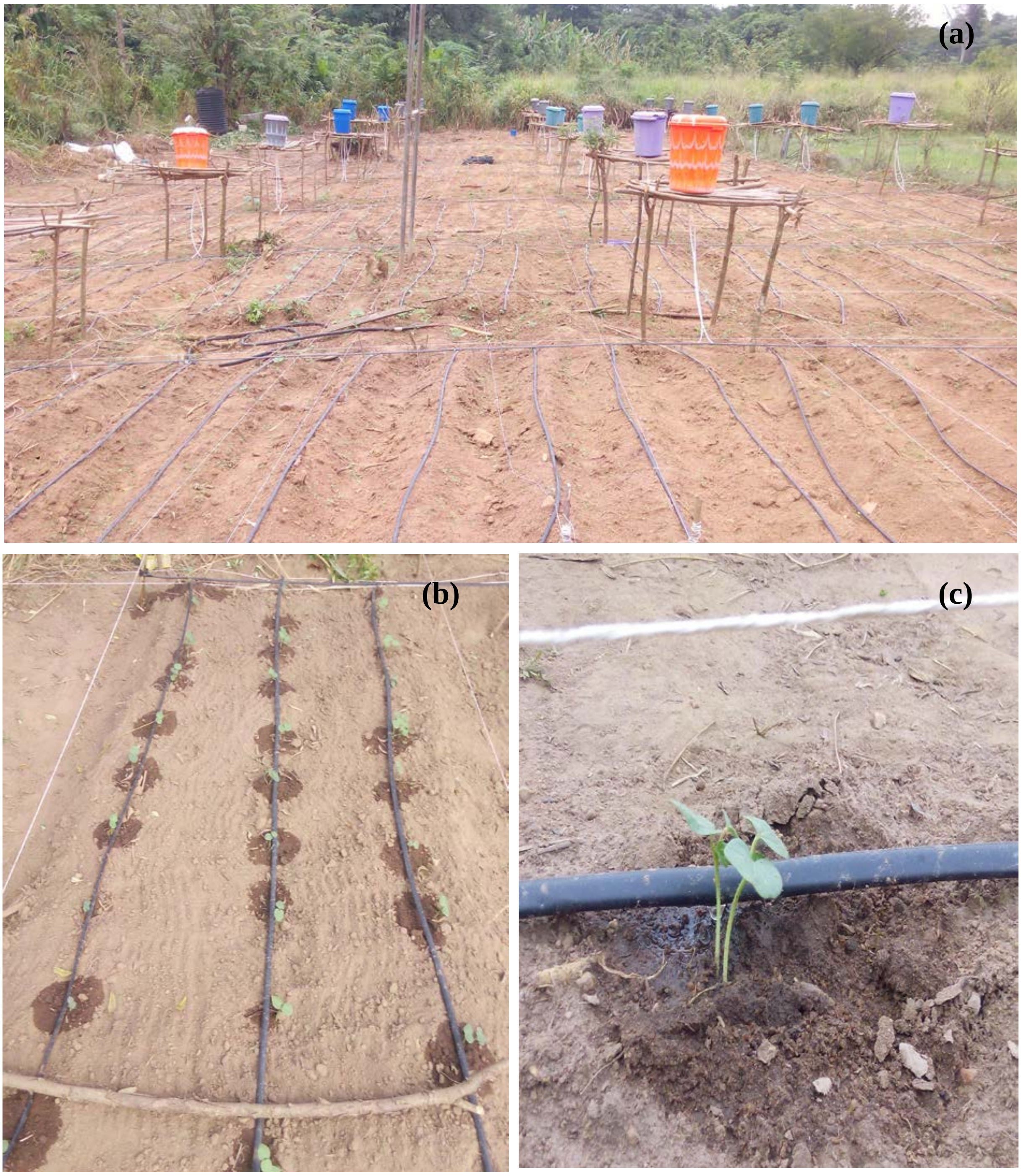

Plate 3.4: Installed drip irrigation showing (a) driplines prior to planting on the field, (b) drip wetting pattern around okra plants, and (c) its manner of water discharge

Plate 3.5: *Gliricidia sepium* leaves (a) and chopped *Pennisetum purpureum* leaves (b) used as mulch for the field experiment

The mulch materials were applied at a 6 t ha^{-1} (600 g m^{-2}) at two weeks after sowing.

3.5.9 Plant analysis

Prior to mulch application, fresh leaf samples of *Gliricidia sepium* and *Pennisetum purpureum* were oven-dried at 75°C and milled with Crown Star MC-42BL electric mill before being analysed for their various chemical components as described below:

3.5.9.1 pH

This was determined in a 1:1 ratio mixture of the milled plant sample and distilled water (Mclean, 1982). Ten grams of milled plant sample was weighed into a 50 ml beaker. Ten millilitres of distilled water was added and the mixture was stirred with a glass rod for 5 minutes. A glass-electrode pH meter was inserted into the suspension to measure the pH.

3.5.9.2 Electrical conductivity

This was determined using the Wheatstone bridge arrangement. The electrode was inserted into the plant-water paste of 1:1 ratio mixture. Sufficient contact between the electrode and the paste was made before the electrical conductivity value was recorded (Mclean, 1982; Udo and Ogunwale, 1986).

3.5.9.3 Organic carbon

This was determined using the loss on ignition method on both mulch materials. Five grams of milled *Gliricidia sepium* and *Pennisetum purpureum* leaf samples were weighed into porcelain crucibles, respectively. These crucibles were placed in a furnace and heated at 500°C for 2 hours when the mulch materials became light tan in appearance. The samples were allowed to cool after removing them from the furnace before reweighing. The loss in weight was determined for each sample by subtracting the final weight from the initial weight. Percentage carbon was calculated as follow:

$$\%\ \text{Carbon} = \frac{\text{Loss in weight}}{\text{Weight of sample used}} \times 100 \qquad (20)$$

3.5.9.4 Total nitrogen

Two grams of duplicate samples were weighed on a filter paper before being transferred to the kjeldhal flask. Two millilitres of distilled water was added and later left to stand for 30 minutes. A 0.02 g powdered pumice, 1.33 g K_2SO_4 catalyst mixture, and 1.5 mL concentrated H_2SO_4 was then added. The mixture was heated cautiously on the digestion rack until frothing stopped. This was allowed too cool after the digest cleared. Ten millilitres of deionized water was added slowly while swirling. The sample was swirled continuously until the undissolved materials were in suspension. The distillation apparatus was flushed with steam water to clean and bring it up to temperature. A 50 mL receiver flask containing 5 mL boric acid-indicator solution was placed under a condenser of the distillation apparatus. The flask with the digested and distilled sample was attached to the steam jet arm of the distillation apparatus. Ten millilitres of 50% NaOH–5% $Na_2S_2O_3$ solution through funnel stopcock. This was later rinsed after closing the stopper. Distillation was initiated by closing the steam by-pass forest, then opening the inlet stopcock on the steam jet arm of the distillation apparatus. When the distillate reached the 35 mL on the receiver flask, distillation was stopped by closing the inlet stopcock first, before opening the steam by-pass. The condenser tip was rinsed with deionized water. The distillate was titrated to first pink colour with 0.01 N H_2SO_4.

The percentage nitrogen was calculated as:

$$\% \text{ N} = \frac{(T - B) \times N \times 1400}{S} \tag{21}$$

Where, T = sample titre (mL), B = blank titre (mL), N = normality of H_2SO_4, and S = sample weight (mg).

3.5.9.5 Phosphorus

Colorimetric determination of phosphorus using vanado-molybdate (yellow) method was carried out. Two grams of the mulch samples were digested (wet) respectively, while 10 mL of the sample solution was extracted with a pipette into a 100 mL volumetric flask. Sixty millilitres of distilled water was added before adding 20 mL of vanado-molybdate reagent. The mixture was diluted to volume, mixed and left to stand for 10 minutes. A standard curve was developed by taking 0, 2, 4, 6 and 10 mL aliquots of the 25 µg P/mL standard solution in a series of 50 mL volumetric flasks and developing the colour. The percent transmittance was determined at 400 nm. Phosphorus was determined from a curve made from the standards.

3.5.9.6 Exchangeable bases

The exchangeable bases were extracted from 5 g of oven-dried plant sample using 100 mL neutral ammonium acetate as the extractant (Rhodes, 1982). Five grams of the oven-dried plant sample was weighed into a plastic bottle and 100 mL of neutral 1 M ammonium acetate was added. The mixture was mechanically shaken for 10 minutes and filtered through Whatman filter paper into a 100 mL volumetric flask. This was later made up to mark with acetate. Calcium and magnesium were determined from the extract by 0.01 M EDTA titration method, while sodium and potassium were determined using the flame photometer (Jackson, 1970).

3.5.9.7 Micronutrient extraction

The hydrochloric acid procedure was used to determine the Fe, Cu, Mn, and Zn content, respectively in the plant samples (Rhodes, 1982). Ten grams of the plant sample was weighed into a plastic bottle and 100 mL of 0.1 M HCl was added before a stopper was inserted. This was shaken for 10 minutes and filtered through Whatman filter paper No. 42. The nutrients were determined using the atomic absorption spectrometer (Adams *et al.*, 1980).

3.5.10 Water sampling

Water sample was collected in a sample bottle from the irrigation water source (stream) prior to application for the field study for laboratory analyses. The samples were homogenised before duplicating for analysis.

3.5.11 Water analysis

The irrigation water parameters and the procedure of analysis adopted for this study are as described in section 3.3.7.

3.5.12 Soil sampling

Disturbed soil samples were collected with the aid of an auger from three spots at 0 – 15 cm and 15 – 30 cm depth per replicate before bulking, respectively to form a composite sample. Triplicate sub-samples were taken per depth per treatment combination (total of 162 disturbed soil samples) for chemical analysis as described in Experiment 2. Two undisturbed soil samples were also taken from two spots at 0 – 15 cm and 15 – 30 cm per replicate (total of 162 undisturbed soil samples) for analysis as described in Experiment 2, respectively.

3.5.13 Data collection

Data collection involving soil, weed and crop parameters are as follows:

3.5.13.1 Soil data

Soil parameters determined in addition to those described in Experiment 2 are described as follows:

(1) Water stable aggregates and mean weight diameter

Water Stable Aggregates (WSA) was determined using a modified Kemper and Rosenau (1986) wet sieving method as described by Nimmo and Perkins (2002). Soil samples were collected at 0 – 15 cm and air dried. A wet-sieving method similar to that described by Kemper and Rosenau (1986), was adopted. The apparatus used for the procedure included a nest of sieves with apertures 4.75, 2.0, 1.0, 0.25 and 0.045 mm, and moisture cans (250 mL capacity).

Sodium hexametaphosphate (calgon - 0.5% $^{w}/_{v}$) was used to separate sand from soil aggregates. Fifty grams (50 g) of air-dry soil aggregates was weighed, after passing through 8 mm sieve. The initial mass was recorded as W_1. The soil sample was thereafter placed on the uppermost (4.75 mm) sieve with other nest of sieves: 2.0 mm, 1.0 mm, 0.25 mm and 0.045 mm placed below it in that order. The nest of sieves was immersed in water such that the soil at the top of 4.75 mm sieve was wet by capillarity. The height of the nest of sieves was adjusted such that the soil sample on the sieves remained immersed in water on the upstroke of the dipping machine. The set of sieves was cycled through the column of water for 10 minutes (30 cycles per min, 4.0 cm stroke length).

The soil retained on each sieve was washed into moisture cans with distilled water, respectively. Each fraction of the retained soil was oven dried at 105°C to a constant mass W_2. Water and 10 mL of calgon (sodium hexametaphosphate) (0.5% $^w/_v$) were added to the oven-dried soil for chemical dispersion and thereafter dispersed for 10 minutes using a mechanical stirrer. The two dispersion processes were carried out to separate the sand particles from the soil aggregates. The sand particles were washed into the corresponding moisture can before oven drying at 105°C to a constant mass W_3.

Computation of Water Stable Aggregate (WSA) and Mean Weight Diameter (MWD)

The proportion of water stable aggregate (WSA) in each of the sieve size fraction was calculated as follows:

$$WSA_i = \frac{W_{2i} - W_{3i}}{W_{1i} - W_3} \qquad (22)$$

where i = 1, 2, 3, ………………, n.

where W_1 = oven dried weight of soil sample

W_2 = oven dried mass of stable aggregate in each sieve fraction

W_3 = oven dried mass of sand particles in each sieve fraction.

Thus, the percentage water stable aggregate (% WSA) was calculated as:

$$\% \, WSA = \frac{W_{2i} - W_{3i}}{W_{1i} - W_{3i}} \times 100 \qquad (23)$$

Aggregate size distribution, in terms of mean weight diameter (MWD), was expressed as:

$$MWD = \sum x_i \, WSA_i \qquad (24)$$

where $\sum$ = summation of the result of all the sieves

i = 1, 2, 3… n

x = mean diameter of the two inter-layered sieve sizes.

The soil structural stability (SS) was estimated as described by Diaz-Zorita *et al.* (2002):

$$SS = \frac{WSA - W_{sand}}{W_{agg} - W_{sand}} \qquad (25)$$

where W_{sand} is the weight of sand particles measured after dispersion of the WSA (> 0.25 mm), and W_{agg} is the total weight of the sieved aggregates (1 to 2 mm diameter).

The soil structural stability index (S) was estimated as described below:

$$S = \frac{\text{Organic matter content (\%)} \times 100}{\text{Clay (\%)} + \text{Silt (\%)}} \qquad (26)$$

S is the structural stability index, where the critical values of S distinguished for numerous savannah soils of West Africa by Pieri (1989) is presented in Appendix 2.

(2) Micro aggregate stability

This involved the determination of the amounts of silt and clay in calgon-dispersed as well as water-dispersed soil samples using Bouyoucos hydrometer method of particle size analysis described by Gee and Bauder (1986).

$$\text{Dispersion ratio (DR)} = \frac{[\text{\% silt + clay } (H_2O)]}{[\text{\% silt + clay (calgon)}]} \times 100 \qquad (27)$$

$$\text{Aggregated silt + clay (ASC)} = [\text{\% silt + clay (calgon)}] - [\text{\% silt + clay } (H_2O)] \qquad (28)$$

$$\text{Clay flocculation index (CFI)} = \frac{[\text{\% clay (calgon)}] - [\text{\% clay } (H_2O)]}{[\text{\% clay (calgon)}]} \times 100 \qquad (29)$$

$$\text{Clay dispersion index (CDI)} = \frac{[\text{\% clay } (H_2O)]}{[\text{\% clay (calgon)}]} \times 100 \qquad (30)$$

(3) Soil penetration resistance

An Eijkelkamp penetrologger (model 6.05), with a standard cone type of 1.0 cm^2, 60° and a penetration speed of 2 cm s^{-1} was used to measure the soil resistance to penetration. Three penetrations were made per replicate per treatment combination, giving a total of 243 penetrations in all.

3.5.13.2 Weed data

Plate 3.6 showed the use of a quadrat for weed density data collection. Weed density was measured at two spots per replicate at 9 weeks after sowing. This was done by placing a 50 × 50 cm quadrat on the middle row, which covered an area occupied by four plant stands (Plant 4, 5, 6 and 7) respectively. The weed species within the quadrat were counted and later excavated using a hand trowel. They were rinsed with water to remove soil particles adhering to their roots and left to drain water for 1 hour before weighing fresh.

3.5.13.3 Crop data

As described in Experiment 2

3.5.14 Statistical analysis

Data analysis was carried out using GenStat statistical package (8th Edition). Data collected were subjected to analysis of variance (ANOVA) procedure while significantly different means were separated using Duncan Multiple Range Test at 5% probability level.

Plate 3.6: Quadrat adopted for weed data collection

CHAPTER 4

RESULTS

4.1 Characteristics of the soil of the experimental site

The physical and chemical properties of the soil of the experimental site are presented in Table 4.1. Although, the site was observed to contain lots of gravels, the soil was a loamy sand, with saturated hydraulic conductivity and bulk density values of 18.3 cm hr^{-1} and 1.46 Mg m^{-3}, respectively. The soil was low in fertility as indicated by a low organic carbon content (15.2 g kg^{-1}) and a total nitrogen content of 1.27 g kg^{-1}. The soil was slightly acidic, with a pH of 6.2, while its available phosphorus, calcium, potassium, manganese and zinc were of 32.0 mg kg^{-1}, 0.91 cmol kg^{-1}, 0.53 cmol kg^{-1}, 102.3 mg kg^{-1} and 1.94 mg kg^{-1}, respectively.

4.2 Screenhouse study

The results of the screenhouse study are presented as follows:

4.2.1 Chemical properties of the irrigation water used for the screenhouse study

The properties of the irrigation water are presented in Table 4.2. The irrigation water used for the screen-house study had nitrate and nitrate-nitrogen values of 0.10 and 0.35 mg L^{-1}, respectively, while boron and iron were 0.5 and 0.1 mg L^{-1}, respectively. The water was alkaline (pH value of 8.5) and an alkalinity of 2.8. The water acidity was 0.40, while its carbonate, sodium, calcium and manganese contents were 0.85, 33.0, 34.0, and 0.20 mg L^{-1}, respectively. The sodium adsorption ratio of the water was 10.64 meq L^{-1} and it had an electrical conductivity value of 497.0 µs cm^{-1}.

4.2.2 Weather conditions of the screenhouse during the study period

The weather conditions in the first (December, 2013 to February, 2014) and second (March to May, 2014) plantings of the screenhouse study are illustrated in Figure 4.1. The average ET_o during the first planting was 4.84 mm day^{-1}, while that

Table 4.1: Pre-experiment physical and chemical properties of the soil

Parameter	Value
pH	6.2
Organic carbon (g kg^{-1})	15.2
Total nitrogen (g kg^{-1})	1.27
Available phosphorus (mg kg^{-1})	32.0
EC (µS cm^{-1})	107.83
Exchangeable bases (cmol kg^{-1})	
Ca	0.91
Mg	0.48
Na	0.07
K	0.53
Exchangeable acidity (cmol kg^{-1})	0.30
Extractable micronutrients (mg kg^{-1})	
Mn	102.3
Fe	23.95
Cu	7.07
Zn	1.94
K_{sat} (cm hr^{-1})	18.3
Bulk density (Mg m^{-3})	1.46
Particle size distribution (g kg^{-1})	
Sand	836
Silt	44
Clay	120
Textural class	Loamy sand

Table 4.2: Chemical composition of the irrigation water used for the screenhouse study

Parameter	Value
pH	8.5
Phosphate (mg L^{-1})	0.34
Available P (mg L^{-1})	ND
Electrical conductivity (µs cm^{-1})	497.0
Acidity (mg L^{-1})	0.40
Alkalinity (mg L^{-1})	2.8
Carbonate (mg L^{-1})	0.85
Chloride (mg L^{-1})	70.0
Sulphate (mg L^{-1})	0.30
Boron (mg L^{-1})	0.50
Bicarbonate (mg L^{-1})	ND
Residual sodium carbonate (mg L^{-1})	0.02
Total suspended solid (mg L^{-1})	ND
Total dissolved solid (mg L^{-1})	ND
Nitrate (mg L^{-1})	0.10
Nitrate-N (mg L^{-1})	0.35
Sodium adsorption ratio (SAR) (meq L^{-1})	7.52
Ca (mg L^{-1})	34.0
Mg (mg L^{-1})	4.5
K (mg L^{-1})	17.1
Na (mg L^{-1})	33.0
Na %	56.6
Mn (mg L^{-1})	0.20
Fe (mg L^{-1})	0.10
Cu (mg L^{-1})	ND
Zn (mg L^{-1})	ND
Pb (mg L^{-1})	ND

ND = Not detected

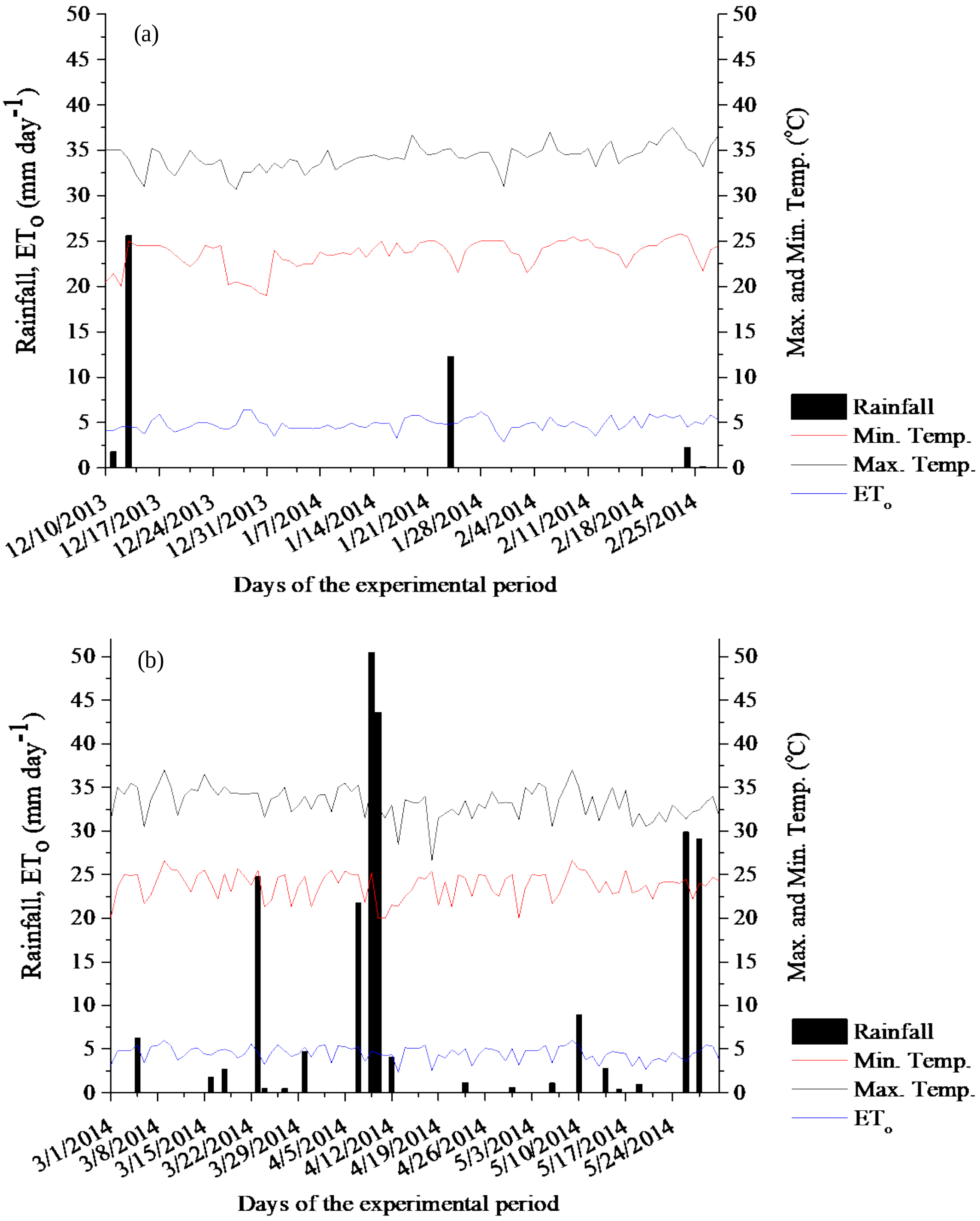

Figure 4.1: Weather characteristics of the (a) first and (b) second planting periods of the screenhouse study

of the second planting was 4.51 mm day^{-1}. However, the minimum temperature of the first planting was lower (23.5°C) than that recorded during the second planting (23.8°C), while the maximum temperature recorded during the first planting was higher (34.2°C) than that recorded during the second planting (33.3°C).

4.2.3 Effects of reference evapotranspiration rates on growth indicators of okra varieties

The growth indices of okra varieties NH47-4 and UI4-30 irrigated with three levels of reference evapotranspiration (ET_o-N, ET_o-M and ET_o-I, respectively) at 2 to 10 WAS at first and second plantings are presented as follows:

4.2.3.1 Number of leaves

Significant ($p<0.05$) variations were observed in the number of leaves of okra varieties grown under the different reference evapotranspiration rates from 2 WAS to 10 WAS at first and second plantings, respectively.

At the first planting, UI4-30 recorded a high mean number (2.5) of leaves than NH47-4 (2.3 leaves) at 2 WAS. Although, NH47-4 recorded higher mean number of 3.5 and 4.5 leaves than UI4-30 (3.0 and 4.2 leaves) at 3 and 4 WAS, respectively, UI4-30 recorded high mean number of leaves between 6.2 and 6.3 at 5 to 10 WAS, with its significantly ($p<0.05$) high peak value of 7.5 at 7 WAS. The NH47-4 also had low mean values between 5.7 and 5.2 at 5 to 10 WAS, while its peak value was 6.8 at 8 WAS (Figure 4.2). With respect to the ET_o treatments, the number of okra leaves produced was only significantly ($p<0.05$) influenced at 10 WAS. Okra plants irrigated with ET_o-M recorded low mean number of 2.3, while those under ET_o-I and ET_o-N had 2.5 leaves at 2 WAS, respectively. Furthermore, okra plants irrigated with ET_o-N recorded the highest mean number of leaves between 3.5 and 6.3 at 3 to 10 WAS, with the peak value of 7.5 at 8 WAS. Low number of leaves was recorded for ET_o-M (3.3 – 6.0) and ET_o-I (3.0 – 5.0), with peak values of 7.0 and 6.7 leaves at 7 and 8 WAS, respectively (Figure 4.2).

Unlike the first planting, UI4-30 had consistently higher number of leaves (2.5 – 6.3) than NH47-4 (2.3 – 5.3 leaves) at 2 to 10 WAS, with significant ($p<0.05$) difference at 8 WAS at the second planting, respectively. The peak values for both varieties were 8.2 for UI4-30 and 7.7 for NH47-4 at 7 WAS (Figure 4.3). Moreover, the number of okra leaves only differed significantly ($p<0.05$) at 8 WAS under the

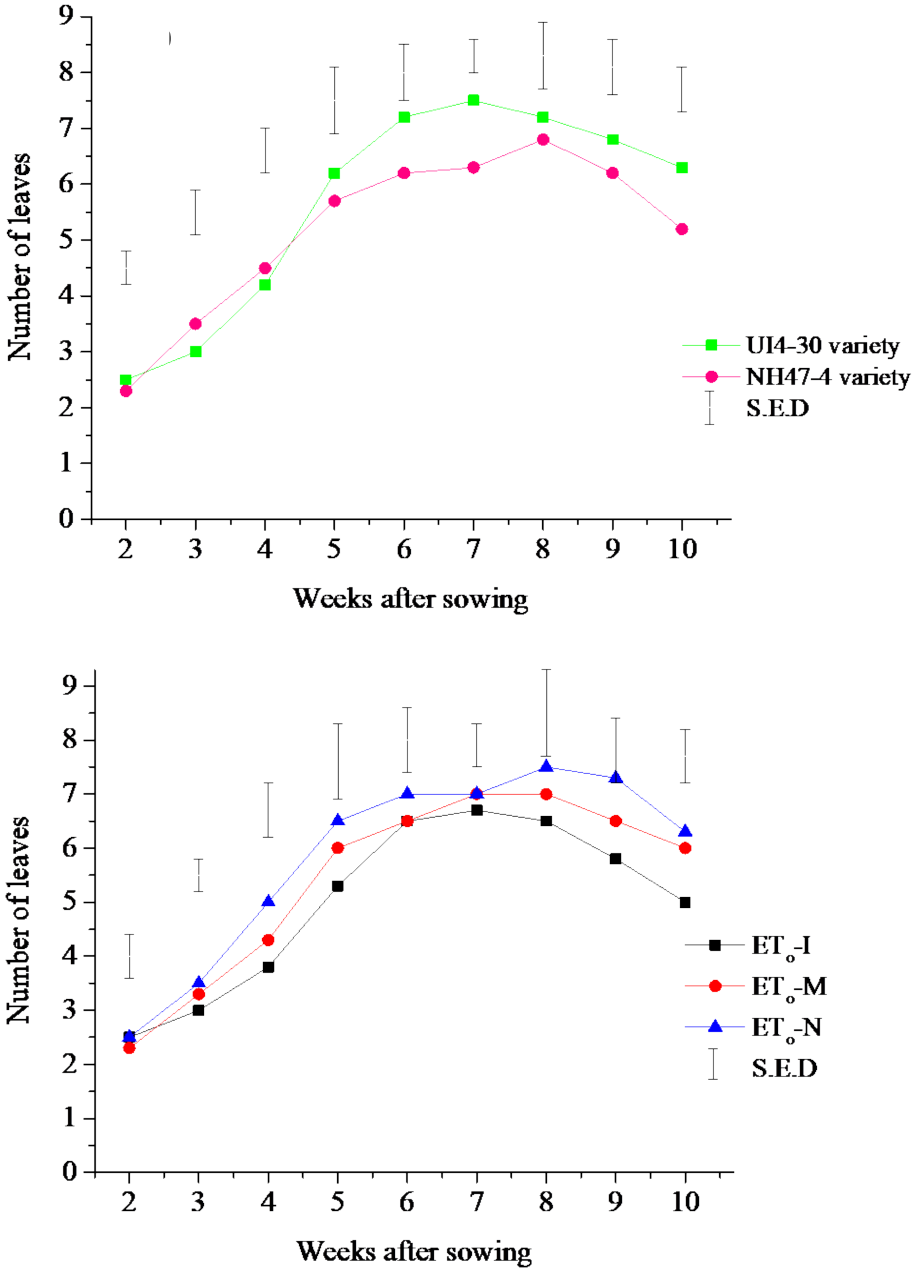

Figure 4.2: Varietal (a) and reference evapotranspiration (b) effects on okra number of leaves at the first planting

Where: ET_o-I = Reference evapotranspiration derived from the International Institute of Tropical Agriculture weather data; ET_o-N = Reference evapotranspiration derived from the Nigerian Meteorological Agency weather data; ET_o-M = Reference evapotranspiration obtained as mean of ET_o-I and ET_o-N.

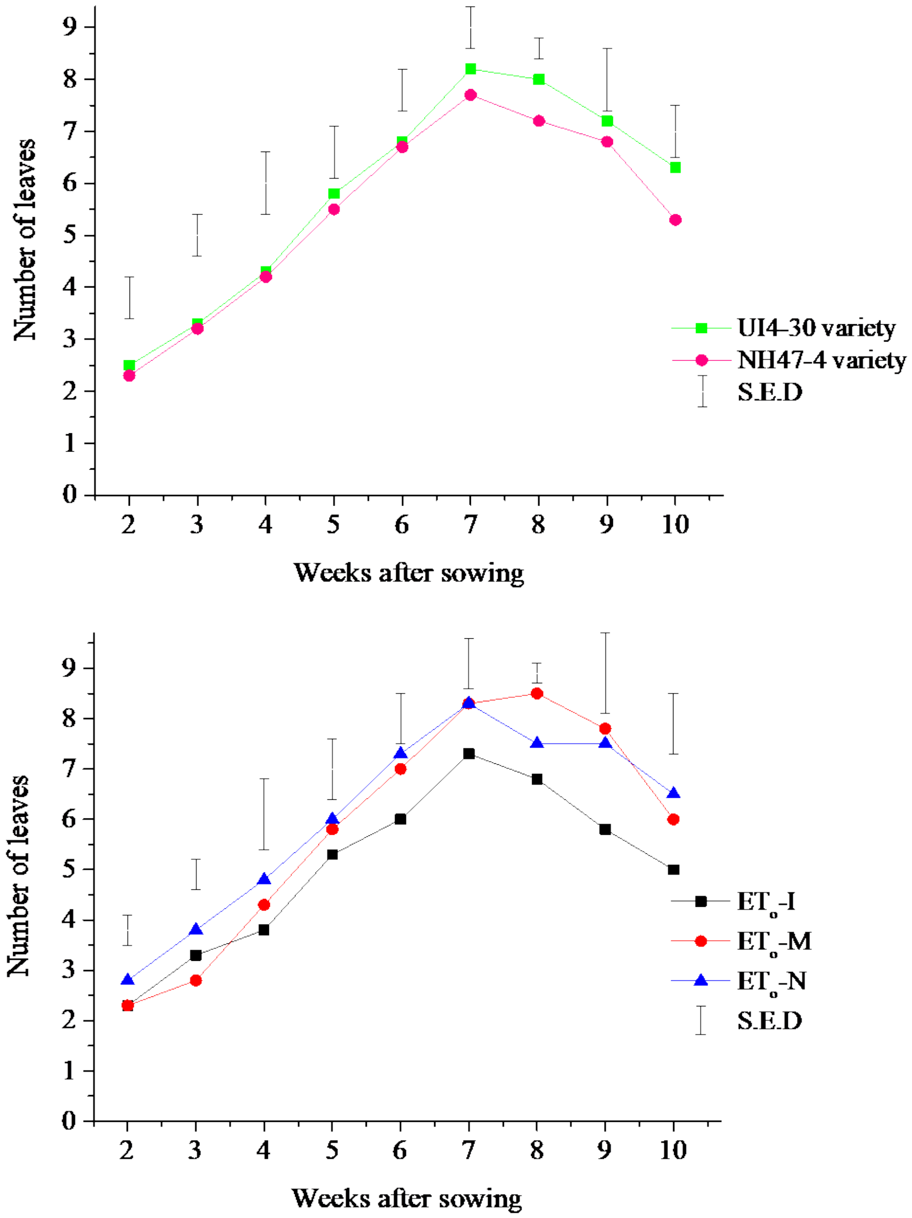

Figure 4.3: Varietal (a) and reference evapotranspiration (b) effects on okra number of leaves at the second planting

Where: ET$_o$-I = Reference evapotranspiration derived from the International Institute of Tropical Agriculture weather data; ET$_o$-N = Reference evapotranspiration derived from the Nigerian Meteorological Agency weather data; ET$_o$-M = Reference evapotranspiration obtained as mean of ET$_o$-I and ET$_o$-N.

different ET_o levels. Okra plants irrigated with ET_o-N recorded the highest number of leaves (2.8 – 8.3) at 2 to 7 WAS, while low values for number of leaves were recorded by plants irrigated with ET_o-M (2.3 – 8.3) and ET_o-I (2.3 – 7.3) at 2 to 7 WAS. At 8 and 9 WAS, okra plants irrigated with ET_o-M recorded the highest number of leaves (8.5 and 7.8), while low values were recorded by okra plants under ET_o-N (7.5 leaves, respectively) and ET_o-I (6.8 and 5.8 leaves). The number of leaves at 10 WAS was in the order: ET_o-N (6.5) > ET_o-M (6.0) > ET_o-I (5.0) as shown in Figure 4.3.

4.2.3.2 Plant height

Figure 4.4 presents the results of plant height of okra varieties grown under different reference evapotranspiration (ET_o) rates at 2 to 10 WAS during the first planting. The growth trend for plant height was similar for all the varieties under the different ET_o rates, with observed increase in plant height from 2 to 10 WAS and the highest value recorded at 10 WAS when the collection of growth data was terminated.

With the exception of 2, 6 and 7 WAS, there was significant ($p<0.05$) variation in the height of UI4-30 and NH47-4 across the ET_o treatments at the first planting. Irrespective of the ET_o-N treatments UI4-30 recorded higher mean plant height values than NH47-4, with its highest value (44.8 cm) at 10 WAS, while a low mean plant height value of 41.7 cm was recorded by NH47-4 at 10 WAS (Figure 4.4). With the exception of 2 WAS, okra plants irrigated with ET_o-N recorded significantly ($p = 0.05$) higher plant height values (12.8 – 46.2 cm) than those irrigated with ET_o-M (9.6 – 44.9 cm) and ET_o-I (10.2 – 38.6 cm) at 3 to 10 WAS, respectively (Figure 4.4). Similarly, UI4-30 had consistently higher plant height than NH47-4 irrespective of the ET_o treatments, with significant ($p<0.05$) differences at 2 to 7 WAS, at the second planting, respectively. Although, there was no significant ($p = 0.05$) difference in the plant height at 10 WAS, UI4-30 recorded a higher plant height (48.3 cm) than NH47-4 (44.0 cm) at the second planting (Figure 4.5). Across the okra varieties, significant ($p<0.05$) differences were observed among the plant height values recorded under the different ET_o levels. Here, plant height was in the order: ET_o-N > ET_o-M > ET_o-I, with ET_o-N recording the highest plant height of 49.6 cm than ET_o-M (47.2 cm) and ET_o-I (41.7 cm) at 10 WAS (Figure 4.5).

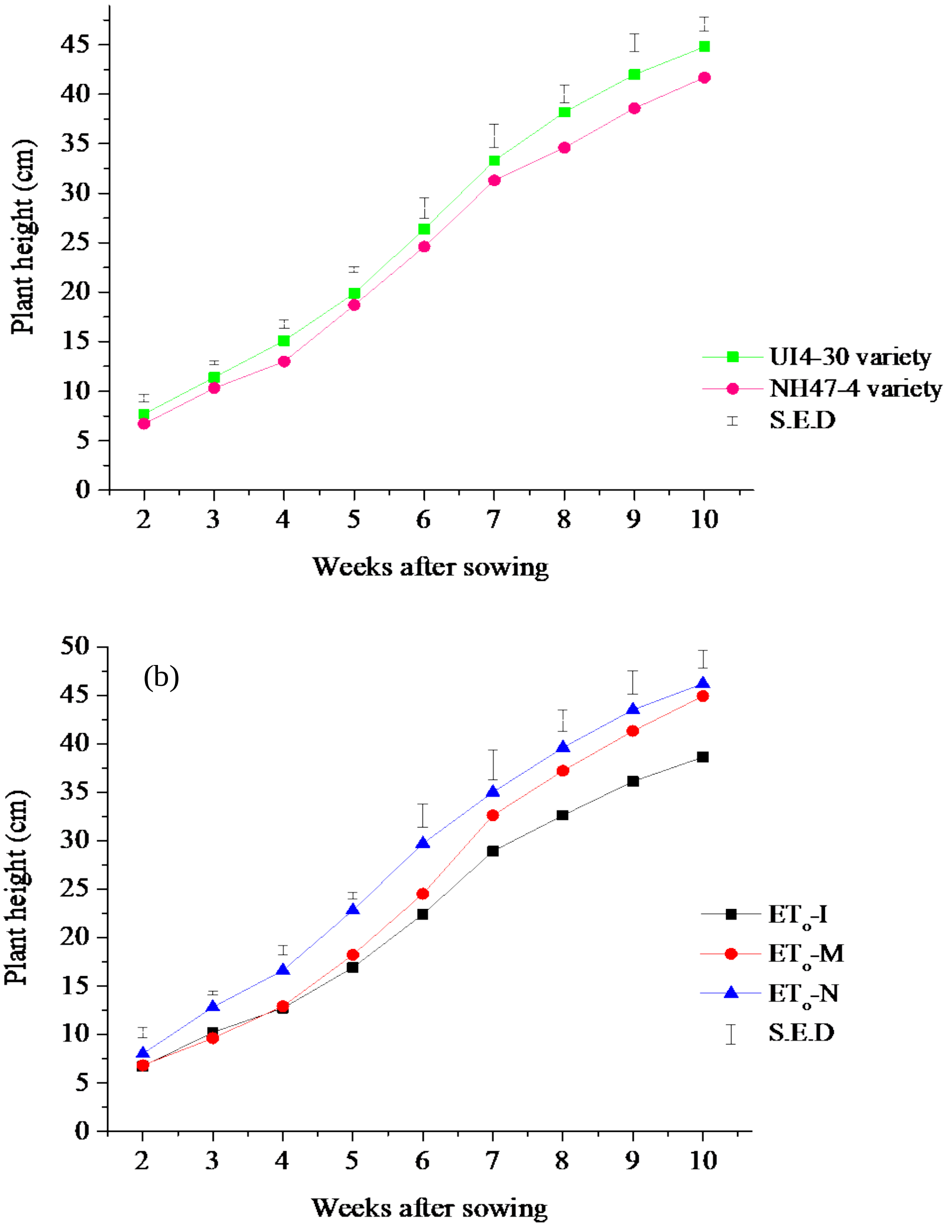

Figure 4.3: Varietal (a) and reference evapotranspiration (b) effects on okra plant height at the first planting

Where: ET_o-I = Reference evapotranspiration derived from the International Institute of Tropical Agriculture weather data; ET_o-N = Reference evapotranspiration derived from the Nigerian Meteorological Agency weather data; ET_o-M = Reference evapotranspiration obtained as mean of ET_o-I and ET_o-N.

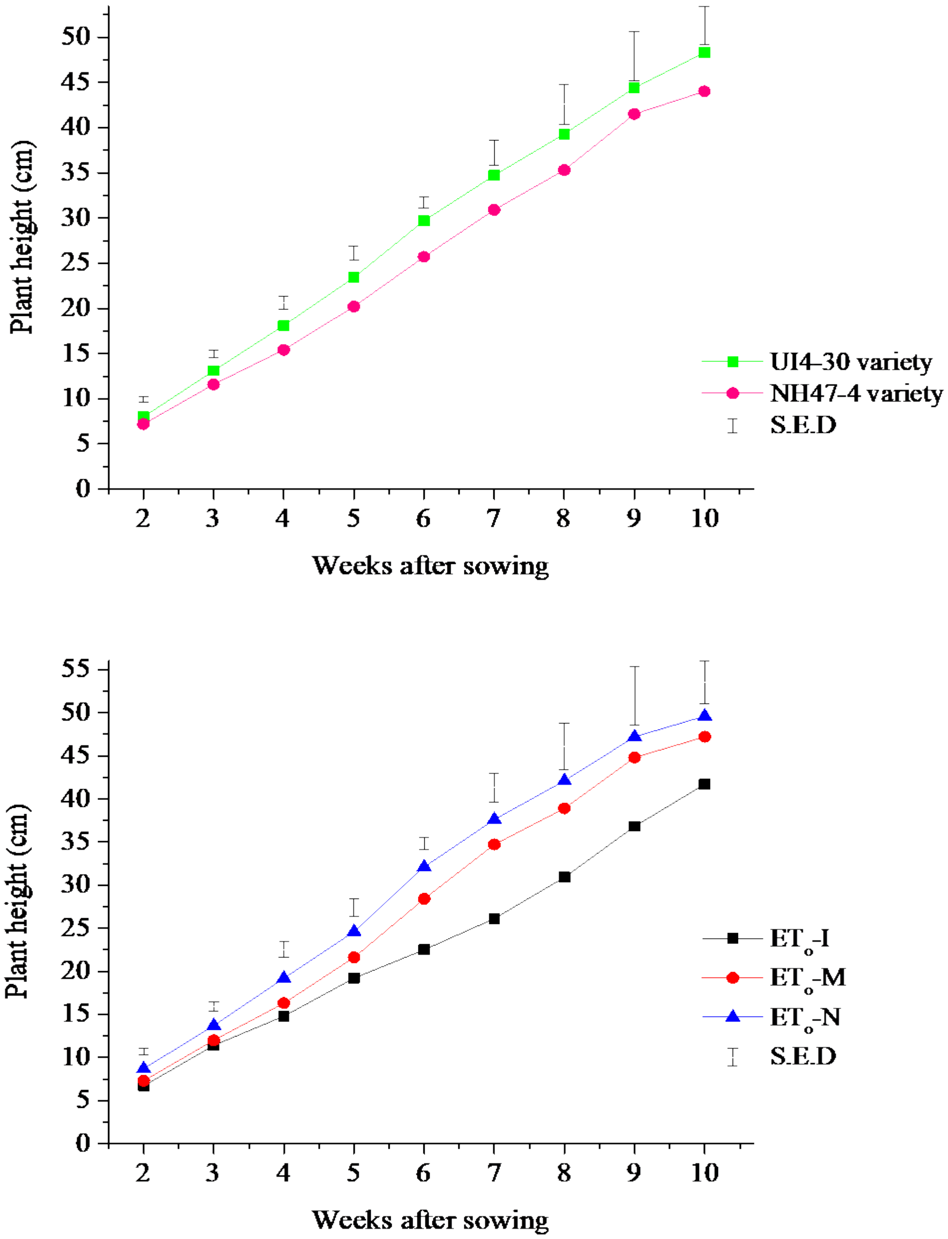

Figure 4.5: Varietal (a) and reference evapotranspiration (b) effects on okra plant height at the second planting

Where: ET$_o$-I = Reference evapotranspiration derived from the International Institute of Tropical Agriculture weather data; ET$_o$-N = Reference evapotranspiration derived from the Nigerian Meteorological Agency weather data; ET$_o$-M = Reference evapotranspiration obtained as mean of ET$_o$-I and ET$_o$-N.

4.2.3.3 Stem diameter

The stem diameters of okra varieties irrigated with different ET_o rates are illustrated in Figures 4.6 and 4.7. There was no significant ($p = 0.05$) difference among the values obtained for stem diameter of okra varieties irrigated with different ET_o levels at 2 to 10 WAS at the first and second plantings, respectively.

At the first planting, the mean stem diameter recorded was in the order: UI4-30 > NH47-4, where UI4-30 recorded a higher mean stem diameter of 7.91 mm than NH47-4 (7.66 mm) at 10 WAS (Figure 4.6). Conversely, okra plants irrigated with ET_o-I recorded the highest mean stem diameter (1.57 mm) at 2 WAS. Although, ET_o-I also recorded higher mean stem diameter (2.49 mm) than ET_o-M (2.47 mm), okra plants irrigated with ET_o-N recorded the highest mean stem diameter of 8.41 mm at 10 WAS, while okra plants under ET_o-M and ET_o-I recorded lower values of 7.99 and 6.96 mm at 10 WAS respectively (Figure 4.6).

Furthermore, at the second planting, UI4-30 recorded higher stem diameter values of 1.77 and 2.75 mm compared to NH47-4 (1.73 and 2.66 mm) at 2 and 3 WAS, respectively. However, at 4 to 10 WAS, NH 47-4 recorded consistently high stem diameter values within the range of 3.77 – 8.75 mm) than UI4-30 (3.74 – 8.17 mm), respectively (Figure 4.7). With respect to the ET_o levels, okra plants irrigated with low irrigation water of ET_o-I recorded consistently low stem diameter within the range of 1.68 – 7.81 mm at 2 to 10 WAS, respectively (Figure 4.7). Although, okra plants irrigated with medium irrigation water level of ET_o-M recorded a higher stem diameter value of 1.79 mm than ET_o-N (1.78 mm) at 2 WAS, okra plants irrigated with ET_o-N recorded higher values (3.01 and 4.04 mm) compared to ET_o-M (2.57 and 3.79 mm) at 3 and 4 WAS, respectively, while at 5 to 10 WAS, ET_o-M recorded higher values within the range of 5.22 – 9.12 mm than ET_o-N (5.04 – 8.42 mm), respectively (Figure 4.7).

4.2.4 Agro-climatic parameters of okra varieties grown under three reference evapotranspiration (ET_o) rates

The results of the crop evapotranspiration (ET_c) and crop coefficient (K_c) values of okra varieties UI4-30 and NH47-4 irrigated with different reference evapotranspiration (ET_o) rates at 2 to 10 WAS at first and second planting are as follows:

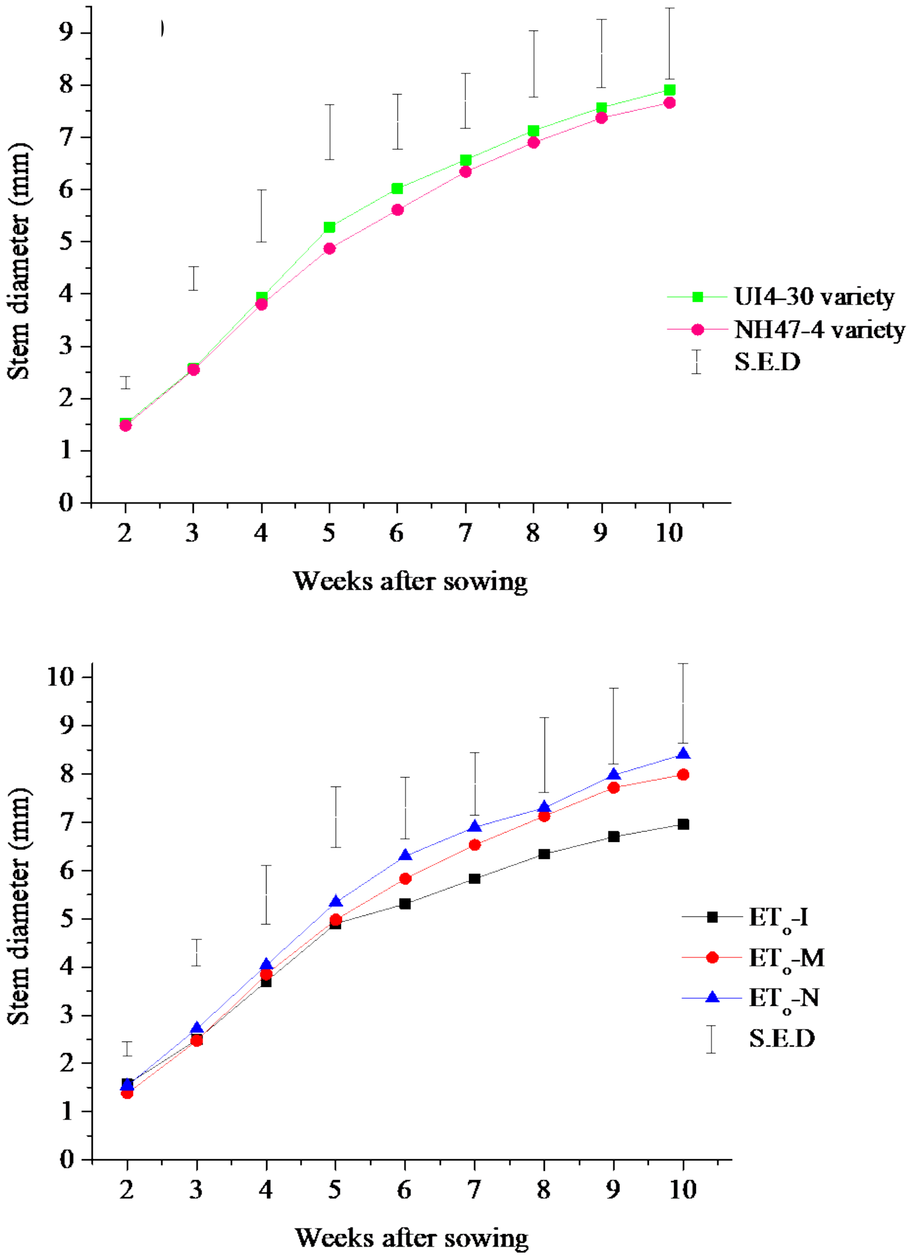

Figure 4.6: Varietal (a) and reference evapotranspiration (b) effects on okra stem diameter at the first planting

Where: ET_o-I = Reference evapotranspiration derived from the International Institute of Tropical Agriculture weather data; ET_o-N = Reference evapotranspiration derived from the Nigerian Meteorological Agency weather data; ET_o-M = Reference evapotranspiration obtained as mean of ET_o-I and ET_o-N

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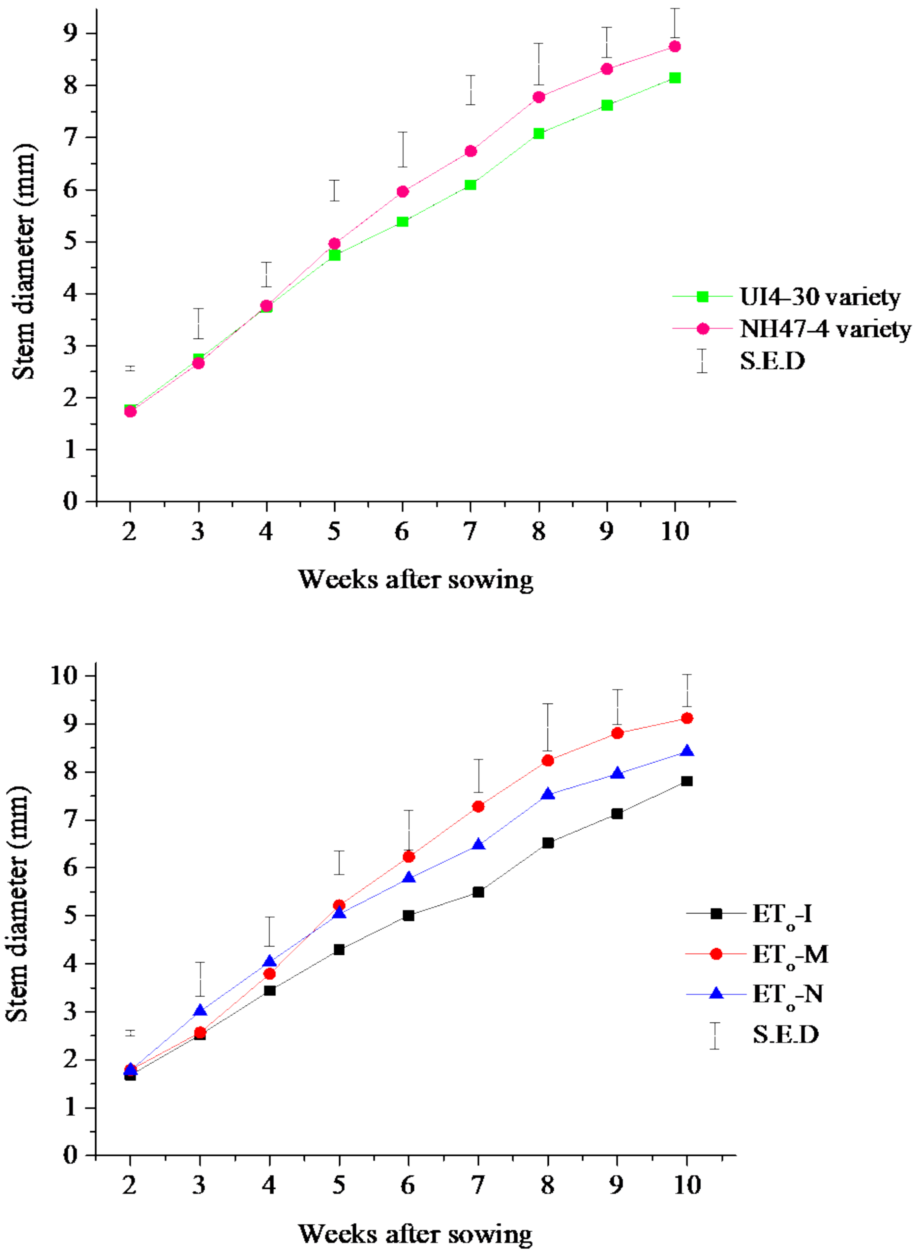


Figure 4.7: Varietal (a) and reference evapotranspiration (b) effects on okra stem diameter at the second planting

Where: ET$_o$-I = Reference evapotranspiration derived from the International Institute of Tropical Agriculture weather data; ET$_o$-N = Reference evapotranspiration derived from the Nigerian Meteorological Agency weather data; ET$_o$-M = Reference evapotranspiration obtained as mean of ET$_o$-I and ET$_o$-N.

4.2.4.1 Crop evapotranspiration (ET_c)

The results of the crop evapotranspiration (ET_c) of the okra varieties irrigated with three reference evapotranspiration (ET_o) treatments at 2 to 10 WAS at first and second plantings are illustrated in Figures 4.8 and 4.9. The ET_c of the okra varieties under the ET_o levels were observed to increase from 2 WAS till the attainment of their respective peak values between 7 and/or 8 WAS, respectively before decreasing in value at 9 WAS at first and second plantings, respectively.

During the first planting, okra ET_c only differed significantly ($p<0.05$) between UI4-30 and NH47-4 at 8 WAS. Irrespective of the ET_o treatments, NH47-4 recorded higher ET_c values between the range of 1.42 – 1.88 mm day^{-1} than UI4-30 (1.31 – 1.76 mm day^{-1}) at 2 to 4 WAS. However, at 5 to 9 WAS, UI4-30 had higher ET_c values (2.56 – 3.25 mm day^{-1}) than NH47-4 (2.54 – 2.99 mm day^{-1}), while at 10 WAS, NH47-4 recorded a higher ET_c value (2.46 mm day^{-1}) than UI4-30 (2.33 mm day^{-1}) (Figure 4.8). With respect to the ET_o levels, there were significant ($p<0.05$) variations in okra ET_c at 2 and 4 – 8 WAS, respectively. Okra plants irrigated with ET_o-N recorded the highest ET_c in the range of 1.68 – 2.87 mm, while those irrigated with ET_o-M had mean ET_c values between 1.34 – 2.49 mm, while those under ET_o-I recorded the lowest ET_c values between 1.07 – 1.83 mm at 2 to 10 WAS, respectively (Figure 4.8).
At the second planting, okra ET_c between NH47-4 and UI4-30 was similar at 2 to 10 WAS. Considering the okra varieties at 2 WAS, ET_c value for NH47-4 (1.04 mm day^{-1}) was higher than that of UI4-30 (1.00 mm day^{-1}), while at 3 and 4 WAS, UI4-30 recorded higher ET_c values (1.40 and 1.82 mm day^{-1}) than NH47-4 (1.34 and 1.72 mm day^{-1}). Although, NH47-4 recorded a higher ET_c value (2.21 mm day^{-1}) than UI4-30 (2.18 mm day^{-1}) at 5 WAS, UI4-30 recorded consistently higher ET_c values within the range of 2.81 – 2.26 mm day^{-1} than NH47-4 (2.75 – 1.97 mm day^{-1}) at 6 – 10 WAS (Figure 4.9). Unlike the trend at the first planting, okra plants irrigated with ET_o-I recorded higher ET_c values (1.01 – 2.21 mm day^{-1}) than plants irrigated with ET_o-M (0.97 – 2.02 mm day^{-1}) at 2 to 5 WAS during the second planting, respectively. Although, okra plants irrigated with ET_o-M recorded higher ET_c values (2.72 – 1.98 mm day^{-1}) than plants under ET_o-I (2.16 – 1.91 mm day^{-1}) at 6 to 10 WAS, respectively, ET_o-N irrigated plants recorded the highest ET_c in the range of 1.82 – 2.46 mm day^{-1} at 2 to 10 WAS, respectively (Figure 4.9).

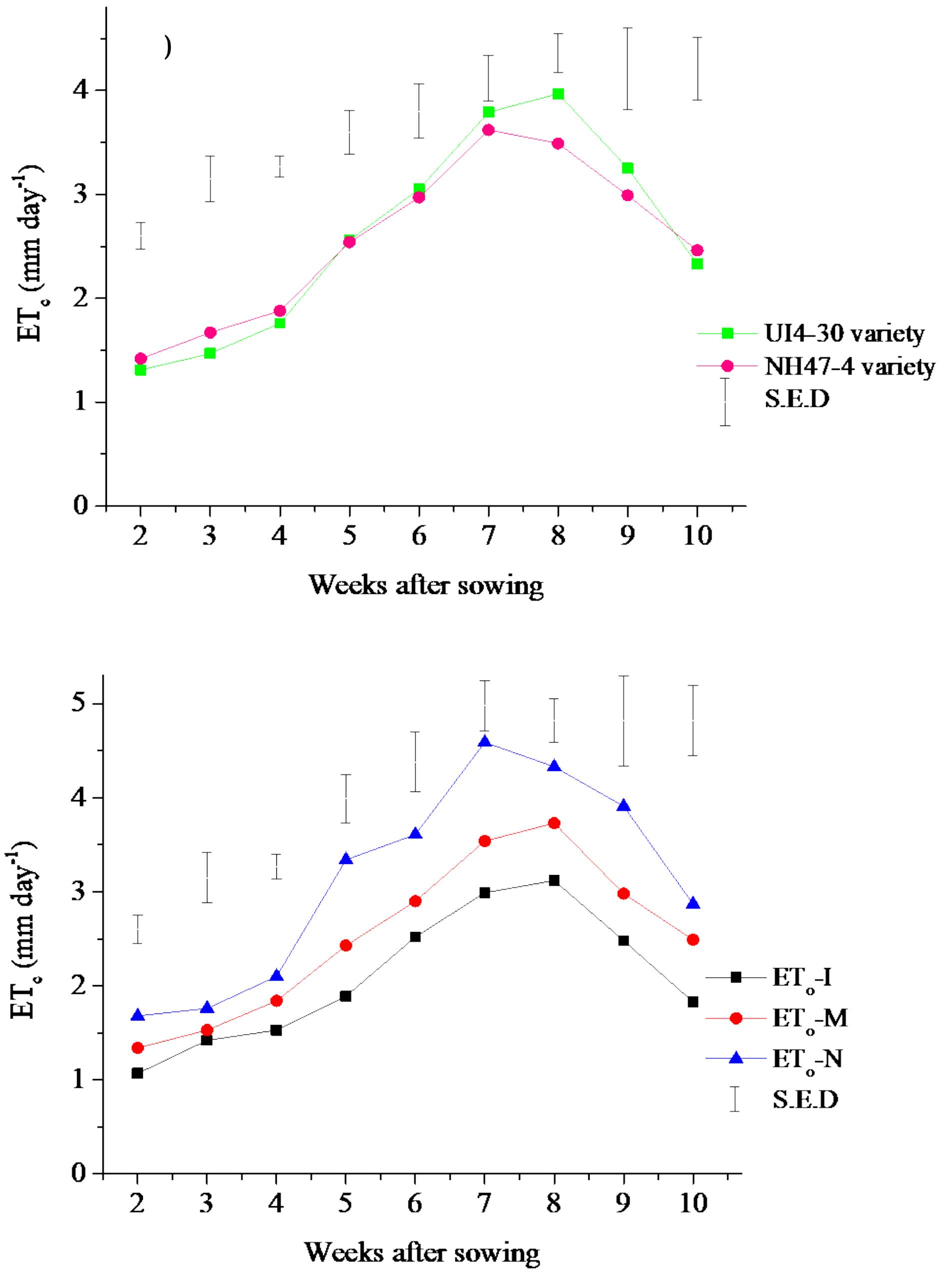


Figure 4.8: Varietal (a) and reference evapotranspiration (b) effects on the crop evapotranspiration of okra at the first planting

Where: ET_o-I = Reference evapotranspiration derived from the International Institute of Tropical Agriculture weather data; ET_o-N = Reference evapotranspiration derived from the Nigerian Meteorological Agency weather data; ET_o-M = Reference evapotranspiration obtained as mean of ET_o-I and ET_o-N.

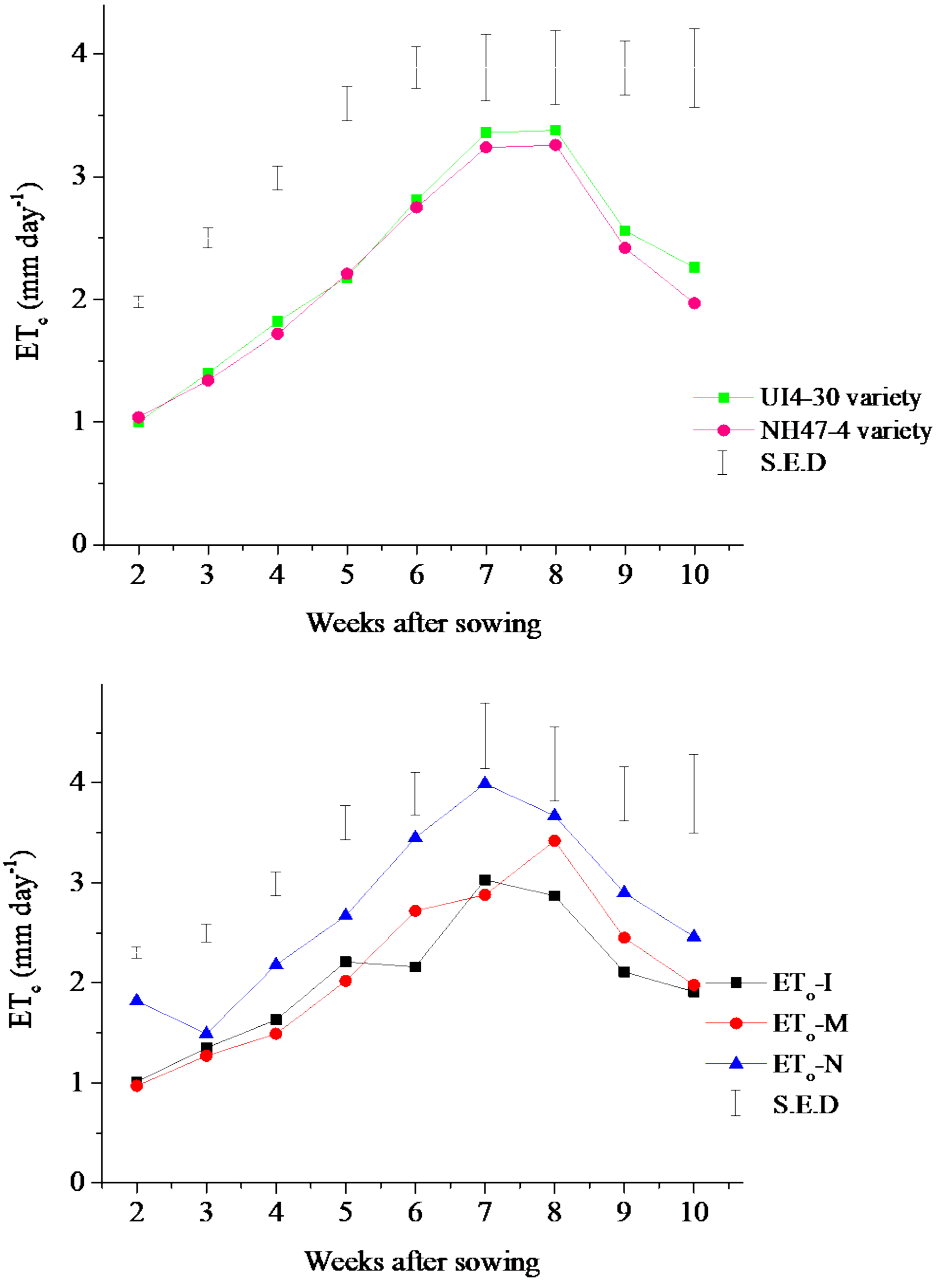


Figure 4.9: Varietal (a) and reference evapotranspiration (b) effects on the crop evapotranspiration of okra at the second planting

Where: ET$_o$-I = Reference evapotranspiration derived from the International Institute of Tropical Agriculture weather data; ET$_o$-N = Reference evapotranspiration derived from the Nigerian Meteorological Agency weather data; ET$_o$-M = Reference evapotranspiration obtained as mean of ET$_o$-I and ET$_o$-N.

4.2.4.2 Crop coefficient

The mean crop coefficient (K_c) values for okra varieties irrigated with the different ET_o treatments from 2 to 10 WAS at first and second planting are reported as follows. Okra varieties irrigated with different ET_o treatments recorded peak K_c values at 7 and 8 WAS, respectively, with drops in K_c values observed for UI4-30 and NH47-4 under the different ET_o treatments at 8 and 9 WAS, respectively.

Though, there was no significant ($p = 0.05$) variation in K_c values of UI4-30 and NH47-4 at the first planting, NH47-4 recorded higher K_c values (0.34 – 0.38) than UI4-30 (0.32 – 0.36) at 2 to 4 WAS, respectively. At 5 to 9 WAS, UI4-30 recorded higher K_c values between the range of 0.51 – 0.63 than NH47-4 (0.50 – 0.58) respectively, while NH47-4 recorded a higher K_c value of 0.47 than UI4-30 (0.45) at 10 WAS (Figure 4.10). Similarly, the K_c of okra was statistically similar among the ET_o treatments. At 2 WAS, okra plants irrigated with ET_o-N recorded the highest ET_c value of 0.36, while ET_o-M and ET_o-I had low K_c values of 0.33 and 0.30, respectively. However, okra plants irrigated with ET_o-I recorded higher K_c values of 0.39, 0.39, 0.65 and 0.77 than ET_o-N (0.37, 0.34, 0.59 and 0.75) and ET_o-M (0.38, 0.37, 0.58 and 0.71) at 3, 4, 6 and 7 WAS, respectively. At 8 to 10 WAS, okra K_c values were in the order: ET_o-N (0.78 – 0.52) > ET_o-M (0.72 – 0.48) > ET_o-I (0.66 – 0.39), respectively (Figure 4.10).

At the second planting, there was no significant ($p = 0.05$) difference in the K_c values of UI4-30 and NH47-4 at 2 to 10 WAS. At 2 WAS, NH47-4 recorded a higher K_c value (0.21) than UI4-30 (0.20), while UI4-30 recorded higher K_c values of 0.28 and 0.36 than NH47-4 (0.27 and 0.34) at 3 and 4 WAS, respectively. Although NH47-4 had higher K_c value (0.47) than UI4-30 (0.46) at 5 WAS, UI4-30 recorded higher K_c values between the range of 0.60 – 0.55 than NH47-4 (0.58 – 0.48) at 6 to 10 WAS, respectively (Figure 4.11). With respect to the ET_o treatments, K_c was only significantly ($p = 0.05$) different at 4 and 6 WAS, respectively. Okra plants irrigated with ET_o-I had the highest K_c values (0.22 and 0.03) at 2 and 3 WAS, while low K_c values were recorded by ET_o-I (0.20 and 0.28) and ET_o-M (0.19 and 0.25) at 2 and 3 WAS, respectively. At 4 to 7 WAS, okra plants irrigated with ET_o-N recorded high K_c values (0.40 – 0.78) than those irrigated with ET_o-I (0.36 – 0.72) and ET_o-M (0.30 – 0.62), respectively. Although, okra plants irrigated with ET_o-M recorded the highest K_c value (0.73) at 8 WAS, the ET_o-N irrigated plants recorded higher K_c values (0.65 and 0.55) than ET_o-M (0.60 and 0.48) and ET_o-I (0.56 and 0.51) at 9 and 10 WAS,

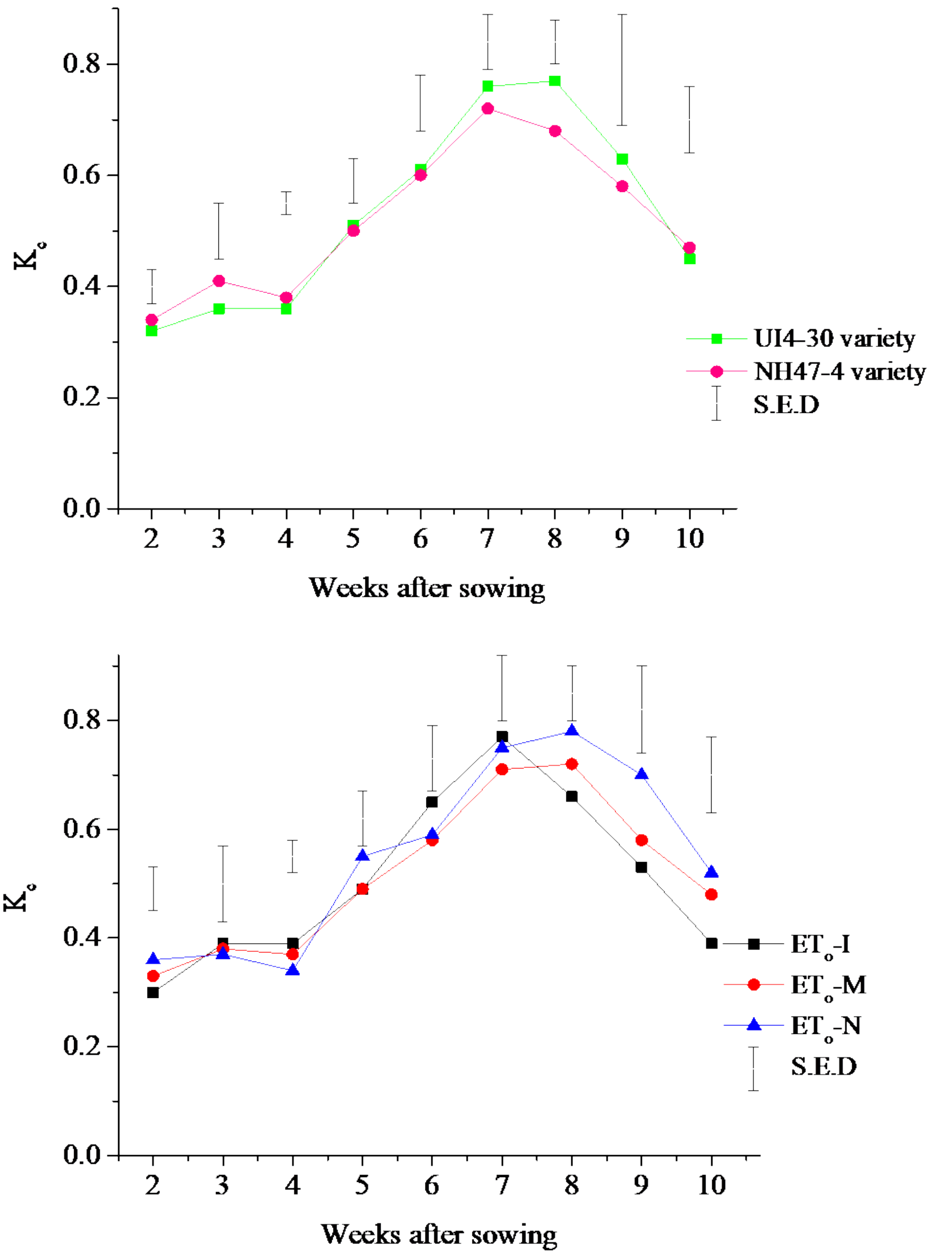


Figure 4.10: Varietal (a) and reference evapotranspiration (b) effects on the crop coefficient of okra at the first planting

Where: ET$_o$-I = Reference evapotranspiration derived from the International Institute of Tropical Agriculture weather data; ET$_o$-N = Reference evapotranspiration derived from the Nigerian Meteorological Agency weather data; ET$_o$-M = Reference evapotranspiration obtained as mean of ET$_o$-I and ET$_o$-N.

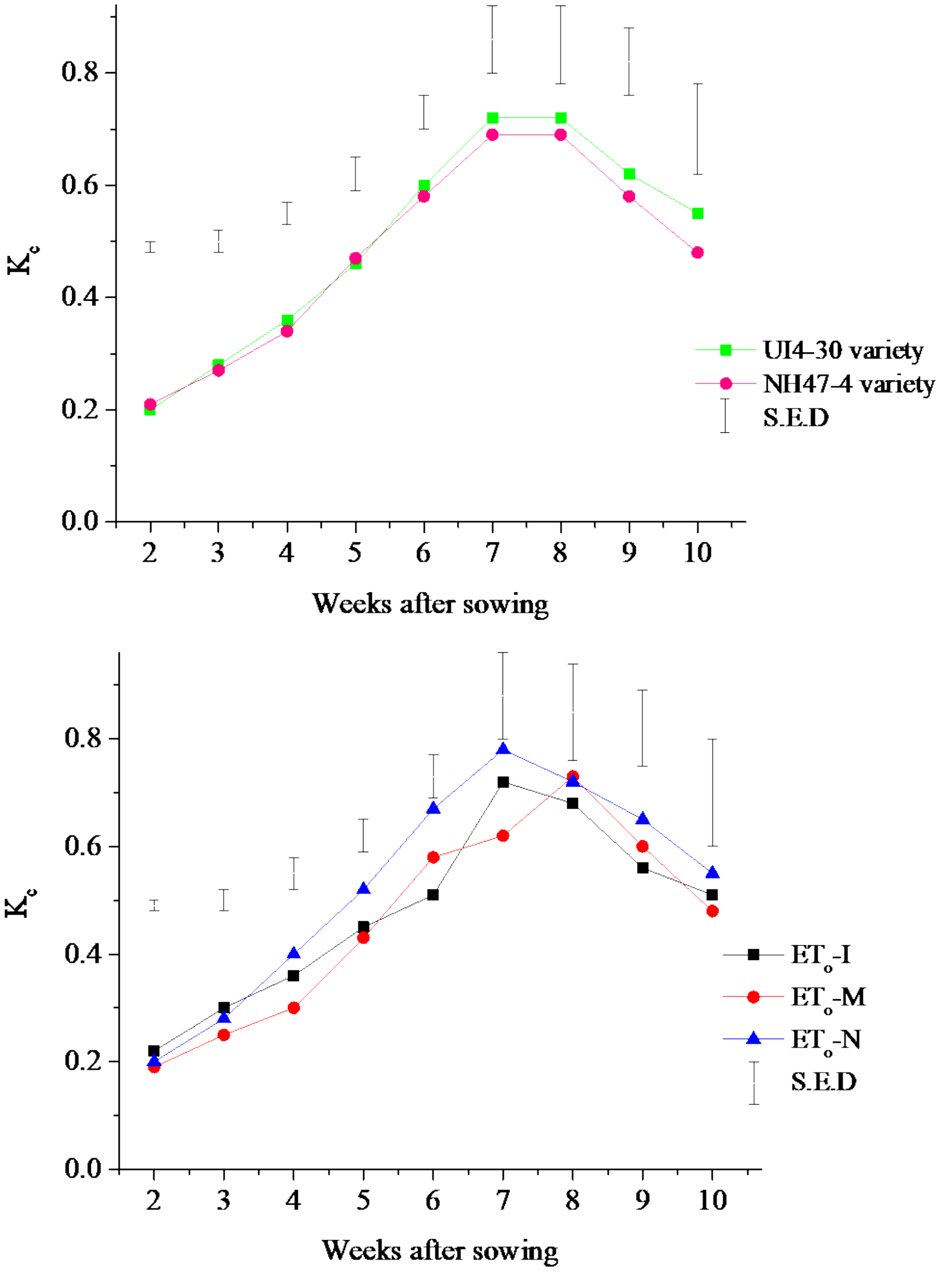


Figure 4.11: Varietal (a) and reference evapotranspiration (b) effects on the crop coefficient of okra at the second planting

Where: ET_o-I = Reference evapotranspiration derived from the International Institute of Tropical Agriculture weather data; ET_o-N = Reference evapotranspiration derived from the Nigerian Meteorological Agency weather data; ET_o-M = Reference evapotranspiration obtained as mean of ET_o-I and ET_o-N.

respectively (Figure 4.11).

4.2.5 Effects of reference evapotranspiration rates on yield parameters of okra varieties

The results of the yield parameters of okra varieties grown under the three irrigation levels (ET_o-M, ET_o-I and ET_o-N) at the first and second planting are presented in Table 4.3.

4.2.5.1 Number of pods per plant

UI4-30 produced significantly ($p<0.05$) higher number of pods than NH47-4 at the first and second planting respectively, irrespective of irrigation treatments (Table 4.3). At the first planting, UI4-30 produced an average of 3.8 pods plant^{-1} while NH47-4 had an average of 2.4 pods plant^{-1} (Table 4.3). Irrespective of varieties, okra plants irrigated with ET_o-N recorded high mean number of pods (4.0) per plant. This was significantly ($p<0.05$) higher than the mean number of pods produced by ET_o-M (3.0 pods plant^{-1}) and ET_o-I (2.3 pods plant^{-1}) at the first planting (Table 4.3). The interaction between the ET_o treatments and okra varieties did not significantly ($p = 0.05$) influence the number of pods produced at first planting (Table 4.3).

Similar to the first planting, okra pods produced by UI4-30 were significantly ($p<0.05$) higher (4.6 pods plant^{-1}) than those produced by NH47-4 (3.1 pods plant^{-1}) at the second planting (Table 4.4). On the other hand, okra plants irrigated with ET_o-N produced significantly ($p<0.05$) higher number of pods (5.3 pods plant^{-1}) than okra plants irrigated with ET_o-M (3.7 pods plant^{-1}) and ET_o-I (2.5 pods plant^{-1}) at the second planting (Table 4.4). The interaction between the ET_o treatments and okra variety also significantly ($p<0.05$) influenced the number of pods produced at the second planting (Table 4.4).

4.2.5.2 Fresh pod weight

The results of the weight of okra fresh pods (FPW) produced by UI4-30 and NH47-4 under the different ET_o treatments at first and second planting are presented in Tables 4.3 and 4.4, respectively. At the first planting, UI4-30 recorded significantly ($p<0.05$) higher FPW (9.76 g plant^{-1}) than NH47-4 which had a mean FPW value of

Table 4.3: Okra yield as influenced by variety and evapotranspiration at the first planting

Treatment	Number of pods per plant	Fresh pods weight	Dry pods weight	Fresh pod length (cm pod^{-1} plant^{-1})	Fresh pod diameter (mm pod^{-1} plant^{-1})	100 seed weight (g)
		g plant^{-1}				
Variety						
NH47-4	2.4±0.24	8.78±1.61	1.34±0.16	4.2±0.79	8.47±1.52	3.93±0.04
UI4-30	3.8±0.40	9.76±1.86	2.38±0.43	4.6±0.72	9.69±1.31	4.30±0.06
S.E.D	0.33	ns	0.17	ns	0.50	0.06
Evapotranspiration (ET_o)						
ET_o-M	3.0±0.37ab	9.72±0.28a	1.51±0.20b	4.4±0.22	9.37±0.36a	4.04±0.11b
ET_o-I	2.3±0.21b	7.47±0.72b	1.15±0.04b	3.9±0.39	7.75±0.70b	4.06±0.05b
ET_o-N	4.0±0.58a	10.62±0.34a	2.93±0.53a	4.9±0.23	10.13±0.28a	4.25±0.12a
S.E.D	0.41	0.68	0.20	ns	0.61	0.07
S.E.D (Variety × ET_o)	ns	ns	0.29	ns	ns	ns
CV (%)	22.7	12.8	19.0	16.1	11.6	2.9

Means with the same letter(s) under the same category in the same column are not significantly different at p = 0.05; ns = not significant at p = 0.05; CV (%) = Coefficient of variation

Table 4.4: Okra yield as influenced by variety and evapotranspiration at the second planting

Treatment	Number of pods per plant	Fresh pods weight (g plant^{-1})	Dry pods weight (g plant^{-1})	Fresh pod length (cm pod^{-1} plant^{-1})	Fresh pod diameter (mm pod^{-1} plant^{-1})	100 seed weight (g)
Variety						
NH47-4	3.1±0.93	9.16±0.95	3.03±0.93	4.4±0.38	9.98±0.89	3.93±0.16
UI4-30	4.6±2.13	10.51±0.47	4.18±1.70	5.7±0.37	9.63±0.79	4.57±0.18
S.E.D	0.40	ns	0.23	0.45	ns	0.06
Evapotranspiration (ET_o)						
ET_o-M	3.7±0.42ab	9.53±1.32	3.36±0.41b	5.1±0.50ab	10.83±1.22	4.21±0.18
ET_o-I	2.5±0.22b	9.27±0.95	2.38±0.13b	4.2±0.29b	7.78±0.67	4.18±0.10
ET_o-N	5.3±0.84a	10.71±0.32	5.08±0.52a	5.9±0.56a	10.82±0.49	4.37±0.17
S.E.D	0.49	ns	0.28	0.56	ns	ns
S.E.D (Variety × ET_o)	0.69	ns	0.40	ns	ns	0.11
CV (%)	22.2	25.0	13.5	19.0	23.0	3.1

Means with the same letter(s) under the same category in the same column are not significantly different at p = 0.05; ns = not significant at p = 0.05; CV (%) = Coefficient of variation

8.78 g plant^{-1} (Table 4.3). With respect to the ET_o treatments, okra plants grown under ET_o-N recorded significantly ($p<0.05$) higher FPW value of 10.62 g plant^{-1} than ET_o-M and ET_o-I which had mean FPW values of 9.72 and 7.47 g plant^{-1}, respectively (Table 4.3). The interaction between ET_o and variety was observed to significantly ($p<0.05$) influence the FPW of okra pods produced at the first planting (Table 4.3).

At the second planting, there was no significant ($p = 0.05$) difference between the FPW of UI4-30 and NH47-4 (Table 4.4). However, UI4-30 had higher FPW (10.51 g plant^{-1}) than NH47-4 (9.16 g plant^{-1}). There was also no significant ($p = 0.05$) difference in the FPW of okra pods produced under the different ET_o treatments. Okra pods irrigated with ET_o-N recorded the highest FPW value of 10.71 g plant^{-1}, followed by ET_o-M (9.53 g plant^{-1}), and least by ET_o-I (9.53 g plant^{-1}) (Table 4.4). Furthermore, the FPW of okra pods produced was not significantly ($p = 0.05$) affected by the interaction between the ET_o treatments and okra varieties during the second planting (Table 4.4).

4.2.5.3 Okra pod length

The results of the length of okra pods (PL) produced by UI4-30 and NH47-4 under the ET_o treatments at the first and second planting are presented in Tables 4.3 and 4.4, respectively.

At the first planting, there was no significant ($p = 0.05$) difference between the PL of UI4-30 and NH47-4, although, UI4-30 recorded higher mean PL value (4.6 cm pod^{-1} plant^{-1}) than NH47-4 (4.2 cm pod^{-1} plant^{-1}) (Table 4.3). There was also no significant ($p = 0.05$) variation in okra PL under the different ET_o treatments. However, okra pods produced under ET_o-N had higher mean PL value (4.9 cm pod^{-1} plant^{-1}) than those produced under ET_o-M (4.4 cm pod^{-1} plant^{-1}) and ET_o-I (3.9 cm pod^{-1} plant^{-1}) (Table 4.3). In addition, there was no significant ($p = 0.05$) difference in the PL values recorded among the interaction combinations of ET_o and variety (Table 4.3).

Furthermore, at the second planting, UI4-30 had significantly ($p<0.05$) higher mean PL value (5.7 cm pod^{-1} plant^{-1}) than NH47-4 (4.4 cm pod^{-1} plant^{-1}) (Table 4.4). Considering the ET_o treatments, okra plants irrigated with ET_o-N had significantly ($p<0.05$) higher mean PL value of 5.9 cm than those irrigated with ET_o-M (5.1 cm pod^{-1} plant^{-1}) and ET_o-I (4.2 cm pod^{-1} plant^{-1}) (Table 4.4). There was no significant (p =

0.05) difference in the mean PL values recorded under the influence of the ET_o × variety interaction (Table 4.4).

4.2.5.4 Okra pod diameter

The results of the diameter of the fresh okra pods (PD) produced at the first and second planting are presented in Tables 4.3 and 4.4. At the first planting, the okra pods produced by UI4-30 had significantly ($p<0.05$) higher PD value (9.69 mm pod^{-1} $plant^{-1}$) than NH47-4 pods (8.47 mm pod^{-1} $plant^{-1}$) as shown in Table 4.3. The ET_o treatments also had significant ($p<0.05$) effect on okra PD, with pods produced under the ET_o-N treatment recording the highest value of 10.13 mm pod^{-1} $plant^{-1}$, while okra plants irrigated with ET_o-M and ET_o-I had low PD values of 9.37 and 7.75 mm pod^{-1} $plant^{-1}$, respectively (Table 4.3). However, there was no significant ($p = 0.05$) variation in the PD of okra under the influence of the ET_o × variety interaction (Table 4.3).

Contrary to the results obtained at the first planting, there was no significant ($p = 0.05$) difference in the PD of okra pods produced by UI4-30 and NH47-4 at the second planting. Here, NH47-4 recorded higher mean PD value (9.98 mm pod^{-1} $plant^{-1}$) than UI4-30 (9.63 mm pod^{-1} $plant^{-1}$) (Table 4.4). There was no significant ($p = 0.05$) variation in okra PD under the influence of the ET_o treatments. However, okra pods produced under ET_o-M recorded the highest mean PD value of 10.83 mm pod^{-1} $plant^{-1}$, while ET_o-N had a mean PD value of 10.82 mm pod^{-1} $plant^{-1}$, and ET_o-I recorded the least PD value of 7.78 mm pod^{-1} $plant^{-1}$ (Table 4.4). Furthermore, there was no significant ($p = 0.05$) variation in the PD values recorded among the various ET_o × variety interaction combinations (Table 4.4).

4.2.5.5 Dry pod weight

The dry weight of okra pods (DPW) produced by UI4-30 and NH47-4 under the influence of the ET_o treatments at the first and second planting are presented in Tables 4.3 and 4.4, respectively. At the first planting, UI4-30 recorded a significantly ($p<0.05$) higher mean DPW value (2.38 g $plant^{-1}$) than NH47-4 (1.34 g $plant^{-1}$) (Table 4.3). The DPW differed significantly ($p<0.05$) among the ET_o treatments. Okra plants irrigated with ET_o-N recorded the highest mean DPW value of 2.93 g $plant^{-1}$, while okra plants under ET_o-M had a mean DPW value of 1.51 g $plant^{-1}$, and the least DPW value of 1.15 g $plant^{-1}$ was recorded by okra plants irrigated with ET_o-I (Table 4.3). In addition, the ET_o × variety interaction had significant ($p<0.05$) influence on the DPW of okra pods produced (Table 4.3).

Similar to the results obtained at the first planting, UI4-30 recorded significantly ($p<0.05$) higher DPW value (4.18 g plant^{-1}) than NH47-4 (3.03 g plant^{-1}) at the second planting (Table 4.4). Furthermore, significant ($p<0.05$) differences in DPW were recorded among the ET_o treatments. Okra pods produced under ET_o-N recorded the highest DPW value of 5.08 g plant^{-1}, while low DPW values were recorded by pods produced under ET_o-M (3.36 g plant^{-1}) and ET_o-I (2.38 g plant^{-1}) (Table 4.4). In addition, okra DPW significantly ($p<0.05$) varied under the influence of the ET_o × variety interaction (Table 4.4).

4.2.5.6 One hundred seed weight

The results of the weight of 100 seeds of okra produced by UI4-30 and NH47-4 under different ET_o treatments are shown in Tables 4.3 and 4.4. Across ET_o treatments, the weight of 100 seeds of okra pods produced by UI4-30 was significantly ($p<0.05$) higher (4.30 g) than those produced by NH47-4 (3.93 g) at the first planting (Table 4.3). In contrast, okra plants irrigated with ET_o-N recorded the highest 100 seed weight of 4.25 g. This was significantly ($p<0.05$) higher than 100 seed weight of 4.06 and 4.04 g recorded by okra plants irrigated with ET_o-I and ET_o-M, respectively at first planting (Table 4.3). However, the interaction between ET_o and variety did not significantly ($p = 0.05$) influence the weight of 100 seeds of okra pods produced (Table 4.3).

Similarly, UI4-30 recorded a significantly ($p<0.05$) higher 100 seed weight value of 4.57 g than NH47-4 which had 100 seed weight of 3.93 g across all the ET_o treatments at the second planting (Table 4.4). Although, the ET_o treatments did not significantly ($p = 0.05$) affect the weight of 100 seeds of okra produced, okra plants irrigated with ET_o-N recorded high 100 seed weight (4.37 g) than those obtained from plants irrigated with ET_o-M (4.21 g) and ET_o-I (4.18 g) at the second planting (Table 4.4). Contrary to the results obtained under the individual treatments, the weight of 100 seeds obtained from pods produced under the influence of the ET_o × variety interaction was significantly ($p = 0.05$) different (Table 4.4).

4.2.6 Shoot weight of okra as affected by reference evapotranspiration rates

There results for okra shoot weight as influenced by differences in variety and ET_o rates are reported as follows:

4.2.6.1 Fresh shoot weight

There was significant ($p<0.05$) difference between the fresh shoot weight (FSW) of UI4-30 (g plant^{-1}) and NH47-4 (1.96 g plant^{-1}) at the first planting (Table 4.5). The FSW of okra varied among the ET_o treatments, where okra plants irrigated with ET_o-N recorded the highest FSW of 2.36 g plant^{-1}, while those irrigated with ET_o-M had mean FSW of 2.16 g plant^{-1}, and ET_o-I had the significantly ($p<0.05$) lowest FSW of 1.66 g plant^{-1} (Table 4.5) at the first planting. However, there was no significant ($p = 0.05$) variation in okra FSW under the influence of the ET_o × variety interaction (Table 4.5).

Furthermore, irrespective of the ET_o treatments, UI4-30 had significantly ($p<0.05$) higher FSW (2.31 g plant^{-1}) than NH47-4 (2.01 g plant^{-1}) at the second planting (Table 4.5). Similarly, okra plants irrigated with ET_o-N also recorded the highest FSW (2.42 g plant^{-1}). Although, this was not significantly ($p = 0.05$) higher than the FSW obtained from okra plants irrigated with ET_o-M (2.27 g plant^{-1}), those irrigated with ET_o-I had the lowest FSW value of 1.79 g plant^{-1} (Table 4.5). In addition, the ET_o × variety interaction did not significantly ($p = 0.05$) influence the FSW of okra at the second planting (Table 4.5).

4.2.6.2 Dry shoot weight

The results of the dry shoot weight (DSW) of okra at the first and second plantings are presented in (Table 4.5). At the first planting, UI4-30 recorded a significantly ($p<0.05$) higher DSW (0.34 g plant^{-1}) than NH47-4 (0.28 g plant^{-1}) irrespective of the ET_o treatments (Table 4.5). Considering the influence of the ET_o treatments, okra plants irrigated with ET_o-N had the highest DSW (0.37 g plant^{-1}), while okra plants irrigated with ET_o-M had a DSW value of 0.33 g plant^{-1}, and those irrigated with ET_o-I recorded a significantly ($p<0.05$) low DSW value of 0.22 g plant^{-1} (Table 4.5). In addition, the ET_o × variety interaction did not significantly ($p = 0.05$) influence the DSW of okra plants at the first planting (Table 4.5).

Table 4.5: Okra shoot weight as influenced by varietal differences and reference evapotranspiration rates

Treatment	FSW (g plant^{-1})	DSW (g plant^{-1})	FSW (g plant^{-1})	DSW (g plant^{-1})
	First planting		Second planting	
Variety				
NH47-4	1.96±0.33	0.28±0.07	2.01±0.08	0.33±0.02
UI4-30	2.15±0.37	0.34±0.07	2.31±0.13	0.35±0.02
S.E.D	0.08	0.01	0.07	0.01
Evapotranspiration (ET_o)				
ET_o-M	2.16±0.05a	0.33±0.02a	2.27±0.11a	0.34±0.01b
ET_o-I	1.66±0.07b	0.22±0.02b	1.79±0.04b	0.28±0.00c
ET_o-N	2.36±0.10a	0.37±0.01a	2.42±0.13a	0.39±0.01a
S.E.D	0.10	0.01	0.09	0.01
S.E.D (Variety × ET_o)	ns	ns	ns	ns
CV (%)	8.2	7.6	7.3	6.2

Means with the same letter(s) under the same category in the same column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, CV (%) = Coefficient of variation, FSW: Fresh shoot weight; DSW: Dry shoot weight.

With respect to the second planting, UI4-30 recorded a significantly ($p<0.05$) higher DSW value (0.35 g plant^{-1}) than NH4-30 (0.33 g plant^{-1}) (Table 4.5). There was also significant ($p<0.05$) variation in the DSW of okra under the influence of the ET_o treatments, with okra DSW being in the order: ET_o-N (0.39 g plant^{-1}) > ET_o-M (0.34 g plant^{-1}) > ET_o-I (0.28 g plant^{-1}) (Table 4.5). In terms of the ET_o × variety interaction, the DSW of okra was not significantly ($p = 0.05$) affected (Table 4.5).

4.2.7 Irrigation water use efficiency

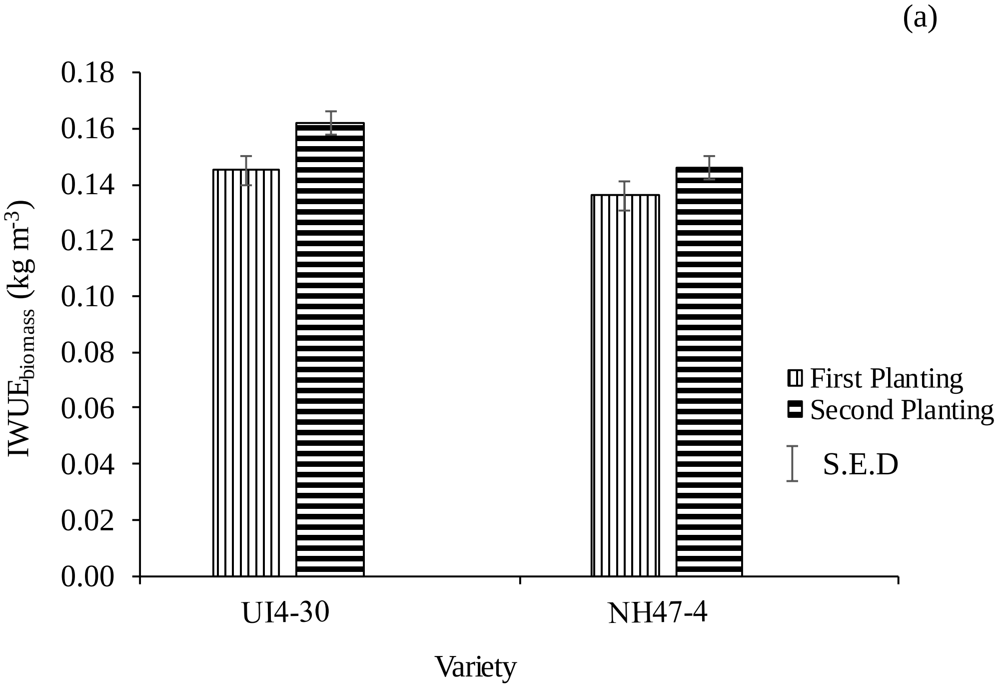
The irrigation water use efficiency of UI4-30 and NH47-4 for shoot ($IWUE_{shoot}$) and pod yield ($IWUE_{yield}$) production under the three ET_o treatments at the first and second planting are reported as follows:

4.2.7.1 Irrigation water use efficiency for shoot production

There was no significant ($p = 0.05$) difference in the $IWUE_{shoot}$ of UI4-30 (0.15 kg m^{-3}) and NH47-4 (0.14 kg m^{-3}) at the first planting (Figure 4.12). There was no significant ($p = 0.05$) difference in the $IWUE_{shoot}$ of okra under the different ET_o treatments, with plants under ET_o-M having the highest value (0.15 kg m^{-3}), while low values were recorded for plants irrigated with ET_o-N (0.14 kg m^{-3}) and ET_o-I (0.13 kg m^{-3}) (Figure 4.12). At the second planting, UI4-30 recorded a significantly ($p<0.05$) higher $IWUE_{shoot}$ (0.16 kg m^{-3}) than NH47-4 (0.15 kg m^{-3}) as shown in Figure 4.12. The $IWUE_{shoot}$ also differed significantly ($p<0.05$) among the ET_o treatments, and was in the order: ET_o-N > ET_o-M > ET_o-I (Figure 4.12).

4.2.7.2 Irrigation water use efficiency for pod production

At the first planting, there was no significant ($p = 0.05$) difference between the $IWUE_{yield}$ of UI4-30 (0.57 kg m^{-3}) and NH47-4 (0.51 kg m^{-3}) as shown in Figure 4.13. There was also no significant ($p = 0.05$) variation in the $IWUE_{yield}$ of okra under the influence of the ET_o treatments. However, okra plants irrigated with ET_o-N recorded a high $IWUE_{yield}$ of 0.56 kg m^{-3}, while ET_o-M and ET_o-I irrigated plants recorded low $IWUE_{yield}$ of 0.53 and 0.51 kg m^{-3}, respectively (Figure 4.13). At the second planting, there was also no significant ($p = 0.05$) difference between the $IWUE_{yield}$ of UI4-30 (0.64 kg m^{-3}) and NH47-4 (0.56 kg m^{-3}) as illustrated in Figure 4.13. There was also no significant ($p = 0.05$) difference in the $IWUE_{yield}$ of okra under the influence of the ET_o treatments. However, okra plants irrigated with ET_o-I recorded a higher



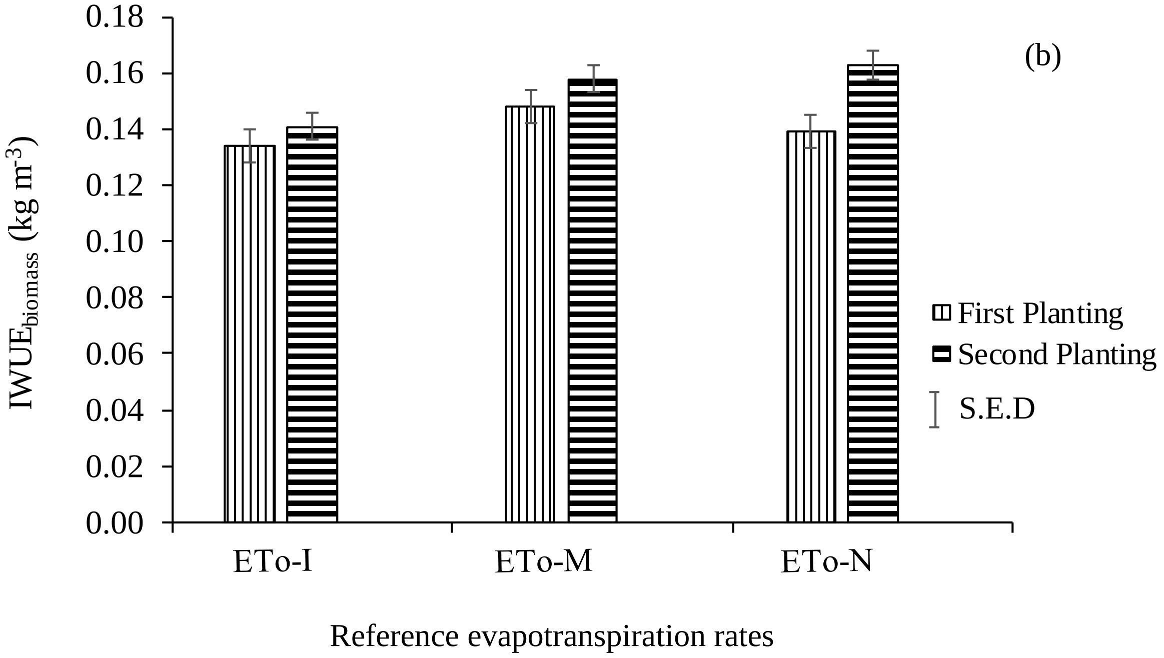


Figure 4.12: Varietal (a) and reference evapotranspiration (b) effects on the irrigation water use efficiency of okra for shoot production

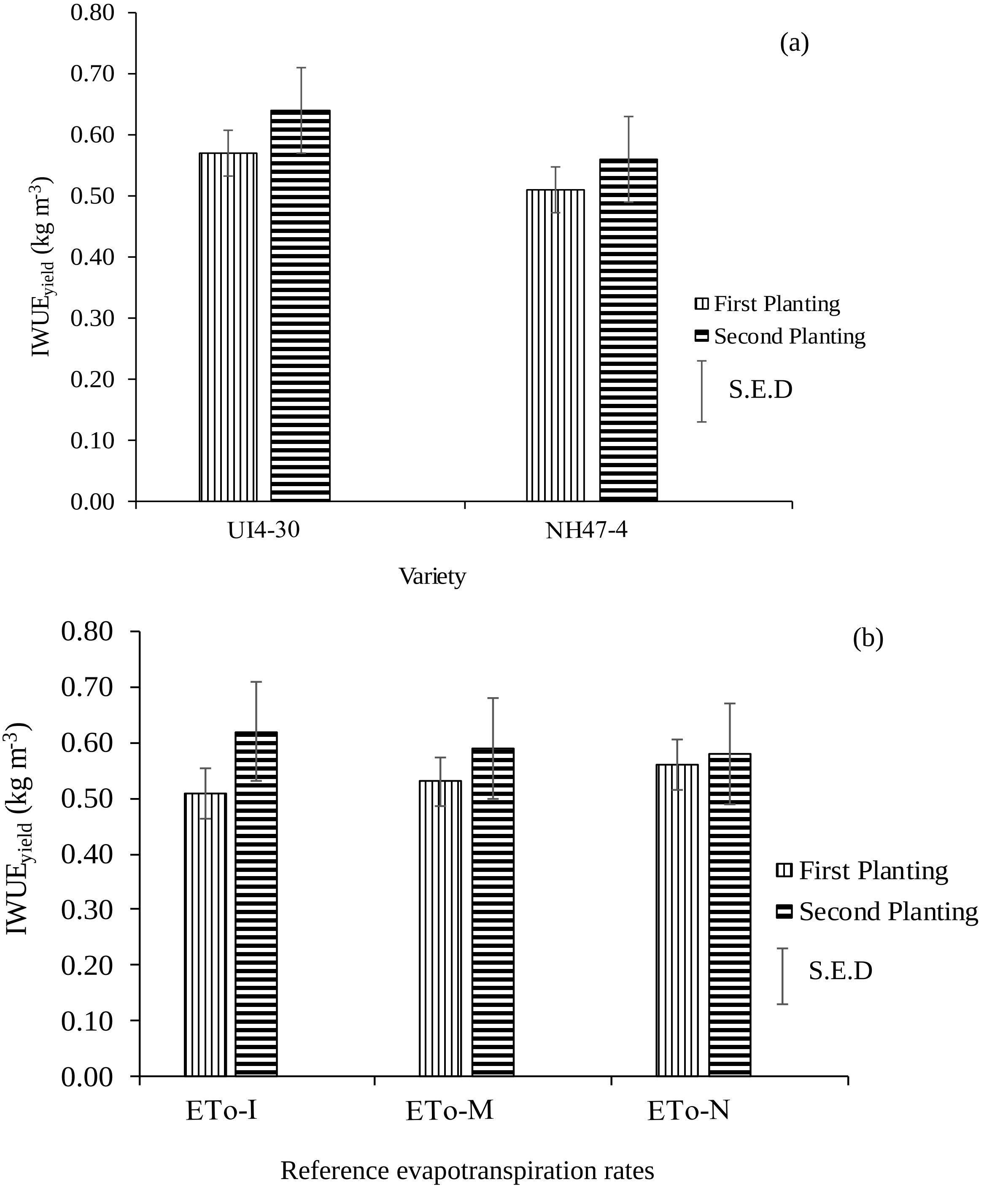


Figure 4.13: Varietal (a) and reference evapotranspiration (b) effects on the irrigation water use efficiency of okra for fresh pod production

$IWUE_{yield}$ (0.62 kg m^{-3}) than ET_o-M (0.59 kg m^{-3}) and ET_o-N (0.58 kg m^{-3}) as shown in Figure 4.13.

4.3 Experiment 2: Preliminary study on land preparation effects on the growth and yield of okra under rainfed conditions

The results of land preparation effects on okra growth and yield under rainfed conditions are as follows:

4.3.1 Growth parameters of okra as influenced by land preparation under rainfed conditions

The effects of land preparation types (Flat, Ridge and Raised bed) on the growth parameters of UI4-30 under rainfed conditions are reported as follows:

4.3.1.1 Number of leaves

Figure 4.14 shows the number of leaves produced by UI4-30 under Flat, Ridge and Raised bed at 2 to 10 WAS, respectively. The number of leaves produced was observed to increase from 2 WAS (2.1, 2.3 and 2.5 leaves) to 7 WAS (7.2, 8.0 and 7.8 leaves) for plants grown on Ridge, Flat and Raised bed, respectively. A decline in number of leaves was observed under all three land preparation types at 8 to 10 WAS, with mean values within the ranges of 6.5 – 7.0 leaves at 8 WAS, to 5.3 – 5.6 leaves at 10 WAS. Although, the number of leaves produced under the three land preparation types did not differ significantly ($p = 0.05$) at 7 to 10 WAS, okra plants grown on Ridge recorded the lowest number of leaves from 2 through 10 WAS, with significant ($p<0.05$) differences at 2 to 6 WAS. Plants grown on Raised bed recorded the highest number of leaves (2.5, 5.1 and 5.6) at 2, 3 and 4 WAS, while those grown on Flat recorded the highest number of leaves (6.3, 7.4, 8.0, 7.0 and 6.4) at 5, 6, 7, 8 and 9 WAS respectively, and Raised bed had the highest number of leaves (5.6) at 10 WAS.

4.3.1.2 Plant height

The height of UI4-30 as affected by land preparation types under rainfed conditions at 2 to 10 WAS is illustrated in Figure 4.15. The plant height of UI4-30 under the three land preparation types was significantly ($p<0.05$) different at 2 to 8 WAS, with mean values within the ranges of 5.1 – 7.5 cm at 2 WAS, and 31.4 – 39.9 cm at 8 WAS, respectively. It was also observed from the results that plants grown on

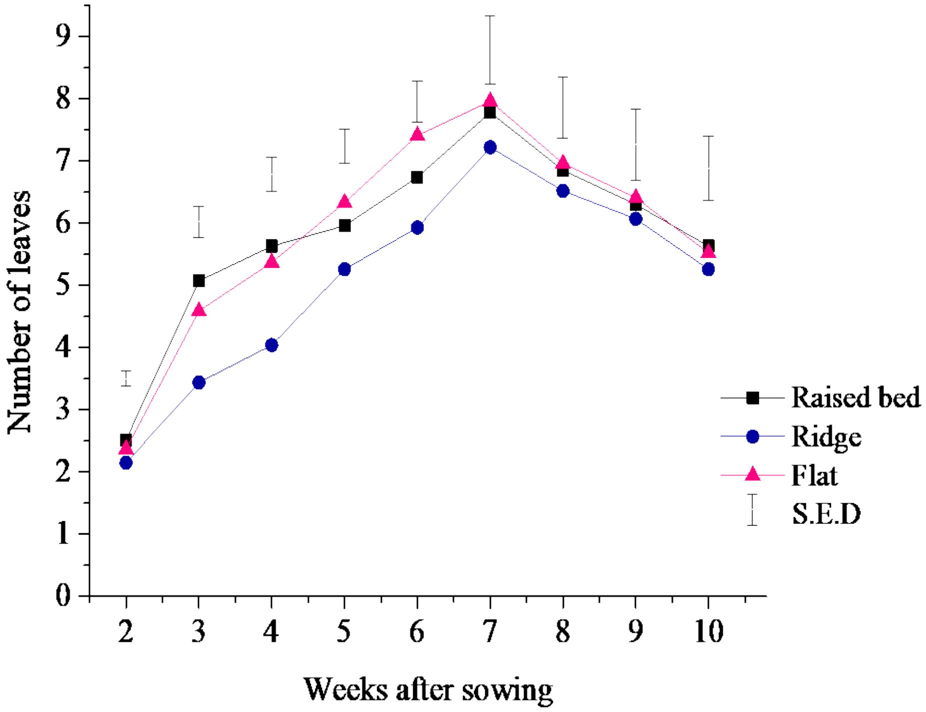


Figure 4.14: Land preparation effects on number of leaves of okra under rainfed conditions

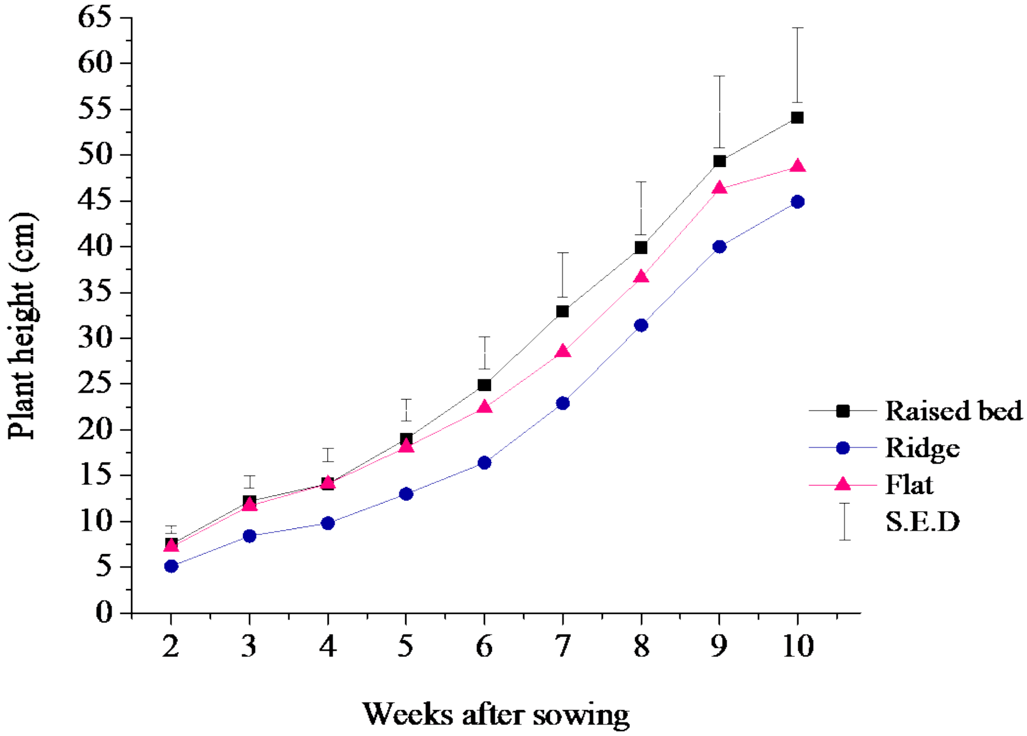


Figure 4.15: Effects of land preparation types on okra plant height under rainfed conditions

Ridge recorded the lowest height at 2 to 10 WAS when data collection was terminated. Although, plants grown on Flat and Raised bed recorded similar plant height of 14.1 cm at 4 WAS, plants grown on Raised bed were consistently higher than those grown on Flat. However, at 9 to 10 WAS, the height of UI4-30 was not significantly ($p = 0.05$) influenced by land preparation types, with peak values of 44.9, 48.7 and 54.1 cm recorded by plants grown on Ridge, Flat and Raised bed at 10 WAS, respectively.

4.3.1.3 Stem diameter

Figure 4.16 shows land preparation effects on the stem diameter of UI4-30 under rainfed conditions. At 2 WAS plants grown on Flat recorded the highest stem diameter of 2.20 mm. However, plants grown on Raised bed produced bigger stems within the range of 3.08 – 7.24 mm than plants grown on Flat, which had values within the range of 2.90 – 6.95 mm at 3 to 8 WAS, respectively. Although, plants grown on Ridge had significantly ($p<0.05$) smaller values in the range of 1.76 – 5.72 mm at 2 to 7 WAS, its highest value (7.36 mm) produced at 10 WAS when data collection was terminated, was not significantly ($p = 0.05$) different from 7.87 and 8.17 mm recorded by plants grown on Raised bed and Flat at 10 WAS, respectively.

4.3.2 Land preparation effects on the yield of okra under rainfed conditions

The influence of land preparation types on yield parameters including the number of pods, weight of fresh pods, fresh pod diameter, length of fresh pod, and dry pod weight, under rainfed conditions, is presented in Table 4.6.

4.3.2.1 Number of pods per plant

Results showed that the land preparation types did not significantly ($p = 0.05$) influence the number of pods produced by UI4-30 under rainfed conditions. However, plants grown on Ridge recorded the highest mean number of 7.6 pods plant^{-1}. This was followed by plants grown on Raised bed with mean number of 7.4 pods plant^{-1}, while those grown on Flat produced mean number of 7.0 pods plant^{-1} (Table 4.6).

4.3.2.2 Fresh pod weight

The land preparation types did not significantly ($p = 0.05$) influence the weight of fresh pods (FPW) produced by UI4-30 under rainfed conditions. However, the highest FPW was recorded by plants grown on Ridge which had a mean FPW value of

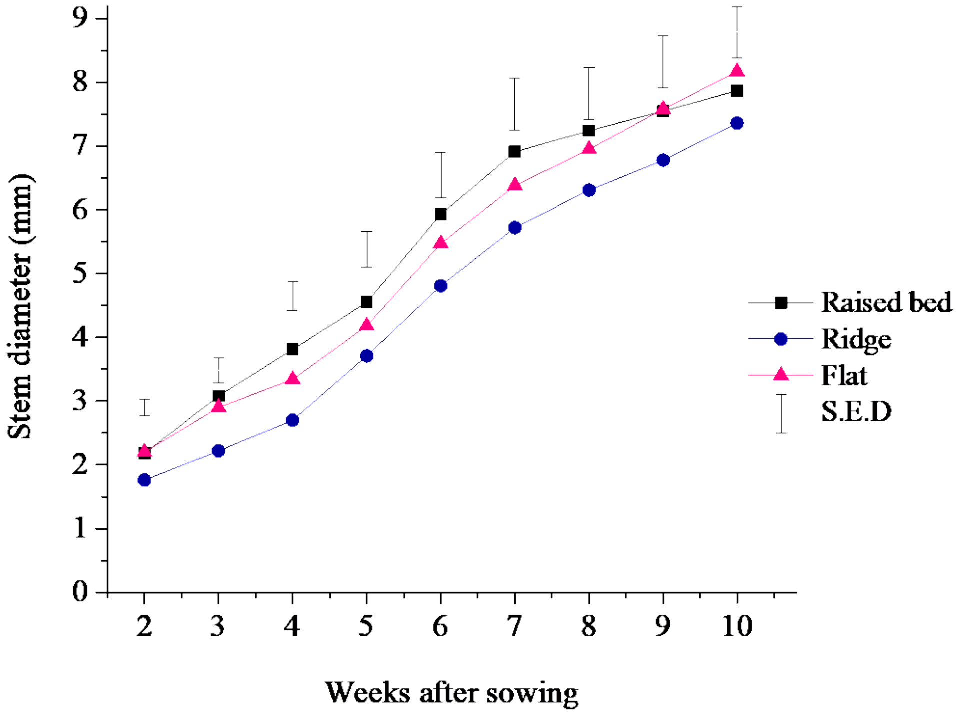


Figure 4.16: Effects of land preparation types on okra stem diameter under rainfed conditions

Table 4.6: Effects of land preparation types on okra yield under rainfed conditions

Treatment	Number of pods (plant^{-1})	Fresh pods weight	Dry pods weight	Pod length (cm pod^{-1} plant^{-1})	Pod diameter (mm pod^{-1} plant^{-1})
		g plant^{-1}			
Raised bed	7.4±0.93	109.57±19.26	7.96±1.46	6.5±0.24	22.32±0.58
Ridge	7.6±0.96	118.49±21.43	7.27±1.31	6.5±0.21	21.13±1.41
Flat	7.0±1.09	107.18±23.91	7.51±1.77	6.1±0.36	21.27±0.92
S.E.D	ns	ns	ns	ns	ns
CV (%)	50.4	73.6	72.7	17.2	17.0

Note: ns = means in the same column are not significantly different at 5% probability level, CV (%) = Coefficient of variation

118.49 g plant^{-1}. Lower mean FPW was recorded by plants grown under Raised bed and Flat, with corresponding FPW values of 109.57 and 107.18 g plant^{-1}, respectively (Table 4.6).

4.3.2.3 Dry pod weight

The results of the dry weight of pods (DPW) produced by UI4-30 under rainfed conditions are presented in Table 4.6. There was no significant ($p = 0.05$) difference in the DPW of okra plants grown under the three land preparation types. However, plants grown on Raised bed recorded the highest DPW of pods produced (7.96 g plant^{-1}), while those grown on Flat recorded a mean DPW value of 7.51 g plant^{-1}, and plants grown on Ridge recorded the lowest DPW value of 7.27 g plant^{-1}.

4.3.2.4 Pod length

The result of the analysis of data obtained for the length of fresh okra pods (PL) produced under rainfed conditions is presented in Table 4.6. The treatments did not significantly ($p = 0.05$) influence the PL of okra pods produced, although, pods produced under Raised bed and Ridge recorded high mean PL value of 6.5 cm pod^{-1} plant^{-1}, respectively, while those grown on Flat had a mean PL value of 6.1 cm pod^{-1} plant^{-1}.

4.3.2.5 Fresh pod diameter (FPD)

Similar to the result of fresh pod length, the land preparation types had no significant ($p = 0.05$) influence on the diameter of fresh okra pods (FPD) produced (Table 4.6). However, fresh pods produced from okra plants grown on Raised bed recorded the highest mean FPD value of 22.32 mm pod^{-1} plant^{-1}. This was followed by the FPD of fresh pods produced on Flat with mean FPD value of 21.27 mm pod^{-1} plant^{-1}, while pods produced by plants grown on Ridge recorded the lowest FPD value of 21.13 mm pod^{-1} plant^{-1}.

4.3.3 Effects of land preparation on the shoot of okra under rainfed conditions

The results of the effects of Raised bed, Ridge and Flat land preparation types on the shoot weight of okra are shown in Table 4.7.

Table 4.7: Shoot weight of okra as influenced by land preparation under rainfed conditions

Treatment	Fresh shoot weight	Dry shoot weight
	g plant^{-1}	
Raised bed	28.24±4.49	4.18±0.89
Ridge	21.44±1.86	2.94±0.45
Flat	22.12±1.91	2.84±0.25
S.E.D	ns	ns
CV (%)	27.1	47.4

Note: ns = means in the same column are not significantly different at 5% probability level, CV (%) = Coefficient of variation

4.3.3.1 Fresh shoot weight

The results of the fresh shoot weight (FSW) of UI4-30 was not significantly (p = 0.05) influenced by the land preparation types under rainfed conditions (Table 4.7). The results showed that okra plants grown on Raised bed recorded a high FSW value of 28.24 g plant^{-1}, while low mean FSW values of 22.12 and 21.44 g plant^{-1} were recorded by okra plants grown on Flat and Ridge, respectively.

4.3.3.2 Dry shoot weight

The result of the effects of the different land preparation types on the dry shoot weight (DSW) of UI4-30 under rainfed conditions is presented in Table 4.7. Although, there was no significant (p = 0.05) difference in the mean DSW of UI4-30 under the three land preparation types, okra plants grown on Raised bed had the highest mean DSW value of 4.18 g plant^{-1}, while DSW values of 2.94 and 2.84 g plant^{-1} were recorded by okra plants grown on Ridge and Flat, respectively.

4.3.4 Effects of land preparation types on soil properties

The influence of three land preparation types on the physical parameters [bulk density, saturated hydraulic conductivity (K_{sat}), porosity characteristics, soil moisture characteristics and penetration resistance] of the soil are reported as follows:

4.3.4.1 Bulk density

The influence of land preparation types on soil bulk density (ρ_b) is shown in Table 4.8. The result showed that land preparation did not significantly (p = 0.05) influence the ρ_b of the soil of the experimental site, although, ρ_b was higher under Flat, which had a mean value of 1.51 Mg m^{-3}. This was followed by Raised bed with mean ρ_b value of 1.44 Mg m^{-3}, while Ridge recorded that lowest ρ_b value of 1.42 Mg m^{-3}.

4.3.4.2 Saturated hydraulic conductivity

The results obtained for saturated hydraulic conductivity of soils from Flat, Raised bed and Ridge land preparation types are presented in Table 4.8. Similar to bulk density, saturated hydraulic conductivity (K_{sat}) was not significantly (p = 0.05) influenced by land preparation types. However, the mean K_{sat} was highest (19.2 cm hr^{-1}) under Ridge. This was followed by Raised bed which recorded a mean K_{sat} value of

Table 4.8: Soil physical properties as influenced by land preparation under rainfed conditions

Treatment	Bulk density (Mg m^{-3})	K_{sat} (cm hr^{-1})	P_T	P_{ma}	P_{mi}
				%	
Flat	1.51±0.08	17.2±3.27	43.02±3.02	13.85±4.08b	29.17±2.08a
Raised bed	1.44±0.02	18.6±3.36	45.66±0.93	21.56±0.74a	24.10±0.83b
Ridge	1.42±0.04	19.2±2.64	46.29±1.56	22.42±1.87a	23.87±0.65b
S.E.D	ns	ns	ns	3.06	1.89
CV (%)	5.9	6.3	7.2	33.6	15.6

Note: means with the same letter in the same column are not significantly different at 5% probability level, ns = means in a column are not significantly different at 5% probability level, K_{sat} = Saturated hydraulic conductivity, P_T = Total porosity, P_{ma} = Macro porosity, P_{mi} = Micro porosity, CV (%) = Coefficient of variation

18.6 cm hr^{-1}, while Flat recorded the lowest mean K_{sat} of 17.2 cm hr^{-1}.

4.3.4.3 Porosity characteristics

Variations in soil total porosity (P_T), macro porosity (P_{ma}), and micro porosity (P_{mi}) as influenced by differences in land preparation types are shown in Table 4.8. The results showed that the land preparation types did not significantly ($p = 0.05$) affect the P_T, even though, Ridge recorded the highest P_T of 46.29%, followed by Raised bed (45.66%) and least by Flat (43.02%). However, P_{ma} was significantly ($p<0.05$) influenced by land preparation types with Ridge recording the highest P_{ma} value of 22.42%, while Raised bed had P_{ma} values of 21.56%, and Flat recorded the significantly ($p<0.05$) lowest P_{ma} value of 13.85%. Similar to P_{ma}, land preparation had significant ($p<0.05$) effect on P_{mi}, in which, Flat recorded the highest P_{mi} value of 29.17%. This was significantly ($p<0.05$) higher than Raised bed and Ridge, which had low P_{mi} values 24.10 and 23.87%, respectively.

4.3.4.4 Soil moisture retention characteristics

The effect of land preparation on soil water retention under different soil suctions is illustrated in the soil water release curve presented in Figure 4.17. Although, there was no significant ($p = 0.05$) difference in the soil moisture content as influenced by the land preparation types at 0 bar suction, the soil moisture content was in the order: Ridge > Flat > Raised bed, with Ridge recording significantly ($p<0.05$) high moisture content values within the range of 0.29 – 0.13 m^3 m^{-3} at 0.1 to 15 bars, while low moisture content values within the range of 0.24 – 0.11 m^3 m^{-3} were recorded at 0.1 to 15 bars by Flat and Raised bed, respectively.

4.3.4.5 Penetration resistance

Figure 4.18 presents the result of the influence of land preparation on soil penetration resistance (PR) under rainfed conditions. Although, there was no significant ($p = 0.05$) difference in the soil PR under the three land preparation types at 0 to 10 cm soil depth, the result showed that Ridge had the lowest PR (0.35 MPa) at the surface level (0 cm depth), while higher PR values of 0.47 and 0.57 MPa were recorded by Raised bed and Flat, respectively. Similar trend was observed at 5 cm depth, with PR values of 0.93, 1.09 and 1.50 MPa recorded by Ridge, Raised bed, and Flat, respectively. At 10 cm soil depth, Flat recorded a low PR value (1.87 MPa) than

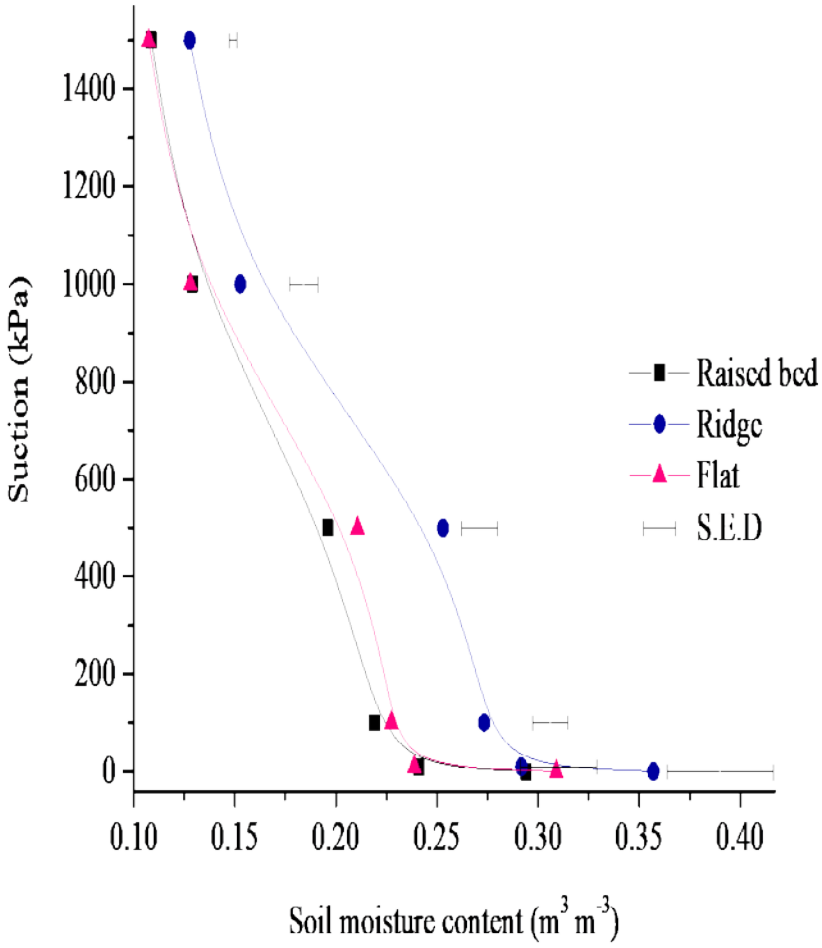


Figure 4.17: Soil moisture retention as influenced by land preparation under rainfed conditions

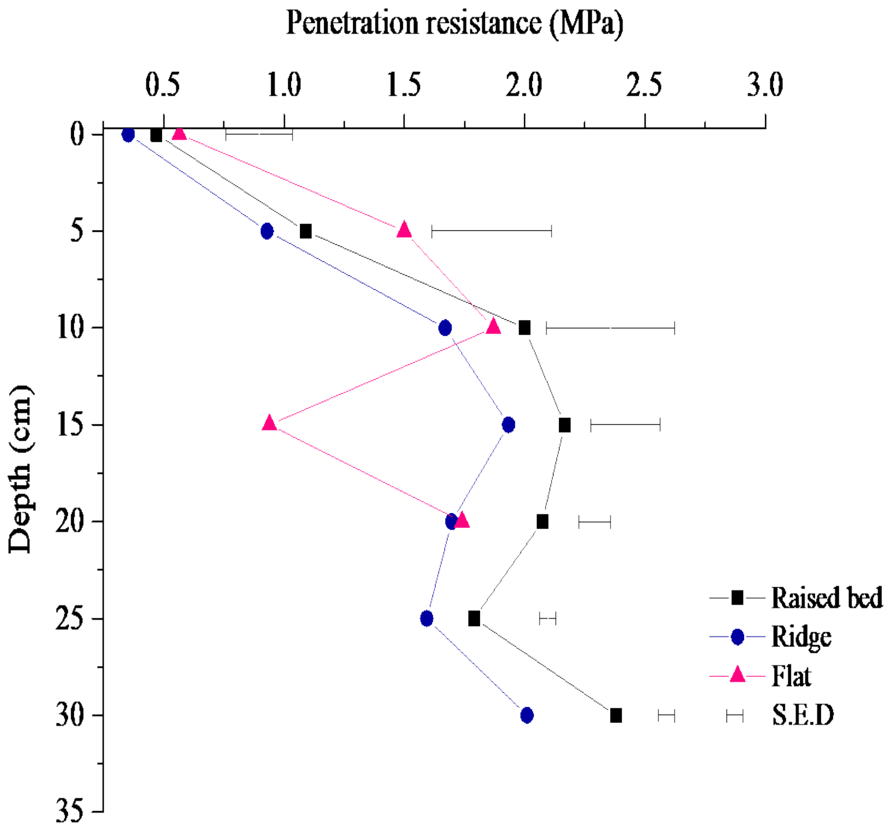


Figure 4.18: Soil penetration resistance as influenced by land preparation under rainfed conditions

Raised bed (2.00 MPa), while Ridge recorded the lowest PR value of 1.67 MPa. Significant ($p<0.05$) differences were observed among the PR values recorded at 15 to 30 cm soil depths, respectively. Plots with Flat recorded a mean low PR value of 0.94 MPa at 15 cm soil depth. This was followed by Ridge (1.93 MPa), while Raised bed recorded a high mean PR value of 2.17 MPa. Although, soil penetration under Flat did not exceed 20 cm soil depth, it recorded lower PR (1.74 MPa) than Raised bed (2.07 MPa), while Ridge recorded the lowest PR value of 1.70 MPa. At 25 to 30 cm soil depths, Ridge recorded lower PR (1.59 and 2.01 MPa, respectively) than Raised bed (1.79 and 2.38 MPa, respectively).

4.4 Dry season irrigation study

The results of the dry season experiments are reported as follows:

4.4.1 Chemical properties of the irrigation water used for the dry season study

The properties of the irrigation water are presented in Table 4.9. The irrigation water used for the dry season field study had pH values of 6.7 (2015/2016 dry season) and 7.1 (2016/2017 dry season). The nitrate-nitrogen values were 0.26 mg L^{-1} (2015/2016 dry season) and 0.87 mg l^{-1} (2016/2017 dry season), while the iron and alkalinity values were 0.07 and 33.2 mg L^{-1} (2015/2016 dry season) and 0.65 and 43.2 mg L^{-1} (2016/2017 dry season), respectively. The electrical conductivity values were 459.0 and 398.0 mg L^{-1} for 2015/2016 and 2016/2017 dry seasons, respectively.

4.4.2 Weather conditions of the experimental periods of the dry season study

The variations in the weather conditions of the 2015/2016 (November to February) and 2016/2017 (November to February) dry season study are shown in Figure 4.19. The mean ET_o during the period of the 2015/2016 planting was 4.93 mm day^{-1}, while that of the 2016/2017 planting was 4.59 mm day^{-1}. However, the minimum temperature of the 2015/2016 planting was lower (22.7°C) than that recorded during the 2016/2017 planting (23.7°C), and the average maximum temperature recorded in the 2015/2016 planting was higher (35.2°C) than that recorded during the 2016/2017 planting (35.1°C).

Table 4.9: Chemical composition of the irrigation waters used for the dry season study

Parameter	2015/2016	2016/2017
pH	6.7	7.1
Phosphate (mg L^{-1})	0.12	0.11
Available P (mg L^{-1})	0.60	0.04
Electrical conductivity (µs cm^{-1})	459.0	398.0
Acidity (mg L^{-1})	6.0	36.0
Alkalinity (mg L^{-1})	33.2	43.2
Carbonate (mg L^{-1})	ND	ND
Chloride (mg L^{-1})	115.20	198.0
Sulphate (mg L^{-1})	1.14	1.61
Boron (mg L^{-1})	ND	ND
Bicarbonate (mg L^{-1})	244.0	274.5
Total suspended solid (mg L^{-1})	63.7	16.50
Total dissolved solid (mg L^{-1})	71.0	7.10
Nitrate (mg L^{-1})	4.38	1.73
Nitrate-N (mg L^{-1})	0.26	0.87
Sodium adsorption ratio (SAR) (mg L^{-1})	0.12	2.3
Ca (mg L^{-1})	445.0	45.0
Mg (mg L^{-1})	73.6	15.0
K (mg L^{-1})	157.5	37.3
Na (mg L^{-1})	1.9	12.50
Na (%)	23.51	45.4
Mn (mg L^{-1})	0.00	0.26
Fe (mg L^{-1})	0.07	0.65
Cu (mg L^{-1})	0.025	0.034
Zn (mg L^{-1})	0.029	0.006
Pb (mg L^{-1})	0.183	0.025

ND = Not detected

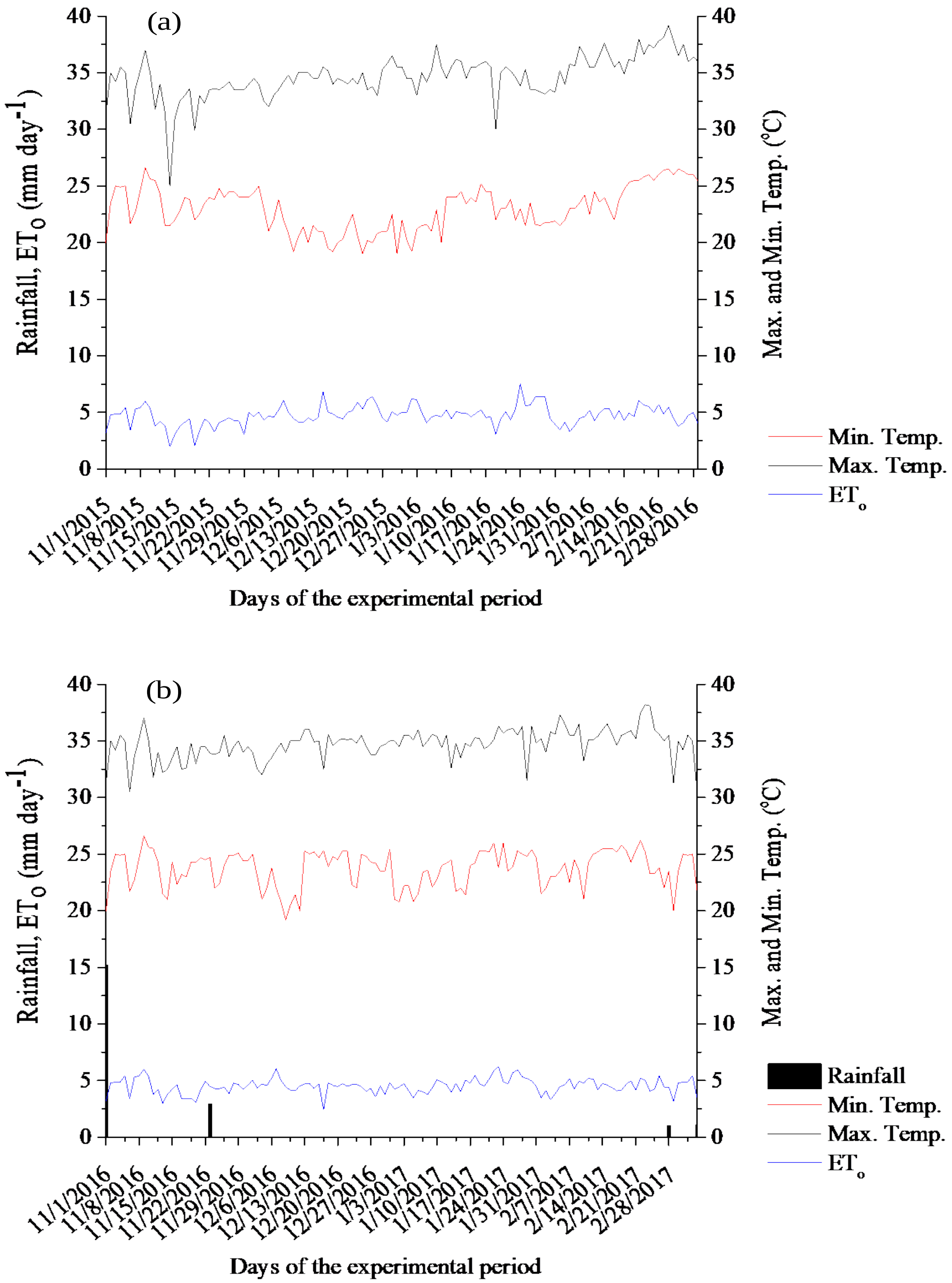


Figure 4.19: Weather conditions during (a) 2015/2016 and (b) 2016/2017 planting periods

4.4.3 Chemical properties of *Gliricidia sepium* and *Pennisetum purpureum* leaves

The *Gliricidia* and *Pennisetum* mulch properties are presented in Table 4.10. The *Gliricidia* mulch and *Pennisetum* mulch were slightly alkaline, having pH values of 7.5 and 7.7, respectively. The total nitrogen of the *Gliricidia* mulch was 3.93%, while that of the *Pennisetum* mulch was 1.91%. The total phosphorus of the *Gliricidia* mulch (0.18%) was higher than that of the *Pennisetum* mulch (0.16%). However, the *Gliricidia* mulch had lower carbon content (87.4%) than the *Pennisetum* mulch (90.4%). Although, both mulch materials had sodium and manganese content of 0.01% and 0.01 mg kg^{-1} respectively, *Gliricidia* mulch had higher calcium content (2.68%) than *Pennisetum* mulch (1.05%).

4.4.4 Effects of land preparation, mulch and irrigation rates on soil physical properties

The results of the soil physical properties as influenced by the sole application or interaction combinations of land preparation, mulch types and irrigation rates in 2015/2016 and 2016/2017 are reported as follows:

4.4.4.1 Soil bulk density as affected by land preparation, mulch and irrigation rates

The results of the bulk density (ρ_b) of the soil after treatment application in 2015/2016 and 2016/2017 are shown in Table 4.11.

In 2015/2016, the soil ρ_b differed significantly ($p<0.05$) among the land preparation types, with Flat recording the significantly ($p<0.05$) highest ρ_b (1.59 Mg m^{-3}), while Ridge and Raised bed recorded low ρ_b of 1.51 Mg^{-3} and 1.48 Mg m^{-3}, respectively (Table 4.11). Conversely, mulch application did not significantly ($p = 0.05$) influence the ρ_b of the soil. However, plots without mulch (Zero mulch) recorded the highest ρ_b value of 1.55 Mg m^{-3}, while plots treated with *Gliricidia* mulch had a mean ρ_b value of 1.52 Mg m^{-3}, and *Pennisetum* mulch plots had the least value (1.51 Mg m^{-3}) as shown in Table 4.11. The soil ρ_b did not differ significantly ($p = 0.05$) among the irrigation rates, even though, CROPWAT irrigated plots recorded the highest value (1.55 Mg m^{-3}), while 100% ET$_c$ irrigated plots had ρ_b of 1.53 Mg m^{-3}, and plots irrigated with 75% ET$_c$ recorded the lowest value (1.50 Mg m^{-3}) (Table

Table 4.10: Chemical composition of *Gliricidia* mulch and *Pennisetum* mulch

Parameter	*Gliricidia* leaves	*Pennisetum* leaves
pH	7.5	7.7
Total nitrogen (%)	3.93	1.91
Total phosphorus (%)	0.18	0.16
Calcium (%)	2.68	1.05
Mg (%)	0.44	0.42
K (%)	1.80	1.88
Na (%)	0.01	0.01
Mn (mg kg^{-1})	0.01	0.01
Fe (mg kg^{-1})	0.10	0.20
Cu (mg kg^{-1})	0.001	0.010
Zn (mg kg^{-1})	0.001	0.003
Total carbon (%)	87.4	90.4
C:N ratio	22.2:1.0	47.3:1.0
Moisture content (%)*	12.61%	28.48%

*Moisture content at point of application

Table 4.11: Effects of land preparation, mulch and irrigation rates on some soil hydro-physical properties in 2015/2016

Treatment	Bulk density	Saturated hydraulic conductivity	Total porosity	Macroporosity	Microporosity
	(Mg m^{-3})	(cm hr^{-1})		%	
Land preparation (LP)					
Raised bed	1.48±0.02b	22.68±1.72	44.29±0.69a	8.19±0.78a	36.10±0.37ab
Ridge	1.51±0.02b	22.35±2.06	42.96±0.64a	5.99±0.64b	36.96±0.48a
Flat	1.59±0.02a	22.15±1.99	39.90±0.57b	4.88±0.58b	35.02±0.44b
S.E.D	0.03	ns	0.95	0.86	0.50
Mulch (M)					
Gliricidia sepium	1.52±0.02	23.62±1.93	42.71±0.79	6.95±0.77a	35.76±0.44
Pennisetum purpureum	1.51±0.02	24.36±2.07	42.94±0.62	7.17±0.62a	35.76±0.46
Zero mulch	1.55±0.02	19.20±1.69	41.50±0.61	4.93±0.66b	36.57±0.42
S.E.D	ns	ns	ns	0.91	ns
Irrigation rate (I)					
100% ET$_c$	1.53±0.02	26.33±1.89a	42.35±0.66	6.97±0.66ab	35.38±0.40
75% ET$_c$	1.50±0.02	19.30±1.80b	43.28±0.74	7.17±0.79a	36.11±0.39
CROPWAT	1.55±0.02	21.55±1.97ab	41.52±0.62	4.92±0.59b	36.60±0.52
S.E.D	ns	2.03	ns	0.75	ns
S.E.D (Land preparation × Irrigation)	0.04	3.53	1.52	1.43	0.84
S.E.D (Irrigation × Mulch)	0.03	ns	1.20	1.49	ns
S.E.D (Land preparation × Mulch)	ns	ns	ns	ns	ns
S.E.D (LP × M × I)	ns	6.55	ns	ns	ns
% CV (Main plot)	1.5	11.1	2.0	14.4	1.5
% CV (Sub-plot)	3.5	19.3	4.8	28.7	3.0
% CV (Sub sub-plot)	4.4	37.0	6.0	52.7	5.5

Means with the same letter(s) under the same category in the same column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, CV (%) = Coefficient of variation.

4.11). Furthermore, significant ($p<0.05$) variations were not recorded among ρ_b values of soil obtained from the various treatment interaction combinations (Table 4.11).

In 2016/2017, soil ρ_b under the different land preparation types did not differ significantly ($p = 0.05$). However, plots with Flat recorded the highest ρ_b value of 1.53 Mg m^{-3}, while Raised bed and Ridge had low values (1.49 and 1.45 Mg m^{-3}), respectively (Table 4.12). Mulch application also had no significant ($p = 0.05$) effect on the soil ρ_b, as plots without mulch (Zero mulch) recorded the highest ρ_b (1.51 Mg m^{-3}), while *Gliricidia* and *Pennisetum* mulch had a mean low ρ_b value of 1.48 Mg m^{-3}, respectively (Table 4.12). Similarly, the irrigation rates had no significant ($p = 0.05$) effect on soil ρ_b, although, plots irrigated with 100% ET$_c$ recorded the highest ρ_b (1.54 Mg m^{-3}), while 75% ET$_c$ had a mean ρ_b value of 1.50 Mg m^{-3}, and CROPWAT recorded the lowest ρ_b value of 1.44 Mg m^{-3} (Table 4.12). Unlike the 2015/2016 dry season, the various treatment combinations had no significant ($p = 0.05$) effect on soil ρ_b in the 2016/2017 dry season (Table 4.12).

4.4.4.2 Effects of land preparation, mulch and irrigation rates on soil saturated hydraulic conductivity

The effects of land preparation, mulch and irrigation rates on soil saturated hydraulic conductivity (K_{sat}) in 2015/2016 and 2016/2017 are presented in Tables 4.11 and 4.12.

In 2015/2016, land preparation had no significant ($p = 0.05$) effect on K_{sat}. Nevertheless, Raised bed recorded the highest K_{sat} value of 22.68 cm hr^{-1}, while Ridge and Flat had low K_{sat} values of 22.35 and 22.15 cm hr^{-1}, respectively (Table 4.11). Mulch also had no significant ($p = 0.05$) effect on K_{sat}. However, plots treated with *Pennisetum* mulch recorded the highest K_{sat} value of 24.36 cm hr^{-1}, while plots treated with *Gliricidia* mulch had a mean K_{sat} value of 23.62 cm hr^{-1}, and the least K_{sat} value of 19.20 cm hr^{-1} was recorded by plots without mulch (Zero mulch) (Table 4.11). Contrarily, the irrigation rates significantly ($p<0.05$) affected the K_{sat} of the soils obtained from the study site. For example, plots irrigated with 100% ET$_c$ recorded the highest K_{sat} value of 26.33 cm hr^{-1}, while those irrigated with CROPWAT had a mean K_{sat} value of 21.55 cm hr^{-1}, and plots irrigated with 75% ET$_c$ recorded the

Table 4.12: Effects of land preparation, mulch and irrigation rates on some soil hydro-physical properties in 2016/2017

Treatment	Bulk density ($\mathrm{Mg\ m^{-3}}$)	Saturated hydraulic conductivity ($\mathrm{cm\ hr^{-1}}$)	Total porosity	Macroporosity	Microporosity
				%	
Land preparation (LP)					
Raised bed	1.49±0.02	21.68±3.34	43.79±0.93	9.62±0.92	34.17±0.73
Ridge	1.45±0.02	23.95±2.65	45.14±0.62	11.04±0.96	34.10±0.76
Flat	1.53±0.03	17.26±1.88	42.26±1.12	9.30±1.14	32.97±0.73
S.E.D	ns	ns	ns	ns	ns
Mulch (M)					
Gliricidia sepium	1.48±0.02	20.79±2.28	43.98±0.81	9.73±0.65	34.26±0.80
Pennisetum purpureum	1.48±0.02	22.31±3.31	44.01±0.91	10.06±1.15	33.95±0.70
Zero mulch	1.51±0.03	19.80±2.52	43.20±1.08	10.17±1.18	33.03±0.70
S.E.D	ns	ns	ns	ns	ns
Irrigation rate (I)					
100% ET_c	1.54±0.02	14.65±1.64b	42.01±0.87	8.14±0.94	33.87±0.75
75% ET_c	1.50±0.02	29.38±3.59a	43.51±0.60	10.65±0.77	32.86±0.59
CROPWAT	1.44±0.03	18.88±1.63b	45.67±1.13	11.17±1.21	34.50±0.83
S.E.D	ns	3.29	ns	ns	ns
S.E.D (Land preparation × Irrigation)	ns	ns	ns	ns	ns
S.E.D (Irrigation × Mulch)	ns	ns	ns	ns	ns
S.E.D (Land preparation × Mulch)	ns	ns	ns	ns	ns
S.E.D (LP × M × I)	ns	ns	ns	ns	ns
% CV (Main plot)	2.9	19.2	3.7	17.2	2.6
% CV (Sub-plot)	5.7	33.0	7.3	33.8	6.9
% CV (Sub sub-plot)	6.7	62.9	8.6	55.2	11.1

Means with the same letter(s) under the same category in the same column are not significantly different at $p = 0.05$, ns = not significantly different at $p = 0.05$, CV (%) = Coefficient of variation.

lowest K_{sat} value of 19.30 cm hr^{-1} (Table 4.11). There were also significant ($p<0.05$) variations in K_{sat} among the treatment combinations (Table 4.11).

In 2016/2017, there was no significant ($p = 0.05$) variation in K_{sat} among the land preparation types. However, plots with Ridge recorded the highest K_{sat} value of 23.95 cm hr^{-1}, while Raised bed and Flat had low mean K_{sat} values of 21.68 and 17.26 cm hr^{-1}, respectively (Table 4.12). Similar to land preparation, the mulch treatments did not significantly ($p<0.05$) influence the soil K_{sat}, even though, plots with *Pennisetum* mulch recorded the highest K_{sat} value of 22.31 cm hr^{-1}, while *Gliricidia* mulch and Zero mulch had low K_{sat} values of 20.79 and 19.80 cm hr^{-1}, respectively (Table 4.12). However, the soil K_{sat} was significantly ($p<0.05$) influenced by the irrigation rates, in which, plots irrigated with 75% ET_c recorded significantly ($p<0.05$) higher mean K_{sat} value of 29.38 cm hr^{-1}, than CROPWAT and 100% ET_c which had low K_{sat} values of 18.88 and 14.65 cm hr^{-1}, respectively (Table 4.12). In addition, the treatment interactions had no significant ($p = 0.05$) effect on the soil K_{sat}.

4.4.4.3 Land preparation, mulch, and irrigation effects on soil total porosity

The results of the effects of land preparation, mulch and irrigation rates on the total porosity (P_T) of the soils of the study site after termination of the experiments in the 2015/2016 and 2016/2017 dry seasons are presented in Tables 4.11 and 4.12, respectively.

In 2015/2016, plots having Raised bed recorded the significantly ($p<0.05$) highest P_T value of 44.29%, whereas Ridge had a mean P_T value of 42.96%, and Zero mulch recorded the significantly ($p<0.05$) lowest P_T value of 39.90% (Table 4.11). Conversely, there was no significant ($p = 0.05$) difference in the P_T of plots treated with mulch. For example, plots with *Pennisetum* mulch application had the highest P_T (42.94%), while plots treated with *Gliricidia* mulch and Zero mulch which had low P_T values of 42.71% and 41.50%, respectively (Table 4.11). The soil P_T was not significantly ($p = 0.05$) influenced by the irrigation rates. Plots irrigated with 75% ET_c recorded the highest P_T value of 43.28%, while 100% ET_c and CROPWAT irrigated plots had low mean P_T values of 42.35% and 41.52%, respectively (Table 4.11). In addition, there were significant ($p<0.05$) differences in the P_T recorded among the various treatment interactions (Table 4.11).

With respect to 2016/2017, the soil P_T did not significantly ($p = 0.05$) vary among land preparation types. Moreover, the highest P_T value (45.14%) was recorded by plots having Ridge, while plots with Raised bed and Flat had low P_T values of 43.79% and 42.26%, respectively (Table 4.12). The application of mulch also had no significant ($p = 0.05$) effect on the soil P_T, although, plots with *Pennisetum* mulch recorded the highest P_T value of 44.01%, while *Gliricidia* mulch and Zero mulch had low P_T values of 43.98% and 43.20% (Table 4.12). Similarly, the soil P_T was not significantly ($p = 0.05$) affected by the irrigation rates. However, plots irrigated with CROPWAT irrigation rates recorded the highest P_T value of 45.67%, while plots with daily application of 75% ET_c and 100% ET_c had low P_T values of 43.51% and 42.01%, respectively (Table 4.12). The treatment interactions did not significantly ($p = 0.05$) affect the soil P_T (Table 4.12).

4.4.4.4 Soil macro porosity as influenced by land preparation, mulch and irrigation rates

The results of the soil macro porosity (P_{ma}) of soils examined under land preparation, mulch, and irrigation effects in 2015/2016 and 2016/2017 are presented in Tables 4.11 and 4.12.

In 2015/2016, soil macro porosity was significantly ($p<0.05$) influenced by land preparation types. Plots with Raised bed had the highest P_{ma} value of 8.19%, while Ridge and Flat had low P_{ma} values of 5.99% and 4.88%, respectively (Table 4.11). With respect to mulch application, *Pennisetum* mulch recorded the highest P_{ma} value of 7.17%, while *Gliricidia* mulch had a mean P_{ma} value of 6.95% and Zero mulch recorded the significantly ($p<0.05$) lowest P_{ma} (4.93%) (Table 4.11). The soil P_{ma} of plots under the irrigation treatments differed significantly ($p<0.05$). For instance, plots irrigated with 75% ET_c recorded the significantly ($p<0.05$) highest P_{ma} value of 7.17%, while 100% ET_c had a mean P_{ma} value of 6.97%, and plots irrigated with CROPWAT had the lowest P_{ma} value of 4.92% (Table 4.11). There were also significant ($p<0.05$) differences in the soil P_{ma} among the various treatment interactions (Table 4.11).

With respect to 2016/2017, the soil P_{ma} did not significantly ($p = 0.05$) vary under the different land preparation types. However, plots having Ridge recorded the highest P_{ma} value of 11.04%, while those with Raised bed and Flat had low P_{ma} values of 9.62% and 9.30%, respectively (Table 4.12). Likewise, the mulch treatments did not significantly ($p = 0.05$) influence the soil P_{ma}, even though, plots without mulch (Zero mulch) recorded the highest P_{ma} value of 10.17%, while those with *Pennisetum* mulch and *Gliricidia* mulch recorded low P_{ma} values of 10.06 ad 9.73%, respectively (Table 4.12). The irrigation treatments had no significant ($p = 0.05$) effect on the soil P_{ma}, although, plots irrigated with CROPWAT irrigation rates recorded the highest P_{ma} value of 11.17%, while plots under 75% ET_c and 100% ET_c recorded low P_{ma} values of 10.65% and 8.14%, respectively (Table 4.12). Consequently, the different interaction combinations had no significant ($p = 0.05$) effect on the soil P_{ma} (Table 4.12).

4.4.4.5 Effects of land preparation, mulch, and irrigation rates on soil micro porosity

The results of the influence of land preparation, mulch, and irrigation on soil micro porosity (P_{mi}) in the 2015/2016 and 2016/2017 dry seasons are shown in Tables 4.11 and 4.12.

In 2015/2016, there was significant ($p<0.05$) difference in the soil P_{mi} under the influence of the mulch, and irrigation types, wherein plots with Ridges recorded the highest P_{mi} value of 36.96%, while Raised bed had a mean P_{mi} value of 36.10%, and Flat recorded the significantly ($p<0.05$) lowest P_{mi} value of 35.02% (Table 4.11). Unlike land preparation, mulch had no significant ($p = 0.05$) effect on the soil P_{mi}, even though, *Gliricidia* mulch and *Pennisetum* mulch recorded high P_{mi} value of 35.76%, respectively, and Zero mulch had a low P_{mi} value of 36.57% (Table 4.11). There was no significant ($p = 0.05$) difference in the P_{mi} value of the plots under the different irrigation rates. However, CROPWAT irrigated plots recorded the highest P_{mi} value of 36.60%, whereas 75% ET_c and 100% ET_c irrigated plots recorded low P_{mi} values of 36.11% and 35.38%, respectively (Table 4.11). In addition, there were significant ($p<0.05$) variations in the soil P_{mi} under the different treatment interactions (Table 4.11).

In 2016/2017, the soil P_{mi} did not significantly ($p = 0.05$) vary under the different land preparation types, in which, plots with Raised bed recorded the highest P_{mi} value of 34.17%, while Ridge had a mean P_{mi} value of 34.10%, and Flat recorded the lowest P_{mi} value of 32.97% (Table 4.12). The soil P_{mi} was not significantly ($p = 0.05$) influenced by the mulch treatments. Plots with *Gliricidia* mulch had the highest P_{mi} value of 34.26%, while *Pennisetum* mulch and Zero mulch recorded low P_{mi} values of 33.95% and 33.03%, respectively (Table 4.12). Similarly, the soil P_{mi} was not significantly ($p = 0.05$) influenced by the irrigation treatments, although, plots irrigated with CROPWAT irrigation rates recorded the highest soil P_{mi} value of 34.50%, while plots with 100% ET_c and 75% ET_c had low P_{mi} values of 33.87% and 32.86%, respectively (Table 4.12). In terms of the interactions in the 2016/2017 dry season, there was no significant ($p = 0.05$) difference in soil P_{mi} (Table 4.12).

4.4.4.6 Effects of land preparation, mulch, and irrigation rates on water stable aggregates

The soil water stable aggregates (WSA) as affected by land preparation types, mulch and irrigation rates in the 2015/2016 and 2016/2017 dry seasons are reported as follows:

In 2015/2016, WSA did not vary significantly ($p = 0.05$) among the land preparation types. However, Flat recorded the highest WSA value of 58.88%, while Ridge had a WSA value of 58.82%, and Raised bed recorded the lowest WSA value of 58.38% (Table 4.13). With respect to mulch application, WSA was significantly ($p<0.05$) affected, with plots treated with *Pennisetum* mulch recording the highest WSA value of 59.43%, followed by *Gliricidia* mulch which had a mean WSA value of 59.11%, and least by Zero mulch which recorded the significantly ($p<0.05$) lowest WSA value of 57.54% (Table 4.13). The WSA of the various plots under the different irrigation rates differed significantly ($p<0.05$) and plots irrigated with 75% ET_c recorded the highest WSA value of 60.21%. Although, this was statistically similar to the WSA (59.30%) obtained for plots treated with CROPWAT irrigation rate, plots treated with 100% ET_c recorded the lowest WSA value of 56.57% (Table 4.13). Furthermore, WSA differed significantly ($p<0.05$) among the various treatment interactions (Table 4.13).

In 2016/2017, the WSA of the soil significantly ($p<0.05$) varied under the land preparation types, with Flat recording the highest WSA value of 56.58%, while Ridge and Raised bed had low mean WSA values of 55.41% and 54.87%, respectively (Table 4.14). With respect to mulch application, WSA was significantly ($p<0.05$) affected, with *Gliricidia* mulch having the highest WSA of 58.21%, while *Pennisetum* mulch had a mean WSA value of 55.99%, and Zero mulch recorded the lowest WSA value of 52.65% (Table 4.14). The irrigation rates also had

Table 4.13: Influence of land preparation, mulch and irrigation rates on soil structural stability characteristics in 2015/2016

Treatment	WSA	MWD	ASC	CDI	CFI	DR	SS	S
	(%)	(mm)	%					
Land preparation (LP)								
Raised bed	58.38±1.21	1.04±0.02	14.72±0.80ab	53.6±7.93	50.8±7.82	20.42±1.74	0.28±0.02	16.15±0.92ab
Ridge	58.82±0.63	1.01±0.03	14.20±0.65b	39.1±5.33	37.0±5.36	19.14±1.81	0.27±0.01	18.37±1.05a
Flat	58.88±0.64	1.05±0.02	16.82±0.82a	61.5±7.28	57.2±7.24	16.41±1.45	0.27±0.01	13.85±1.09b
S.E.D	ns	ns	0.48	ns	ns	ns	ns	1.01
Mulch (M)								
Gliricidia sepium	59.11±0.78a	1.05±0.02a	15.22±0.71	51.7±7.42	52.1±7.52	18.35±1.65ab	0.28±0.02	18.15±1.32a
Pennisetum purpureum	59.43±0.81a	1.06±0.02a	15.58±0.67	50.6±6.76	50.6±6.76	15.78±1.61b	0.28±0.01	15.67±0.81ab
Zero mulch	57.54±0.97b	0.99±0.03b	14.94±0.92	51.9±6.97	42.2±6.55	21.83±1.70a	0.26±0.01	14.55±0.92b
S.E.D	0.29	0.03	ns	ns	ns	1.64	ns	0.27
Irrigation rate (I)								
100% ET_c	56.57±0.83b	0.97±0.03b	13.25±0.64b	68.7±9.02a	63.3±9.22a	25.48±1.63a	0.25±0.01	17.11±1.08
75% ET_c	60.21±0.77a	1.07±0.02a	17.51±0.67a	41.2±5.52b	40.5±5.52b	13.78±1.57b	0.29±0.01	14.14±1.16
CROPWAT	59.30±0.85a	1.06±0.02a	14.99±0.88b	44.3±5.38b	41.2±4.95b	16.71±1.42b	0.28±0.02	17.12±0.86
S.E.D	0.42	0.02	1.02	7.13	5.04	2.39	ns	ns
S.E.D (Land preparation × Irrigation)	0.53	0.04	1.22	ns	13.97	ns	ns	1.59
S.E.D (Mulch × Irrigation)	0.58	0.05	1.13	ns	8.51	ns	ns	0.79
S.E.D (Land preparation × Mulch)	0.47	ns	0.70	ns	11.49	2.82	ns	1.08
S.E.D (LP × M × I)	0.88	0.08	1.50	18.60	18.34	ns	0.06	1.72
% CV (Main Plot)	0.9	2.7	8.2	17.0	12.8	15.7	8.3	4.3
% CV (Sub-plot)	0.8	4.3	6.7	34.6	40.5	18.1	13.5	10.9
% CV (Sub sub-plot)	1.8	10.2	8.5	36.3	36.9	32.3	26.2	5.0

Means with the same letter(s) under the same category in the same column are not significantly different at $p = 0.05$, ns = not significantly different at $p = 0.05$, WSA = Water stable aggregate, MWD = Mean weight diameter, ASC = Aggregated silt and clay, CDI = Clay dispersion index, CFI = Clay flocculation index, DR = Dispersion ration, SS = Soil structural stability, S = Soil structural stability index, CV (%) = Coefficient of variation.

Table 4.44: Land preparation, mulch, and irrigation rates influence on soil structural stability characteristics in 2016/2017

Treatment	WSA	MWD	ASC	CDI	CFI	DR	SS	S
	(%)	(mm)	%					
Land preparation (LP)								
Raised bed	54.87±0.83b	0.97±0.02	3.36±0.19a	70.33±2.43	29.67±2.43	63.67±1.70b	0.22±0.02	38.58±0.91
Ridge	55.41±0.65ab	0.99±0.01	2.74±0.35b	68.45±1.61	31.55±1.61	73.53±5.00a	0.23±0.02	44.68±3.38
Flat	56.58±0.75a	0.99±0.02	3.17±0.24a	71.21±2.44	28.79±2.44	65.92±2.13ab	0.24±0.02	39.26±1.65
S.E.D	0.40	ns	0.22	ns	ns	3.47	ns	ns
Mulch (M)								
Gliricidia sepium	58.21±0.63a	1.03±0.01a	3.03±0.29	67.43±1.31	32.57±1.31	68.90±4.00	0.25±0.03	43.06±2.08
Pennisetum purpureum	55.99±0.66b	0.99±0.02b	3.14±0.25	69.57±2.17	30.43±2.17	66.07±2.45	0.23±0.02	40.19±2.26
Zero mulch	52.65±0.55c	0.93±0.01c	3.09±0.29	72.99±2.75	27.01±2.75	68.15±3.51	0.20±0.01	39.27±2.47
S.E.D	0.55	0.02	ns	ns	ns	ns	ns	ns
Irrigation rate (I)								
100% ET_c	54.40±0.72b	0.95±0.02b	3.11±0.16	70.16±2.09ab	29.84±2.09ab	64.85±1.37	0.21±0.02	38.01±1.08
75% ET_c	57.35±0.71a	1.02±0.02a	3.02±0.32	66.49±1.05b	33.51±1.05a	69.68±4.41	0.25±0.01	40.80±2.89
CROPWAT	55.10±0.73b	0.98±0.01ab	3.14±0.31	73.34±2.87a	26.66±2.87b	68.59±3.55	0.22±0.02	43.72±2.38
S.E.D	0.42	0.01	ns	0.93	0.93	ns	ns	ns
S.E.D (Land preparation × Irrigation)	0.70	0.02	0.38	ns	ns	5.61	0.03	ns
S.E.D (Mulch × Irrigation)	ns	ns	0.49	ns	ns	5.85	ns	ns
S.E.D (Land preparation × Mulch)	0.88	0.03	ns	ns	ns	ns	ns	ns
S.E.D (LP × M × I)	1.52	ns	0.84	7.38	7.38	10.57	ns	ns
% CV (Main plot)	0.9	0.9	8.7	1.6	3.8	4.9	8.4	9.4
% CV (Sub-plot)	1.5	3.5	14.9	8.1	18.8	10.9	20.0	13.5
% CV (Sub sub-plot)	3.6	6.1	36.4	13.5	31.4	19.9	40.4	24.3

Means with the same letter(s) under the same category in the same column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, WSA = Water stable aggregate, MWD = Mean weight diameter, ASC = Aggregated silt and clay, CDI = Clay dispersion index, CFI = Clay flocculation index, DR = Dispersion ration, SS = Soil structural stability, S = Soil structural stability index, CV (%) = Coefficient of variation.

significant ($p<0.05$) impact on soil WSA, with 75% ET_c recording a high WSA value of 57.35%, while CROPWAT and 100% ET_c irrigated plots had low WSA values of 55.10% and 54.40%, respectively (Table 4.14). Furthermore, there were significant ($p<0.05$) effects in the WSA of the soil among the various interaction combinations (Table 4.14).

4.4.4.7 Effects of land preparation, mulch and irrigation rates on soil mean weight diameter

The soil mean weight diameter (MWD) under land preparation, mulch and irrigation treatments in the 2015/2016 and 2016/2017 dry seasons are presented in Tables 4.13 and 4.14, respectively.

In 2015/2016, there was no significant ($p = 0.05$) difference in MWD among the land preparation types, even though, plots with Flat recorded the highest MWD of 1.05 mm, while Raised bed and Ridge had low MWD values (1.04 mm and 1.01 mm), respectively (Table 4.13). With respect to mulch application, MWD differed significantly ($p<0.05$) and plots treated with *Pennisetum* mulch had the highest MWD value of 1.06 mm. This was followed by *Gliricidia* mulch which had a MWD value of 1.05 mm, while Zero mulch recorded the significantly ($p<0.05$) lowest MWD value of 0.99 mm (Table 4.13). The MWD of soil of the experimental site differed significantly ($p<0.05$) among the irrigation rates, in which plots irrigated with 75% ET_c recorded the highest MWD value of 1.07 mm, while CROPWAT irrigated plots had a MWD value of 1.06 mm, and those irrigated with 100% ET_c had the lowest MWD value of 0.97 mm (Table 4.13). There were also significant ($p<0.05$) differences in MWD obtained among the various treatment interactions (Table 4.13).

In 2016/2017, the soil MWD did not differ significantly ($p<0.05$) among the land preparation types, although, plots with Flat and Ridge recorded a MWD value of 0.99 mm, respectively, while Raised bed had a low mean MWD value of 0.97 mm (Table 4.14). The mulch types significantly ($p<0.05$) enhanced the soil MWD, as *Gliricidia* mulch plots recorded the highest MWD value of 1.03 mm, while *Pennisetum* mulch plots had a MWD value of 0.99 mm, and Zero mulch plots recorded the lowest MWD value of 0.93 mm (Table 4.14). The soil MWD also differed significantly ($p<0.05$) among the irrigation rates, with plots irrigated with 75% ET_c recording the highest WSA value of 1.02 mm, while those irrigated with CROPWAT and 100% ET_c irrigation rates having low MWD values of 0.98% and 0.95%, respectively (Table 4.14). In addition, there were significant ($p<0.05$) differences in the soil MWD among the various treatment interactions (Table 4.14).

4.4.4.8 Land preparation, mulch, and irrigation rate effects on soil aggregated silt and clay

The results for the soil aggregated silt and clay (ASC) under the land preparations, mulch, and irrigation rates in 2015/2016 and 2016/2017 are presented in Tables 4.13 and 4.14, respectively.

In 2015/2016, the land preparation types significantly ($p<0.05$) influenced the soil ASC, with Flat recording the highest ASC (16.82%), while Raised bed had a mean ASC value of 14.72% and Ridge recorded the lowest ASC value of 14.20% (Table 4.13). In contrast to the aforementioned, the mulch treatments did not significantly ($p<0.05$) influence the soil ASC, although, the application of *Pennisetum* mulch gave the highest ASC value of 15.58%, while *Gliricidia* mulch had an ASC value of 15.22% and Zero mulch recorded the lowest ASC value of 14.94% (Table 4.13). The irrigation rates significantly ($p<0.05$) influenced the soil ASC and plots irrigated with 75% ET_c had the highest ASC value of 17.51%, while CROPWAT and 100% ET_c had low ASC values of 14.99% and 13.25%, respectively (Table 4.13). Significant ($p<0.05$) differences were also recorded in the soil ASC among the interaction combinations (Table 4.13).

In 2016/2017, the soil ASC differed significantly ($p<0.05$) among the land preparation types, as soil samples obtained from Raised bed recorded the highest ASC value of 3.36%. This was followed by Flat which had a mean ASC value of 3.17%, while Ridge recorded the lowest ASC value of 2.74% (Table 4.14). The mulch treatments did not significantly ($p = 0.05$) enhance the soil ASC, even though, *Pennisetum* mulch had the highest ASC (3.14%), while Zero mulch and *Gliricidia* mulch had low mean ASC values of 3.09% and 3.03%, respectively (Table 4.14). The soil ASC did not significantly ($p = 0.05$) differ under the irrigation rates, although, plots irrigated with CROPWAT irrigation rate recorded the highest ASC value of 3.14%, while 100% ET_c and 75% ET_c recorded low ASC values of 3.11% and 3.02%, respectively (Table 4.14). In addition, there were significant ($p<0.05$) differences in the soil ASC among the various treatment interactions (Table 4.14).

4.4.4.9 Effects of land preparation, mulch, and irrigation rates on clay dispersion index

The results of the clay dispersion index (CDI) of the soil under the land preparation, mulch, and irrigation treatments in 2015/2016 and 2016/2017 are presented in Tables 4.13 and 4.14, respectively.

With respect to 2015/2016, the soil CDI did not differ significantly ($p = 0.05$) among the land preparation types. However, the highest CDI value of 61.50% was obtained from Flat, while Raised bed and Ridge had low CDI values of 53.60% and 39.1%, respectively (Table 4.13). The soil CDI was not significantly ($p = 0.05$) enhanced by the mulch treatments, even though, Zero mulch had the highest mean CDI value of 51.90%, and *Gliricidia* mulch and *Pennisetum* mulch recorded low CDI values of 51.70% and 50.60%, respectively (Table 4.13). Contrarily, the irrigation rates significantly ($p<0.05$) influenced the soil CDI. For instance, soil samples obtained from plots irrigated with 100% ET_c recorded the highest mean CDI (68.70%), while CROPWAT and 75% ET_c had low CDI values of 44.30% and 41.20%, respectively (Table 4.13). Furthermore, the soil CDI differed significantly among the interaction combinations (Table 4.13).

In 2016/2017, land preparation had no significant ($p = 0.05$) effect on the CDI values recorded. However, Flat recorded the highest CDI value of 71.21%, while low CDI values of 70.33% and 68.45% were recorded by Raised bed and Ridge, respectively (Table 4.14). Mulch application did not significantly ($p = 0.05$) influence the soil CDI, even though, soils obtained from Zero mulch plots recorded the highest CDI of 72.99%, while *Pennisetum* mulch and *Gliricidia* mulch recorded low mean CDI values of 69.57% and 67.43%, respectively (Table 4.14). Moreover, the soil CDI was significantly ($p<0.05$) affected by the irrigation rates. Here, plots under the CROPWAT irrigation rate had the highest CDI (73.34%), while 100% ET_c had a mean CDI value of 70.16%, and 75% ET_c recorded the least CDI value of 66.49% (Table 4.14). Similar to the 2015/2016 dry season, the soil CDI varied significantly ($p<0.05$) among the treatment interactions in the 2016/2017 dry season (Table 4.14).

4.4.4.10 Clay flocculation index as affected by land preparation, mulch and irrigation rates

The clay flocculation index (CFI) of soils obtained from the experimental plots under land preparation, mulch and irrigation treatments in 2015/2016 and 2016/2017 are presented in Tables 4.13 and 4.14, respectively.

In 2015/2016, CFI was similar among the land preparation types. Moreover, Flat recorded the highest CFI of 57.20%, while Raised bed and Ridge had low mean CFI of 50.80% and 37.00%, respectively (Table 4.13). In a similar way, CFI did not differ significantly ($p = 0.05$) among the mulch treatments. Although, *Gliricidia* mulch recorded the highest CFI of 52.10%, while *Pennisetum* mulch recorded a mean CFI of 50.60%, and Zero mulch had the lowest CFI of 42.20% (Table 4.13). In contrast, CFI differed significantly ($p<0.05$) among the irrigation rates as plots irrigated with 100% ET_c recorded the highest CFI of 63.30%, while those under CROPWAT irrigation rate and 75% ET_c had low CFI values of 41.20% and 40.50%, respectively (Table 4.13). Furthermore, the various interaction combinations significantly ($p<0.05$) influenced the soil CFI (Table 4.13).

In 2016/2017, land preparation had no significant ($p = 0.05$) effect on the soil CFI, even though, Ridge recorded the highest mean CFI of 31.55%, while Raised bed and Flat recorded low mean CFI of 29.67% and 28.79%, respectively (Table 4.14). In a similar way, mulch application had no significant ($p = 0.05$) effect on the soil CFI, although, *Gliricidia* mulch recorded the highest CFI of 32.57%, while *Pennisetum* mulch and Zero mulch recorded low CFI of 30.43% and 27.01%, respectively (Table 4.14). However, the soil CFI was significantly ($p<0.05$) influenced by irrigation treatments, with 75% ET_c recording the highest mean CFI of 33.51%, while 100% ET_c recorded a mean CFI of 29.84%, and CROPWAT recorded the lowest CFI value of 26.66% (Table 4.14). Furthermore, there were significant ($p<0.05$) differences in the soil CFI among the various treatment interactions (Table 4.14).

4.4.4.11 Soil dispersion ratio as influenced by land preparation, mulch and irrigation rates

The effects of land preparation, mulch and irrigation rates on soil dispersion ratio (DR) after termination of the field experiments in 2015/2016 and 2016/2017 are presented in Tables 4.13 and 4.14.

The soil DR was not significantly ($p = 0.05$) different under land preparation, even though, Raised bed had the highest DR of 20.42%, while Ridge and Flat recorded low DR of 19.14% and 16.41%, respectively (Table 4.13). The mulch treatments significantly ($p<0.05$) influenced the soil DR (Table 4.13). Plots without mulch (Zero mulch) recorded the highest DR of 21.83%, while *Gliricidia* mulch and *Pennisetum* mulch had low DR values of 18.35% and 15.78%, respectively. The irrigation rates significantly ($p<0.05$) affected the soil DR of the experimental site in 2015/2016. Plots irrigated with 100% ET_c recorded the highest DR value of 25.48%. This was followed by plots under CROPWAT irrigation rate which had a mean DR of 16.71%, while 75% ET_c recorded the lowest DR of 13.78% (Table 4.13). In addition, there were significant ($p<0.05$) differences in soil DR among the various treatment interactions (Table 4.13).

In 2016/2017, land preparation had significant effect on the soil DR, with Ridge recording the highest mean DR of 73.53%, while Flat had a mean DR of 65.92% and Raised bed recorded the lowest DR of 63.67% (Table 4.14). However, mulch application had no significant ($p = 0.05$) effect on the soil DR, even though *Gliricidia* mulch recorded the highest mean DR of 68.90%, while Zero mulch and *Pennisetum* mulch recorded low mean DR of 68.15% and 66.07%, respectively (Table 4.14). Similar to mulch application, the soil DR was not significantly ($p = 0.05$) affected by the irrigation rates, although, 75% ET_c recorded the highest mean DR of 69.68%, while CROPWAT and 100% ET_c recorded low DR values of 68.59% and 64.85%, respectively (Table 4.14). In addition, there were significant ($p<0.05$) differences among in the soil DR among the various treatment interactions (Table 4.14).

4.4.4.12 Effects of land preparation, mulch, and irrigation rates on soil structural stability

The results of the effects of land preparation, mulch, and irrigation rates on the structural stability (SS) of soils obtained after the termination of the experiments in the 2015/2016 and 2016/2017 dry seasons are presented in Tables 4.13 and 4.14, respectively.

With respect to 2015/2016, SS was similar under the land preparation types, although, soils obtained from plots with Raised bed had the highest mean SS value of 0.28, while Ridge and Flat had a low mean SS value of 0.27, respectively (Table 4.13).

Similarly, SS did not differ significantly ($p = 0.05$) among the mulch treatments, even though, *Gliricidia* mulch and *Pennisetum* mulch application gave the highest SS value of 0.28, respectively, and Zero mulch had a low mean SS value of 0.26 (Table 4.13). The irrigation rates did not significantly ($p = 0.05$) affect the soil SS, although, soils obtained from plots irrigated with 75% ET_c recorded the highest SS of 0.29, while CROPWAT had a mean SS of 0.28, and 100% ET_c had the lowest SS of 0.25 (Table 4.13). Contrarily, significant ($p<0.05$) differences were observed in soil SS among the treatment interactions as presented in Table 4.13.

In 2016/2017, the soil SS did not differ significantly ($p = 0.05$) under the land preparation types. However, Flat recorded the highest SS value of 0.24, while Ridge and Raised bed had mean SS values of 0.23 and 0.22, respectively (Table 4.14). In a similar way, the mulch treatments did not significantly ($p = 0.05$) influence the soil SS, even though, *Gliricidia* mulch plots had the highest SS value of 0.25, while *Pennisetum* mulch had a mean SS of 0.23, and Zero mulch recorded the lowest SS of 0.20 (Table 4.14). The soil SS was not significantly ($p = 0.05$) influenced by the irrigation rates, although, plots irrigated with 75% ET_c had a high SS of 0.25, while low SS values of 0.22 and 0.21 were recorded by CROPWAT and 100% ET_c irrigated plots (Table 4.14). However, significant ($p<0.05$) differences in soil SS was observed among the treatment interactions as shown in Table 4.14.

4.4.4.13 Land preparation, mulch and irrigation rates effects on soil structural stability index

The results of the structural stability index (S) of soils obtained from the experimental plots under land preparation, mulch, and irrigation treatments in the 2015/2016 and 2016/2017 dry seasons are presented in Tables 4.13 and 4.14, respectively.

In 2015/2016, the land preparation types significantly ($p<0.05$) affected the soil S, with Ridge recording the highest S value of 18.37, while Raised bed and Flat had low mean S values of 16.15 and 13.85, respectively (Table 4.13). Furthermore, the mulch treatments had significant ($p<0.05$) influence on the soil S, and *Gliricidia* mulch had the highest S value of 18.15, while *Pennisetum* mulch had a mean S value of 15.67, and Zero mulch gave the lowest S value of 14.55 (Table 4.13). However, the irrigation rates did not significantly ($p = 0.05$) influence S, even though CROPWAT recorded the highest mean value of 17.12, while 100% ET_c and 75% ET_c had low mean values of 17.11 and 14.14, respectively (Table 4.13). In addition, S was significantly ($p<0.05$) different among the treatment interactions (Table 4.13).

In 2016/2017, land preparation had no significant ($p = 0.05$) effect on the soil S, even though the highest S value of 44.68 was recorded under Ridge, while Flat and Raised bed recorded low S values of 39.26 and 38.58, respectively (Table 4.14). In a similar way, mulch application did not significantly ($p = 0.05$) influence S, although, *Gliricidia* mulch recorded the highest S value of 43.06, while *Pennisetum* mulch and Zero mulch had low S values of 40.19 and 39.27, respectively (Table 4.14). The soil S was not significantly ($p = 0.05$) influenced by the irrigation treatments. However, CROPWAT irrigated plots recorded the highest S value of 43.72, while 75% ET_c and 100% ET_c had low mean S values of 40.80 and 38.01, respectively (Table 4.14). Furthermore, the treatment interactions did not significantly ($p = 0.05$) influence the soil S in the 2016/2017 dry season (Table 4.14).

4.4.4.14 Soil moisture retention as affected by land preparation, mulch, and irrigation rates

The soil moisture content as influenced by land preparation, mulch, and irrigation treatments at different suctions in 2015/2016 and 2016/2017 are reported as follows:

In 2015/2016, there were significant ($p<0.05$) variations in soil moisture content under the land preparation types, with a range of mean values in the order: Ridge (0.45 – 0.21 $m^3\ m^{-3}$) > Raised bed (0.43 – 0.18 $m^3\ m^{-3}$) > Flat (0.43 to 0.16 $m^3\ m^{-3}$) at 0 to 15 bars, respectively (Figure 4.20). With respect to mulch application, the soil moisture content was only significantly ($p<0.05$) influenced at 1 bar suction. Under the mulch category, Figure 4.20 showed that soil moisture content at 0 bar, 1 bar, and 5 bars, was in the order: *Pennisetum* mulch (0.44 to 0.33 $m^3\ m^{-3}$) ≥ *Gliricidia* mulch (0.44 to 0.33 $m^3\ m^{-3}$) > Zero mulch (0.43 to 0.32 $m^3\ m^{-3}$). However, at 0.1 bar, *Gliricidia* mulch recorded the highest soil moisture content of 0.37 $m^3\ m^{-3}$, while all the mulch treatments recorded soil moisture contents of 0.23 $m^3\ m^{-3}$ and 0.18 $m^3\ m^{-3}$ at 10 bars and 15 bars, respectively. Considering the irrigation rates, the range of soil moisture content was in the order: CROPWAT (0.46 – 0.22 $m^3\ m^{-3}$) > 75% ET_c (0.43 – 0.18 $m^3\ m^{-3}$) > 100% ET_c (0.43 – 0.14 $m^3\ m^{-3}$) at 0 to 15 bars, with significant ($p<0.05$) differences at 0, 0.1, 5, 10 and 15 bars, respectively (Figure 4.20). In addition, there

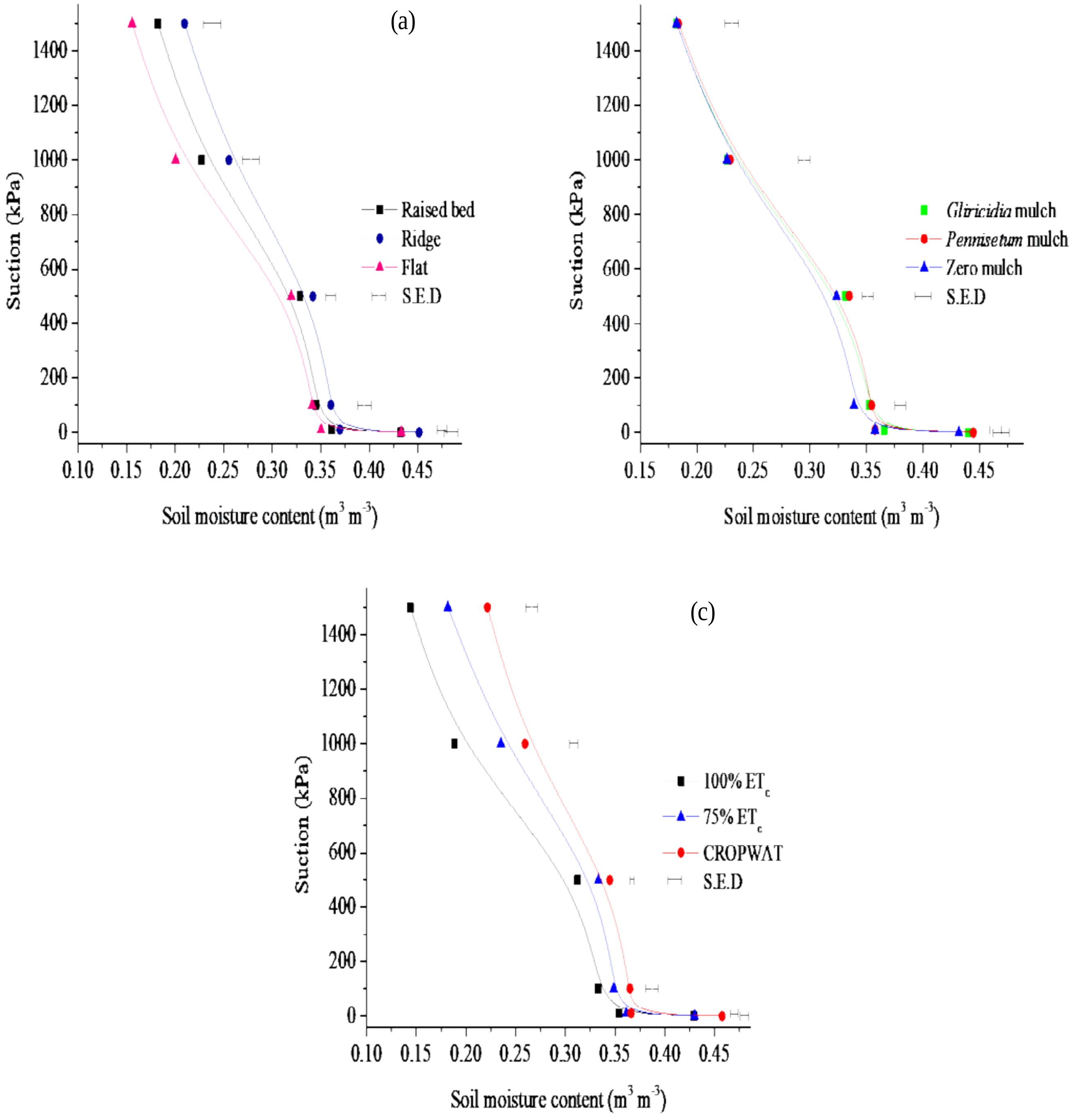


Figure 4.20: Soil moisture content as affected by (a) land preparation, (b) mulch, and (c) irrigation rates in 2015/2016

were significant ($p<0.05$) variations in the soil moisture content under the influence of the treatment interactions at various soil suctions in 2015/2016 (Figure 4.21).

In 2016/2017, the soil moisture content at 0 to 15 bars did not significantly ($p = 0.05$) vary under the different land preparation types. Although, plots with Raised bed recorded the highest soil moisture content values (0.44, 0.32 and 0.13 $m^3 m^{-3}$) at 0 bar, 1 bar and 15 bars, respectively, it had low moisture content (0.21 $m^3 m^{-3}$) than Ridge (0.22 $m^3 m^{-3}$) and Flat (0.22 $m^3 m^{-3}$) at a suction of 10 bars (Figure 4.22). In a similar way to land preparation, the application of mulch did not significantly ($p = 0.05$) influence the soil moisture content at the various levels of suction. However, *Gliricidia* mulch and *Pennisetum* mulch increased the soil moisture content by recording higher mean values in the range of 0.43 to 0.23 $m^3 m^{-3}$, than Zero mulch plots (0.41 to 0.20 $m^3 m^{-3}$) at 0 to 10 bars, while all the mulch treatments had a mean soil moisture content of 0.12 $m^3 m^{-3}$ at 15 bars (Figure 4.22). However, the soil moisture content was only significantly ($p<0.05$) influenced by the irrigation treatments at 5 and 15 bars respectively. Although, plots irrigated with 75% ET_c recorded the lowest soil moisture content at all suctions, the soil moisture content pattern was irregular in the 2016/2017 dry season. For instance, plots irrigated with CROPWAT irrigation rate recorded the highest soil moisture content (0.45 and 0.35 $m^3 m^{-3}$) at 0 and 0.1 bar, respectively. While the highest soil moisture content values at 1 bar (0.32 $m^3 m^{-3}$), 5 bars (0.31 $m^3 m^{-3}$) and 15 bars (0.13 $m^3 m^{-3}$) were recorded by plots irrigated with CROPWAT irrigation schedule and 100% ET_c, the highest soil moisture content (0.24 $m^3 m^{-3}$) at 10 bars was recorded by plots irrigated with daily application of 100% ET_c (Figure 4.22). It is also worthy to note that in the 2016/2017 dry season, none of the interaction combinations had significant ($p<0.05$) effect on the soil moisture content at 0 to 15 bars (Figure 4.23).

4.4.4.15 Effects of land preparation, mulch, and irrigation rates on soil penetration resistance

The results of land preparation, mulch, and irrigation effects on the soil penetration resistance (PR) in 2015/2016 and 2016/2017 are reported as follows:

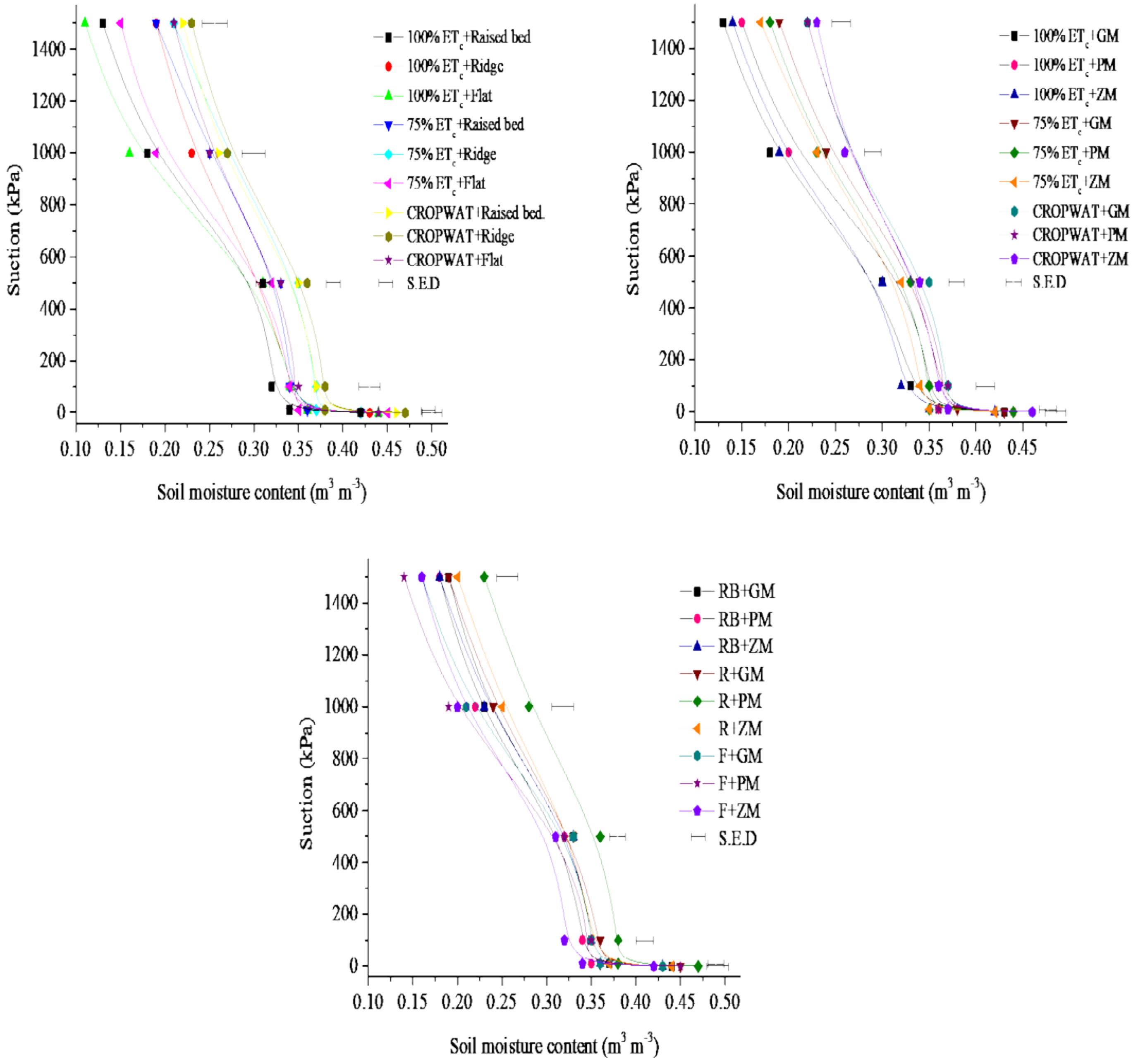


Figure 4.21: Soil moisture content as influenced by (a) irrigation rate and land preparation, (b) irrigation rate and mulch, and (c) land preparation and mulch interactions in 2015/2016

RB = Raised bed, R = Ridge, F = Flat, GM = *Gliricidia* mulch, PM = *Pennisetum* mulch, ZM = Zero mulch

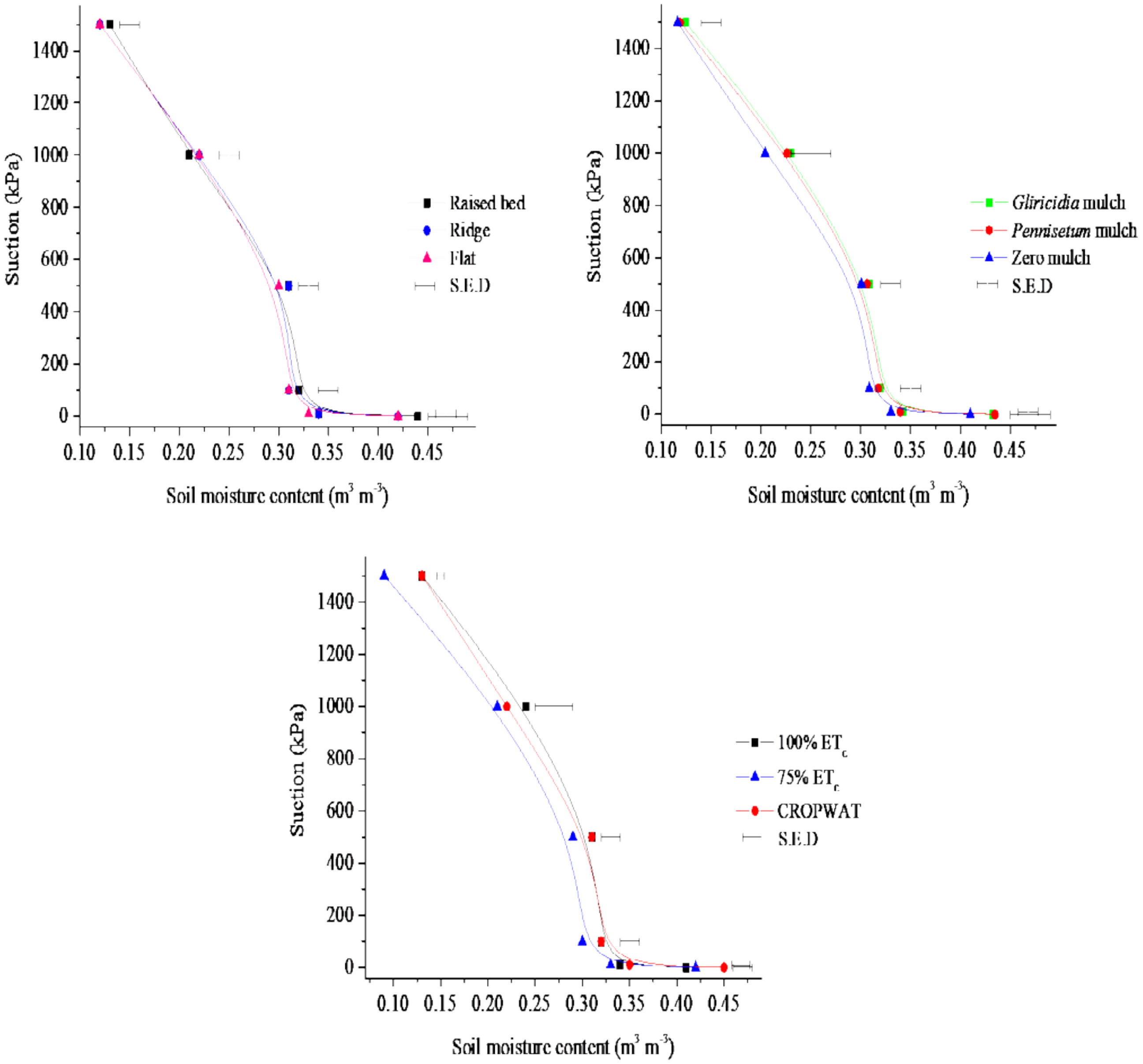


Figure 4.22: Effects of (a) land preparation, (b) mulch, (c) irrigation rates on soil moisture content in 2016/2017

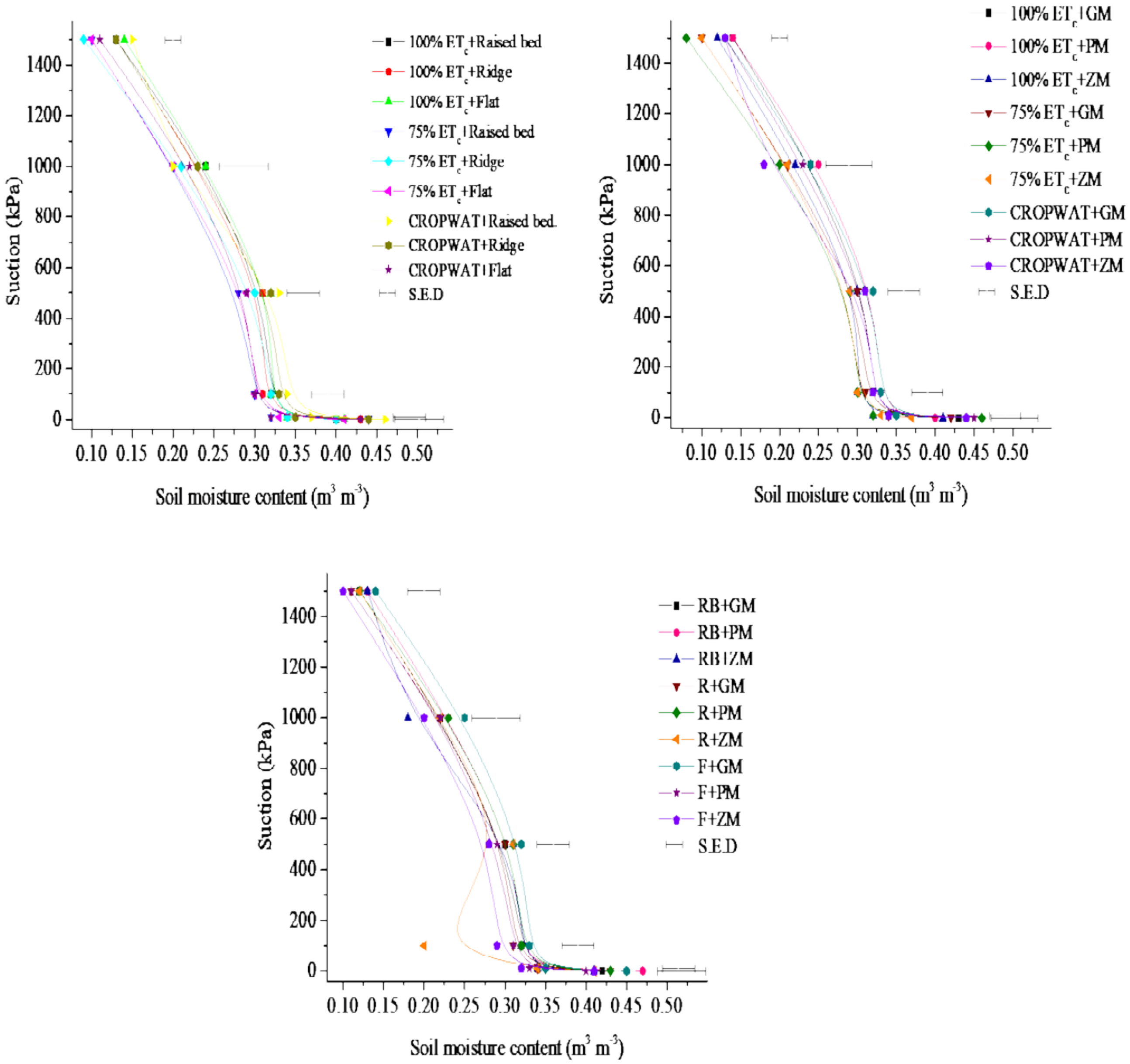


Figure 4.23: Soil moisture content as influenced by (a) irrigation rate and land preparation, (b) irrigation rate and mulch, and (c) land preparation and mulch interactions in 2016/2017

RB = Raised bed, R = Ridge, F = Flat, GM = *Gliricidia* mulch, PM = *Pennisetum* mulch, ZM = Zero mulch

In 2015/2016, significant ($p<0.05$) differences in PR values were recorded at 0 – 15 cm depth under the land preparation types, with Ridge recording the lowest PR values between the range of 0.15 – 0.95 MPa at 0 – 30 cm depth. Although, Raised bed recorded lower PR values between the range of 0.37 – 1.77 MPa than Flat (0.42 – 2.01 MPa) at 0 – 15 cm, Flat had lower PR between the range of 1.75 – 1.20 MPa than Raised bed (1.86 – 1.48 MPa) at 20 – 30 cm depth (Figure 4.24). Irrespective of the soil depth, the mulch treatments had no significant ($p = 0.05$) impact on the soil PR. Although, at 0 – 5 cm depth, plots with *Gliricidia* mulch recorded the lowest PR values of 0.30 – 0.78 MPa, they also had the highest PR value of 1.96 MPa at 15 cm, while *Pennisetum* mulch recorded the lowest PR values of 1.35 and 1.53 MPa at 10 cm and 15 cm soil depths, respectively. With the exception of 15 cm depth, plots without mulch (Zero mulch) recorded the highest PR values between the range of 0.33 – 1.63 MPa at 0 – 30 cm depth, respectively (Figure 4.24). With respect to the irrigation rates, the soil PR was not significantly ($p = 0.05$) affected at 0 – 30 cm depth. At 0 and 5 cm depths, plots irrigated with 100% ET_c had the highest PR values (0.37 and 0.88 MPa), while 75% ET_c recorded the lowest PR values of 0.28 and 0.79 MPa. However, at 10 – 30 cm depth, 100% ET_c recorded lower PR values between the range of 1.27 – 0.97 MPa than 75% ET_c (1.52 – 1.69 MPa), while CROPWAT had the lowest PR values of 1.64, 1.50 and 0.96 MPa at 15, 25 and 30 cm depths, respectively (Figure 4.24). In addition, the treatment interactions had no significant ($p = 0.05$) effect in the PR of the soil in 2015/2016 (Figure 4.25).

In 2016/2017, PR was significantly ($p<0.05$) influenced by the land preparation types at 0 – 15 cm. Plots with Ridge recorded the lowest PR values (0.08 – 0.28 MPa) at 0 – 5 cm, while Flat recorded the lowest PR values (0.65 – 0.43 MPa) at 10 – 20 cm, and Raised bed had the lowest PR values (0.32 and 0.18 MPa) at 25 and 30 cm depth, respectively (Figure 4.26). With the exception of PR at 15 cm, the application of mulch did not significantly ($p = 0.05$) influence the soil PR. With the exception of PR at 25 cm, *Gliricidia* mulch plots recorded the lowest PR values (0.17 – 0.36 MPa) at 0 – 20 cm depth, and 0.09 MPa at 30 cm depth, while plots under *Pennisetum* mulch recorded lower PR values within the range of 0.24 – 0.22 MPa than Zero mulch (0.29 – 0.22 MPa) at 0 – 30 cm depth, respectively (Figure 4.26). The resistance offered to cone penetration was not significantly ($p = 0.05$) influenced by the irrigation treatments. At the surface, plots irrigated with 75% ET_c recorded the lowest PR value

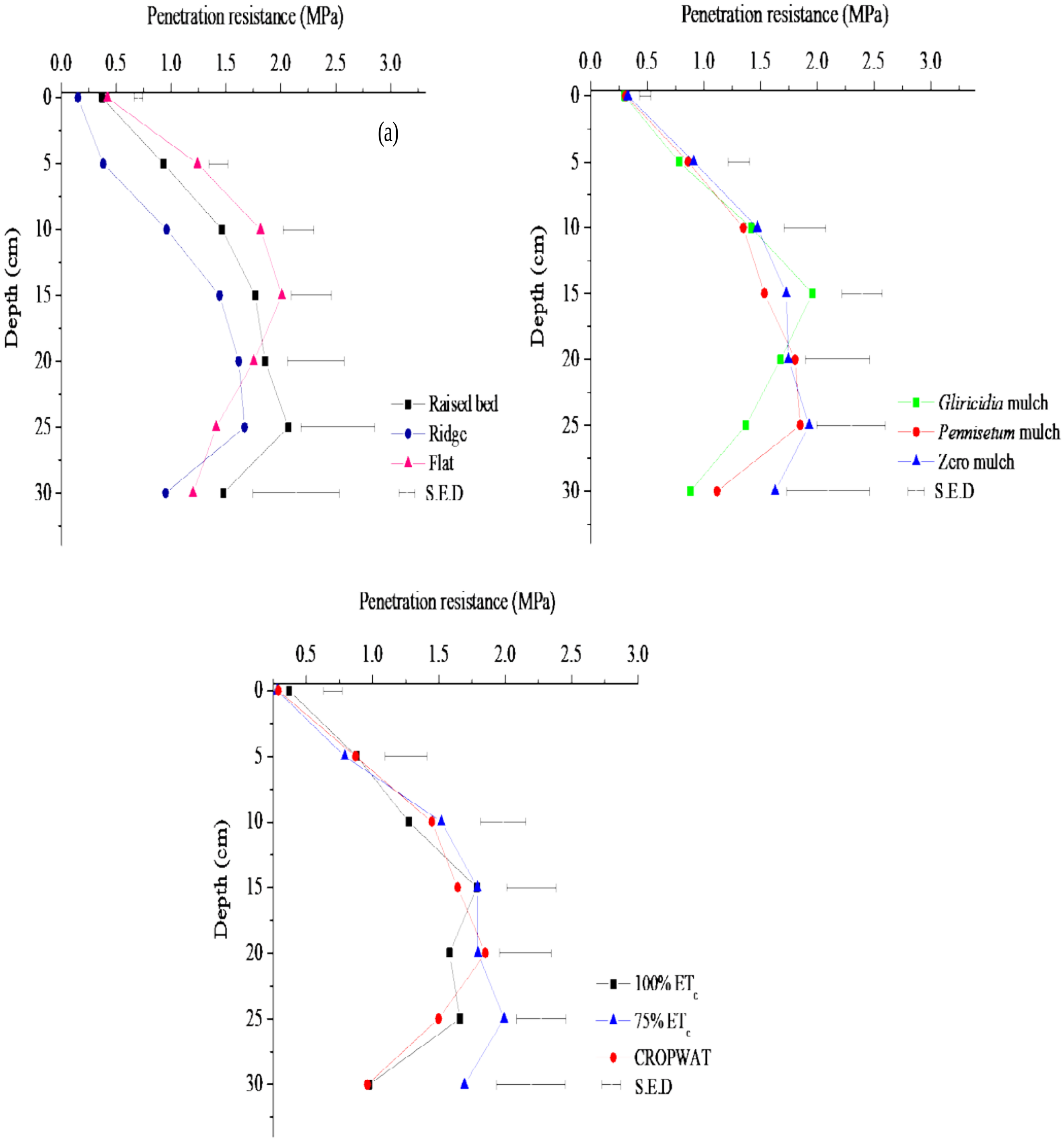


Figure 4.24. Penetration resistance as affected by (a) land preparation, (b) mulch, and (c) irrigation rates during 2015/2016

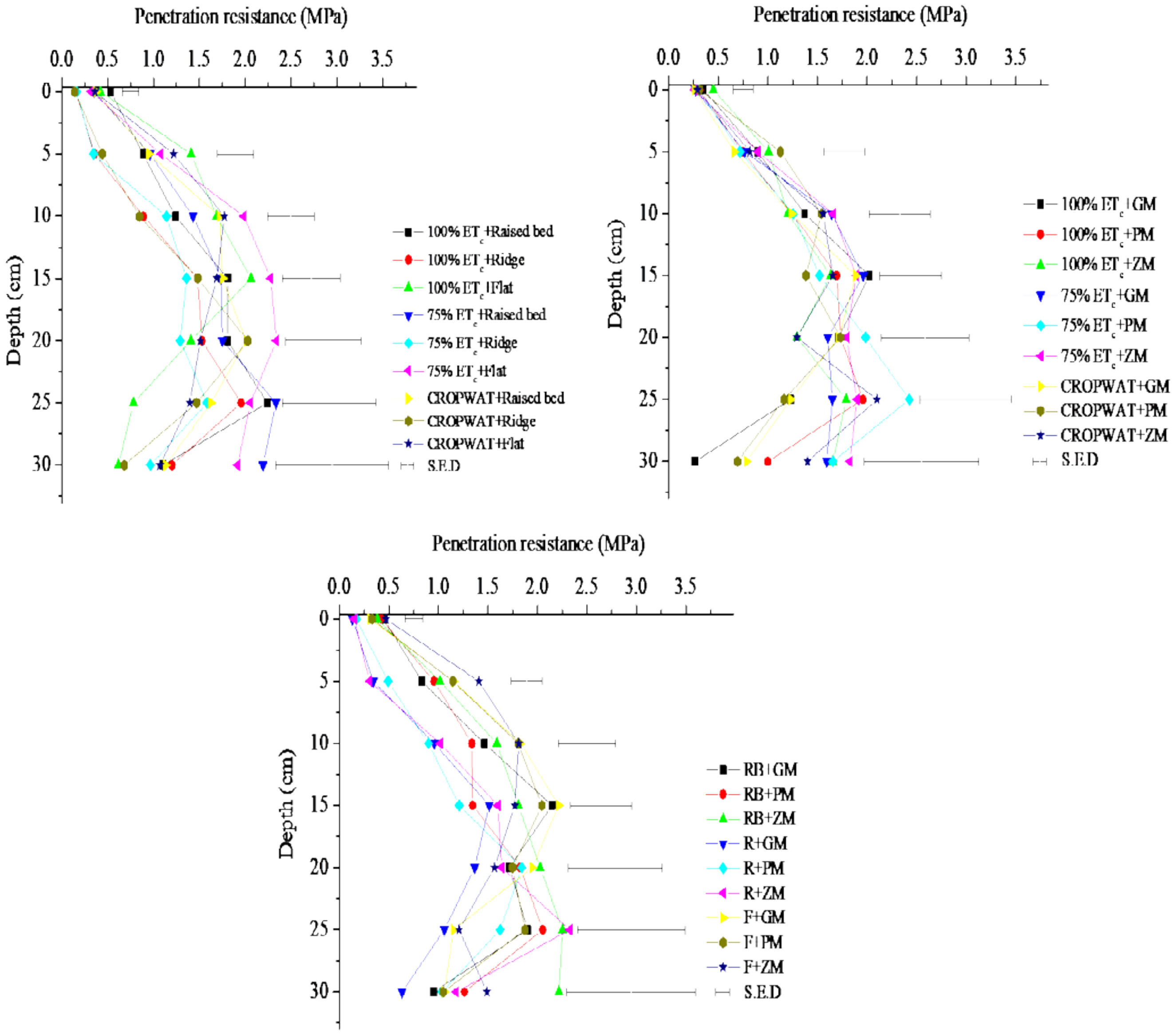


Figure 4.25: Soil penetration resistance as influenced by (a) irrigation rate and land preparation, (b) irrigation rate and mulch, and (c) land preparation and mulch interactions in 2015/2016

RB = Raised bed, R = Ridge, F = Flat, GM = *Gliricidia* mulch, PM = *Pennisetum* mulch, ZM = Zero mulch

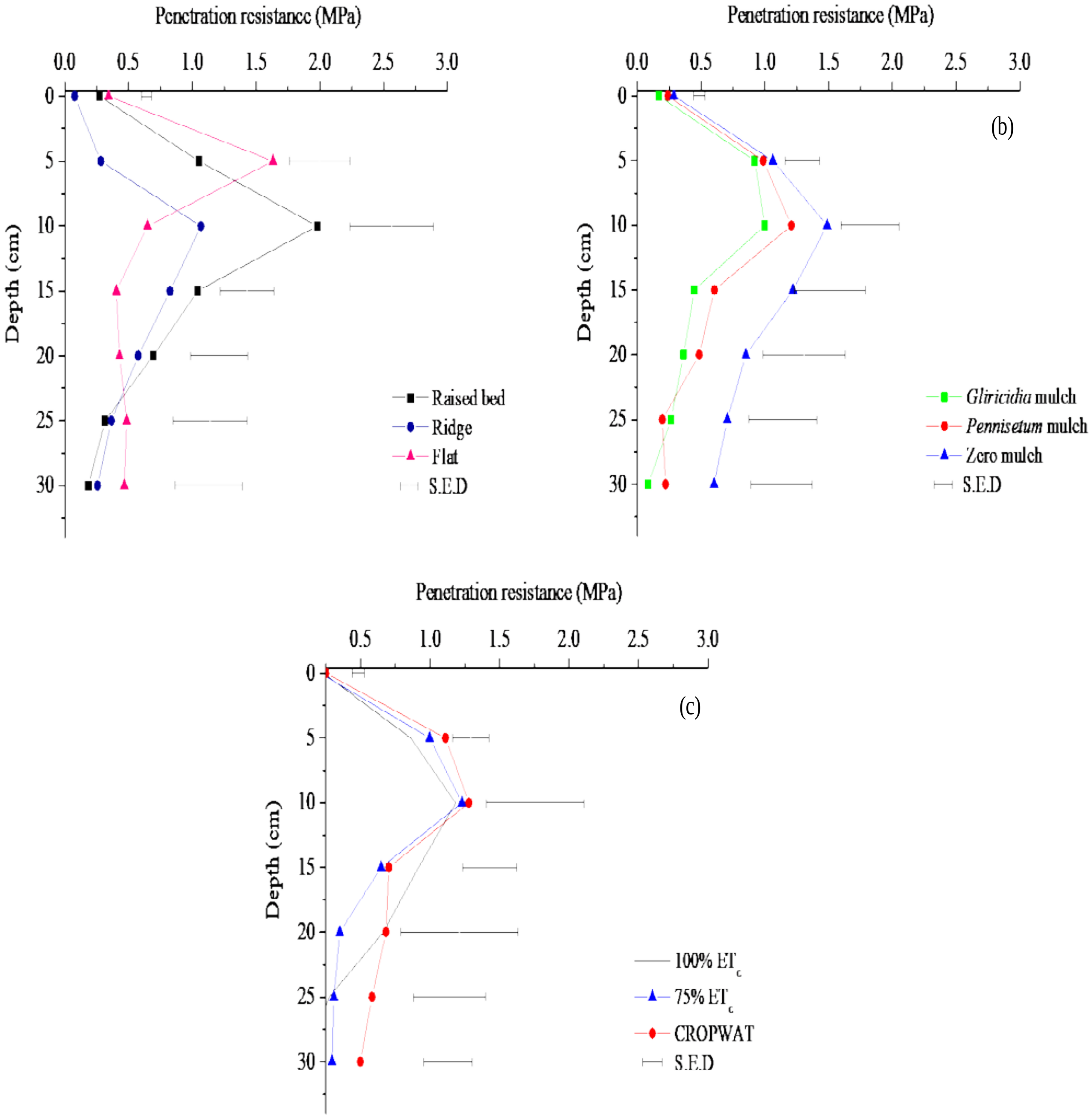


Figure 4.26: Effects of (a) land preparation, (b) mulch, and (c) irrigation rates on soil penetration resistance in 2016/2017

of 0.21 MPa, while plots irrigated with 100% ET_c and CROPWAT irrigation schedules recorded high PR values of 0.23 and 0.25 MPa, respectively. Plots irrigated with 75% ET_c had consistently low PR values between the range of 1.23 – 0.35 MPa at 10 – 20 cm depth, while at 25 and 30 cm depth, plots irrigated with 100% ET_c recorded the lowest PR values of 0.27 and 0.11 MPa, respectively (Figure 4.26). Furthermore, there were significant ($p<0.05$) variations in the soil PR under the different treatment interactions in 2016/2017 (Figure 4.27).

4.4.5 Effects of land preparation, mulch and irrigation rates on soil chemical properties

The results of the laboratory analyses of the experimental soils showed the effects of the treatments and their various interaction combinations on some soil chemical properties such as soil pH, major nutrients, minor nutrients, exchangeable acidity, and electrical conductivity.

4.4.5.1 Soil pH as influenced by land preparation, mulch, and irrigation rates

The effects of land preparation, mulch and irrigation rates on soil pH in 2015/2016 and 2016/2017 are reported as follows:

In 2015/2016, soil pH did not differ significantly ($p = 0.05$) among the land preparation types, even though, Raised bed and Ridge recorded the highest soil pH value of 6.1, respectively and Flat had low soil pH of 6.0 (Table 4.15). In a similar way, the mulch treatments had no significant ($p = 0.05$) effect on soil pH, although, *Gliricidia* mulch and Zero mulch recorded the highest soil pH value of 6.1, respectively, while plots with *Pennisetum* mulch had low pH value of 6.0 (Table 4.15). The soil pH was also not significantly ($p = 0.05$) influenced by the irrigation treatments. However, plots under daily application of 75% ET_c recorded the highest soil pH value of 6.2, while those under CROPWAT irrigation rate and 100% ET_c had mean soil pH values of 6.1 and 5.9, respectively (Table 4.15). In addition, soil pH was not significantly ($p = 0.05$) influenced by the treatment interactions in 2015/2016 (Table 4.15).

Similar to the results obtained in 2015/2016, soil pH was statistically similar under the three land preparation types in 2016/2017, in which, Flat recorded the highest pH value of 6.9, while Raised bed and Ridge had a low pH value of 6.8, respectively (Table 4.16). However, mulch application had significant ($p<0.05$)

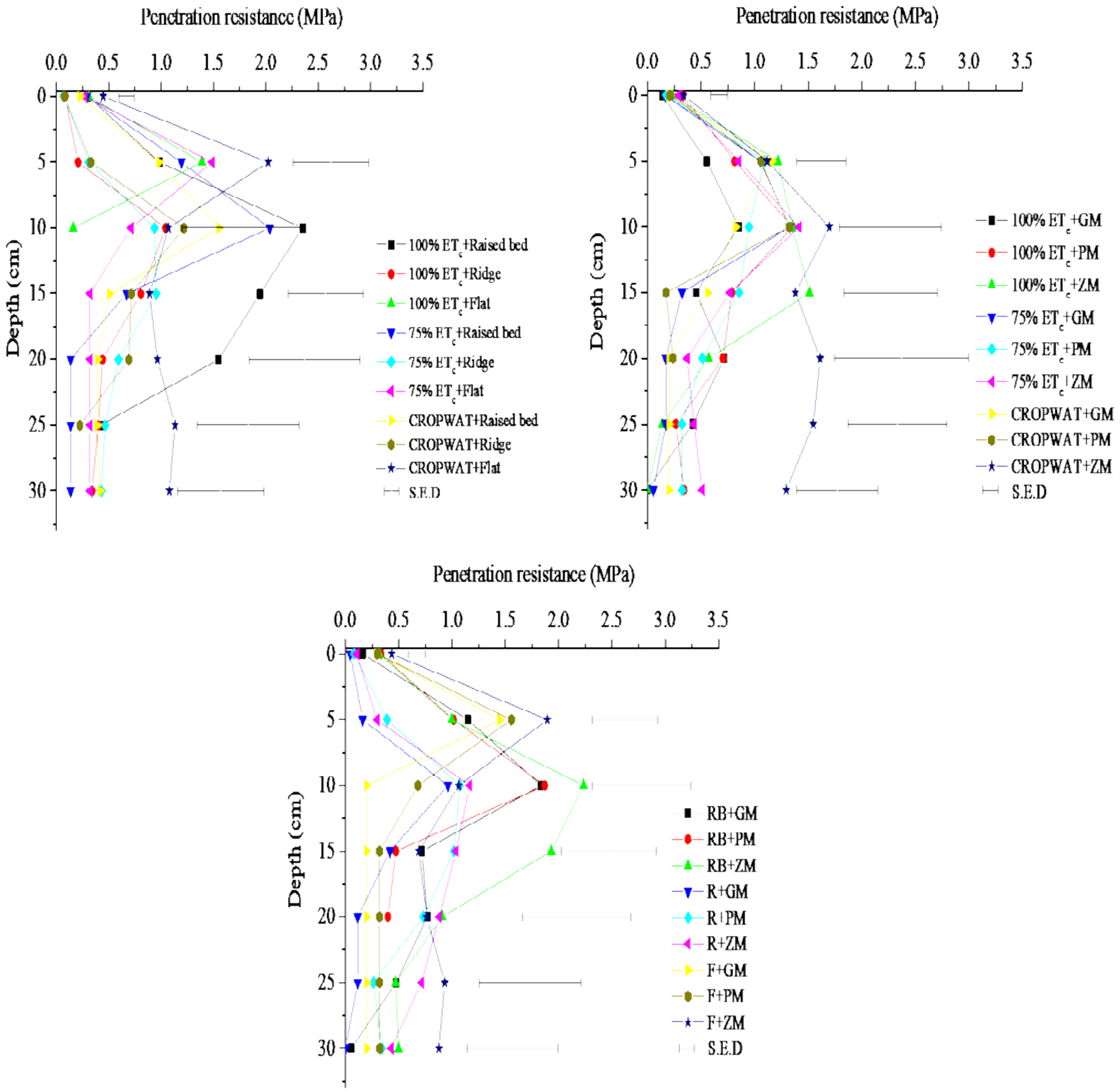


Figure 4.27: Soil penetration resistance as influenced by (a) irrigation rate and land preparation, (b) irrigation rate and mulch, and (c) land preparation and mulch interactions during 2016/2017

RB = Raised bed, R = Ridge, F = Flat, GM = *Gliricidia* mulch, PM = *Pennisetum* mulch, ZM = Zero mulch

Table 4.55: Land preparation, mulch and irrigation rates effects on some soil chemical properties in 2015/2016

Treatment	pH	Total Org. C	Total N	Avail P	Mn	Fe	Cu	Zn	Pb	K	Ca	Mg	Na	Ex. Acidity	EC
		g kg^{-1}		mg kg^{-1}						cmol kg^{-1}					(μS cm^{-1})
Land preparation (LP)															
Raised bed	6.1±0.19	16.3±1.02ab	1.7±0.10a	14.6±1.28	375.4±5.70ab	336.7±20.35	5.4±0.34c	6.7±0.63ab	13.6±0.52	0.8±0.04	0.6±0.11b	1.1±0.05a	0.4±0.02	0.4±0.03	296.4±32.81b
Ridge	6.1±0.18	17.7±0.57a	1.8±0.07a	14.4±1.00	389.9±7.92a	322.3±17.59	6.7±0.36a	6.4±0.56b	13.2±0.72	0.8±0.03	0.8±0.16a	1.0±0.04ab	0.3±0.02	0.4±0.03	380.2±33.72a
Flat	6.0±0.14	14.6±0.85b	1.5±0.07b	12.5±1.54	367.1±10.24b	296.6±25.08	6.0±0.37b	7.5±0.45a	12.6±0.57	0.8±0.07	0.4±0.04c	0.9±0.07b	0.3±0.01	0.4±0.03	235.4±23.39c
S.E.D	ns	0.91	0.10	ns	7.18	ns	0.12	0.38	ns	ns	0.09	0.05	ns	ns	12.36
Mulch (M)															
GsM	6.1±0.16	17.9±1.04a	1.8±0.08a	14.0±1.25	381.6±8.03	304.7±21.35	6.2±0.36a	7.4±0.61	13.1±0.78	0.8±0.03	0.7±0.14	0.9±0.06b	0.4±0.01	0.4±0.03	317.7±32.90
PpM	6.0±0.14	16.1±0.67ab	1.7±0.08ab	14.2±1.54	366.5±8.71	339.6±22.89	5.7±0.37b	6.4±0.46	12.3±0.51	0.9±0.07	0.6±0.11	1.0±0.06ab	0.3±0.01	0.4±0.03	287.8±30.51
ZM	6.1±0.21	14.6±0.75b	1.5±0.08b	13.2±1.07	384.4±7.89	311.3±19.41	6.2±0.37a	6.8±0.58	13.9±0.46	0.8±0.03	0.5±0.11	1.1±0.05a	0.3±0.02	0.4±0.03	306.4±32.19
S.E.D	ns	0.83	0.07	ns	ns	ns	0.09	ns	ns	ns	ns	0.06	ns	ns	ns
Irrigation rate (I)															
100% ET$_c$	5.9±0.15	15.9±0.68	1.7±0.07	15.4±1.48	345.6±6.00c	312.8±15.83b	5.8±0.21b	6.1±0.38b	14.6±0.67a	0.8±0.04	0.7±0.17	1.1±0.04b	0.3±0.02	0.3±0.03b	201.4±22.68b
75% ET$_c$	6.2±0.19	15.8±1.10	1.6±0.11	12.8±1.19	379.5±7.74b	255.4±20.26c	8.6±0.10a	8.7±0.40a	11.8±0.54b	0.9±0.06	0.6±0.11	0.7±0.04c	0.3±0.01	0.4±0.03a	526.3±19.57a
CROPWAT	6.1±0.17	16.8±0.74	1.7±0.06	13.3±1.17	407.4±7.56a	387.3±21.57a	3.7±0.09c	5.8±0.70b	13.0±0.52b	0.8±0.03	0.5±0.04	1.2±0.05a	0.3±0.01	0.4±0.03a	184.2±6.56b
S.E.D	ns	ns	ns	ns	7.48	10.57	0.06	0.69	0.40	ns	ns	0.06	ns	0.03	12.61
S.E.D (LP × I)	ns	1.51	0.16	2.43	12.61	41.44	0.18	0.87	1.20	ns	0.15	0.10	ns	ns	21.55
S.E.D (I × M)	ns	ns	ns	2.80	ns	ns	0.14	ns	1.04	ns	0.14	ns	ns	ns	ns
S.E.D (LP × M)	ns	ns	0.14	ns	ns	ns	ns	0.73	1.25	ns	0.14	0.10	ns	0.07	ns
S.E.D (LP×M×I)	ns	ns	0.24	ns	ns	65.88	0.29	1.39	ns	ns	0.24	ns	ns	ns	46.59
% CV (Main plot)	6.5	6.9	7.1	16.9	2.8	4.7	1.5	14.2	4.3	15.6	20.7	9.0	7.2	9.3	5.9
% CV (Sub-plot)	10.7	13.7	14.1	22.4	4.7	21.8	4.9	13.5	14.9	18.9	36.4	13.4	17.3	30.5	10.0
% CV (Sub sub-plot)	19.7	21.7	18.1	49.2	9.7	27.8	6.4	27.3	22.0	35.1	51.4	24.9	24.9	41.0	23.5

Means with the same letter(s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, CV (%) = Coefficient of variation.

Table 4.16: Effects of land preparation, mulch and irrigation rates on some soil chemical properties in 2016/2017

Treatment	pH	Total Org. C	Total N	Avail P	Mn	Fe	Cu	Zn	Pb	K	Ca	Mg	Na	Ex. Acidity	EC
		g kg^{-1}		mg kg^{-1}						cmol kg^{-1}					(µS cm^{-1})
Land preparation (LP)															
Raised bed	6.8±0.03	20.4±0.51	2.0±0.06	10.7±1.51	92.2±1.90a	10.7±0.66b	1.2±0.04	8.5±0.13b	1.2±0.10b	0.2±0.01	2.8±0.08	1.1±0.04	0.9±0.01a	0.3±0.02a	227.3±4.26
Ridge	6.8±0.01	19.7±0.70	1.9±0.05	12.6±1.14	86.5±1.48b	13.6±1.53ab	1.1±0.03	9.5±1.01a	1.6±0.08a	0.2±0.01	2.8±0.07	1.0±0.02	0.8±0.01b	0.3±0.02a	226.7±4.00
Flat	6.9±0.01	19.5±0.56	1.9±0.07	10.1±0.72	86.4±1.09b	14.6±1.82a	1.1±0.05	8.8±0.74ab	1.4±0.10ab	0.2±0.01	2.7±0.06	1.1±0.02	0.9±0.01a	0.2±0.01b	226.1±6.20
S.E.D	ns	ns	ns	ns	2.07	1.08	ns	0.29	0.07	ns	ns	ns	0.01	0.01	ns
Mulch (M)															
GsM	6.7±0.02b	20.9±0.62a	2.1±0.05a	11.1±0.80ab	90.7±1.67a	13.5±1.44ab	1.2±0.02a	8.7±0.59ab	1.5±0.11a	0.2±0.02	2.7±0.05b	1.0±0.03	0.8±0.01b	0.3±0.02	231.8±3.92
PpM	6.8±0.03a	19.7±0.58ab	1.9±0.05b	13.3±1.57a	87.8±1.67b	11.2±1.09b	1.1±0.04b	8.6±0.45b	1.4±0.10a	0.2±0.01	2.9±0.09a	1.1±0.03	0.9±0.01a	0.3±0.02	225.0±5.64
ZM	6.8±0.01a	19.0±0.54b	1.9±0.06b	9.0±0.87b	86.6±1.39b	14.3±1.71a	1.1±0.05b	9.5±1.01a	1.2±0.08b	0.2±0.01	2.7±0.06b	1.1±0.04	0.9±0.01a	0.3±0.02	223.3±4.90
S.E.D	0.01	0.56	0.06	0.97	1.40	0.82	0.02	0.27	0.07	ns	0.05	ns	0.01	ns	ns
Irrigation rate (I)															
100% ET$_c$	6.8±0.02	19.1±0.45b	1.9±0.06b	10.4±1.26	88.8±1.00	19.7±1.83a	1.2±0.04a	11.3±1.05a	1.5±0.10a	0.2±0.02a	2.8±0.08a	0.9±0.02b	0.8±0.01	0.2±0.02b	232.3±5.51a
75% ET$_c$	6.9±0.01	19.0±0.49b	2.0±0.04ab	12.2±1.31	86.9±2.03	8.4±0.25b	1.0±0.05b	6.7±0.26c	1.4±0.12a	0.1±0.01b	2.5±0.05b	1.1±0.02a	0.8±0.01	0.2±0.02b	220.0±4.35c
CROPWAT	6.7±0.03	21.5±0.69a	2.1±0.07a	10.8±0.91	89.4±1.61	10.8±0.51b	1.1±0.02a	8.8±0.09b	1.2±0.07b	0.2±0.01a	3.0±0.05a	1.1±0.03a	0.8±0.01	0.3±0.02a	227.8±4.51b
S.E.D	ns	0.29	0.02	ns	ns	0.81	0.02	0.08	0.04	0.01	0.05	0.05	ns	0.01	1.60
S.E.D (LP × I)	0.04	0.67	0.06	2.18	3.32	1.73	ns	0.41	0.10	0.02	0.13	0.07	ns	0.02	8.06
S.E.D (I × M)	0.03	ns	ns	ns	ns	1.41	0.04	0.40	0.10	0.01	0.08	0.05	0.02	ns	6.97
S.E.D (LP × M)	0.03	0.89	0.10	1.95	2.87	1.58	0.06	0.48	0.11	0.02	0.11	0.04	0.02	ns	ns
S.E.D (LP×M×I)	0.05	ns	ns	3.22	4.78	2.65	0.09	0.79	0.19	0.03	0.17	0.07	0.03	ns	ns
% CV (Main plot)	0.5	1.8	1.2	10.4	2.2	7.6	2.5	1.1	3.4	3.4	2.1	5.7	1.8	4.6	0.9
% CV (Sub-plot)	0.6	4.5	4.5	26.5	5.0	17.7	9.8	6.8	10.1	11.5	6.3	6.1	3.2	6.9	5.2
% CV (Sub sub-plot)	0.8	10.3	11.4	31.9	5.8	23.2	6.8	11.3	17.4	16.7	6.1	4.9	2.8	31.7	7.8

Means with the same letter(s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, CV (%) = Coefficient of variation.

influence on pH, with *Pennisetum* mulch and Zero mulch recording the highest pH value of 6.8, respectively, while *Gliricidia* mulch had low pH of 6.7 (Table 4.16). The irrigation rates had no significant ($p = 0.05$) effect on soil pH in 2016/2017. However, daily application of 75% ET_c recorded the highest pH value of 6.9, while 100% ET_c and CROPWAT had low pH values of 6.8 and 6.7, respectively (Table 4.16). In addition, significant ($p<0.05$) differences were observed in the pH values of soil among the interaction combinations (Table 4.16).

4.4.5.2 Effects of land preparation, mulch and irrigation rates on soil organic carbon

The total organic carbon content (total org. C) of the soil of the experimental site as influenced by land preparation, mulch and irrigation rates in 2015/2016 and 2016/2017 are presented in Tables 4.15 and 4.16, respectively.

In 2015/2016, land preparation had significant ($p<0.05$) effect on the soil total org. C content. Soil samples obtained from plots with Ridge recorded the highest mean total org. C value of 17.7 g kg^{-1}, while Raised bed had a mean total org. C value of 16.3 g kg^{-1}, and Flat recorded the significantly ($p<0.05$) lowest total org. C value of 14.6 g kg^{-1} (Table 4.15). Mulch application also had significant ($p<0.05$) effect on the soil total org. C content, with *Gliricidia* mulch recording the highest total org. C of 17.9 g kg^{-1}, while *Pennisetum* mulch had a mean total org. C of 16.1 g kg^{-1}, and Zero mulch recorded the significantly ($p<0.05$) lowest total org. C of 14.6 g kg^{-1} (Table 4.15). However, total org. C was not significantly ($p = 0.05$) affected by the irrigation rates. However, soils obtained from plots irrigated with CROPWAT irrigation rate recorded the highest total org. C value of 16.8 g kg^{-1}, while those from 100% ET_c and 75% ET_c recorded low total org. C values of 15.9 and 15.8 g kg^{-1}, respectively (Table 4.15). There were also significant ($p<0.05$) differences in the total org. C content of the soil among the different treatment interactions (Table 4.15).

In 2016/2017, there was no significant ($p = 0.05$) variation in the total org. C content of the soil under the land preparation types. However, Raised bed recorded the highest total org. C value of 20.4 g kg^{-1}, while Ridge had a mean total org. C value of 19.7 g kg^{-1}, and Flat recorded the lowest total org. C value of 19.5 g kg^{-1} (Table 4.16). However, mulch application had significant ($p<0.05$) impact on the total org. C content of the soil, with *Gliricidia* mulch recording the highest total org. C value of 20.9 g kg^{-1}, while *Pennisetum* mulch and Zero mulch recorded low mean total org. C values (19.7 and 19.5 g kg^{-1}), respectively (Table 4.16). Similarly, the irrigation rates had significant ($p<0.05$) effect on the total org. C. Here, CROPWAT recorded the significantly ($p<0.05$) highest total org. C value of 21.5 g kg^{-1}, while 100% ET_c and 75% ET_c had low total org. C values (19.1 and 19.0 g kg^{-1}), respectively (Table 4.16). In addition, there were significant ($p<0.05$) differences in the total org. C content of the soil among the different treatment interactions (Table 4.16).

4.4.5.3 Effects of land preparation, mulch and irrigation rates on soil nitrogen

The total nitrogen (total N) of the experimental soil as influenced by land preparation, mulch and irrigation in 2015/2016 and 2016/2017 are presented in Tables 4.15 and 4.16, respectively.

In 2015/2016, total N was significantly ($p<0.05$) influenced by land preparation, wherein Ridge recorded the highest total N value of 1.8 g kg^{-1}, Raised bed had a mean total N value of 1.7 g kg^{-1}, and Flat recorded the significantly ($p<0.05$) lowest total N value of 1.5 g kg^{-1} (Table 4.15). The total N was significantly ($p<0.05$) affected by mulch application, where *Gliricidia* mulch recorded the highest total N value of 1.8 g kg^{-1}, *Pennisetum* mulch had a mean total N value of 1.7 g kg^{-1} and Zero mulch recorded the significantly ($p<0.05$) lowest total N value of 1.5 g kg^{-1} (Table 4.15). However, total N was not significantly ($p = 0.05$) influenced by the irrigation treatments, even though, plots irrigated 100% ET_c and CROPWAT irrigation schedule recorded the highest total N value of 1.7 g kg^{-1}, respectively and 75% ET_c had the lowest total N (1.6 g kg^{-1}) (Table 4.15). Significant ($p<0.05$) variations in total N was observed among the various treatment interactions (Table 4.15).

In 2016/2017, total N did not differ significantly ($p = 0.05$) among the land preparation types, although, Raised bed recorded the highest total N value of 2.0 g kg^{-1}, while a low total N value of 1.9 g kg^{-1} was recorded by Ridge and Flat, respectively (Table 4.16). However, mulch application had significant ($p<0.05$) effect on the soil total N, where *Gliricidia* mulch recorded the significantly ($p<0.05$) highest total N value of 2.1 g kg^{-1}, while *Pennisetum* mulch and Zero mulch had a low total N value of 1.9 g kg^{-1}, respectively (Table 4.16). Similar to the mulch treatments, the irrigation rates had significant ($p<0.05$) effect on the soil total N content, with CROPWAT recording the highest total N value of 2.1 g kg^{-1}. This was followed by 75% ET_c which recorded a mean total N value of 2.0 g kg^{-1}, while 100% ET_c recorded the lowest total

N value of 1.9 g kg^{-1} (Table 4.16). Significant ($p<0.05$) variations in total N were also observed among the various treatment interactions (Table 4.16).

4.4.5.4 Effects of land preparation, mulch and irrigation rates on soil available phosphorus

The results of the available phosphorus (avail. P) of soil samples obtained from the experimental site after land preparation, mulch and irrigation applications in 2015/2016 and 2016/2017 are presented in Tables 4.15 and 4.16.

In 2015/2016, the land preparation types had no significant ($p = 0.05$) effect on avail. P. However, Raised bed recorded the highest mean avail. P value of 14.6 mg kg^{-1}, while Ridge had a mean avail. P value of 14.4 mg kg^{-1}, and the lowest mean avail. P value of 12.5 mg kg^{-1} was recorded by Flat (Table 4.15). In a similar way, the mulch types had no significant ($p = 0.05$) effect of soil avail. P, even though *Pennisetum* mulch had the highest avail. P value of 14.2 mg kg^{-1}, while *Gliricidia* mulch which had a mean avail. P value of 14.0 mg kg^{-1}, and Zero mulch had the lowest avail. P value of 13.2 mg kg^{-1} (Table 4.15). The soil avail. P was also not significantly ($p = 0.05$) affected by the irrigation rates, even though, plots irrigated with 100% ET_c recorded the highest avail. P of 15.4 mg kg^{-1}, while CROPWAT and 75% ET_c had low mean avail. P values of 13.3 mg kg^{-1} and 12.8 mg kg^{-1}, respectively (Table 4.15). However, significant ($p<0.05$) variations in soil avail. P was recorded among the various treatment interactions (Table 4.15).

In 2016/2017, there was no significant variation in the avail. P content of the soil under the various land preparation types, although, Ridge recorded the highest avail. P value of 12.6 mg kg^{-1}, while Raised bed and Flat had low mean avail. P values of 10.7 and 10.1 mg kg^{-1}, respectively (Table 4.16). Unlike the land preparation, mulch application had significant ($p<0.05$) effect on the avail. P content of the soil. Here, *Pennisetum* mulch recorded the highest avail. P value of 13.3 mg kg^{-1}, while *Gliricidia* mulch had a mean avail. P value of 11.1 mg kg^{-1}, and Zero mulch recorded the significantly ($p<0.05$) lowest avail. P value of 9.0 mg kg^{-1} (Table 4.16). The avail. P content of the soil was not significantly ($p = 0.05$) different under the different irrigation rates. However, 75% ET_c recorded the highest avail. P value of 12.2 mg kg^{-1}, while CROPWAT and 100% ET_c recorded low avail. P values of 10.8 and 10.4 mg kg^{-1}, respectively (Table 4.16). In addition, there were significant ($p<0.05$) differences in the soil avail. P recorded among the various treatment interactions.

4.4.5.5 Manganese content of soil as affected by land preparation, mulch and irrigation rates

The manganese (Mn) content of the experimental soil as influenced by land preparation, mulch and irrigation treatments in 2015/2016 and 2016/2017 are presented in Tables 4.15 and 4.16, respectively.

In 2015/2016, significant ($p<0.05$) differences were recorded among the Mn values obtained under the three land preparation types. Soil samples obtained from plots with Ridge recorded the highest Mn value of 389.9 mg kg^{-1}, while Raised bed had a mean Mn value of 375.4 mg kg^{-1}, and Flat recorded the lowest Mn value of 367.1 mg kg^{-1} (Table 4.15). However, mulch had no significant ($p = 0.05$) effect of the Mn content of the soils. Zero mulch recorded the highest Mn content of 384.4 mg kg^{-1}, while *Gliricidia* mulch and *Pennisetum* mulch had low Mn values of 381.6 mg kg^{-1} and 366.5 mg kg^{-1} (Table 4.15). Soil Mn content was significantly ($p<0.05$) influenced by the irrigation rates. Soils collected from CROPWAT irrigated plots recorded the highest Mn content of 407.4 mg kg^{-1}, while 75% ET$_c$ recorded a mean Mn value of 379.5 mg kg^{-1}, and 100% ET$_c$ recorded the lowest Mn value of 345.6 mg kg^{-1} (Table 4.15). Significant ($p<0.05$) variations were recorded among the Mn values obtained under the different treatment interactions (Table 4.15).

In 2016/2017, there was significant ($p<0.05$) variation in the Mn content of the soil under the various land preparation types, where Raised bed recorded the significantly ($p<0.05$) highest Mn value of 92.2 mg kg^{-1}, while Ridge and Flat had low Mn values of 86.5 and 86.4 mg kg^{-1}, respectively (Table 4.16). Moreover, mulch application also had significant effect on the soil Mn content, with *Gliricidia* mulch recording the significantly ($p<0.05$) highest M value of 90.7 mg kg^{-1}, while *Pennisetum* mulch and Zero mulch recorded low Mn values of 87.8 and 86.6 mg kg^{-1}, respectively (Table 4.16). The soil Mn content was not significantly ($p = 0.05$) influenced by the irrigation schedule treatments, although, CROPWAT recorded the highest Mn value of 89.4 mg kg^{-1}, while 100% ET$_c$ and 75% ET$_c$ had low mean Mn values of 88.8 and 86.9 mg kg^{-1}, respectively (Table 4.16). In addition, significant ($p<0.05$) variations were recorded among the Mn values obtained under the different treatment interactions (Table 4.16).

4.4.5.6 Effects of land preparation, mulch and irrigation rates on the soil iron content

The iron (Fe) content of the experimental soil as influenced by land preparation, mulch and irrigation treatments in 2015/2016 and 2016/2017 are presented in Tables 4.15 and 4.16, respectively.

In 2015/2016, the land preparation types had no significant ($p = 0.05$) effect on the Fe content of the soil. However, soil samples from Raised bed recorded the highest Fe value of 336.7 mg kg^{-1}, while those collected from Ridge had a mean Fe value of 322.3 mg kg^{-1}, and Flat recorded the lowest Fe value of 296.6 mg kg^{-1} (Table 4.15). In a similar way, mulch application had no significant ($p = 0.05$) effect on the Fe content of the soil, even though, *Pennisetum* mulch recorded the highest Fe value of 339.6 mg kg^{-1}, while Zero mulch and *Gliricidia* mulch had low Fe values of 311.3 mg kg^{-1} and 304.7 mg kg^{-1}, respectively (Table 4.15). However, with respect to the irrigation rates, the Fe content of the soil was significantly ($p<0.05$) affected, with soil samples obtained from plots irrigated with CROPWAT irrigation rate recording the highest mean Fe content of 387.3 mg kg^{-1}. This was followed by soil samples obtained from plots under 100% ET$_c$, which had a mean Fe content of 312.8 mg kg^{-1}, while 75% ET$_c$ recorded the lowest Fe value of 255.4 mg kg^{-1} (Table 4.15). Significant ($p<0.05$) differences were also observed in the soil Fe content among the treatment interactions (Table 4.15).

In 2016/2017, Fe concentration varied significantly ($p<0.05$) under the various land preparation types. For instance, Flat recorded the significantly ($p<0.05$) highest Fe value of 14.6 mg kg^{-1}, while Ridge and Raised bed recorded low Fe values of 13.6 and 10.7 mg kg^{-1}, respectively (Table 4.16). Similarly, the application of mulch also had significant ($p<0.05$) impact on the Fe concentration of the soil, as plots without mulch (Zero mulch) recorded the significantly ($p<0.05$) highest mean Fe value of 14.3 mg kg^{-1}, while low Fe values were recorded by *Gliricidia* mulch (13.5 mg kg^{-1}) and *Pennisetum* mulch (11.2 mg kg^{-1}) (Table 4.16). The irrigation rates had significant ($p<0.05$) effect on the Fe concentration of the soil, with 100% ET$_c$ recording the significantly ($p<0.05$) highest Fe value of 19.7 mg kg^{-1}, while CROPWAT had a low mean Fe value of 10.8 mg kg^{-1}, and 75% ET$_c$ recorded the least Fe value of 8.4 mg kg^{-1} (Table 4.16). Consequently, significant ($p<0.05$) differences were observed in the soil Fe content among the treatment interactions (Table 4.16).

4.4.5.7 Effects of land preparation, mulch and irrigation treatments on the copper content of soil

The resultant effects of land preparation, mulch and irrigation treatments on the copper (Cu) content of the soil of the experimental site in 2015/2016 and 2016/2017 are presented in Tables 4.15 and 4.16, respectively.

In 2015/2016, Cu was significantly ($p<0.05$) influenced by land preparation as Ridge recorded the significantly ($p<0.05$) highest Cu value of 6.7 mg kg^{-1}. This was followed by Flat which had a mean Cu value of 6.0 mg kg^{-1}, while Raised bed recorded the lowest mean Cu value of 5.4 mg kg^{-1} (Table 4.15). The application of mulch was also found to significantly ($p<0.05$) influence the Cu content of the soil. For instance, *Gliricidia* mulch and Zero mulch recorded high Cu value of 6.2 mg kg^{-1}, respectively, while *Pennisetum* mulch recorded a low Cu value of 5.7 mg kg^{-1} (Table 4.15). The concentration of Cu was also significantly ($p<0.05$) influenced by the irrigation treatments, where soil samples obtained from plots irrigated with 75% ET$_c$ recorded the highest Cu value of 8.6 mg kg^{-1}, while 100% ET$_c$ and CROPWAT had low Cu values of 5.8 mg kg^{-1} and 3.7 mg kg^{-1}, respectively (Table 4.15). Significant ($p<0.05$) differences were also observed in the Cu values among the treatment interactions (Table 4.15).

With respect to 2016/2017, the Cu concentration of the soil did not vary significantly ($p = 0.05$) under the different land preparation types, although, Raised bed recorded the highest Cu value of 1.2 mg kg^{-1}, while Ridge and Flat had a low Cu value of 1.1 mg kg^{-1}, respectively (Table 4.16). Moreover, the Cu concentration of the soil was significantly ($p<0.05$) affected by the application of the mulch treatments. For example, *Gliricidia* mulch recorded the highest Cu value of 1.2 mg kg^{-1}, while *Pennisetum* mulch and Zero mulch had a low mean Cu value of 1.1 mg kg^{-1}, respectively (Table 4.16). The soil Cu content was significantly ($p<0.05$) influenced by the irrigation treatments, where 100% ET$_c$ recorded the highest Cu value of 1.2 mg kg^{-1}, while CROPWAT had a low mean Cu value of 1.1 mg kg^{-1}, and 75% ET$_c$ recorded the lowest Cu value (1.0 mg kg^{-1}) (Table 4.16). Significant ($p<0.05$) differences were also observed in the Cu values among the treatment interactions (Table 4.16).

4.4.5.8 Effects of land preparation, mulch and irrigation rates on the zinc content of soil

The zinc (Zn) content of the experimental soil as influenced by land preparation, mulch and irrigation treatments in 2015/2016 and 2016/2017 are presented in Tables 4.15 and 4.16, respectively.

In 2015/2016, the Zn content of the soil differed significantly ($p<0.05$) under the land preparation types, as Flat recorded the highest Zn value of 7.5 mg kg^{-1}, while Raised bed and Ridge had low Zn values of 6.7 and 6.4 mg kg^{-1}, respectively (Table 4.15). However, mulch application had no significant ($p = 0.05$) impact on the Zn content of the experimental soil, even though, soils collected from *Gliricidia* mulch plots recorded the highest Zn content of 7.4 mg kg^{-1}, while Zero mulch and *Pennisetum* mulch had low mean Zn values of 6.8 mg kg^{-1} and 6.4 mg kg^{-1}, respectively (Table 4.15). The Zn content of the experimental soil was significantly ($p<0.05$) affected by the irrigation rates, with 75% ET$_c$ recording the highest Zn value of 8.7 mg kg^{-1}, while 100% ET$_c$ and CROPWAT recorded low Zn values of 6.1 mg kg^{-1} and 5.8 mg kg^{-1}, respectively (Table 4.15). There were also significant ($p<0.05$) differences in the Zn content of the soil among the various treatment interactions (Table 4.15).

In 2016/2017, the Zn content of the soil varied significantly ($p<0.05$) under the different land preparation types, where Ridge recorded the highest Zn value of 9.5 mg kg^{-1}, while Flat and Raised bed had low Zn values of 8.8 and 8.5 mg kg^{-1}, respectively (Table 4.16). The application of mulch also had significant ($p<0.05$) effect on the Zn concentration of the soil. Zero mulch had the highest Zn value of 9.5 mg kg^{-1}, while *Gliricidia* mulch and *Pennisetum* mulch recorded low Zn values of 8.7 and 8.6 mg kg^{-1}, respectively (Table 4.16). The Zn content of the soil was also significantly ($p<0.05$) influenced by the irrigation treatments, in which, 100% ET$_c$ recorded the highest Zn value of 11.3 mg kg^{-1}, while CROPWAT had a mean Zn value of 8.8 mg kg^{-1}, and 75% ET$_c$ recorded the lowest Zn value of 6.7 mg kg^{-1} (Table 4.16). In addition, there were significant ($p<0.05$) effects on the Zn content of the soil among the various treatment interactions (Table 4.16).

4.4.5.9 Effects of land preparation, mulch and irrigation rates on the lead content of soil

The lead (Pb) content of the experimental soil as influenced by land preparation, mulch and irrigation applications in 2015/2016 and 2016/2017 are presented in Tables 4.15 and 4.16, respectively.

With respect to 2015/2016, land preparation did not significantly ($p = 0.05$) affect the Pb concentrations of the soil. For instance, Raised bed recorded the highest Pb concentration of 13.6 mg kg^{-1}. This was not significantly ($p = 0.05$) higher than Ridge and Flat which had Pb concentrations of 13.2 mg kg^{-1} and 12.6 mg kg^{-1}, respectively (Table 4.15). In a similar way to land preparation effect, mulch did not have a significant ($p = 0.05$) effect on the concentration of Pb in the soil. Although, Zero mulch had the highest Pb concentration (13.9 mg kg^{-1}), it was not significantly ($p = 0.05$) different from *Gliricidia* mulch and *Pennisetum* mulch which had low Pb concentrations of 13.1 mg kg^{-1} and 12.3 mg kg^{-1}, respectively (Table 4.15). Contrarily, the Pb content of the soil was significantly ($p<0.05$) affected by the irrigation rates. Soil samples obtained from plots with daily application of 100% ET_c contained the highest Pb content of 14.6 mg kg^{-1}, while those from CROPWAT irrigation rate and daily application of 75% ET_c had Pb concentrations of 13.0 mg kg^{-1} and 11.8 mg kg^{-1}, respectively (Table 4.15). Significant ($p<0.05$) differences were also recorded in the Pb concentration of the soil among the various treatment interactions (Table 4.15).

In 2016/2017, the Pb concentration of the soil was found to vary significantly ($p<0.05$) under the different land preparation types, where the highest Pb value (1.6 mg kg^{-1}) was recorded by Ridge, while Flat and Raised bed recorded low Pb values of 1.4 and 1.2 mg kg^{-1}, respectively (Table 4.16). Furthermore, the Pb concentration of the soil was significantly ($p<0.05$) influenced by the mulch types, as *Gliricidia* mulch recorded the highest Pb value of 1.5 mg kg^{-1}, while *Pennisetum* mulch had a mean Pb value of 1.4 mg kg^{-1}, and Zero mulch recorded the lowest Pb value of 1.2 mg kg^{-1} (Table 4.16). The irrigation treatments also had significant ($p<0.05$) effect on the concentration of Pb in the soil. For example, 100% ET_c recorded the highest Pb value of 1.5 mg kg^{-1}, while 75% ET_c had a mean Pb value of 1.4 mg kg^{-1}, and CROPWAT recorded the lowest Pb value of 1.2 mg kg^{-1} (Table 4.16). In addition, the treatment effects had significant ($p<0.05$) effect on the Pb concentration of the soil (Table 4.16).

4.4.5.10 Influence of land preparation, mulch and irrigation rates on soil exchangeable potassium

The soil exchangeable potassium (K) content of the experimental site as influenced by land preparation, mulch and irrigation in 2015/2016 and 2016/2017 are presented in Tables 4.15 and 4.16, respectively.

In 2015/2016, the K concentration of the soil was not significantly ($p = 0.05$) influenced by land preparation, as all the land preparation types had a mean K value of 0.8 cmol kg^{-1}, respectively (Table 4.15). In a similar way, mulch application did not have a significant ($p = 0.05$) effect on K concentration, with *Pennisetum* mulch recording a mean K value of 0.9 cmol kg^{-1}, while *Gliricidia* mulch and Zero mulch had a mean K value of 0.8 cmol kg^{-1}, respectively (Table 4.15). Similarly, the irrigation rates had no significant ($p = 0.05$) effect on the K concentration of the soil. However, 75% ET_c recorded the highest K value of 0.9 cmol kg^{-1}, while 100% ET_c and CROPWAT had low K value of 0.8 cmol kg^{-1}, respectively (Table 4.15). Furthermore, there was no significant ($p = 0.05$) difference in K value among the various interaction combinations in 2015/2016 (Table 4.15).

In 2016/2017, land preparation did not significantly ($p = 0.05$) influence the K concentration of the soil, as all the land preparation types had a mean K value of 0.2 cmol kg^{-1}, respectively (Table 4.16). A similar observation was noted for mulch application, as all the mulch treatments had a mean K value of 0.2 cmol kg^{-1} (Table 4.16). However, significant ($p<0.05$) differences were recorded in K concentrations under influence of the irrigation treatments, where plots under 100% ET_c and CROPWAT rates had the highest K value of 0.2 cmol kg^{-1}, respectively, while 75% ET_c had a low K value of 0.1 cmol kg^{-1} (Table 4.16). The various treatment combinations also had significant ($p<0.05$) effect on the K concentration of the soil (Table 4.16).

4.4.5.11 Effects of land preparation, mulch and irrigation rates on soil calcium content

The soil exchangeable calcium (Ca) content of the experimental site as influenced by land preparation, mulch and irrigation treatments in 2015/2016 and 2016/2017 are presented in Tables 4.15 and 4.16, respectively.

In 2015/2016, the concentration of Ca in the experimental soil varied significantly ($p<0.05$) under the three land preparation types. Ridge had the highest Ca content (0.8 cmol kg^{-1}), and this was followed Raised bed (0.6 cmol kg^{-1}), while Flat had the lowest Ca content of 0.4 cmol kg^{-1} (Table 4.15). With respect to mulch application, the Ca concentration of the soil did not vary significantly ($p = 0.05$), although, soil samples obtained from plots with *Gliricidia* mulch recorded the highest Ca concentration of 0.7 cmol kg^{-1}, while low Ca values were recorded for plots treated with *Pennisetum* mulch (0.6 cmol kg^{-1}) and Zero mulch (0.5 cmol kg^{-1}) (Table 4.15). The soil exchangeable Ca was not significantly ($p = 0.05$) influenced by the irrigation rates, even though, daily application of 100% ET_c recorded the highest Ca concentration of 0.7 cmol kg^{-1}, while 75% ET_c and CROPWAT had mean Ca values of 0.6 and 0.5 cmol kg^{-1}, respectively (Table 4.15). In addition, all the interaction combinations had significant ($p<0.05$) effect on the Ca content of the soil of the experimental site (Table 4.15).

In 2016/2017, the Ca content of the soil did not vary significantly ($p = 0.05$) under the land preparation types, where Raised bed and Ridge had a high Ca value of 2.8 cmol kg^{-1}, respectively, while Flat recorded a low Ca value of 2.7 cmol kg^{-1} (Table 4.16). However, the mulch treatments had significant ($p<0.05$) influence on the Ca content of the soil, as *Pennisetum* mulch recorded the highest Ca value of 2.9 cmol kg^{-1}, *Gliricidia* mulch and Zero mulch had a low Ca value of 2.7 cmol kg^{-1} (Table 4.16). Similarly, the irrigation treatments had significant ($p<0.05$) impact on the Ca content of the soil, as CROPWAT recorded the highest Ca value of 3.0 cmol kg^{-1}, while 100% ET_c and 75% ET_c recorded low Ca values of 2.8 and 2.5 cmol kg^{-1}, respectively (Table 4.16). The soil Ca content was observed to vary significantly ($p<0.05$) among the treatment interactions as shown in Table 4.16.

4.4.5.12 Soil magnesium content as affected by land preparation, mulch and irrigation treatments

The magnesium (Mg) content of the soil of the experimental site as influenced by land preparation, mulch and irrigation treatments in 2015/2016 and 2016/2017 are presented in Tables 4.15 and 4.16, respectively.

In 2015/2016, the results of the chemical analysis of soil samples obtained from the study site after termination of the experiment showed that Mg varied significantly ($p<0.05$) under the land preparation types, with Raised bed recording the highest value of 1.1 cmol kg^{-1}, while Ridge had a mean value of 1.0 cmol kg^{-1}, and Flat recorded the lowest value of 0.9 cmol kg^{-1} (Table 4.15). The Mg was significantly

($p<0.05$) affected by the application of mulch, with Zero mulch recording the significantly ($p<0.05$) highest Mg value of 1.1 cmol kg^{-1}, while *Pennisetum* mulch and *Gliricidia* mulch had mean Mg values of 1.0 cmol kg^{-1} and 0.9 cmol kg^{-1}, respectively (Table 4.15). The irrigation rates also had significant ($p<0.05$) effect on the magnesium (Mg) content of the experimental soil, where soil samples obtained from CROPWAT irrigated plots had the highest Mg content of 1.2 cmol kg^{-1}. This was followed by 100% ET$_c$ which had a mean Mg value of 1.1 cmol kg^{-1}, while 75% ET$_c$ had the lowest Mg value of 0.7 cmol kg^{-1} (Table 4.15). Significant ($p<0.05$) variations in the Mg concentration of the soil were also observed among the various treatment interactions as shown in Table 4.15.

In 2016/2017, the land preparation types had no significant ($p = 0.05$) effect on the Mg concentration of the soil. Moreover, Raised bed and Flat recorded the highest Mg value of 1.1 cmol kg^{-1}, respectively, while Ridge had a low Mg value of 1.0 cmol kg^{-1} (Table 4.16). Mulch application had no significant ($p = 0.05$) effect on the Mg content of the soil, with *Pennisetum* mulch and Zero mulch recording a higher Mg value of 1.1 cmol kg^{-1} than *Gliricidia* mulch which had a low Mg value of 1.0 cmol kg^{-1} (Table 4.16). However, the Mg concentration of the soil was significantly ($p<0.05$) influenced by the irrigation treatments, where soils obtained from plots irrigated with 75% ET$_c$ and CROPWAT irrigation rates recorded a high Mg value of 1.1 cmol kg^{-1}, respectively, while 100% ET$_c$ recorded a significant ($p<0.05$) low Mg value of 0.9 cmol kg^{-1} (Table 4.16). In addition, there were significant ($p<0.05$) variations in the Mg concentration of the soil obtained among the various treatment interactions (Table 4.16).

4.4.5.13 Effects of land preparation, mulch and irrigation rates on soil sodium content

The soil sodium (Na) content after the application of the experimental treatments in 2015/2016 and 2016/2017, are presented in Tables 4.15 and 4.16, respectively.

In 2015/2016, the soil Na concentration was not significantly ($p = 0.05$) influenced by the land preparation types, even though, Raised bed recorded the highest Na value of 0.4 cmol kg^{-1}, while Ridge and Flat had mean a Na value of 0.3 cmol kg^{-1}, respectively (Table 4.15). Similar to the results obtained for land preparation, mulch also had no significant ($p = 0.05$) effect on the Na concentration of the soil, as

Gliricidia mulch recorded the highest Na value of 0.4 cmol kg^{-1}, while *Pennisetum* mulch and Zero mulch had a mean Na value of 0.3 cmol kg^{-1}, respectively (Table 4.15). The irrigation rates did not significantly ($p = 0.05$) influence the sodium (Na) content of the soil of the experimental site, as 100% ET_c, 75% ET_c, and CROPWAT irrigation rates recorded a mean Na value of 0.3 cmol kg^{-1}, respectively (Table 4.15). It is also worthy to note that, the Na concentration of the soil of the experimental site was not significantly ($p = 0.05$) affected by the treatment interactions (Table 4.15).

In 2016/2017, there was significant ($p<0.05$) variation in the Na concentration of the soil under the different land preparation types, with Raised bed and Flat recording a high Na value of 0.9 cmol kg^{-1} than Ridge, which had a low Na value of 0.8 cmol kg^{-1}, respectively (Table 4.16). Similar to land preparation, mulch application significantly ($p<0.05$) influenced the Na content of the soil, as *Pennisetum* mulch and Zero mulch recorded a high Na value of 0.9 cmol kg^{-1}, respectively, while *Gliricidia* mulch recorded a low Na value of 0.8 cmol kg^{-1} (Table 4.16). However, there was no significant ($p = 0.05$) difference in the Na concentration of the soil after the application of the irrigation treatments, as all the treatments recorded a mean Na value of 0.8 cmol kg^{-1}, respectively (Table 4.16). The soil Na content was observed to vary significantly ($p<0.05$) among the treatment interactions as shown in Table 4.16.

4.4.5.14 Effects of land preparation, mulch and irrigation rates on soil exchangeable acidity

The results of the analysis of the soil exchangeable acidity (ex. acidity) as influenced by land preparation, mulch and irrigation treatments in 2015/2016 and 2016/2017 are presented in Tables 4.15 and 4.16, respectively.

In 2015/2016, the land preparation types did not significantly ($p = 0.05$) affect the soil ex. acidity, as all the land preparation types had a mean ex. acidity value of 0.4 cmol kg^{-1}, respectively (Table 4.15). This was also the case for mulch application, where all the mulch types also recorded a mean ex. acidity value of 0.4 cmol kg^{-1}, respectively (Table 4.15). However, the ex. acidity of the soil was significantly ($p<0.05$) affected by the irrigation rates, where soil samples from CROPWAT irrigated plots and daily application of 75% ET_c recorded high ex. acidity value of 0.4 cmol kg^{-1}, respectively, while 100% ET_c had a low ex. acidity value of 0.3 cmol kg^{-1} (Table 4.15). They were also significant ($p<0.05$) variations in soil ex. acidity among the various treatment interactions (Table 4.15).

In 2016/2017, the soil ex. acidity did not vary significantly ($p = 0.05$) under the different land preparation types, where Raised bed and Ridge recorded a high ex. acidity value of 0.3 cmol kg^{-1}, respectively, and Flat had a low ex. acidity value of 0.2 cmol kg^{-1} (Table 4.16). There was no variation in the soil ex. acidity after mulch application, as all the mulch treatments had a mean ex. acidity value of 0.3 cmol kg^{-1}, respectively (Table 4.16). However, the soil ex. acidity was significantly ($p<0.05$) affected by the irrigation treatments. Soils obtained from plots irrigated with CROPWAT irrigation rate recorded a significantly ($p<0.05$) high soil ex. acidity value of 0.3 cmol kg^{-1}, while those obtained from 100% ET_c and 75% ET_c recorded a low mean soil ex. acidity value of 0.2 cmol kg^{-1}, respectively (Table 4.16). Similar to the 2015/2016 dry season, significant ($p<0.05$) variations were recorded in soil ex. acidity among the various treatment interactions in 2016/2017 (Table 4.16).

4.4.5.15 Land preparation, mulch and irrigation rates effects on soil electrical conductivity

The results of the analysis of the soil electrical conductivity (EC) as influenced by land preparation, mulch and irrigation treatments in 2015/2016 and 2016/2017 are presented in Tables 4.15 and 4.16, respectively.

In 2015/2016, the land preparation types had significant ($p<0.05$) effect on the EC values of the soil, with Ridge recording the significantly ($p<0.05$) highest EC value of 380.2 µS cm^{-1}, while Raised bed had a mean EC value of 296.4 µS cm^{-1}, and Flat recorded the least EC value of 235.4 µS cm^{-1} (Table 4.15). However, mulch did not significantly ($p = 0.05$) affect the soil EC, even though, Zero mulch recorded the highest EC value of 306.4 µS cm^{-1}, while *Gliricidia* mulch and *Pennisetum* mulch had low EC values of 317.7 µS cm^{-1} and 287.8 µS cm^{-1}, respectively (Table 4.15). However, there was significant ($p<0.05$) difference in the EC values recorded under irrigation rates, where soil samples obtained from plots irrigated with 75% ET_c recorded the significantly ($p<0.05$) highest EC value of 526.3 µS cm^{-1}, while 100% ET_c and CROPWAT recorded low EC values of 201.4 µS cm^{-1} and 184.2 µS cm^{-1}, respectively (Table 4.15). There were also significant ($p<0.05$) variations in EC values recorded among the treatment interactions (Table 4.15).

With respect to 2016/2017, there was no significant ($p = 0.05$) variation in the soil EC under the different land preparation types. However, Raised bed had the highest EC value of 227.3 µS cm^{-1}, while Ridge and Flat recorded low EC values of

226.7 and 226.1 µS cm^{-1}, respectively (Table 4.16). Similar to land preparation, mulch application did not significantly ($p = 0.05$) influence the soil EC, as *Pennisetum* mulch recorded the highest EC value of 225.0 µS cm^{-1}, while Zero mulch and *Gliricidia* mulch had low EC values of 223.3 and 231.8 µS cm^{-1}, respectively (Table 4.16). Contrarily, the irrigation rates had significant ($p<0.05$) impact on the soil EC. For instance, 100% ET_c recorded the significantly ($p<0.05$) highest EC value of 232.3 µS cm^{-1}, while CROPWAT plots had mean EC of 227.8 µS cm^{-1}, and 75% ET_c had the least EC value of 220.0 µS cm^{-1} (Table 4.16). There were also significant ($p<0.05$) variations in EC values recorded among the treatment interactions (Table 4.16).

4.4.6 Effects of land preparation, mulch and irrigation rates on weed density and biomass

The response of weeds to the land preparation, mulch and irrigation treatments in 2015/2016 and 2016/2017 are reported as follows:

4.4.6.1 Weed density

In 2015/2016, there was no significant ($p = 0.05$) difference in the weed density among the different land preparation types. However, plots with Flat recorded the highest weed density of 14.0 weeds m^{-2}, while Raised bed and Ridge plots had low values of 13.2 and 12.9 weeds m^{-2}, respectively (Figure 4.28). Similarly, the application of mulch had no significant ($p = 0.05$) effect on weed density, although, Zero mulch and *Pennisetum* mulch recorded high weed density value of 13.9 weeds m^{-2}, respectively, while *Gliricidia* mulch plots recorded a low value of 12.4 weeds m^{-2} (Figure 4.28). The irrigation treatments were observed to significantly ($p<0.05$) influence the population of weeds in each plot. Plots irrigated with CROPWAT irrigation rates recorded the significantly ($p<0.05$) highest weed density of 22.7 m^{-2}, while low weed density values of 10.7 and 6.7 m^{-2} were recorded under 100% ET_c and 75% ET_c irrigated plots, respectively (Figure 4.28).

In 2016/2017, there was significant ($p<0.05$) difference in the weed density observed among the land preparation types, where Flat recorded the highest weed density value of 28.6 m^{-2}, while Raised bed and Ridge recorded low values of 13.7 and

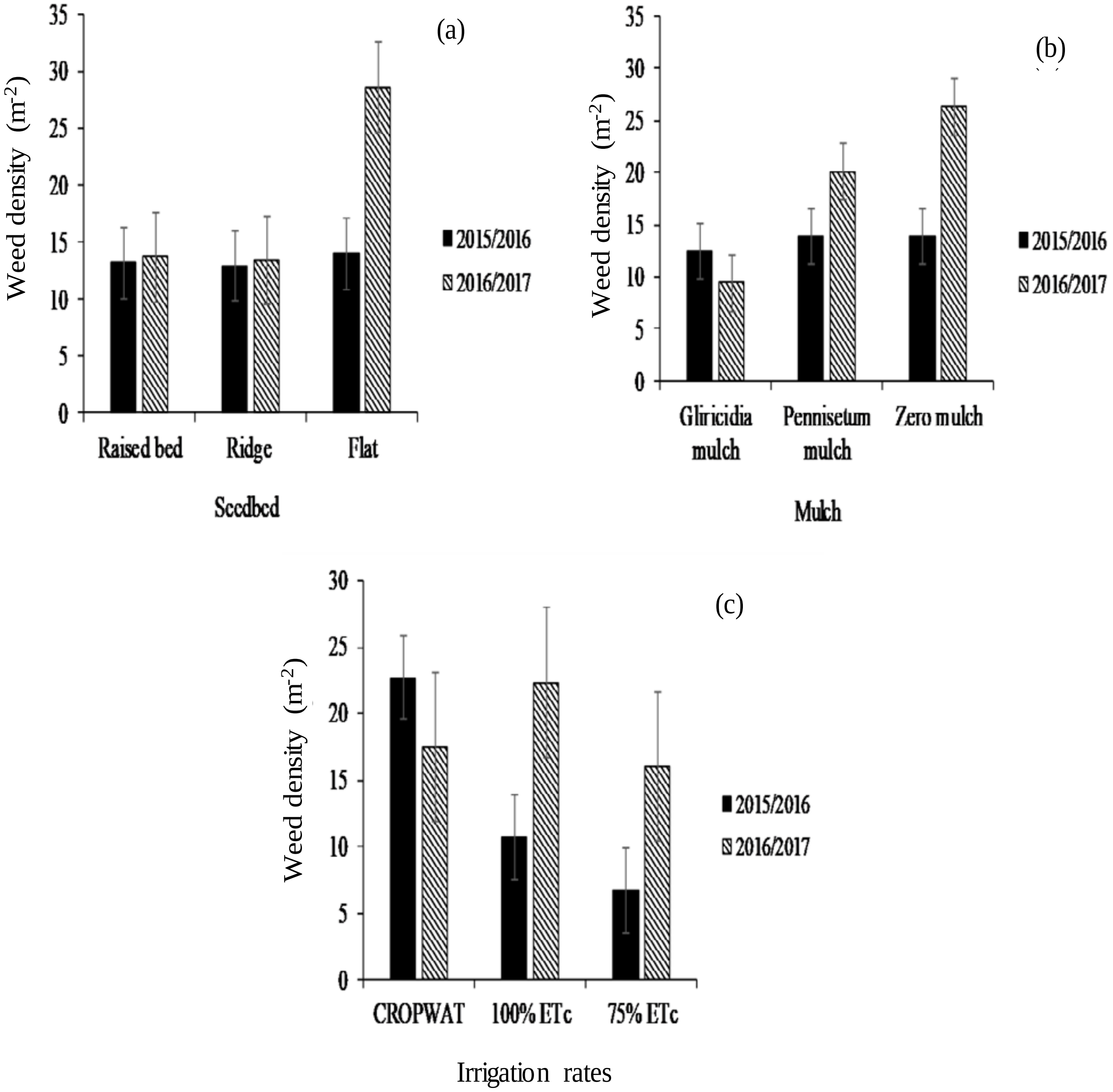


Figure 4.28: Effects of (a) land preparation, (b) mulch and (c) irrigation rates on weed density

Bars are standard error of differences of means

13.4 weeds m^{-2}, respectively (Figure 4.28). Similar to land preparation, mulch had significant ($p<0.05$) impact on the weed density of the experimental site. Here, plots without mulch (Zero mulch) recorded the highest mean value of 26.3 weeds m^{-2}, while *Pennisetum* mulch plots had a mean weed density value of 20.1 m^{-2}, and *Gliricidia* mulch plots recorded the lowest mean value of 9.4 weeds m^{-2} (Figure 4.28). However, weed density was not significantly ($p = 0.05$) influenced by the irrigation treatments, although, plots irrigated with 100% ET_c recorded the highest weed density of 22.3 weeds m^{-2}, while CROPWAT and 75% ET_c irrigated plots recorded low mean weed densities of 17.5 and 16.0 weeds m^{-2}, respectively (Figure 4.28).

4.4.6.2 Weed biomass

Figure 4.29 shows the effects of land preparation, mulch types and irrigation rates on weed biomass in 2015/2016 and 2016/2017 seasons, respectively. In 2015/2016, weed biomass did not significantly ($p = 0.05$) vary under the different land preparation types. However, plots with Raised bed recorded a high mean weed biomass value of 14.26 g m^{-2}, while Flat and Ridge had low mean weed biomass values of 13.97 and 10.59 g m^{-2}, respectively (Figure 4.29). On the contrary, mulch had significant ($p<0.05$) effect on weed biomass, with the control plots (Zero mulch) recording the highest mean weed biomass value of 17.40 g m^{-2}, while *Gliricidia* mulch plots had a mean weed biomass of 11.76 g m^{-2}, and *Pennisetum* mulch plots recorded the lowest mean weed biomass value of 9.67 g m^{-2} (Figure 4.29). Weed biomass was not significantly ($p = 0.05$) affected by the irrigation treatments, although, plots irrigated with 100% ET_c recorded the highest weed biomass of 14.36 g m^{-2}, while CROPWAT irrigated plots recorded a mean weed biomass value of 14.11 g m^{-2}, and plots irrigated with 75% ET_c had the least weed biomass of 10.35 g m^{-2} (Figure 4.29).

In 2016/2017, weed biomass did not significantly ($p = 0.05$) vary under the land preparation types. Here, Flat plots recorded the significantly ($p<0.05$) highest weed biomass value of 38.8 g m^{-2}, while Raised bed had mean weed biomass of 36.6 g m^{-2}, and Ridge had the lowest weed biomass of 19.0 g m^{-2} (Figure 4.29). However, the weed biomass was significantly ($p<0.05$) affected by the mulch treatments, in which, Zero mulch plots had a high weed biomass of 40.9 g m^{-2}, while *Gliricidia* mulch and

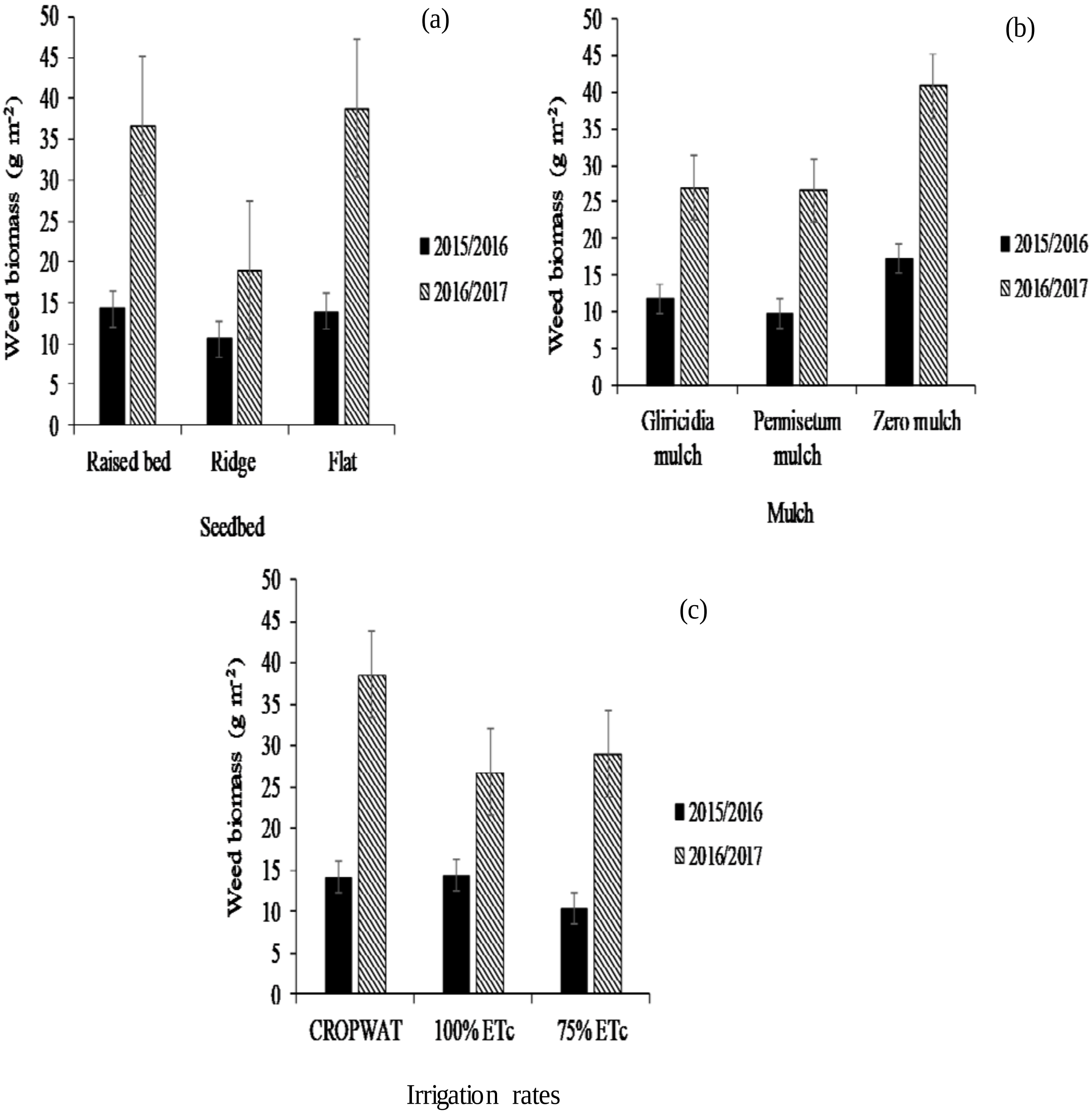


Figure 4.29: Effects of (a) land preparation, (b) mulch and (c) irrigation rates on weed biomass

Bars are standard error of differences of means

Pennisetum mulch plots had low mean weed biomass of 26.9 and 26.6 g m^{-2}, respectively (Figure 4.29). In addition, weed biomass did not differ significantly (p = 0.05) under the irrigation rates, even though, plots irrigated with CROPWAT irrigation rate recorded a high weed biomass value of 38.5 g m^{-2}, while plots irrigated with 75% ET_c and 100% ET_c had low weed biomass values of 29.0 and 26.8 g m^{-2}, respectively (Figure 4.29).

4.4.7 Growth of okra (UI4-30 variety) as influenced by the sole effect and interactions of land preparation, mulch and irrigation rates

The effects of land preparation (Raised bed, Ridge and Flat), mulch (*Gliricidia* mulch, *Pennisetum* mulch and Zero mulch), irrigation rates (100% ET_c, 75% ET_c and CROPWAT), and their various interaction combinations on okra growth parameters are reported as follows:

4.4.7.1 Number of leaves

Irrespective of the treatments applied and their various interaction, number of leaves of okra was observed to increase from 3 WAS up till 6 and/or 7 WAS when a peak value was obtained, before decreasing at 7 or 8 WAS.

In 2015/2016, the number of leaves produced by okra plants grown under the different land preparation types were not significantly ($p<0.05$) influenced at 8 and 9 WAS, respectively. Okra plants grown on Raised bed had consistently high number of leaves within the range of 3.6 – 4.8 leaves at 3 to 7 WAS, while those grown on Ridge had mean number of leaves within the range of 3.5 – 4.7 leaves, and plants grown on Flat had the least number of leaves (3.1 – 4.5 leaves), at 3 to 7 WAS, respectively. Although, all the land preparation types resulted to a mean number of 3.9 leaves at 9 WAS, okra plants grown on Ridge had the highest mean number of 3.6 leaves at 10 WAS (Figure 4.30). In the 2015/2016 dry season, the okra plants under all the mulch treatments had a mean number of 3.4 leaves at 3 WAS, respectively. Although, Zero mulch plants recorded the highest mean number of leaves (4.3 and 4.7) at 4 and 5 WAS, the trend in the range of number of leaves produced was *Gliricidia* mulch (5.1 – 3.9) > *Pennisetum* mulch (4.9 – 3.7) > Zero mulch (4.8 – 2.6) at 6 to 10 WAS, respectively (Figure 4.30). With respect to the irrigation rates, okra plants irrigated with 100% ET_c recorded the highest mean number of 3.6 leaves at 3 WAS, while low mean number of leaves were recorded by 75% ET_c (3.5) and CROPWAT (3.1) at

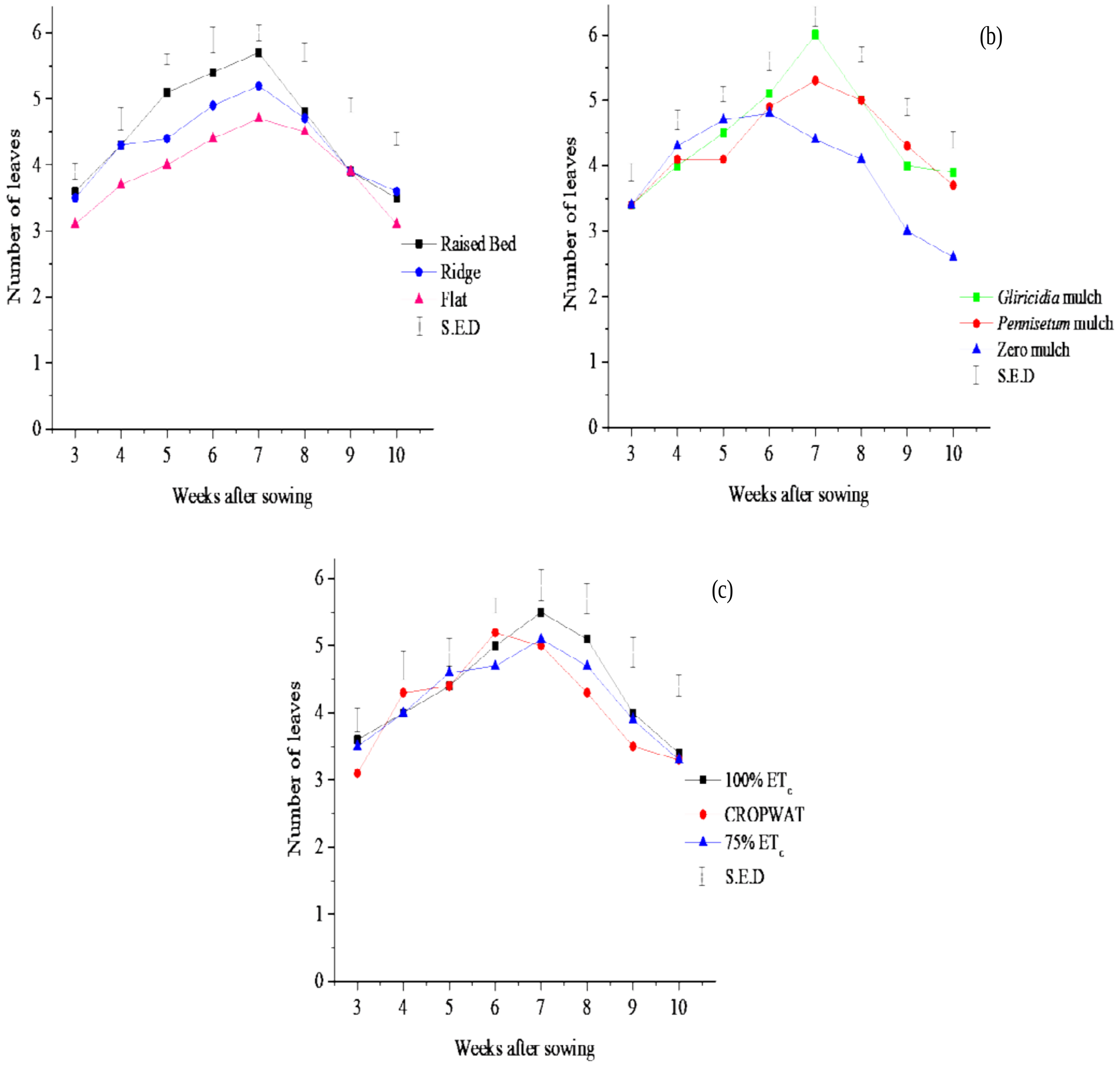


Figure 4.30: Effects of (a) land preparation, (b) mulch, and (c) irrigation rates on okra number of leaves in 2015/2016

3 WAS, respectively (Figure 4.30). Although, the irrigation rates only significantly (p = 0.05) influenced the number of leaves at 6 WAS, plants under CROPWAT irrigation rates had high mean number of leaves (4.3 – 5.2) than 100% ET_c (4 – 5 leaves) and 75% ET_c (4 – 4.7 leaves) at 4 to 6 WAS, respectively. However, the trend in the mean number of leaves produced was in the order: 100% ET_c (5.5 – 3.4 leaves) > 75% ET_c (5.1 – 3.3 leaves) > CROPWAT > (5 – 3.3 leaves) at 7 to 10 WAS, respectively (Figure 4.30). In addition, the interaction between the land preparation, mulch and irrigation treatments were found to significantly ($p<0.05$) influence the number of leaves produced at various weeks of okra growth in 2015/2016 (Figure 4.31).

In 2016/2017, with the exception of 3 WAS, land preparation had significant ($p<0.05$) influence on the number of okra leaves produced at 4 to 10 WAS, respectively. With the exception of 5 and 9 WAS, where Ridge recorded the highest mean number of 7.0 and 6.7 leaves, respectively, okra plants grown on Raised bed produced the highest mean number of 4.4, 6.2, 7.6, 8.0 and 7.4 leaves at 3, 4, 6, 7 and 8 WAS, respectively, while okra plants grown on Flat had the lowest mean number of leaves within the range of 4.1 – 3.4 leaves at 3 to 10 WAS, respectively (Figure 4.32). Furthermore, the mulch types had significant ($p<0.05$) impact on the number of okra leaves produced at 3 to 10 WAS. The trend in number of leaves produced was *Gliricidia* mulch > *Pennisetum* mulch > Zero mulch, where the highest peak number of leaves (8.3) was produced by okra plants grown on *Gliricidia* mulch plots at 7 WAS, while *Pennisetum* mulch and Zero mulch recorded low mean number of 6.8 and 6.5 leaves at 7 and 6 WAS, respectively (Figure 4.32). The irrigation treatments only significantly ($p<0.05$) influenced okra number of leaves at 3 WAS, with 100% ET_c irrigated plants recording high mean numbers of 4.7 and 6.3 leaves, compared with CROPWAT (4.3 and 5.4 leaves) and 75% ET_c (3.7 and 6 leaves) irrigated plants at 3 and 4 WAS, respectively. However, the range of number of leaves produced was in the order: 75% ET_c (7.0 – 7.2) > 100% ET_c (6.7 – 7.0) > CROPWAT (6.1 – 6.9) at 5 to 7 WAS, respectively, while at 8 to 10 WAS, it was in the order: 100% ET_c (6.6 – 4.4) > CROPWAT (6.3 – 4.3) > 75% ET_c (6.2 – 3.9), respectively (Figure 4.32). Furthermore, the number of leaves of okra was significantly ($p<0.05$) affected by the treatment interactions at various weeks after sowing (Figure 4.33).

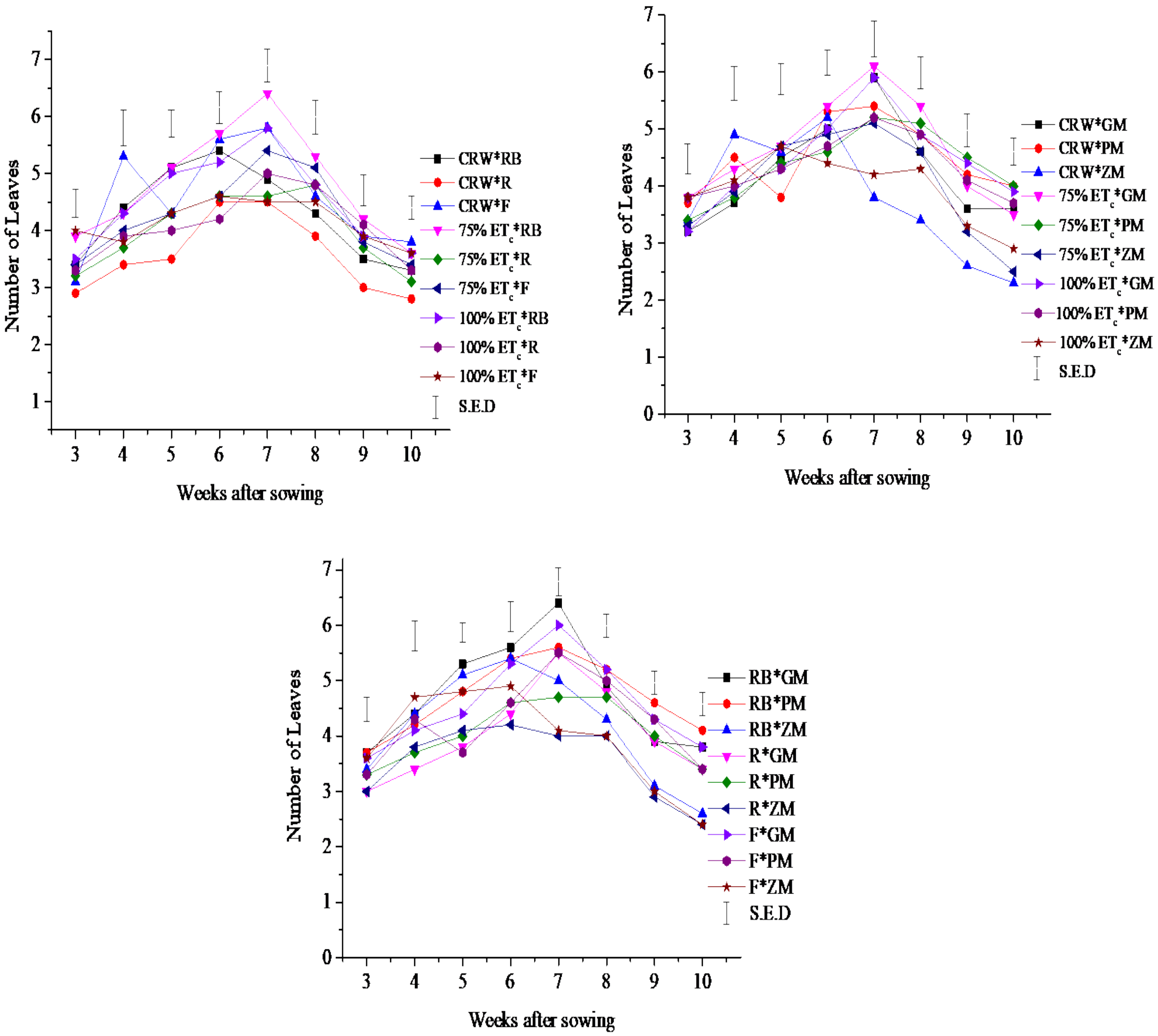


Figure 4.31: Number of okra leaves as influenced by (a) irrigation rate and land preparation, (b) irrigation rate and mulch, and (c) land preparation and mulch interactions in 2015/2016

RB = Raised bed; R = Ridge; F = Flat; GM = *Gliricidia* mulch; PM = *Pennisetum* mulch; ZM = Zero mulch.

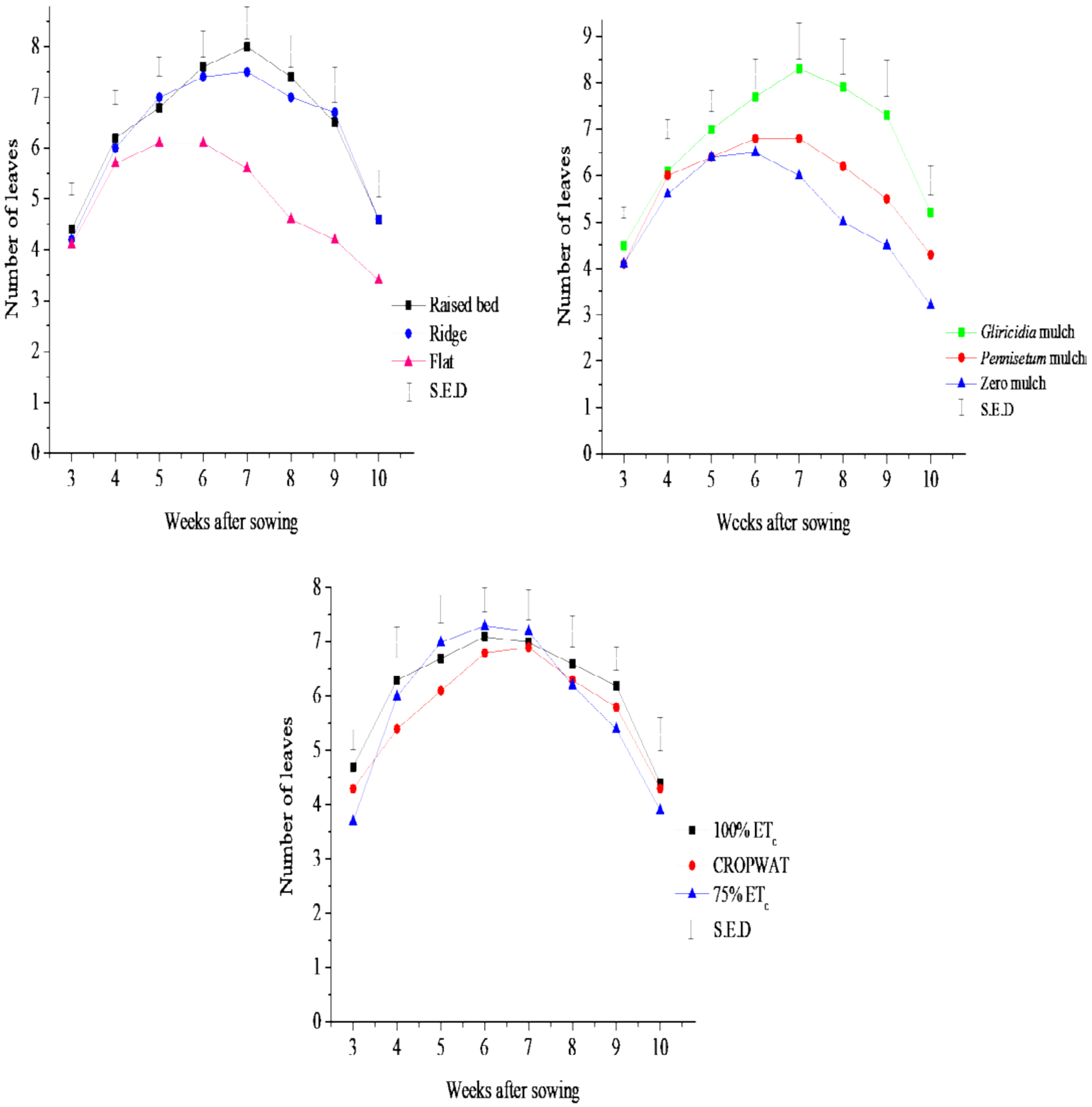


Figure 4.32: Effects of (a) land preparation, (b) mulch, and (c) irrigation rates on okra number of leaves in 2016/2017

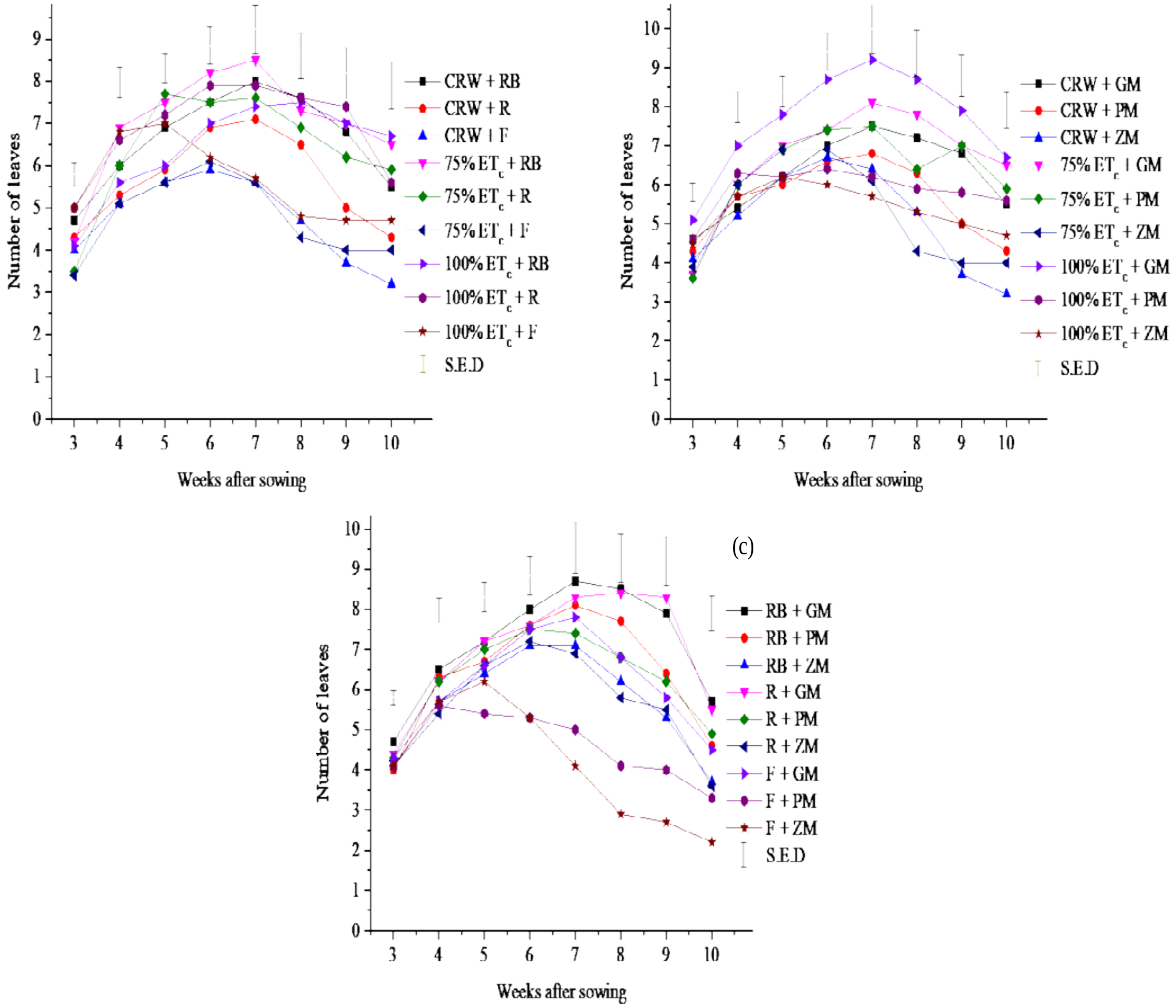


Figure 4.33: Okra number of leaves as influenced by (a) irrigation rate and land preparation, (b) irrigation rate and mulch, and (c) land preparation and mulch interaction in 2016/2017

RB = Raised bed; R = Ridge; F = Flat; GM = *Gliricidia* mulch; PM = *Pennisetum* mulch; ZM = Zero mulch.

4.4.7.2 Plant height

The height of okra plants increased with increase in weeks after sowing, thus attaining respective peak values at 10 WAS when data collection was terminated in 2015/2016 and 2016/2017, respectively.

In 2015/2016, significant ($p<0.05$) differences were observed in the height of okra plants grown on Raised bed, Ridge and Flat at 3 to 10 WAS, respectively. The height of okra plants grown on the three land preparation types was in the order: Raised bed > Flat > Ridge at 3 to 10 WAS, respectively. At 10 WAS, Raised bed recorded the significantly ($p<0.05$) highest plant height value of 24.2 cm, while Flat and Ridge had short plants of 20.8 and 20.2 cm, respectively (Figure 4.34). The application of mulch also significantly ($p<0.05$) influenced okra plant height at 3 WAS through 10 WAS, respectively. The plant height of okra under mulch application was in the order: *Gliricidia* mulch > *Pennisetum* mulch > Zero mulch, with *Gliricidia* mulch recording the highest plant height value of 24.3 cm at 10 WAS, while *Pennisetum* mulch and Zero mulch had low plant height values of 21.5 and 19.4 cm at 10 WAS, respectively (Figure 4.34). The height of okra plant was also significantly ($p<0.05$) affected by the irrigation treatments at 3 WAS through 5 WAS. Okra plants irrigated with daily application of 75% ET_c recorded the significantly ($p<0.05$) highest plant height value of 15.9 cm at 4 WAS, while 100% ET_c and CROPWAT recorded low plant height values of 15.7 and 13.0 cm, at 4 WAS respectively. However, at 10 WAS when data collection was terminated, CROPWAT irrigated plants recorded the highest plant height value of 23.2 cm, while 75% ET_c and 100% ET_c had low plant height values of 21.1 and 20.9 cm, respectively (Figure 4.34). The height of okra plants was also significantly ($p<0.05$) affected by the treatment interactions at various weeks after sowing (Figure 4.35).

In 2016/2017, okra plant height was significantly ($p<0.05$) influenced by the land preparation types at 3 to 10 WAS, with plants grown on Raised bed recording superior values than those grown on Flat and Ridge in the 2016/2017 dry season, respectively. At 3 WAS, okra plants grown on Ridge had higher mean plant height value (6.8 cm) than those on Flat (6.7 cm), while at 4 to 9 WAS, Flat recorded higher mean plant height values within the range of 8.7 – 21.9 cm than Ridge which had a range of plant height values within 8.5 – 19.6 cm at 4 to 9 WAS, respectively. Plant height values were highest at 10 WAS when data collection was terminated. Okra plants grown on Raised bed recorded the significantly ($p<0.05$) highest mean plant

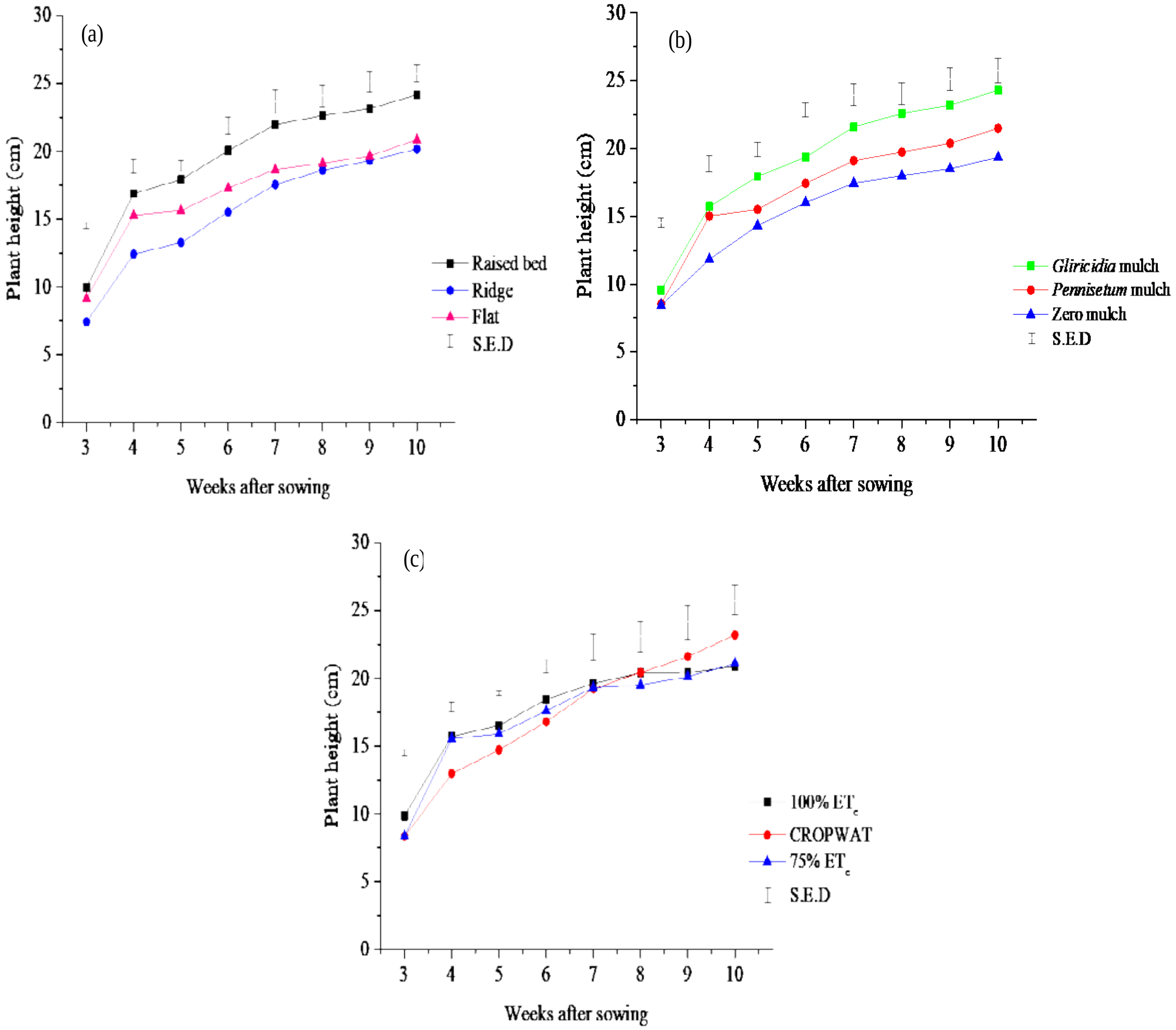


Figure 4.34: Okra plant height as influenced by (a) land preparation, (b) mulch, and (c) irrigation rates (c) in 2015/2016

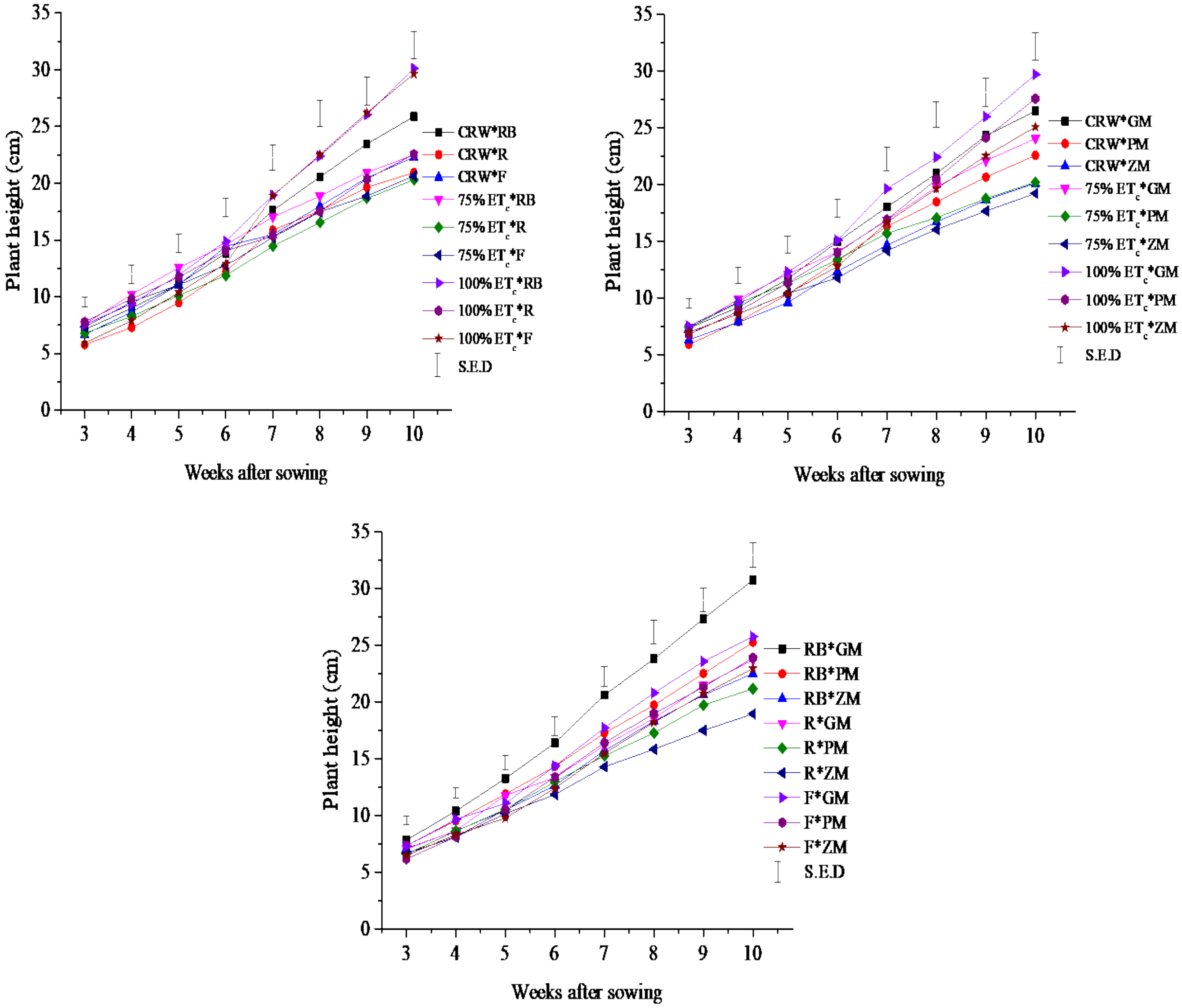


Figure 4.35: Okra plant height as influenced by (a) irrigation rate and land preparation, (b) irrigation rate and mulch, and (c) land preparation and mulch interactions in 2015/2016

RB = Raised bed; R = Ridge; F = Flat; GM = *Gliricidia* mulch; PM = *Pennisetum* mulch; ZM = Zero mulch.

height value of 26.2 cm, while Flat recorded low plant height value of 24.2 cm and Ridge had the least plant height value of 21.3 cm at 10 WAS (Figure 4.36). In a similar way to land preparation in the 2016/2017 dry season, mulch significantly ($p<0.05$) influenced the height of okra plants at 3 to 10 WAS, with *Gliricidia* mulch recording the highest plant height of 7.4 cm at 3 WAS. This was followed by Zero mulch, with mean plant height value of 6.8 cm, while *Pennisetum* mulch had the lowest mean plant height value of 6.7 cm at 3 WAS. Furthermore, plants mulched with *Gliricidia* mulch was consistently superior with highest mean plant height values within the range of 9.6 – 26.7 cm at 4 to 10 WAS, respectively. This was followed by okra plants mulched with *Pennisetum* mulch, with mean plant height values within the range of 8.8 – 23.4 cm, while those under Zero mulch had mean values in the range of 8.4 – 21.5 cm at 4 to 10 WAS, respectively (Figure 4.36). Among the irrigation rates, plant height was not significantly ($p = 0.05$) influenced at 3 to 7 WAS. Okra plants irrigated with 75% ET_c recorded the highest plant height of 7.2 and 9.4 cm at 3 and 4 WAS, respectively, while low values were recorded by 100% ET_c (7.1 and 9.0 cm) and CROPWAT (6.5 and 8.3 cm) at 3 and 4 WAS, respectively. Although, 75% ET_c produced taller plants (11.3 cm) than CROPWAT (10.5 cm) at 5 WAS, CROPWAT had higher mean plant height values within the range of 13.5 – 21.2 cm than 75% ET_c which had plant height values within the range of 13.1 – 19.5 cm, while 100% ET_c recorded the highest mean plant height values (14.0 – 24.2 cm) at 6 to 9 WAS, respectively. At 10 WAS, the tallest plants with mean value of 27.4 cm were produced by 100% ET_c, while CROPWAT and 75% ET_c had short plants with mean values of 23.1 and 21.2 cm, respectively (Figure 4.36). The height of okra plants was also significantly ($p<0.05$) affected by the treatment interactions at various weeks after sowing (Figure 4.37).

4.4.7.3 Stem diameter

In a similar way to plant height, stem diameter was observed to increase with increase in weeks after sowing under the different treatment combinations, thus attaining respective peak values at 10 WAS when data collection was terminated in 2015/2016 and 2016/2017, respectively.

In 2015/2016, okra plants grown on Raised bed recorded the highest stem diameter value at 3 to 10 WAS, respectively. At 3 WAS, Raised bed recorded the significantly ($p<0.05$) highest stem diameter of 2.41 mm, while Ridge and Flat had

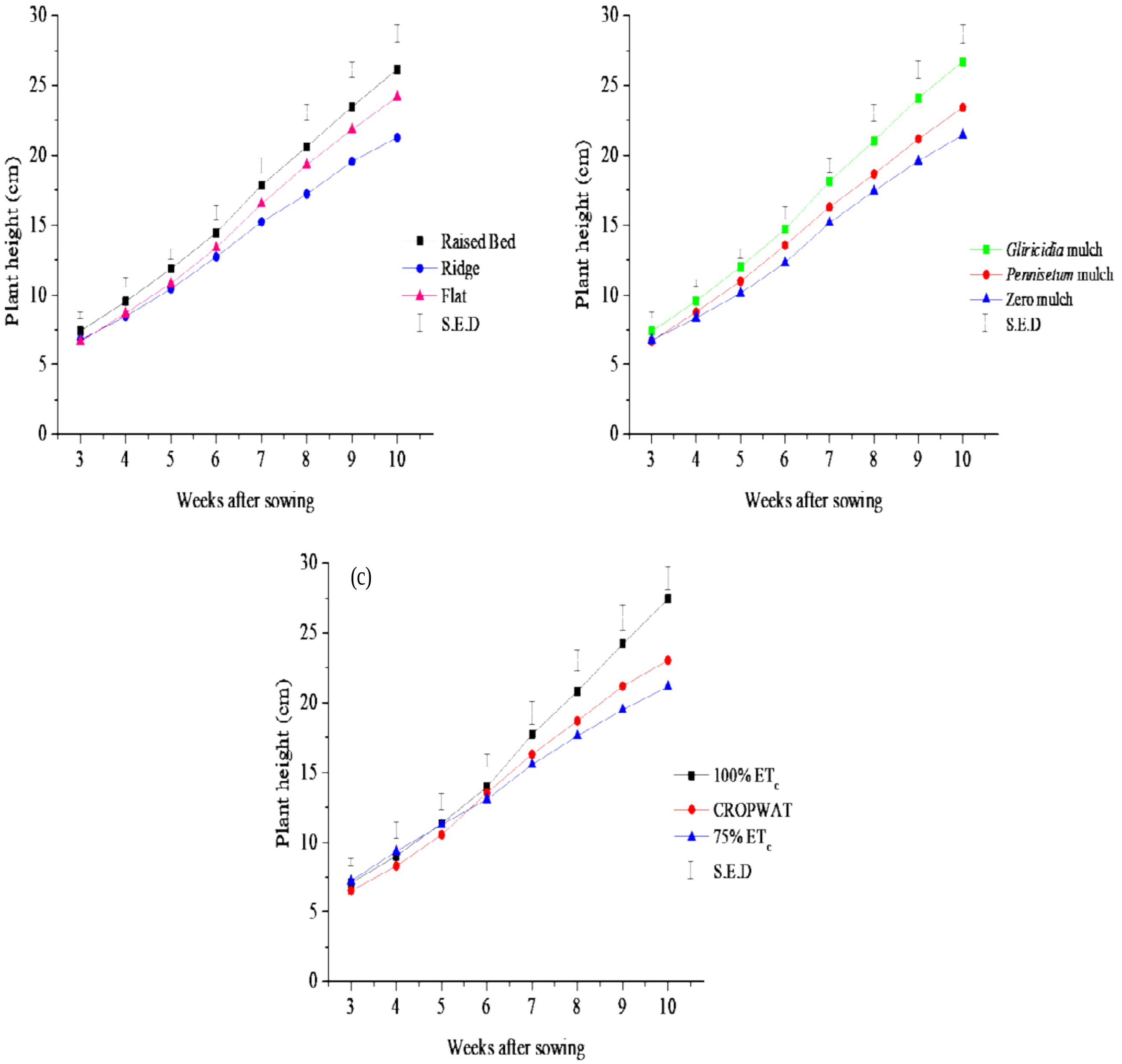


Figure 4.36: Effects of (a) land preparation, (b) mulch, and (c) irrigation rates on okra plant height in 2016/2017

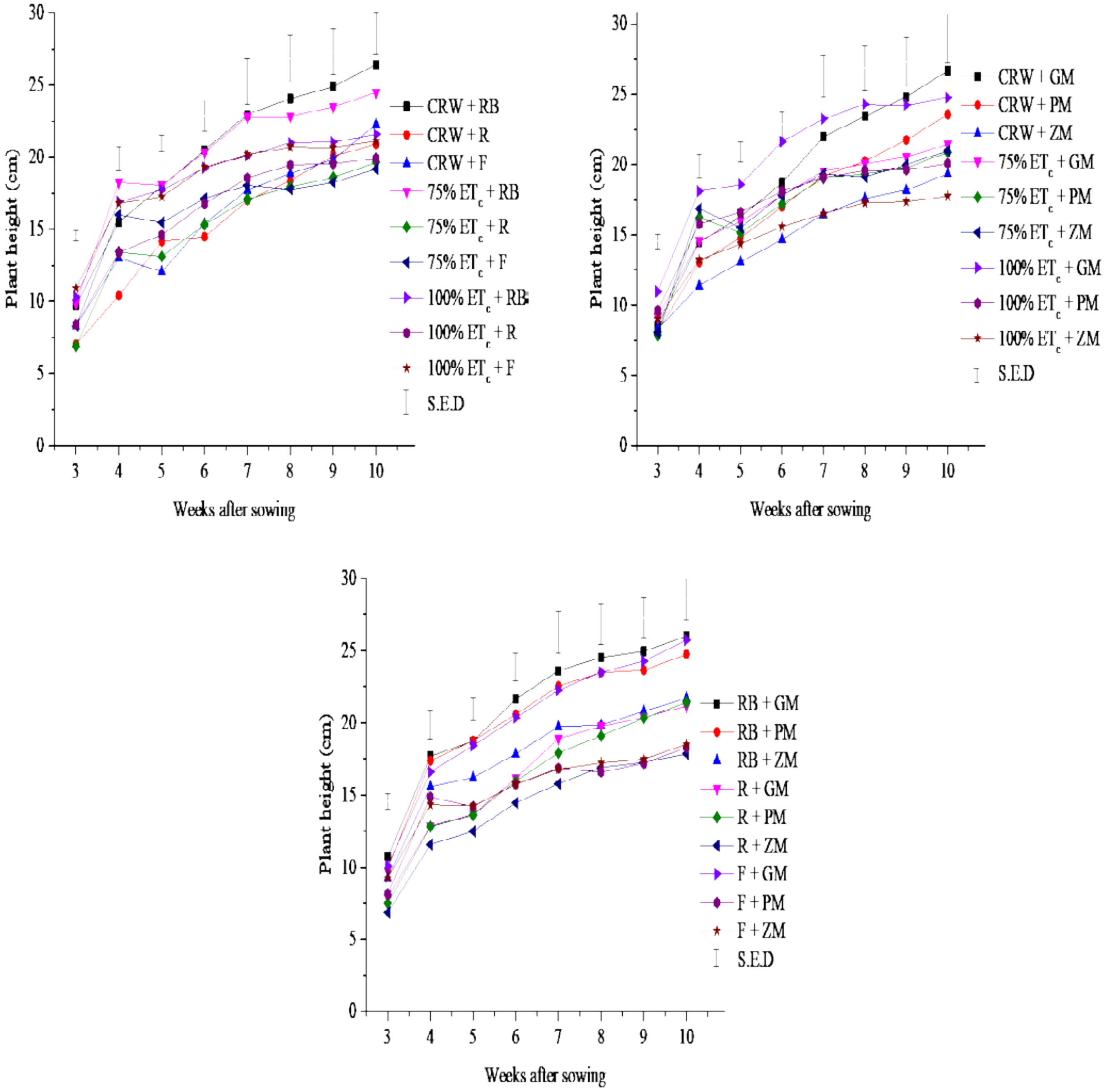


Figure 4.37: Okra plant height as influenced by (a) irrigation rate and land preparation, (b) irrigation rate and mulch, and (c) land preparation and mulch interactions in 2016/2017

RB = Raised bed; R = Ridge; F = Flat; GM = *Gliricidia* mulch; PM = *Pennisetum* mulch; ZM = Zero mulch.

low stem diameter values of 2.36 and 2.21 mm, respectively. At 4 to 6 WAS, Raised bed recorded the highest stem diameter values within the range of 3.05 – 4.03, while Flat recorded higher stem diameter values within the range of 2.96 – 3.93 mm than Ridge which had a range of stem diameter values between 2.83 and 3.89 mm at 4 to 6 WAS, respectively. Although, okra plants grown on Flat recorded higher stem diameter value (4.89 mm) than those grown on Ridge (4.88 mm), the peak values at 10 WAS showed that okra plants grown on Raised bed recorded the significantly ($p<0.05$) highest stem diameter value of 6.14 mm, while those grown on Ridge had higher stem diameter value of 5.93 mm than Flat which had a mean stem diameter value of 5.77 mm (Figure 4.38). On the other hand, the effect of mulch on okra stem diameter had a consistent pattern throughout the weeks of data collection, where the peak values were recorded at 10 WAS, when data collection was terminated. Okra plants mulched with *Gliricidia* mulch recorded consistently highest stem diameter values throughout the period of data collection, with the significantly ($p<0.05$) highest peak value of 6.17 mm at 10 WAS. This was higher than plants mulched with *Pennisetum* mulch, which had a peak stem diameter value of 5.96 mm at 10 WAS, while plants without mulch (Zero mulch) recorded the consistently lowest stem diameter values all through the period of data collection, with a peak value of 5.72 mm at 10 WAS in the 2015/2016 dry season (Figure 4.38). The irrigation treatments had significant ($p<0.05$) effect on okra stem diameter at 3 to 10 WAS. Okra stem diameter growth was in the order of 100% ET_c > CROPWAT > 75% ET_c, with 100% ET_c recording the significantly ($p<0.05$) highest value of 7.02 mm at 10 WAS, whereas okra plants irrigated with CROPWAT and 75% ET_c irrigation schedules had low stem diameter values of 5.43 and 5.39 mm at 10 WAS, respectively (Figure 4.38). The stem diameter of okra plants was also significantly ($p<0.05$) affected by the treatment interactions at various weeks after sowing (Figure 4.39). In 2016/2017, okra stem diameter was observed to vary significantly ($p<0.05$) at 3 WAS through 10 WAS under the land preparation types. With the exception of 3 WAS, okra stem diameter was in the order: Raised bed > Ridge > Flat at 4 to 10 WAS. At 10 WAS, Raised bed recorded the significantly ($p<0.05$) highest peak stem diameter value of 6.52 mm, while low stem diameter values were recorded by Ridge (6.36 mm) and Flat (5.67 mm) at 10 WAS, respectively (Figure 4.40). Okra stem diameter differed significantly ($p<0.05$) after mulch application at 5 to 10 WAS, respectively. The stem diameter under the mulch treatment application was in the order: *Gliricidia* mulch > *Pennisetum* mulch >

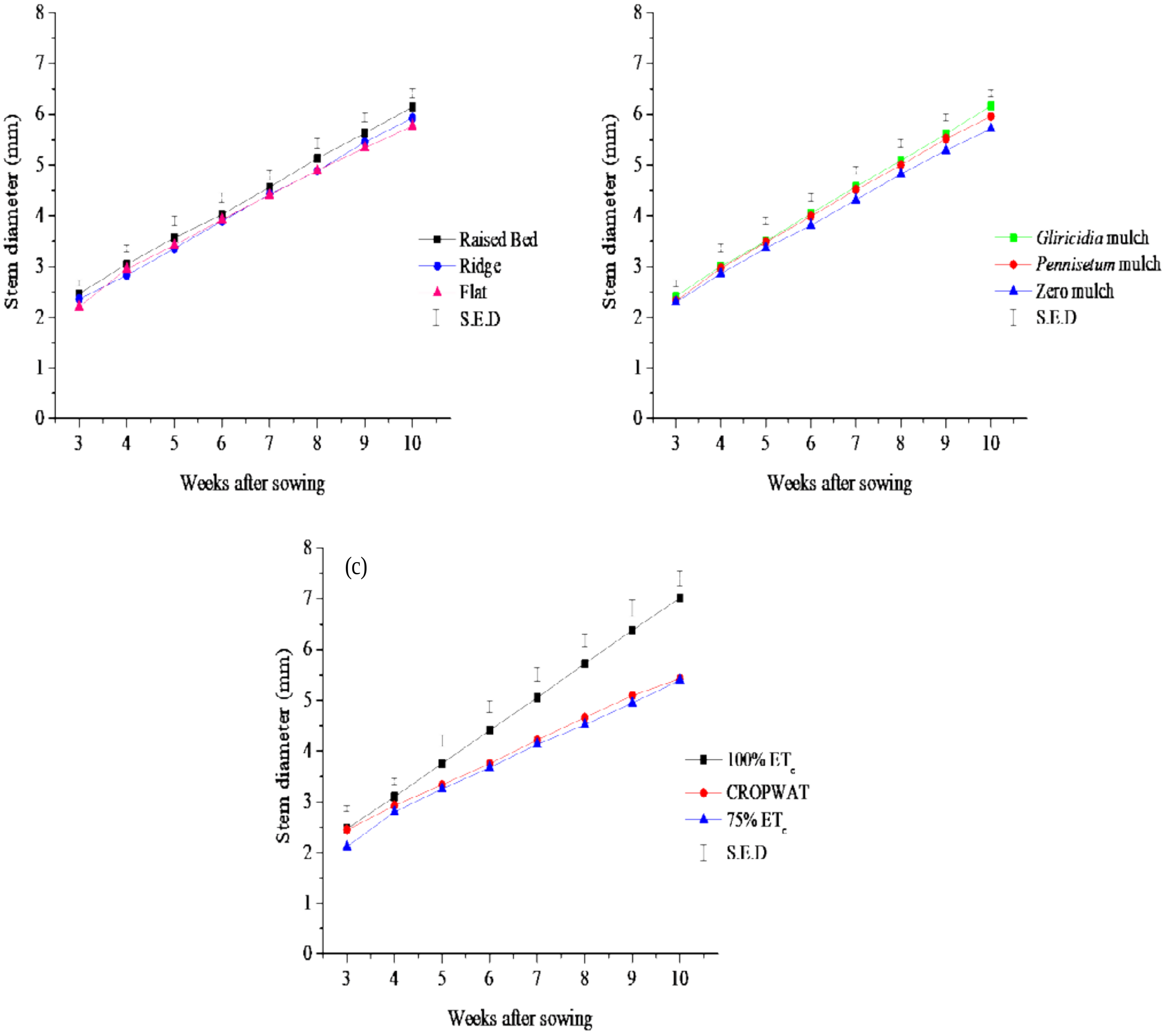


Figure 4.38: Influence of land preparation (a), mulch (b), and irrigation rates (c) on the stem diameter of okra in 2015/2016

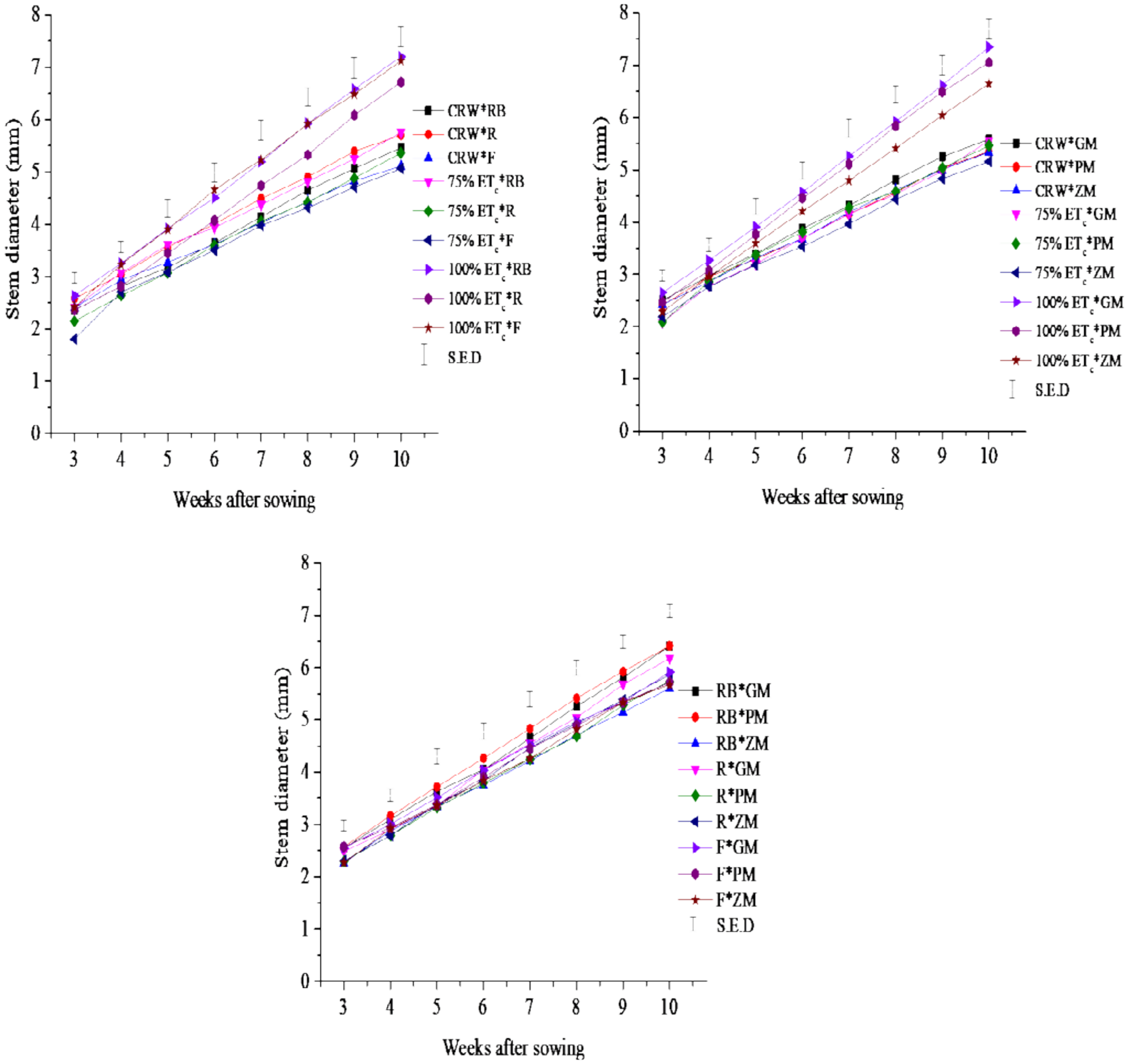


Figure 4.39: Okra stem diameter as influenced by (a) irrigation rate and land preparation, (b) irrigation rate and mulch, and (c) land preparation and mulch interactions in 2015/2016

RB = Raised bed; R = Ridge; F = Flat; GM = *Gliricidia* mulch; PM = *Pennisetum* mulch; ZM = Zero mulch.

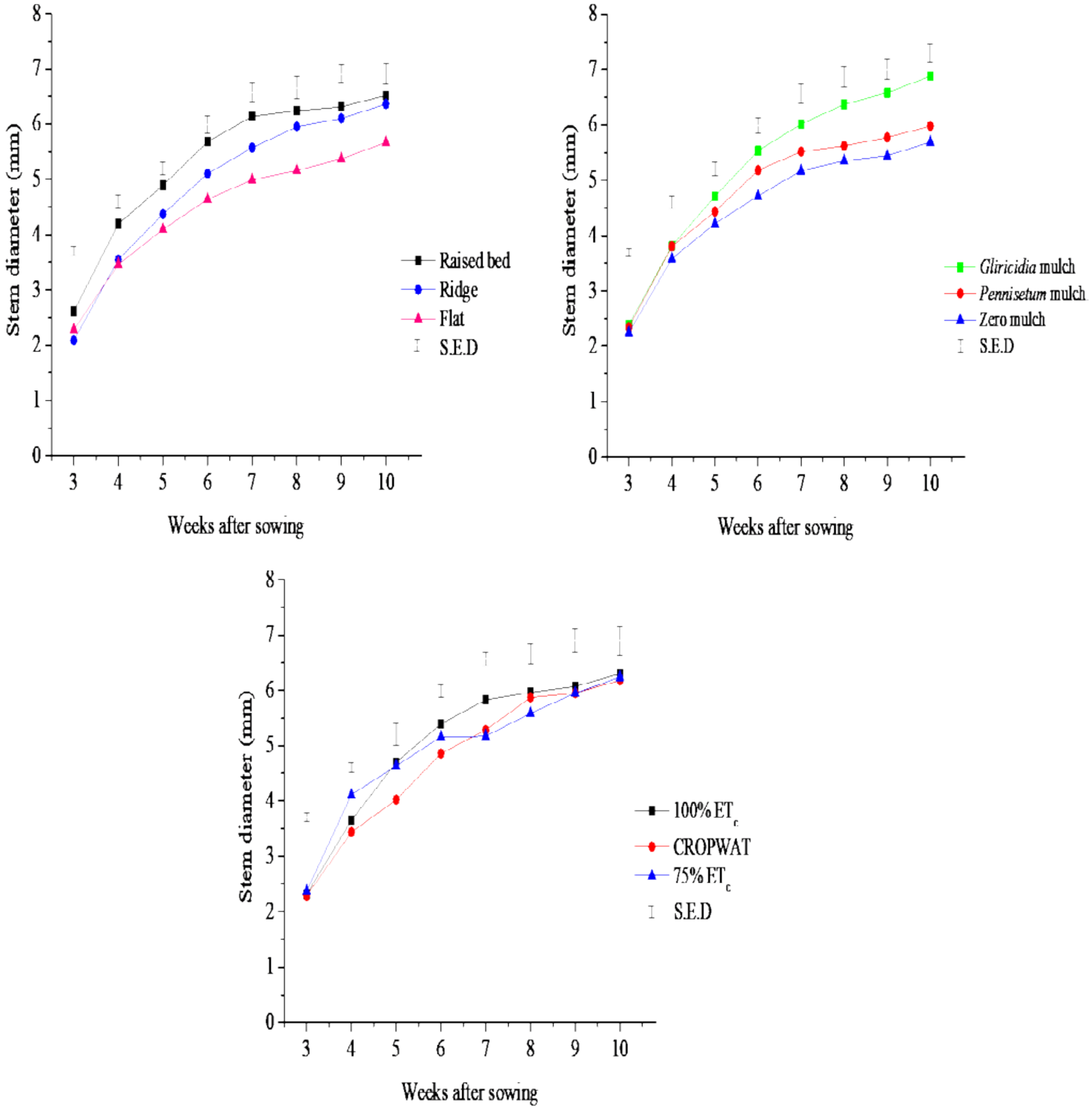


Figure 4.40: Effects of (a) land preparation, (b) mulch and (c) irrigation rates on okra stem diameter in 2016/2017

Zero mulch at 3 to 10 WAS. At 10 WAS, *Gliricidia* mulch recorded the significantly ($p<0.05$) highest stem diameter value of 6.88 mm, while *Pennisetum* mulch had a mean peak stem diameter value of 5.98 mm, and Zero mulch had the lowest peak stem diameter value of 5.69 mm at 10 WAS, respectively (Figure 4.40). The irrigation rates only had significant ($p<0.05$) effect on the stem diameter of okra at 4, 6 and 7 WAS respectively. With the exception of 3 and 4 WAS, okra plants irrigated with 100% ET_c had bigger stems than those irrigated with 75% ET_c and CROPWAT irrigation rates, respectively. At 10 WAS, 100% ET_c recorded the highest peak stem diameter value of 6.30 mm, while 75% ET_c and CROPWAT had low stem diameter values of 6.24 and 6.18 mm, respectively (Figure 4.40). Okra stem diameter was found to vary significantly ($p<0.05$) at various weeks after sowing among the different treatment interactions (Figure 4.41).

4.4.8 Okra shoot weight as influenced by land preparation, mulch and irrigation application

The effects of the sole application and various interaction combinations of land preparation, mulch and irrigation rates on the fresh and dry shoot weights of okra in 2015/2016 and 2016/2017 are reported as follows:

4.4.8.1 Influence of land preparation, mulch and irrigation rates on the fresh shoot weight of okra

The fresh shoot weight (FSW) of okra produced under the influence of land preparation, mulch, irrigation rates, and their various interactions in 2015/2016 and 2016/2017 are reported as follows:

In 2015/2016, the land preparation types had significant ($p<0.05$) effect on the FSW of okra. Raised bed recorded the highest FSW value of 2.36 g plant^{-1}, while Flat had a mean FSW value of 2.35 g plant^{-1}, and Ridge recorded the lowest FSW value of 1.80 g plant^{-1} (Table 4.17). Similarly, mulch also significantly ($p<0.05$) influenced the FSW of okra. For instance, *Gliricidia* mulch recorded the highest FSW value of 2.56 g plant^{-1}. This was followed by *Pennisetum* mulch, with mean FSW value of 2.26 g plant^{-1}, while Zero mulch had the lowest FSW value of 1.68 g plant^{-1} (Table 4.17). However, the irrigation rates did not significantly ($p = 0.05$) influence the FSW of okra, although, 100% ET_c recorded the highest FSW value of 2.35 g plant^{-1}, while CROPWAT and 75% ET_c had low FSW values of 2.15 and 2.00 g plant^{-1}, respectively

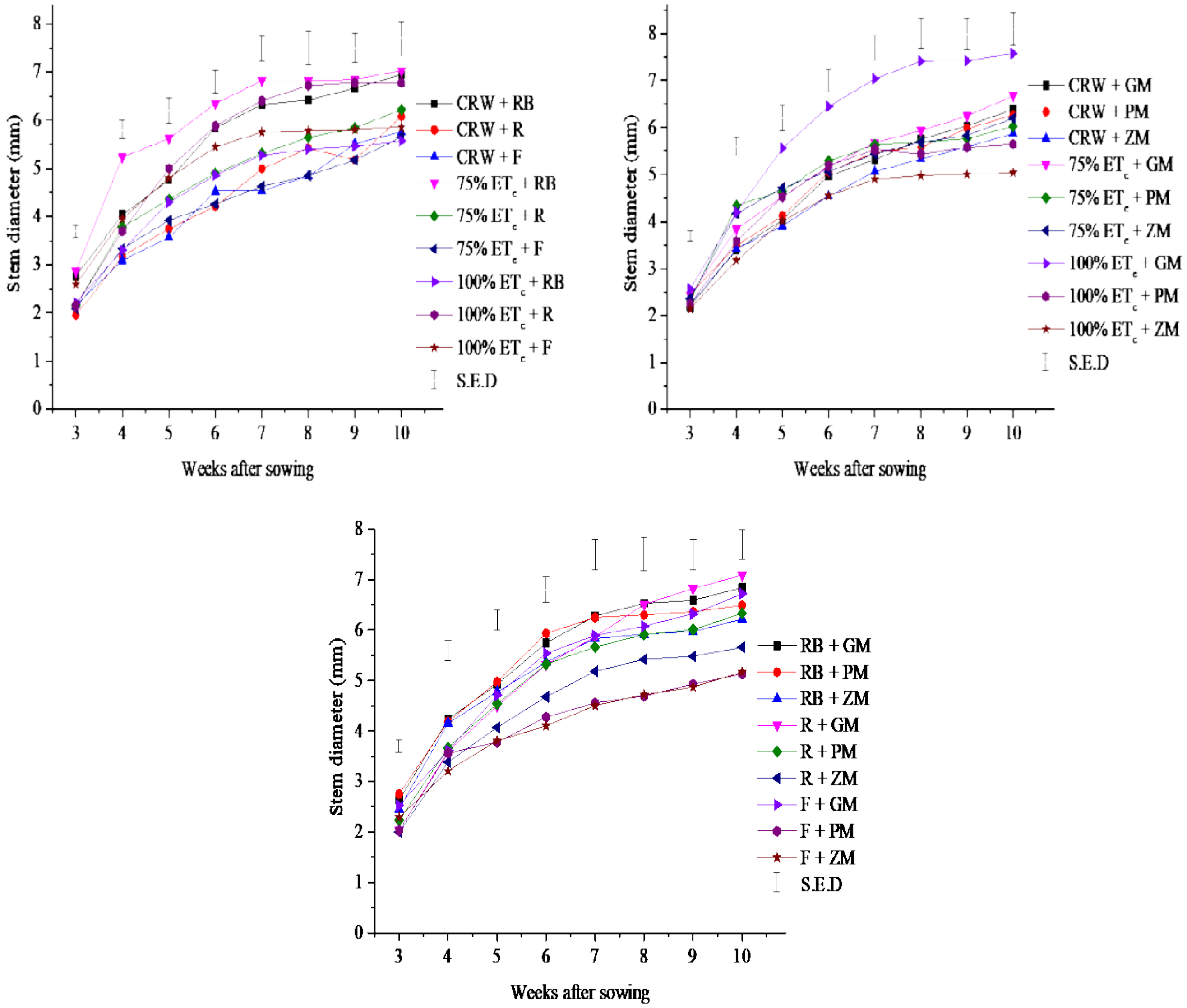


Figure 4.41: Okra stem diameter as influenced by (a) irrigation rate and land preparation, (b) irrigation rate and mulch, and (c) land preparation and mulch interactions in 2016/2017

RB = Raised bed; R = Ridge; F = Flat; GM = *Gliricidia* mulch; PM = *Pennisetum* mulch; ZM = Zero mulch.

Table 4.17: Shoot weight of okra as influenced by land preparation, mulch and irrigation rates during 2015/2016 and 2016/2017

	2015/2016		2016/2017	
	Fresh shoot weight (g plant^{-1})	Dry shoot weight (g plant^{-1})	Fresh shoot weight (g plant^{-1})	Dry shoot weight (g plant^{-1})
Land preparation (LP)				
Raised bed	2.36±0.17a	0.71±0.05	4.72±0.53	1.98±0.11a
Ridge	1.80±0.17b	0.64±0.07	3.89±0.44	1.73±0.09a
Flat	2.35±0.16a	0.70±0.04	3.64±0.49	1.26±0.10b
S.E.D	0.16	ns	ns	0.08
Mulch (M)				
Gliricidia sepium	2.56±0.21a	0.83±0.07a	5.49±0.54a	1.98±0.09a
Pennisetum purpureum	2.26±0.17a	0.75±0.05a	4.24±0.54a	1.80±0.13a
Zero mulch	1.68±0.11b	0.48±0.03b	2.52±0.23b	1.19±0.06b
S.E.D	0.20	0.06	0.54	0.09
Irrigation rate (I)				
100% ET$_c$	2.35±0.15	0.70±0.08ab	4.01±0.46	1.64±0.11
75% ET$_c$	2.00±0.20	0.56±0.05b	3.41±0.43	1.54±0.08
CROPWAT	2.15±0.15	0.80±0.05a	4.84±0.56	1.79±0.13
S.E.D	ns	0.06	ns	ns
S.E.D (LP × I)	0.27	0.13	0.89	0.14
S.E.D (M × I)	ns	0.10	0.95	0.15
S.E.D (LP × M)	ns	ns	0.91	0.14
S.E.D (LP × M × I)	ns	0.19	ns	0.25
% CV (Main-plot)	8.8	11.2	16.8	6.1
% CV (Sub-plot)	15.4	25.9	25.4	9.7
% CV (Sub sub-plot)	33.8	30.5	48.6	19.0

Means with the same letter(s) under the same category in a column are not significantly different at $p = 0.05$, ns = not significantly different at $p = 0.05$, CV (%) = Coefficient of variation.

(Table 4.17). In addition, the FSW of okra had significant ($p<0.05$) variations among the treatment interactions (Table 4.17).

In 2016/2017, land preparation did not significantly ($p = 0.05$) influence okra FSW, although, okra plants grown on Raised bed recorded the highest FSW value of 4.72 g plant^{-1}, while Ridge and Flat had low mean FSW values of 3.89 and 3.64 g plant^{-1}, respectively (Table 4.17). In contrast, the mulch treatments had significant ($p<0.05$) effect on the FSW of okra, with plants grown on *Gliricidia* mulch plots recording the highest FSW value of 5.49 g plant^{-1}, while *Pennisetum* mulch recorded a mean FSW value of 4.24 g plant^{-1}, and Zero mulch had the significantly ($p<0.05$) lowest FSW value of 2.52 g plant^{-1} (Table 4.17). Furthermore, the irrigation treatments did not significantly ($p = 0.05$) influence the FSW of okra in the 2016/2017 dry season. However, CROPWAT irrigated plants had the highest FSW value of 4.84 g plant^{-1}, while plants irrigated with 100% ET_c and 75% ET_c had low FSW values of 4.01 and 3.41 g plant^{-1} (Table 4.17). In addition, the FSW of okra had significant ($p<0.05$) variations among the various treatment combinations (Table 4.17).

4.4.8.2 Dry shoot weight as affected by land preparation, mulch and irrigation rates

The effects of land preparation, mulch, irrigation rates, and their interaction on the dry shoot weight (DSW) of okra in the 2015/2016 and 2016/2017 dry seasons are reported as follows:

In 2015/2016, there was no significant ($p = 0.05$) difference in the DSW of okra under the land preparation types. Under this category, Raised bed had the highest DSW value of 0.71 g plant^{-1}, while Flat and Ridge recorded low DSW values of 0.70 and 0.68 g plant^{-1}, respectively (Table 4.17). However, the mulch types had significant ($p<0.05$) effect on the DSW of okra, where *Gliricidia* mulch recorded the highest value of 0.83 g plant^{-1}, followed by *Pennisetum* mulch (0.75 g plant^{-1}), and least by Zero mulch (0.48 g plant^{-1}). Okra DSW was also significantly ($p<0.05$) influenced by the irrigation treatments, with CROPWAT recording the highest mean value of 0.80 g plant^{-1}. This was followed by 100% ET_c which had DSW value of 0.70 g plant^{-1}, while 75% ET_c recorded the least DSW value of 0.56 g plant^{-1} (Table 4.17). Furthermore, there were significant ($p<0.05$) variations in the DSW of okra under the different treatment interactions as shown in Table 4.17.

In 2016/2017, the DSW of okra varied significantly with land preparation types. For example, Raised bed recorded the highest DSW value of 1.98 g plant^{-1}, while Ridge had a mean DSW value of 1.73 g plant^{-1}, and Flat recorded the significantly ($p<0.05$) lowest DSW value of 1.26 g plant^{-1} (Table 4.17). Similar to land preparation, the application of mulch also had significant ($p<0.05$) influence on the DSW of okra, where *Gliricidia* mulch recorded the highest DSW value of 1.98 g plant^{-1}. This was followed by *Pennisetum* mulch which had a mean DSW value of 1.80 g plant^{-1}, while Zero mulch recorded the lowest DSW value of 1.19 g plant^{-1} (Table 4.17). On the contrary, the DSW of okra was not significantly ($p = 0.05$) influenced by the irrigation treatments, even though, CROPWAT recorded the highest DSW value of 1.79 g plant^{-1}, while 100% ET_c and 75% ET_c had low DSW values of 1.64 and 1.54 g plant^{-1}, respectively (Table 4.17). In 2016/2017, all the interaction combinations also had significant ($p<0.05$) effect on the DSW of okra (Table 4.17).

4.4.9 Yield characteristics of okra (UI4-30 variety) as influenced by land preparation, mulch and irrigation rates

The influence of the sole application and interaction of land preparation, mulch and irrigation treatments on the yield characteristics of okra are as follows:

4.4.9.1 Effects of land preparation, mulch and irrigation rates on the number of pods of okra

The number of pods produced per okra plant under the influence of land preparation, mulch, irrigation rates and their various interaction combinations in 2015/2016 and 2016/2017 are presented in Tables 4.18 and 4.19.

In 2015/2016, the number of pods produced per plant was significantly ($p<0.05$) influenced by the land preparation types. For example, plants grown on Raised bed recorded the significantly ($p<0.05$) highest number of 5.6 pods plant^{-1}, while low number of pods plant^{-1} (4.5) was recorded by Ridge and Flat, respectively (Table 4.18). Unlike land preparation, mulch application did not significantly ($p = 0.05$) affect the number of pods produced per plant. However, okra plants mulched with *Gliricidia* mulch had the highest number of 5.1 pods plant^{-1}, while *Pennisetum* mulch and Zero mulch had low mean values of 4.9 and 4.6 pods plant^{-1}, respectively (Table 4.18). The number of okra pods produced per plant under the irrigation treatments varied significantly, with okra plants grown under daily

Table 4.68: Effects of land preparation, mulch and irrigation rates on the yield characteristics of okra in 2015/2016

Treatment	No. of pods per plant	Fresh pod weight (g plant^{-1})	Pod diameter (mm pod^{-1} plant^{-1})	Pod length (cm pod^{-1} plant^{-1})	Dry pod weight (g plant^{-1})
Land preparation (LP)					
Raised bed	5.6±0.29a	13.92±1.07a	13.87±0.31a	5.0±0.10a	4.48±0.23a
Ridge	4.5±0.30b	13.53±1.29a	11.65±0.38b	4.0±0.12b	4.43±0.33a
Flat	4.5±0.19b	9.79±0.46b	11.12±0.36b	3.8±0.12b	2.79±0.25b
S.E.D	0.17	1.11	0.50	0.17	0.42
Mulch (M)					
Gliricidia sepium	5.1±0.26	13.44±1.12	12.80±0.32a	4.3±0.12	4.13±0.31
Pennisetum purpureum	4.9±0.22	11.91±0.64	12.24±0.36ab	4.4±0.13	3.64±0.25
Zero mulch	4.6±0.32	11.88±1.21	11.61±0.42b	4.2±0.14	3.93±0.29
S.E.D	ns	ns	0.39	ns	ns
Irrigation rate (I)					
100% ET_c	4.9±0.29ab	13.51±1.24a	12.14±0.35	4.2±0.13	3.37±0.29b
75% ET_c	5.4±0.30a	13.81±1.10a	12.62±0.37	4.4±0.14	4.84±0.27a
CROPWAT	4.2±0.19b	9.91±0.55b	11.89±0.40	4.3±0.13	3.49±0.27b
S.E.D	0.32	0.86	ns	ns	0.34
S.E.D (LP × I)	0.40	1.79	0.77	0.26	0.68
S.E.D (M × I)	0.50	1.72	ns	ns	ns
S.E.D (LP × M)	0.42	1.86	ns	ns	ns
S.E.D (LP × M × I)	0.77	3.14	ns	ns	ns
% CV (Main-plot)	8.2	8.5	3.2	3.2	10.6
% CV (Sub-plot)	7.4	18.9	8.6	8.4	22.6
% CV (Sub sub-plot)	20.5	31.3	11.6	14.7	40.7

Means with the same letter(s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, CV (%) = Coefficient of variation application of 75% ET_c recording the significantly ($p<0.05$) highest number of 5.4 pods plant^{-1}. This was followed by okra plants grown under daily application of 100% ET_c with a mean value of 4.9 pods plant^{-1}, while plants under CROPWAT irrigation rate had the lowest number of pods plant^{-1} (4.2) as shown in Table 4.18. The number of okra pods produced was significantly ($p<0.05$) influenced by the treatment interactions (Table 4.18).

In 2016/2017, the number of pods produced was significantly ($p<0.05$) influenced by the land preparation types, with plants grown on Raised bed recording the significantly ($p<0.05$) highest number of 11.2 pods plant^{-1}, while Flat had 8.7 pods plant^{-1}, and Ridge had the lowest number of 6.4 pods plant^{-1} (Table 4.19). However, mulch application did not significantly ($p = 0.05$) influence the number of pods produced, although, *Gliricidia* mulch recorded the highest number of 9.5 pods, while *Pennisetum* mulch and Zero mulch had low numbers of 8.5 and 8.4 pods plant^{-1}, respectively (Table 4.19). The irrigation rates did not significantly ($p = 0.05$) affect the number of okra pods produced per plant, even though plants irrigated with 75% ET_c recorded the highest mean number of 9.0 pods plant^{-1}, while CROPWAT and 100% ET_c recorded low mean values of 8.8 and 8.7 pods plant^{-1}, respectively (Table 4.19). Unlike the treatment interactions in the 2015/2016 dry season, there was no significant ($p = 0.05$) difference in the number of okra pods produced under the various treatment interactions in 2016/2017 (Table 4.19).

4.4.9.2 Effects of land preparation, mulch and irrigation rates on okra fresh pod weight

The results of the fresh weight of okra pods produced per plant (FPW) under the influence of land preparation, mulch, irrigation rates and their various interactions in 2015/2016 and 2016/2017 are presented in Tables 4.18 and 4.19, respectively.

In 2015/2016, land preparation had significant ($p<0.05$) effect on okra FPW, with Raised bed recording the highest FPW value of 13.92 g plant^{-1}. This was followed by Ridge which had a mean FPW value of 13.53 g plant^{-1}, while Flat recorded the significantly ($p<0.05$) lowest FPW value of 9.79 g plant^{-1} (Table 4.18). In contrast, mulch application had no significant ($p = 0.05$) effect on the FPW of okra, even though, *Gliricidia* mulch recorded the highest FPW value of 13.44 g plant^{-1},

Table 4.19: Effects of land preparation, mulch and irrigation rates on the yield characteristics of okra in 2016/2017

Treatment	No. of pods per plant	Fresh pod weight (g plant^{-1})	Pod diameter (mm pod^{-1} plant^{-1})	Pod length (cm pod^{-1} plant^{-1})	Dry pod weight (g plant^{-1})
Land preparation (LP)					
Raised bed	11.2±0.82a	60.30±4.31a	18.93±0.27a	5.4±0.10a	7.70±0.49a
Ridge	6.4±0.50c	27.80±2.21b	16.71±0.32b	4.3±0.12b	3.42±0.27b
Flat	8.7±0.73b	30.60±2.93b	16.18±0.30b	4.2±0.12b	4.41±0.41b
S.E.D	1.22	5.88	0.50	0.17	0.85
Mulch (M)					
Gliricidia sepium	9.5±0.79	44.50±4.06	17.86±0.29a	4.6±0.12	5.98±0.52
Pennisetum purpureum	8.5±0.77	39.80±4.02	17.29±0.33ab	4.7±0.13	5.07±0.47
Zero mulch	8.4±0.62	34.30±2.62	16.66±0.34b	4.6±0.13	4.49±0.34
S.E.D	ns	ns	0.39	ns	ns
Irrigation rate (I)					
100% ET_c	8.7±0.75	38.80±3.83	17.19±0.31	4.6±0.12	4.98±0.47
75% ET_c	9.0±0.74	41.60±3.76	17.68±0.32	4.7±0.13	5.30±0.43
CROPWAT	8.8±0.70	38.20±3.36	16.95±0.33	4.6±0.13	5.26±0.45
S.E.D	ns	ns	ns	ns	ns
S.E.D (LP × I)	ns	ns	0.77	0.26	ns
S.E.D (M × I)	ns	ns	ns	ns	ns
S.E.D (LP × M)	ns	ns	ns	ns	ns
S.E.D (LP × M × I)	ns	ns	ns	ns	ns
% CV (Main-plot)	22.9	26.3	2.2	2.9	12.9
% CV (Sub-plot)	29.3	31.6	6.1	7.8	34.9
% CV (Sub sub-plot)	44.8	49.8	8.2	13.6	54.8

Means with the same letter(s) under the same category in a column are not significantly different at $p = 0.05$, ns = not significantly different at $p = 0.05$, CV (%) = Coefficient of variation while *Pennisetum* mulch and Zero mulch had mean FPW values of 11.91 and 11.88 g plant^{-1}, respectively (Table 4.18). The FPW of okra was significantly ($p<0.05$) different under the irrigation treatments. Here, plants irrigated with 75% ET_c recorded the highest FPW value of 13.81 g plant^{-1}, while those under 100% ET_c had low FPW value of 13.51 g plant^{-1}, and CROPWAT recorded the significantly ($p<0.05$) lowest FPW value of 9.91 g plant^{-1} (Table 4.18). Furthermore, the treatment interactions showed significant ($p<0.05$) differences in the FPW of okra in 2015/2016 (Table 4.18).

In 2016/2017, okra FPW was significantly ($p<0.05$) different under the land preparation types, where plants grown on Raised bed recorded the significantly ($p<0.05$) highest FPW value of 60.30 g plant^{-1}, while Flat and Ridge recorded low mean FPW values of 30.60 and 27.80 g plant^{-1}, respectively (Table 4.19). Unlike land preparation, mulch had no significant ($p = 0.05$) effect on the FPW of okra. However, *Gliricidia sepium* mulch recorded the highest FPW value of 44.50 g plant^{-1}, while *Pennisetum purpureum* mulch and Zero mulch had low FPW values of 39.80 and 34.30 g plant^{-1}, respectively (Table 4.19). There was no significant ($p = 0.05$) difference in the FPW values recorded among the various irrigation treatments. However, plants irrigated with 75% ET_c recorded the highest FPW value of 41.60 g plant^{-1}, while those under 100% ET_c and CROPWAT irrigation rate had low mean FPW values of 38.80 and 38.20 g plant^{-1}, respectively (Table 4.19). Furthermore, in the 2016/2017 dry season, the interaction among the treatments had no significant ($p = 0.05$) effect on the FPW of okra (Table 4.19).

4.4.9.3 Okra pod diameter as influenced by land preparation, mulch and irrigation treatments

The results of the effects of land preparation, mulch and irrigation rates on the diameter of okra pods (PD) produced in 2015/2016 and 2016/2017 are shown in Tables 4.18 and 4.19, respectively.

With respect to 2015/2016 okra cultivation, land preparation had significant ($p<0.05$) on the PD of okra pods produced. Okra pods produced from plants grown on Raised bed recorded the significantly ($p<0.05$) highest PD value of 13.87 mm pod^{-1} plant^{-1}, while Ridge and Flat recorded low PD values of 11.65 and 11.12 mm pod^{-1} plant^{-1}, respectively (Table 4.18). The PD was significantly ($p<0.05$) influenced by mulch application. Here, PD was significantly ($p<0.05$) highest (12.80 mm pod^{-1} plant^{-1}) under *Gliricidia sepium* mulch, while *Pennisetum purpureum* mulch and Zero mulch had low mean PD values of 12.24 and 11.61 mm pod^{-1} plant^{-1}, respectively (Table 4.18). However, the PD of okra was not significantly ($p = 0.05$) affected by irrigation rates, although, okra pods produced under 75% ET_c recorded the highest PD value of 12.62 mm pod^{-1} plant^{-1}, while 100% ET_c and CROPWAT recorded low PD values of 12.14 and 11.89 mm pod^{-1} plant^{-1}, respectively (Table 4.18). In addition, the treatment interactions had significant ($p<0.05$) effect on okra PD (Table 4.18).

In 2016/2017, land preparation had significant ($p<0.05$) effect on the PD of okra pods produced, with plants grown on Raised bed recording the significantly ($p<0.05$) highest PD value of 18.93 mm pod^{-1} plant^{-1}, while those grown on Ridge and Flat had low mean PD values of 16.71 and 16.18 mm pod^{-1} plant^{-1}, respectively (Table 4.19). Mulch application also had significant ($p<0.05$) effect on the PD of okra pods produced. Here, *Gliricidia sepium* mulch recorded the highest PD value of 17.86 mm pod^{-1} plant^{-1}, while *Pennisetum purpureum* mulch had a mean PD value of 17.29 mm pod^{-1} plant^{-1}, and Zero mulch recorded the significantly ($p<0.05$) lowest PD value of 16.66 mm pod^{-1} plant^{-1} (Table 4.19). However, okra PD was also not significantly ($p = 0.05$) affected by the irrigation treatments, even though, 75% ET_c recorded the highest PD value of 17.68 mm pod^{-1} plant^{-1}, while 100% ET_c and CROPWAT had low mean PD values of 17.19 and 16.95 mm pod^{-1} plant^{-1}, respectively (Table 4.19). On the contrary, the PD of okra harvested under the treatment interactions showed significant ($p = 0.05$) differences as presented in Table 4.19.

4.4.9.4 Okra pod length as influenced by land preparation, mulch and irrigation rates

The results of the length of okra pods (PL) produced under the influence of land preparation, mulch and irrigation rates in 2015/2016 and 2016/2017 are presented in Tables 4.18 and 4.19, respectively.

In 2015/2016, land preparation significantly ($p<0.05$) influenced the PL of okra pods, with pods produced by plants grown on Raised bed recording the significantly ($p<0.05$) highest mean PL value of 5.0 cm pod^{-1} plant^{-1}, while Ridge and Flat recorded low mean PL values of 4.0 and 3.8 cm pod^{-1} plant^{-1}, respectively (Table 4.18). The application of mulch did not significantly ($p = 0.05$) influence the PL of okra pods produced, even though *Pennisetum purpureum* mulch recorded the highest PL value of 4.4 cm pod^{-1} plant^{-1}, while *Gliricidia sepium* mulch had a mean PL value of 4.3 cm pod^{-1} plant^{-1}, and Zero mulch recorded the lowest PL value of 4.2 cm pod^{-1} plant^{-1}

(Table 4.18). The irrigation treatments had no significant ($p = 0.05$) effect on the PL of okra pods produced. However, okra plants under 75% ET_c produced the longest pods, with mean PL value of 4.4 cm pod^{-1} plant^{-1}, while CROPWAT and 100% ET_c recorded mean PL values of 4.3 and 4.2 cm pod^{-1} plant^{-1}, respectively (Table 4.18). Furthermore, in 2015/2016, PL of okra pods was significantly ($p<0.05$) affected by the treatment interactions (Table 4.18).

In a similar way to 2015/2016, PL varied significantly under the land preparation types in 2016/2017. Okra plants grown on Raised bed had the significantly ($p<0.05$) highest PL value of 5.4 cm pod^{-1} plant^{-1}, while Ridge and Flat had low PL values of 4.3 and 4.2 cm pod^{-1} plant^{-1} (Table 4.19). Mulch application did not significantly ($p<0.05$) influence the PL of okra pods produced, although, *Pennisetum purpureum* mulch recorded the highest PL value of 4.7 cm pod^{-1} plant^{-1}, while *Gliricidia sepium* mulch and Zero mulch recorded a low mean PL value of 4.6 cm pod^{-1} plant^{-1}, respectively (Table 4.19). The irrigation treatments did not significantly ($p = 0.05$) affect the PL of okra pods produced in the 2016/2017 dry season. However, okra plants irrigated with 75% ET_c produced the longest pods with mean PL value of 4.7 cm pod^{-1} plant^{-1}, while 100% ET_c and CROPWAT plants produced pods with a mean PL value of 4.6 cm pod^{-1} plant^{-1}, respectively (Table 4.19). In addition, significant ($p<0.05$) differences were recorded for okra PL under the different treatment interactions (Table 4.19). Plates 4.1, 4.2 and 4.3 show fresh okra pods produced under the various combinations of irrigation rates, land preparation and mulch treatments.

4.4.9.5 Effects of land preparation, mulch and irrigation rates on dry pod weight of okra

The results of the dry weight of okra pods (DPW) produced under the influence of land preparation, mulch and irrigation applications in 2015/2016 and 2016/2017 are presented in Tables 4.18 and 4.19, respectively.

In 2015/2016, okra DPW varied significantly under the different land preparation types, with pods harvested from plants grown on Raised bed recording the highest DPW value of 4.48 g plant^{-1}. This was followed by Ridge which

Plate 4.1: Okra pod yield from daily application 75% ET_c in combination with land preparation and mulch treatments

Note: Okra yields obtained from 75% ET_c in combination with Raised bed + *Gliricidia sepium* mulch (a), Raised bed + *Pennisetum purpureum* mulch (b), Raised bed + Zero mulch (c), Flat + *Gliricidia sepium* mulch (d), Flat + *Pennisetum purpureum* mulch (e), Flat + Zero mulch (f), Ridge + *Gliricidia sepium* mulch (g), Ridge + *Pennisetum purpureum* mulch (h), Ridge + Zero mulch (i)

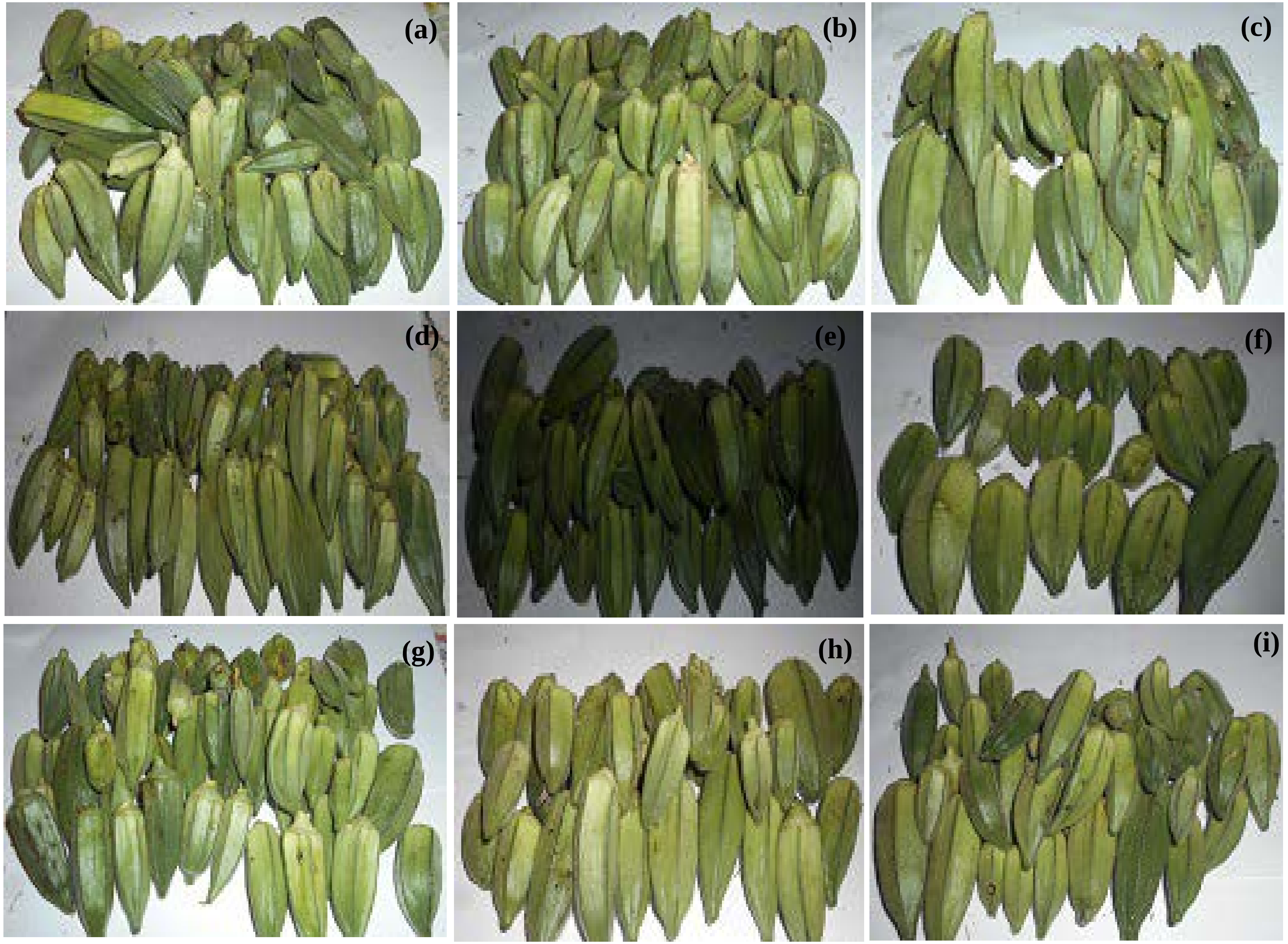


Plate 4.2: Okra pod yield under daily application 100% ET_c in combination with land preparation and mulch treatments

Note: Okra yields obtained from 100% ET_c in combination with Raised bed + *Gliricidia sepium* mulch (a), Raised bed + *Pennisetum purpureum* mulch (b), Raised bed + Zero mulch (c), Flat + *Gliricidia sepium* mulch (d), Flat + *Pennisetum purpureum* mulch (e), Flat + Zero mulch (f), Ridge + *Gliricidia sepium* mulch (g), Ridge + *Pennisetum purpureum* mulch (h), Ridge + Zero mulch (i)

Plate 4.3: Okra pod yield under CROPWAT irrigation rate in combination with land preparation and mulch treatments

Note: Okra yields obtained from CROPWAT irrigation rate in combination with Raised bed + *Gliricidia* mulch (a), Raised bed + *Pennisetum* mulch (b), Raised bed + Zero mulch (c), Flat + *Gliricidia* mulch (d), Flat + *Pennisetum* mulch (e), Flat + Zero mulch (f), Ridge + *Gliricidia* mulch (g), Ridge + *Pennisetum* mulch (h), Ridge + Zero mulch (i) had a mean DPW value of 4.43 g plant^{-1}, while Flat recorded the significantly ($p<0.05$) lowest DPW value of 2.79 g plant^{-1} (Table 4.18). On the contrary, mulch application had no significant ($p = 0.05$) effect on the DPW of okra. Pods obtained from *Gliricidia* mulch plots recorded the highest mean DPW value of 4.13 g plant^{-1}, while Zero mulch had a mean DPW value of 3.93 g plant^{-1}, and *Pennisetum* mulch recorded the lowest mean DPW value of 3.64 g plant^{-1} (Table 4.18). However, the irrigation rates had significant ($p<0.05$) effect on the DPW of okra pods produced. Okra pods harvested from plants irrigated with 75% ET_c recorded the significantly ($p<0.05$) highest DPW value of 4.84 g plant^{-1}, while CROPWAT and 100% ET_c had low mean DPW values of 3.49 and 3.37 g plant^{-1}, respectively (Table 4.18). In terms of the interactions, there were significant ($p<0.05$) variations in the DPW of okra pods as shown in Table 4.18.

In 2016/2017, the DPW of okra pods significantly ($p<0.05$) varied among the land preparation types. For instance, Raised bed recorded the significantly ($p<0.05$) highest DPW value of 7.70 g plant^{-1}, while Flat and Ridge had low DPW values of 4.41 and 3.42 g plant^{-1}, respectively (Table 4.19). Mulch application had no significant ($p = 0.05$) effect on the DPW of okra pods produced. Moreover, *Gliricidia* mulch recorded the highest DPW value of 5.98 g plant^{-1}, while *Pennisetum* mulch and Zero mulch had low mean DPW values of 5.07 and 4.49 g plant^{-1}, respectively (Table 4.19). The DPW of okra pods produced did not differ significantly ($p = 0.05$) among the irrigation treatments, although, pods produced from okra plants under 75% ET_c recorded the highest DPW value of 5.30 g plant^{-1}, while CROPWAT and 100% ET_c had low mean DPW values of 5.26 and 4.98 g plant^{-1}, respectively (Table 4.19). However, there were significant ($p<0.05$) differences in okra DPW among the treatment interactions (Table 4.19).

CHAPTER 5

DISCUSSION

The irrigation water used for the study was rich in nitrogen, calcium, magnesium, sodium and bicarbonates, respectively. Similar observations were reported by Mon *et al.* (2007), who noted high concentrations of calcium, magnesium and sodium bicarbonates in irrigation water obtained from wells. They further explained that the quality of the water supplied by the well could have been due to its flow from an extended aquifer. Although, the pH values of the water used for the experiments were within the range (7.0 to 9.0) recorded by Mon *et al.* (2007), the pH of the water used for the screenhouse study was higher than the normal pH range (6.5 to 8.4) for irrigation (FAO, 2007).

With respect to salinity, the water used for the screenhouse study had a higher electrical conductivity (EC) than the average EC (460 µs cm^{-1}) of water obtained from a similar source (well) for irrigation by Al-Ghobari (2011), while those used for the field experiments were relatively low. FAO (2007) explained that differences in chemical quality of irrigation waters from similar sources could be due to variations in the chemical constituents dissolved from the different geological strata through and over which the waters flowed. Hamid *et al.* (1966) stated that water with EC lower than 1500 µs cm^{-1} is safe for irrigation as the irrigation waters used for this study belonged to the medium salinity hazard class. Tank and Chandel (2010) reported that the SAR values showed that the waters used for this study were suitable for irrigation purpose. They also reported that the %Na values showed that the irrigation water used for the screenhouse experiment and the 2016/2017 experiment were permissible (Class 3) for irrigation purpose, while that used for the 2015/2016 experiment was good (Class 2) for irrigation purpose. This is because high soluble sodium in soil solution has direct adverse effect on crop yield (Hussain *et al.*, 2010). On the average, the irrigation water salinity rating for water used for this study was C2–S1 (low sodium hazard and medium salinity hazard).

The summary of the weather data showed that there were variations in weather conditions within and between the experimental periods, as the first planting periods had higher ET_o and maximum temperatures than the second planting periods for all the studies. Sardans *et al*. (2008) earlier reported that ambient temperature and rainfall showed distinct seasonal patterns that altered soil microclimate, influenced microbial composition and function, and thus, affected okra growth and yield.

The study showed that plant growth parameters of UI4-30 and NH47-4 okra varieties responded differently to the different levels of irrigation. The number of leaves produced across 10 WAS by UI4-30 and NH47-4 was significantly influenced by the levels of irrigation water applied. Although the number of okra leaves reported by Panigrahi and Sahu (2013) were higher than those reported in this study, there was no significant response of number of leaves per plant to irrigation treatments. The peak number of leaves produced by both varieties (UI4-30 and NH47-4) was observed to increase with increase in irrigation water levels at both plantings. This trend corroborates the results of Aujla *et al*. (2005), who reported high number of secondary branches of cotton (*Gossypium hirsutun* L. cv. LH 1556) due to increase in levels of water application from cumulative pan evaporation (Epan). Abd El-Kader *et al*. (2010) also observed that okra leaf production increased with increase in irrigation water levels. Similarly, Panigrahi and Sahu (2013) reported high number of leaves produced by okra plants with high irrigation water level of 25% available soil moisture depletion (ASMD).

Furthermore, varietal effect with respect to efficient use of water for vegetative growth was also observed as UI4-30 variety produced high peak number of leaves under all the ET_o treatments than NH47-4 variety at both plantings. This is in consonance with the findings of Jamala *et al*. (2011) and Panigrahi and Sahu (2013). It can be inferred from the study that lower level of water application of ET_o-M was sufficient to optimize the number of leaves produced by UI4-30 variety compared with NH47-4 variety under ET_o-N.

With respect to okra plant height, UI4-30 was observed to produce taller plants than NH47-4 under all the irrigation water levels. As observed for number of leaves at the first planting, the potential of UI4-30 for producing taller plants than NH47-4 even under a lower irrigation water level was observed as UI4-30 irrigated with lower water level (ET_o-M) produced taller plants than NH47-4 irrigated with a higher water level (ET_o-N) at 10 WAS. Even though this result disagrees with those of Panigrahi and

Sahu (2013) who reported higher plant height for okra plants under higher levels of irrigation water than those under lower irrigation water levels, Jamala *et al*. (2011), also reported varietal influence on the height of okra where a local (V_3) variety was shorter in height than improved (V1) and serial (V2) varieties. Moreover, only from 4 to 10 WAS and 3 to 10 WAS was UI4-30, irrigated with the highest water level (ET_o-N), significantly different from NH47-4 at both plantings, respectively. This could be attributed to little or no variation in soil moisture across the lysimeters at 2 WAS due to their uniform moisture content of 100% field capacity, which in turn resulted to insignificant variation in crop growth parameters at the earlier stages of the study.

In terms of okra stem diameter, NH47-4 irrigated with high irrigation water level of ET_o-N was superior to other treatment combinations at the first and second planting, respectively. However, at lower levels of irrigation, UI4-30 had higher stem diameter than NH47-4 at the first and second planting. Similarly, Chattaraj *et al*. (2011) noted that wheat variety PBW-502 recorded higher values than HD-2987 under adequate irrigation, but had a lower value than HD-2987 under limited irrigation. It was also observed during the first planting that UI4-30 irrigated with lower water levels of ET_o-M and ET_o-I recorded higher stem diameter values than UI4-30 and NH47-4 irrigated with higher water levels of ET_o-N and ET_o-M from 7 to 10 WAS, respectively. Similar observations were reported for okra plants by Abd El-Kader *et al*. (2010) and Panigrahi and Sahu (2013). However, no appreciable difference was observed for stem diameter values of UI4-30 and NH47-4 under the different irrigation water levels. This result disagrees with those of Panigrahi and Sahu (2013), who reported significant differences among stem diameter values obtained from okra plants under different levels of irrigation water. In addition, values obtained for okra stem diameter in this study were lower than those obtained in the study of Panigrahi and Sahu (2013).

The superior growth performance of UI4-30 over NH47-4 in both first and second planting may be due to the fact that it could be more suited to the prevailing weather conditions associated with the planting periods (dry season) than NH47-4. The superior performance of improved okra variety under dry season conditions has earlier been reported (Jamala *et al*., 2011). Although, Majanbu *et al*. (1988) reported high growth for NH47-4 under rainfed conditions, Ijoyah *et al*. (2009) reported poor growth and yield performance by NH47-4 under dry season relative to better yield obtained under wet season. These indicate that the season of planting okra plays an important role in determining the growth characters of okra varieties. Irrespective of the differences in growth parameters, both varieties performed better during the second planting period. The higher crop growth observed during the second planting may be due to the fact that this planting period was at the on-set of the rainy season where the temperature was low due to low solar radiation and reduced associated heat stress when compared with the first planting. This is in line with the reports of Randhawa (1967) who noted seasonal effects on okra growth and development.

Furthermore, the significantly low plant growth parameters recorded under low irrigation water level (ET_o-I) could be attributed to high soil moisture depletion under this irrigation water level. This result supports those obtained for capsicum (Hegde, 1989) and sugar beet (Sepaskhah and Kamgar Haghighi, 1997). In addition, Abd El-Kader *et al*. (2010) explained that okra crop water use is high even though it can offer some resistance to drought. Hence, the significant influence of levels of irrigation water on okra growth and development in both first and second planting.

With respect to yield characteristics, the study showed that significantly higher number of pods, fresh pod weight, dry pod weight, pod length and 100 seed weight were produced from UI4-30 across all irrigation water levels as compared to NH47-4 at the first planting. At second planting, the high yield potential of UI4-30 over NH47-4 was further revealed when compared irrespective of irrigation water level applied. Similar observations were reported by Jamala *et al*. (2011) who noted consistently higher number of fruits under improved okra variety (V_1) as compared to lower number of fruits produced by serial (V_2) and local (V_3) okra varieties at first, second and third week of harvest, irrespective of the levels of water applied. Furthermore, Jamala *et al*. (2011) also reported longer fruits, weightier fruits and higher fresh fruit yield (t ha^{-1}) under improved okra variety (V_1) than serial (V_2) and local (V_3) okra varieties, respectively.

The significant differences observed between yield parameters of UI4-30 and NH47-4 irrespective of the quantity of irrigation water applied could be due to their genetic variations (Anshebo *et al*., 2004). The superior yield obtained from UI4-30 can also be attributed to its large number of leaves. A variety with large number of leaves have been reported to easily trap more sunlight for photosynthesis, thus producing greater assimilates during their photosynthetic activities than those with smaller number of leaves (Van den Berge and Laurie, 2004; Dhanasekar and Pandey, 2005; Ahmed *et al*., 2012; Iyagba *et al*., 2012; Kareem, 2013). The low yield recorded for

NH47-4 in this study could be due to its poor response to dry season conditions as the sensitivity of okra varieties to environmental changes has also been reported in earlier studies (Ezeakume, 2004; Katung, 2007; Ijoyah *et al*., 2009). This clearly indicates that UI4-30 could be beneficial for dry season okra production as it gave higher pod yield production.

In considering the levels of irrigation water applied irrespective of the okra varieties, high level irrigation water (ET_o-N) recorded the highest yields over medium (ET_o-M) and low level irrigation water (ET_o-I) application in both first and second planting, respectively. Although, differences in some of the yield parameters under the different levels of irrigation water application was not significant, the trend in yield production is similar to those of Olufayo *et al*. (2006). They noted higher yield under 1Ep (full pan evaporation) than ¾Ep (three-quarter pan evaporation) and ½Ep (half pan evaporation), respectively. In another study on evapotranspiration and yield of okra, Panigrahi and Sahu (2013) reported that full root-root zone irrigation (FRI) had significantly higher number of pods than lower irrigation rates. Contrary to the higher values for pod length and pod diameter recorded for okra under high irrigation water level (ET_o-N) in relation to those of lower water levels (ET_o-M and ET_o-I), an earlier study on okra (Panigrahi and Sahu, 2013) revealed that lower levels of irrigation water (APRI and FPRI) produced longer and weightier pods than those produced under higher level of irrigation water (FRI).

The significant difference in yield parameters of okra under different levels of irrigation has earlier been reported by Abd El-Kader *et al*. (2010). Although Panigrahi and Sahu (2013) attributed smaller fruits under FRI to its increased number of fruits, the bigger fruits produced under ET_o-N in this study could be attributed to the longer time for fruit development (between fruiting and harvest time) benefitted by plants under this treatment. On the other hand, it could be inferred that water application level of ET_o-N kept soil moisture at a level that maximized okra growth and yield at both plantings, respectively. Hence, the significantly lower yield recorded for low irrigation level (ET_o-I) could be due to high degree of depletion of available soil moisture under this irrigation water level than higher levels at various weeks of plant growth (Panigrahi and Sahu, 2013).

The insignificant influence of the variety × ET_o interaction on the shoot weight of okra could be due to the similarity of the two varieties in their growth response under each irrigation water level. In a similar study on cotton (*Gossypium hirsutum*

L.), Ioannis *et al*. (2015) reported no significant interaction between genotypes and irrigation levels (100% daily ET_c and 50% daily ET_c) in two planting seasons. The consistently low fresh and dry shoot weights recorded under NH47-4 in both first and second planting corroborates the results of earlier studies (Chattaraj *et al*., 2011; Srikrishnah *et al*., 2012; Pushpa *et al*., 2013). Moreover, the higher fresh and dry shoot produced by UI4-30 over NH47-4 could be attributed to its superior vegetative growth as influenced by its genetic make-up for better adaptability to the prevailing weather conditions in both first and second planting, respectively. Naidu *et al*. (1996) explained that the higher biomass production of one variety over the other could also be due to superior genetic potential. Although Pushpa *et al*. (2013) noted that the stem of the plants could be the major factor responsible for variation in biomass production between two or more crop varieties, the differences in this study could be due to plant height and number of leaves, as the stem diameter of the varieties did not vary significantly.

Although, the fresh and dry shoot weight of okra under ET_o-N and ET_o-M were similar at first and second planting, okra shoot under ET_o-N was higher, while shoot production under ET_o-I was the lowest among the three levels of irrigation. An earlier study by Christou *et al*. (2003), revealed significant ($p<0.05$) influence of irrigation levels (no irrigation, 50% ET_o, and 100% ET_o) on biomass (leaves, stems and total) produced by cardoon (*Cynara cardunculus*), switchgrass (*Panicum virgatum*) and giant reed (*Arundo donax*) in two growing seasons. The lowest dry weight of shoot produced under ET_o-I supports the results of Nkgapele and Mphosi (2012) who reported lower biomass yields under low irrigation water level.

The superior shoot weight recorded under ET_o-N buttresses the superior vegetative growth recorded by plants under it when compared to those observed under other irrigation levels. Christou *et al*. (2003) reported that highest biomass accumulation and highest dry matter were obtained from well-watered treatments of 100% ET_c than those of deficit irrigation, while dry cotton sticks were reported highest for drip irrigation E-pan ratio of 0.4 than those of E-pan 0.3 and 0.2, respectively (Aujla *et al*., 2005). Panigrahi and Sahu (2013) explained that the higher values for vegetative growth components (stem, branch, leaf) of okra plants under high irrigation level contributed to the higher portion of the shoot weight recorded in comparison to lower irrigation levels in okra cultivation. They explained that the more quantity of total dried biomass under high irrigation level indicates that the plants under this treatment synthesized more photosynthates than those under lower treatments. Thus, it could also be inferred from this study that high irrigation level of ET_o-N enhanced the photosynthetic potentials of okra relative to lower irrigation levels that could have resulted to water shortage at critical stages of crop development.

The crop evapotranspiration and crop coefficient values of UI4-30 and NH47-4 were observed to vary in amount under the different irrigation levels, and at various weeks of plant growth. This shows the variation in crop water demand at various okra phenological stages as influenced by the changes in daily environmental conditions. The crop evapotranspiration (ET_c) of UI4-30 and NH47-4 under the three irrigation levels rose from the initial stages of plant growth before decreasing at a later stage after attaining their respective peaks at 7 and 8 WAS, respectively. This suggests that both varieties have similar trend in weekly ET_c values, irrespective of irrigation levels, with their respective peaks between 7 and 8 WAS. In a similar study on *Corchorus olitorius*, Odofin *et al*. (2011) reported a rise in ET_c from 2.7 and 2.8 to 6.8 and 6.6 mm day^{-1} before dropping to 2.2 and 2.0 mm day^{-1} for *Amugbadu* and *Oniyaya* varieties. Aliku and Oshunsanya (2016) also reported peak okra ET_c at mid-season stage for three agro-ecological zones in Nigeria. The peak ET_c at this stage could be due to high water demand by the varieties which is needed to compensate for the water use for various physiological processes such as flowering and fruiting. The peak ET_c at this stage could have also been enhanced by the large number of leaves recorded by the two varieties at this growth stage under the different irrigation levels. Similarly, Maina *et al*. (2014) reported that measured ET_c of rice crop was low at the early stage of crop growth but gradually increased as the rice plant grew into development stage. Panigrahi and Sahu (2013) reported that higher atmospheric evaporative demand and the maximum plant growth during 7 to 8 weeks resulted to higher ET_c at this stage of plant growth. Generally, ET_c increases as percentage ground cover increases and maximum ET_c is attained during the mid-season stage when ground cover is about 70 to 80% (Van der Gulik and Nyvall, 2001). The reduction in number of leaves could have been responsible for the drop in ET_c values at the later stages of the crop's growth since it bears the stomata that are responsible for transpiration. This is because transpiration reduces at the later stages due to senescence (Aliku and Oshunsanya, 2016).

The difference between the weekly ET_c values of the two varieties, with UI4-30 losing more water by evapotranspiration than NH47-4 at both plantings supports the results of Odofin *et al*. (2011), who observed consistently higher ET_c for *Amugbadu* variety than *Oniyaya* variety for two growing seasons. This variation could be due differences in growth habits as observed in the number of leaves and plant height exhibited by the two varieties during the first and second planting, respectively. For instance, UI4-30 which recorded higher ET_c under the different irrigation levels was taller and had higher number of leaves than NH47-4 under the different irrigation levels at both first and second planting. The higher number of leaves produced by UI4-30 could have enhanced higher ground cover and consequently higher ET_c values. Odofin *et al*. (2011) explained that the reason for the higher ET_c recorded by *Amugbadu* variety over *Oniyaya* variety was due to its wide-open branches relative to the nearly erect branches produced by *Oniyaya* variety. They further reported that *Amugbadu* variety had a wider canopy, and by extension, a higher percentage ground cover than *Oniyaya* variety during the different stages of growth, especially during the crop development and mid-season stages. According to Allen and Pereira (1998), the major factors that govern ET_c levels are resistance to transpiration, crop height, crop roughness, reflection, leaf area, ground coverage and crop rooting characteristics. The differences in these crop factors result in different ET_c levels for dissimilar crop types and varieties and for different crop growth stages under identical environmental conditions (Odofin *et al.*, 2011).

The trend of ET_c values under the different irrigation levels supports the results of Panigrahi and Sahu (2013) who reported that total ET_c value followed the same trend of depth of irrigation water applied under different irrigation treatments. The significantly highest ET_c recorded by okra plants under the highest irrigation level (ET_o-N) could be due to higher transpiration of the crops resulting from high water supply under this treatment as compared to those of other irrigation levels as ET_c was observed to increase with increase in irrigation level. Panigrahi and Sahu (2013) also reported higher magnitude of ET_c in different growth stages of okra under high irrigation level. Candogan and Yezgan (2010) noted higher seasonal evapotranspiration values with increase in irrigation levels of Class A Pan evaporation for young dwarf cherry trees at the first and second year of planting.

Similar to crop evapotranspiration, crop coefficient values of UI4-30 and NH47-4 were observed to gradually increase from 2 WAS until it attained peak values between 7 and 8 WAS before dropping at 9 WAS at first and second planting, respectively. Stegman *et al*. (1977) explained that when the ground cover is incomplete, the K_c is only about 0.2 but could later attain the peak K_c value of about 1.1, while similar trend was observed for *Corchorus olitorius* varieties by Odofin *et al*. (2011). In comparison, the trend of ET_c and K_c of UI4-30 irrigated with ET_o-N, and NH47-4 irrigated with ET_o-N, ET_o-M and ET_o-I at 4 WAS during the first planting, contradicts Odofin *et al*. (2011) who stated that K_c and ET_c are governed by the same factors and that the former increases as the latter increases. This result could be due to variations in specific crop characteristics under different irrigation levels (ET_o rates) as K_c could be more of a crop determined parameter than ET_c which could be more of a combination of crop and weather determined parameter. According to Allen *et al*. (1998), K_c is affected by crop type, stage of growth of the crop and cropping pattern. FAO (2007), stated that K_c varies mainly with specific crop characteristics, while Allen *et al*. (1998), defined K_c as properties of plants used for predicting evapotranspiration. In another study, the K_c of rice fluctuated steadily at the beginning and later increased as the plant grew older (Maina *et al*., 2014). The trend in K_c values could have been influenced by the number of leaves produced at the different crop growth stages as it determines the size of the crop canopy.

The peak values recorded between 8 and 9 WAS corroborate the result of Maina *et al*. (2014) who noted that highest K_c for rice was recorded just before the reproductive stage of rice (50 – 60 days after transplanting). The decrease in K_c values also corroborates those reported for date palm by Mazahrih *et al*. (2012). Although, they explained that the decrease in K_c at the later stage of crop growth and development was due to low temperature and pruning process, it could thus be inferred that the drop in K_c values at the later stage of okra growth (9 and 10 WAS) could be due to the drop in the number of leaves as the plants defoliated during this period of growth as senescence occurred. In an earlier report, Fraust (1989) explained that declining K_c values during this maturity stage might be due to reduced sensitivity of the stomata as leaves begin to senescence. Thus, K_c varies across the growing season (Kassem, 2007), as its values show a curve which peaks during the flowering/fruiting (mid-season) after growing from emergence (initial stage) through vegetative (development stage), and drops during senescence (late stage) (Faloye and Alatise, 2015). They also explained that the K_c result shows that the highest water requirement occurs at the flowering and pod formation (mid-season) stage.

The high K_c values recorded by UI4-30 even at low irrigation levels of ET_o-M and ET_o-I than NH47-4 at high irrigation level of ET_o-N at first and second planting, could be due to their differences in adaptation to the prevailing experimental conditions which consequently influenced their potential for foliage production, a major crop factor that affects crop water use amongst crop varieties. According to Snyder and O’Connell (2007), K_c differs with crop type and variety, growth stage, growing season and weather condition. Similarly, Odofin *et al*. (2011) reported consistently higher K_c values for *Amugbadu* variety than *Oniyaya* variety from 3 to 9 weeks after transplanting. They explained that this trend was due to higher evapotranspiration losses by *Amugbadu* variety. Another explanation for higher K_c exhibited by UI4-30 over NH47-4 could be due to its plant height. This confirms the results of Bhandari (2012) who explained that the higher the K_c are observed for taller plants and longer growing seasons.

The variations in K_c values under the different irrigation levels across the growth stages of both varieties is an illustration of the influence of irrigation level on K_c. The higher K_c values recorded under high irrigation level of ET_o-N corroborates the findings of Panigrahi and Sahu (2013) who reported high K_c values under high irrigation level. They explained that higher K_c values at flowering/reproductive stage of plants under high irrigation level could be due to higher ET_c under this treatment. The higher K_c values recorded at the first planting, relative to the second could be due to the differences in climatic conditions which varied between days, weeks and months of crop growth. Variations in K_c values between planting seasons have also been shown (Odofin *et al*., 2011). Bhandari (2012) stated that K_c values vary with month and locality of cultivation. He further reported that K_c was higher as the number of days increased. Large seasonal K_c variations were observed between the different ET_r methods (Jia *et al*., 2007), with higher K_c values recorded under the various combinations of okra varieties and irrigation levels at first planting than second planting. Maina *et al*. (2014) also noted that change in crop development and weather parameters such as humidity could be responsible for variation in K_c during the same period or between growing periods. The overall trend in K_c values obtained in this study was different from the FAO reported pattern. This might be due to the variations in crop varieties and climatic conditions governing the period and location of planting. Similar report was obtained for maize by Abedinpour (2015), who explained that different maize varieties might have different crop water use and evapotranspiration patterns. Alternatively, it could be that FAO K_c values are generalized ones and recommended for a wide range of climatic conditions (Abedinpour, 2015).

The efficiency of irrigation water for shoot and yield production by UI4-30 and NH47-4 varied significantly under the different irrigation levels (ET_o-N, ET_o-I and ET_o-M) during the first and second plantings. This could be due to differences in efficiency in utilizing available water under the prevailing weather conditions and thus, further illustrates the influence of available water on irrigation water use efficiency (IWUE) of a particular crop variety or varieties for growth and yield production. The superiority of UI4-30 over NH47-4 in efficiently utilizing available water for growth and yield production was observed in its higher IWUE under each irrigation level at the first and second plantings. Although, the optimum potential of UI4-30 and NH47-4 for efficient utilization of irrigation water for yield production ($IWUE_{pod\ yield}$) was highest under high irrigation level at first planting, the results showed that UI4-30 could be more efficient in utilizing available water for yield production than NH47-4 across the respective irrigation treatments. Furthermore, the results showed that even at lower irrigation levels of ET_o-I and ET_o-M, UI4-30 recorded higher $IWUE_{pod\ yield}$ than NH47-4 under higher irrigation levels of ET_o-M and ET_o-N at the first and second plantings, respectively. This could be attributed to its superior genetic ability to produce higher pod yield irrespective of the irrigation levels than NH47-4 under the prevailing weather conditions. Significant variations between varieties and cultivars in terms of IWUE have been observed for crops like wheat (Balouchi, 2010). In an earlier study on wheat cultivars, Boutraa *et al*. (2010) reported decrease in water use efficiency of several cultivars with the exception of *Sandy-1* and *Al-gaimi* varieties, under severe water deficit treatment, hence, pointing out their superiority over the others. It has been shown that irrigation water use efficiency is influenced by crop yield potential, irrigation method, estimation and measurement of evapotranspiration, crop environment and climatic characteristics of the region (Kuscu *et al*., 2013). Thus, it could be inferred from this study that UI4-30 has greater potential, as influenced by its genetic make-up, for producing higher photosynthetic assimilates than NH47-4, thereby optimizing its growth and yield production with low irrigation water level under dry season crop production. This could also partly be attributed to its large number of leaves produced during this period of growth. This implies that high shoot and pod yield could be obtained with lower usage of water by growing UI4-30 in comparison with NH47-4. As such, some percentage of irrigation water could be saved by cultivating UI4-30 with low irrigation level (ET_o-M) when compared to high water level (ET_o-N) irrigated NH47-4 under the prevailing climatic condition. Mansouri-Far *et al*. (2010) stated that irrigation water can be conserved and yields maintained in crops sensitive to drought stress under limited conditions by selecting more tolerant varieties, as large differences in water use efficiency exist between species (Tardieu, 2013).

The study also revealed that irrigation levels significantly influenced the irrigation water use efficiency of okra for pod yield and biomass production. In terms of yield production, it was evident from the study that high irrigation rates result to high irrigation water use efficiency for pod production. Although, this was consistent with the findings of Oktem (2006), it disagreed with the findings of Gallardo *et al*. (1996) and Aujla *et al*. (2005) who reported that water use efficiency of lettuce and cotton were not affected by irrigation treatments. According to Gallardo *et al*. (1996), lettuce dry matter and fresh weight were linearly related to total water use, leading to similarity in water use efficiency, while Aujla *et al*. (2005) reported that water use efficiency remained almost constant with decrease in quantity of water applied. The highest irrigation water use efficiency recorded under high irrigation level (ET_o-N) supports the findings where high root production, total dry matter and WUE were recorded under high irrigation level of 100% Epan (Prabhakar *et al*., 1991). This result could have resulted from the fact that available water under this irrigation treatment (ET_o-N) compensated for water loss during the plant's physiological process such that the environmental conditions did not adversely affect yield production via water stress conditions, hence enabling the plants to efficiently produce higher yield that could make-up for water use under the prevailing climatic conditions, relative to other irrigation treatments. Lower water use efficiency resulting from water stress conditions due to insufficient water application has been reported by other researchers (Shangguan *et al*., 2000; Karam *et al*., 2002; Boutraa *et al*., 2010). Contrariwise, Kang *et al*. (2002) reported that high moisture treatment gave the greatest evapotranspiration and biomass, but did not produce the highest grain yield and gave relatively low WUE. Hashem *et al*. (2011) reported that highest water use efficiency was obtained by lowest irrigation level of 80% ET_o. They also reported that increase in irrigation level to 100 and 120% ET_o led to decrease in water use efficiency.

The results from this study corroborates the findings of Luvai *et al*. (2014) who reported high irrigation water use efficiency for high irrigation level (120% ET_c) than lower levels of 100, 80, and 60% ET_c on *Matinyani* soil type. However, they also reported that low irrigation level of 60% ET_c recorded higher irrigation water use efficiency than high irrigation levels on *Kyondoni* soil type. Furthermore, this result was also not in line with those of Abdel-Razzak *et al.* (2016) who reported that lower irrigation water levels positively affected irrigation water use efficiency where 50% ET_c increased irrigation water use efficiency value by 14.80 and 3.64% over 100 and 75% ET_c irrigation rates. Wang *et al.* (2012) reported that WUE decreased with increase in irrigation rates, where they noted that the low irrigation treatment had higher WUE (3.5 and 5.0 kg ha^{-1} mm^{-1}) than high irrigation treatment (2.7 and 3.8 kg ha^{-1} mm^{-1}), while the medium irrigation treatment had a medium WUE (3.1 and 4.4 kg ha^{-1} mm^{-1}), in 2006 and 2007, respectively.

Irrigation water use efficiency for shoot production ($IWUE_{shoot}$) did not differ significantly under the various combinations of okra varieties and irrigation levels. The study revealed that UI 4-30 and NH 47-4 grown under medium irrigation level (ET_o-M) had the highest $IWUE_{shoot}$ at first and second planting, respectively. It could be inferred from this study that medium irrigation level (ET_o-M) enhanced partitioning of much of the photosynthetic assimilates produced by both varieties towards vegetative growth than yield development. In other words, increased translocation of dry matter produced towards vegetative growth per unit water under this irrigation treatment could have resulted to its high $IWUE_{shoot}$. In a similar study on okra, Panigrahi and Sahu (2013) reported that $IWUE_{biomass}$ was superior in moderate irrigation of FPRI treatment than low (APRI) and high (FRI) irrigation. They explained that the superior $IWUE_{biomass}$ was due to higher dry matter partitioning towards vegetative growth with least amount of irrigation water consumption under this treatment. Similar results were recorded under maize cultivation by Kang *et al*. (2002); Quezada *et al*. (2011); and Kuscu *et al*. (2013). The consistently low WUE under ET_o-I supports the results of Kang *et al*. (2002) who attributed low WUE to inefficient use of stored soil water, and reported that ET and above-ground biomass were highest under continuous high soil moisture conditions.

The study also revealed seasonal variations in irrigation water use efficiency of UI4-30 and NH47-4 varieties under the three ET_o levels, with higher values recorded at the second planting than at the first planting. The differences in climatic conditions which influenced crop water use relative to crop growth and yield at both first and second planting could have been responsible for this variation. Wang *et al*. (2012) reported that WUE in 2007 was higher than that observed in 2006 due to better climatic conditions which were favourable to the formation of grain yield. Earlier studies with reports on the variation in seasonal irrigation water use efficiency include those of Kuscu *et al*. (2013), who reported seasonal variations in irrigation water use efficiency with maximum values recorded during the first year of planting, while Abdel-Razzak *et al*. (2016) recorded higher values for best treatments during the second season. However, Musick *et al*. (1994) reported that WUE did not vary with seasonal evapotranspiration. According to Kang *et al*. (2002), the relationship between WUE and evapotranspiration or irrigation water use shows large spatial and temporal variability.

Prior to the commencement of the field experiment, the soil in the study area was characterized by high sand content (loamy sand) which indicates low water retention capacity. The dominance of sand-sized fractions in this location has earlier been documented by Babalola *et al*. (2000) who reported that high value of sand fraction compared to silt and clay fractions are typical of soils in south-western Nigeria. Chris-Emenyonu and Onweremadu (2011) explained that these soils are formed largely from the coastal plain, while Oguike and Mbagwu (2009) and Akpan-Idiok (2012) reported that loamy sand lacks adsorption capacity for basic plant nutrients. The chemical constituents of the soil revealed that the soil was low in the basic nutrient elements required for plant growth. Although, the soil was slightly acidic, its pH was within the optimum range (6.0 – 7.0) for most agricultural crops, but below 6.5 where nutrients are readily available (Lal, 1994). The slightly acidic conditions of the soil could be due to leaching of basic cations which is peculiar to coarse textured soils under tropical environments characterized by high rainfall in most parts of the year. Busari *et al*. (2005) reported that low soil pH values could result from the amount of plant residues removed at previous harvests, and the amount and type of fertilisers used to crop.

The soil organic carbon was below the threshold (2% organic C) reported by the Federal Ministry of Agriculture, Water Resources and Rural Development (1989). The low soil organic carbon could be attributed to the continuous cropping activities carried out in previous studies on the site, where no soil amendment was used. This low soil organic carbon content (< 2% organic C) is an indication of a major decline in soil quality (Federal Ministry of Agriculture, Water Resources and Rural Development, 1989). Juo *et al*. (1994) reported that continuous cropping of Alfisols, Ultisols and Oxisols in the tropics resulted in a rapid decline in soil organic carbon in the surface soil during the first few years following land clearing. In comparison, lower values of soil organic carbon were reported by Akpan-Idiok (2012) who noted that organic carbon values below 1.5% were rated low, and may not sustain an intensive cropping system. The total nitrogen was also lower than the critical value of 0.15% reported for tropical soils by Enwezor *et al*. (1989). The low level of nitrogen could be attributed to intensive farming carried out in the study area which was accompanied by significant nutrient mining impact. Enwezor *et al*. (1989) also reported that low levels of nitrogen in soils may be related to intense leaching and erosion due to rainfall. The soil available phosphorus was high when compared to the critical range (8 to 12 mg kg^{-1}) reported for tropical soils by Enwezor *et al*. (1989). The soil available phosphorus also exceeded the value (15 mg kg^{-1}) regarded as productive soils zone (FPDD, 1990). In comparison to critical values of 2.0 and 0.20 cmol kg^{-1} reported by Adeoye and Agboola (1984) and Isirimah *et al*. (2003) for calcium and potassium respectively, mean values of calcium and potassium were high. The high values recorded for available phosphorus and the micronutrients could have resulted from the fallow period which the land went through. This period allows for the process of natural regeneration to take place within the soil system and thus, improves soil fertility status.

The effects of land preparation on saturated hydraulic conductivity, bulk density, compaction, total porosity, aggregate stability and soil moisture content have been earlier reported (Angers and Eriksen-Hamel, 2008; Veiga *et al*., 2008; Ewulo *et al*., 2011). The low saturated hydraulic conductivity values recorded under Flat compared to Raised bed and Ridge in 2015/2016 and 2016/2017 could be due to the low amount of macro pores in the Flat seedbeds. This result agrees with the findings of Srivastava *et al*. (2000) who also reported significantly lower hydraulic conductivity in zero-tillage (Flat) plots. In Southwest Nigeria, Aiyelari *et al*. (2002) and Agbede and Adekiya (2009) also reported high saturated hydraulic conductivity for Ridge plots over no-tillage (Flat) plots. On the contrary, Bhattacharyya *et al*. (2006b, 2008) recorded higher saturated hydraulic conductivity values under zero-tillage (Flat) than tilled (Raised bed and Ridge) plots. McGarry *et al*. (2000) attributed increase in saturated hydraulic conductivity value in Flat seedbed to the contributions of earthworm channels and termite galleries. In addition, Singh *et al*. (2002) explained that the decrease in saturated hydraulic conductivity in the surface soil layer was probably due to destruction of soil aggregates and reduction of non-capillary pores, whereas the pore continuity was probably maintained due to better aggregate stability and pore geometry in zero tillage (Flat) plots (Bhattacharyya *et al*., 2006a). The significant effect of the land preparation types on soil bulk density in 2015/2016 has earlier been reported (Aiyelari *et al*., 2002; Agbede and Adekiya, 2009). Singh and Kaur (2012) explained that bulk density varies with management practices, as well as with inherent soil qualities.

The result obtained for soil bulk density under the land preparation types in 2016/2017 corroborates the findings of Aiyelari *et al*. (2002) who reported that seedbeds did not significantly affect soil bulk density at 6 and 9 months after planting. Several other studies have also reported results contrary to the significant influence of land preparation types on soil bulk density (Dao, 1996; Martinez *et al*., 2008; Panday *et al*., 2008). The consistent high bulk density values recorded under the Flat land preparation type in this study in 2015/2016 and 2016/2017 confirms the results of Aiyelari *et al*. (2002) and Agbede and Adekiya (2009). The results of three years of tillage study showed that manual Ridge had consistent low soil bulk density values than Flat (Agbede and Adekiya, 2009). The low soil bulk density recorded by Raised bed relative to Ridge in 2015/2016 has earlier been noted by Zhang *et al*. (2012), who reported that planting on Raised bed improved soil physical properties especially in the root zone. The significantly high value of soil bulk density under Flat plots may be due to the non-disturbance of the soil matrix, which resulted in less total porosity compared to the other treatments (Bhattacharyya *et al*., 2008). In other words, the high value of bulk density recorded under Flat land preparation could have been due to compactness of the soil, as opposed to the looseness of the soil under Raised bed and Ridge land preparation types (Dhiman *et al*., 1998; Ram *et al*., 2006). In an earlier study, Sujatha (1992) reported that the lowest soil bulk density was recorded under Raised bed in relation to Flat and other land preparation types. They further reported that this leads to a high total porosity in Raised bed than Ridge and Flat, respectively. According to Singh and Kaur (2012), bulk density in the upper layer of no-tillage (Flat) soils was increased, resulting to a decrease in the amount of coarse pores. This could also be attributed to the consistent low values recorded for all the porosity characteristics under Flat land preparation relative to Raised bed and Ridge in 2015/2016 and 2016/2017, respectively.

The land preparation types did not significantly influence the soil macro aggregate stability. Here, the consistent high values recorded under Flat land preparation supports the results of Bhattacharyya *et al*. (2006a) who observed better aggregate stability and pore geometry maintenance under zero-tillage (Flat) plots. On the other hand, low water stable aggregates and mean weight diameter under Raised bed and Ridge, relative to Flat, confirms the report of Singh *et al*. (2002) who noted destruction of soil aggregates by tillage (Raised bed and Ridge) practices. In an earlier study, Lal *et al*. (1994) observed better aggregation under zero-tillage (Flat). Contrary findings have been reported in literature. For instance, Singh and Kaur (2012) reported that soil aggregation was higher under Raised beds, and was static across seasons. According to Czyz (2004) and Botta *et al*. (2005), contrasting effects of soil management experiments are mostly related to management factors. Although the superiority of Flat in maintaining good macro aggregate stability was also reflected in the micro aggregate stability of the soil in 2015/2016, this was not the case with its soil structural stability index in 2015/2016 and 2016/2017, as well as its micro aggregate stability in 2016/2017.

The improved soil micro aggregate stability under Raised bed in 2016/2017 and the high structural stability index recorded under Ridge in both seasons can be attributed to their high organic matter content (Valentin, 1994). This could also be responsible for their higher water retention capacity relative to Flat at various suctions. The consistent low soil water content recorded under Flat across all suctions in 2015/2016 could be attributed to the preponderance of meso-pores (intermediary pores) which was not recorded in this study. The low soil moisture content under Flat supports the findings of Licht and Al-Kaisi (2005). Although Ridge had consistently higher soil moisture than Raised bed across the various suctions in 2015/2016, the higher soil moisture content recorded under Raised bed relative to Ridge at 1500 kPa in 2016/2017 supports the findings of Sujatha (1992), who attributed high groundnut yield under Raised bed to its increase in soil moisture retention relative to Ridge and Flat, respectively. Although, the significant difference observed in soil moisture retention under the land preparation types in 2015/2016 disagrees with the findings of Erbach *et al*. (1992) and Srivastava *et al*. (2000), the results obtained in 2016/2017 corroborate their observation that different types and extent of land preparation did not have any major influence on soil water content.

The consistent higher penetration resistance obtained from Flat, in relation to Raised bed and Ridge, especially at the surface soil level (0 – 15 cm), is in consonance with the findings of Erbach *et al*. (1992), Carman (1997) and Martinez *et al*. (2008), who reported higher soil penetration resistance under zero-tillage (Flat) plots relative to tilled (Raised bed and Ridge) plots. The results in this study also corroborate those of Licht and Al-Kaisi (2005), who reported that land preparation treatments significantly influenced soil penetration resistance at the top 10 cm soil depth. However, low penetration resistance recorded by Flat at lower soil depths (below 15 cm) relative to Raised bed and Ridge, could be attributed to the presence of burrows which were also evident at the surface of some Flat land preparation plots (McGarry *et al*., 2000). The depths with great compaction below the tilled levels of Raised bed and Ridge could have been responsible for their higher penetration resistance relative to Flat, as land preparation types have been reported to be less influential on penetration resistance as depth increases (Erbach *et al*., 1992; Vyn and Raimbault, 1993; Unger and Jones, 1998). The variations in penetration resistance between 2015/2016 and 2016/2017 has also been demonstrated by Licht and Al-Kaisi (2005), who observed similar seasonal variations between May – June, 2001 and June – July, 2002.

The study also showed that mulch application significantly improved some of the soil physical properties, as *Pennisetum* mulch plots had low bulk density, high saturated hydraulic conductivity, high total porosity, and high macro porosity. The *Pennisetum* mulch plots also had more improved water stable aggregates, higher mean weight diameter of particles, higher aggregated silt and clay, lower clay flocculation index, lower dispersion ratio, and higher structural stability than *Gliricidia* mulch plots in 2015/2016, while the reverse was the case in 2016/2017. The consistent high structural stability index and improved soil physical characteristics recorded under *Gliricidia* mulch relative to *Pennisetum* mulch in 2016/2017 could be attributed to its high organic carbon contribution to the soil (Valentin, 1994). Irrespective of the variations in the effects of the mulch materials on the soil physical properties, the improved soil moisture retention, soil macro aggregate and soil micro aggregate characteristics under *Gliricidia* mulch and *Pennisetum* mulch supports the report of Agyenim-Boateng and Dennis (2001), who noted that the use of crop residues improves aggregation of soil and modifies the transport and retention of water, heat and air in the soil. Mando (1997) earlier reported that mulch types had significant effect on saturated hydraulic conductivity due to increased number of macropores. Mando (1997) also reported greater number of macropores in mulched plots compared to bare plots. Mbagwu (1991) earlier reported that mulch applied at 2 – 6 t ha^{-1} increased soil water retention and percentage aggregate stability, while reducing soil compaction measured via bulk density. The application of grass mulch at 6 t ha^{-1}

reduced soil bulk density and increased water stable aggregate and mean weight diameter across all tillage practices compared with unmulched plots (Adelana *et al*., 2013). Other studies have reported higher soil moisture under organic mulches due to their ability to reduce surface sealing relative to the control (Box *et al*., 1996; Nkansah *et al*., 2003; Ghosh *et al*., 2006).

As observed in this study, several studies have also reported the reduction in penetration resistance after mulch application (Buerkert and Lamers, 1999; Oyedele *et al*., 2009). According to Mando (1997), soil penetration resistance was greater in unmulched plots than mulched plots which had lower bulk density and higher porosity values, respectively. The superior performance of *Gliricidia* mulch over *Pennisetum* mulch in reducing soil penetration resistance supports the results of Oyedele *et al*. (2009), who reported lower penetration resistance for *Gliricidia sepium* than *Enterolobium cyclocarpum*. The high bulk density recorded by *Gliricidia* mulch plots against *Pennisetum* mulch plots supports the results of Oyedele *et al*. (2009), who also reported high bulk density for *Gliricidia sepium* than *Enterolobium cyclocarpum*. The inverse of the bulk density result recorded for total porosity under *Gliricidia* mulch relative to *Pennisetum* mulch was also in line with the results of Oyedele *et al*. (2009). The influence of the mulch materials on the soil physical properties could be due to their influence on soil organic carbon.

The significant influence of the irrigation treatments on the soil saturated hydraulic conductivity in 2015/2016 and 2016/2017 has earlier been documented by Frenkel *et al*. (1977). They explained that plugging of pores by dispersed clay particles is a major cause of reduced soil hydraulic conductivity for surface soils irrigated with sodic waters. Thus, it can be inferred from the results of this study that the low saturated hydraulic conductivity values recorded under high irrigation water levels of 100% ET_c and CROPWAT irrigation rates in 2015/2016 and 2016/2017, could have resulted from more pores being plugged by dispersed clay particles under these treatments relative to 75% ET_c. This could also have had a pronounce effect on the soil bulk density and porosity characteristics of the soil, as Shalhevet (1994) reported that saturated hydraulic conductivity and macro porosity are strongly affected by the composition of the irrigation water. Although, CROPWAT irrigated plots had higher total porosity than plots irrigated with 75% ET_c, the high bulk density values, and the plugging effect of the dispersed clay (which could have resulted to a degree of “seal” formation) could have resulted to the lower total porosity values recorded under 100%

ET_c and CROPWAT irrigation treatments, relative to irrigation at 75% ET_c in the 2015/2016 dry season (Dexter, 2004).

In addition, the influence of the irrigation treatments on pore plugging was also revealed by the high clay dispersion index and dispersion ratio recorded for plots irrigated with 100% ET_c and CROPWAT irrigation rates in 2015/2016 and 2016/2017. This could have resulted to the better macro aggregate stability and soil structural stability recorded under 75% ET_c than CROPWAT and 100% ET_c, respectively. The high structural stability index exhibited by 100% ET_c and CROPWAT irrigation rates may be as a result of the high organic matter that was deposited into the soil via the high volume of water application associated with these treatments (Franzluebbers, 2002). According to Valentin (1994), minor increases in organic matter content may have a more beneficial effect upon the structural stability of sandy soils than a higher increase in finer textured soils. This could also be responsible for the high soil water content at various suctions under the CROPWAT irrigation treatment. The variation in penetration resistance across the soil depths could have been influenced by the difference in soil wetness distribution, as cone penetrometers are mostly affected by the soil water content and bulk density (Vaz and Hopmans, 1999; Vaz *et al*., 2001).

The insignificant effect of the land preparation types on soil pH (2015/2016 and 2016/2017) and exchangeable acidity (2015/2016) suggests that land preparation do not have a direct effect on soil pH. This confirms the report of Aiyelari *et al*. (2002). The decrease and increase in soil pH under the land preparation types in 2015/2016 and 2016/2017 were also observed in the soil pH values recorded among tillage treatments in 1994 and 1995 by Aiyelari *et al*. (2002). The significant effect of the land preparation types on total organic carbon and total nitrogen in the 2015/2016 dry season is not in consonance with the results of Aiyelari *et al*. (2002) and Agbede and Adekiya (2009), who reported that tillage treatments did not significantly influence organic carbon and total nitrogen, respectively. The increase in the total organic carbon content of the soil under the land preparation types, where Ridge and Raised bed had highest values in 2015/2016 and 2016/2017, respectively, did not support the report of Agbede (2007, 2008), who observed a reduction in soil organic carbon due to tillage treatments. The high total nitrogen, available phosphorus, magnesium and calcium values recorded under Raised bed and Ridge relative to Flat, supports the results of Agbede and Adekiya (2009) who reported that these land preparation types increased total nitrogen, available phosphorus and potassium over

Flat. The improved availability of total nitrogen in Raised bed over Flat has also been earlier documented (Gilliam *et al*., 2011; Zhang *et al*., 2012). Zhang *et al*. (2012) suggested that the improved microclimate in Raised beds could stimulate microbial decomposition of organic matter and increase the rate of mineralization of organic nitrogen (Saviozzi *et al*., 2002; Govaerts *et al*., 2007; Verachtert *et al*., 2009) which was not measured in this study. The decrease in available phosphorus across all the land preparation types confirms the results of Aiyelari *et al*. (2002), who attributed decrease in available phosphorus to leaching effect and uptake by crop.

Total nitrogen and available phosphorus contents did not exhibit any particular trend between Ridge and Raised bed, as Ridge recorded higher values than Raised bed in 2015/2016, while the reverse was the case in 2016/2017. The high total nitrogen and available phosphorus observed for Ridge over Raised bed and Flat in 2015/2016 was also noted by Agbede and Adekiya (2009). They explained that the significant enhancement of soil total nitrogen, available phosphorus, potassium, and calcium under tilled soils compared with untilled (Flat) could be due to enhanced mineralization of soil organic matter and consequent release of nutrients, since land preparation is known to enhance organic matter mineralization (Janzen *et al*., 1998). The high calcium recorded under Ridge disagrees with the results of Aiyelari *et al*. (2002), who attributed low calcium content under Ridge to higher tillage intensity relative to other treatments. On the average, soil micro nutrients were greatly enhanced under Raised bed than the other land preparation types. This was evident in its high potassium, calcium and magnesium contents under Raised bed, relative to Ridge and Flat, respectively. This supports the results of Li *et al*. (2013), who reported higher potassium and calcium contents under Raised bed than no-till (Flat) and traditional tillage systems in China. The exchangeable acidity of the soil was similar in trend to the soil pH, while the sodium content was consistently low under Ridge in relation to Raised bed and Flat. This is a reflection of the dominance of calcium in the exchange site of the soils in the Ridge plot.

Furthermore, the effect of the mulch treatments on okra growth and yield can be attributed to their influence of the soil properties, as Dilipkumar *et al*. (1990) reported that organic mulch improves the physical, chemical and biological properties of soils, as it adds nutrients to the soil and ultimately enhances the crops yield. Oslen and Gounder (2001) also noted that mulch application improves soil quality. Considering the mulch treatments, the low soil pH values recorded under *Pennisetum* mulch and *Gliricidia* mulch plots compared with Zero mulch plots in 2015/2016 and 2016/2017, disagrees with the results of Miyazawa *et al*. (1993). Contrary results were also reported by Karlen *et al*. (1994), who observed that soil pH increased significantly with crop residue application. Moreover, the mulch treatments did not influence the soil exchangeable acidity in both seasons. However, the consistent improvement of the total organic carbon and total nitrogen content of the soil by *Gliricidia* mulch and *Pennisetum* mulch in 2015/2016 and 2016/2017 confirms the result of Kristensen *et al*. (2003), who reported that the incorporation of crop residue makes organic matter more readily available, and thus, results to improved availability of nitrogen (Gilliam *et al*., 2011; Zhang *et al*., 2012). The mulch materials also improved the soil available phosphorus content, where *Pennisetum* mulch was observed to be a better supplier of phosphorus than *Gliricidia* mulch. Mulch application was observed to improve soil micronutrient availability. This confirms the results of Agbede and Ojeniyi (2009), who reported that exchangeable potassium, calcium and magnesium were enhanced by mulch application. On the average, *Pennisetum* mulch proved to better enhance soil micronutrients than *Gliricidia* mulch in this study. The consistent high electrical conductivity values recorded by *Gliricidia* mulch plots showed that this mulch material was not able to counteract the effect of the irrigation water on the soil salinity. The result contradicts those of Yang *et al*. (2006), who reported that surface mulching decreased salinity hazards, which is in line with the results obtained from *Pennisetum* mulch plots. From the results obtained in this study, it can be inferred that the effect of mulch on soil salinity is dependent on the mulch material used.

The study also showed that the irrigation treatments affected the chemical properties of the soil of the experimental site. This could be due to the fact that the irrigation water contained some basic nutrients that are essential for plant growth (Yermiyahu *et al*., 2007). This was reflected in the increase in the soil organic carbon and total nitrogen in 2015/2016 and 2016/2017, respectively, with high values recorded under high irrigation water rates of CROPWAT and 100% ET_c. In an earlier study, Yadav *et al*. (2002) reported that long-term irrigation with sewage water added large amounts of carbon, major- and micro-nutrients to soil. In the top 60 cm of an alluvial soil, they reported improved organic matter of up to 1.24 – 1.78%, build up in total nitrogen (2, 908 kg ha^{-1}), and available K (305 kg ha^{-1}) after irrigation water application. The low total nitrogen recorded for 75% ET_c supports the results of Owusu-Sekyere and Annan (2010) who attributed low total nitrogen content under

60% and 70% ET_c to greater utilization than 100% ET_c, while the high value for potassium recorded under 60% and 70% ET_c compared to 100% ET_c was also similar to that obtained in this study in 2015/2016.

Furthermore, the reduction in available phosphorus content after the application of the irrigation treatments do not support the result of Yadav *et al*. (2002) who reported higher values of available phosphorus (58 kg ha^{-1}) and total phosphorus (2, 115 kg ha^{-1}) after application of sewage irrigation water. The reduction in available phosphorus across all the irrigation treatments in this study could be attributed to phosphorus fixation resulting from the high iron content in the soil (Giesler *et al*., 2004). Considering the soil pH levels, Giesler *et al*. (2002) explained that irrigation water can affect phosphorus availability via increased fixation due to the redistribution of aluminium and iron, or as a result of its high calcium and alkalinity. However, this was not the case in this study, as the trend in soil pH, calcium and available phosphorus did not follow a particular pattern in 2015/2016 and 2016/2017, respectively. Contrarily, Mohammad and Mazahreh (2003) reported that wastewater irrigation decreased soil pH but also increased soil phosphorus. The increase in lead and manganese concentrations by the three irrigation treatments, with high values recorded under high irrigation rates of 100% ET_c and CROPWAT irrigation rate, supports the results of Yadav *et al*. (2002), who also reported a build-up in the lead and manganese concentrations of soil after irrigation water application. In Harare, Zimbabwe, Mapanda *et al*. (2005) reported significant increase in copper, zinc and lead concentrations after irrigating a vegetable garden with wastewater, while results from an earlier study by Mohammad and Mazahreh (2003) also noted increases in iron and manganese levels after wastewater irrigation. The increase in soil salinity after 2015/2016 and 2016/2017 irrigation application is in line with the results of Mohammad and Mazahreh (2003), who also recorded increase in the soil salinity level after irrigating with wastewater. Although, the irrigation treatments recorded similar increase in the sodium concentration of the soil, the reduction in calcium concentration was not similar. Grattan and Grieve (1998) explained that salinity dominated by sodium salts not only reduces calcium availability but reduces calcium transport and mobility to growing regions of the plant, which affects the quality of both vegetative and reproductive organs. This may have resulted to the low yield recorded under high irrigation water application levels of 100% ET_c and CROPWAT irrigation rate which had high electrical conductivity values in 2015/2016 and 2016/2017, respectively.

The low calcium concentration recorded under 75% ET_c and CROPWAT irrigated plots could suggest an increase in soil carbonate and bicarbonate contents under both treatments. Murray and Grant (2007) explained that even though carbonate is relatively insoluble, bicarbonate is soluble and tends to enhance the sodium in the soil water (in solution) by removing calcium from solution so that sodium and magnesium dominates the exchange site. They explained further that the high concentrations of carbonate and bicarbonate are not an issue since the soil pH values under the treatments are less than 7. This could also have been due to high residual sodium carbonate values under 75% ET_c and CROPWAT irrigation rate treatments (Duncan *et al*., 2000). Prasad *et al*. (2001) also reported that increase in the residual sodium carbonate of the irrigation water resulted to increase in soil sodium concentration, with corresponding decrease in its potassium and calcium contents.

The effects of land preparation on weed density and weed biomass was also evident in this study. Ridge was observed to be more effective in weed control than Raised bed as it had consistently low weed density and weed biomass. This could be attributed to better destruction of weed seedlings and exposure of their seeds to harsh environmental conditions that reduced their chances of germinating under favourable conditions. This result corroborates that of Kayode and Ademiluyi (2008) who observed better weed control under manual ridging, and also noted that zero tillage (Flat) had the highest weed density and weed biomass relative to other treatments. The results of this study also confirmed the potentials of mulch in reducing weed emergence. In relation to the results of Hochmuth *et al*. (2001) who reported that mulching increases crop yield by suppressing weed growth, the study finds *Gliricidia* mulch and *Pennisetum* mulch as effective mulch materials for reducing weeds on irrigated farms during dry season farming. In line with the results of Silva *et al*. (2009) who reported that *Gliricidia sepium* significantly decreased the population of some weed species, the superior performance of *Gliricidia* mulch over *Pennisetum* mulch in this study could be due to its leaf stability and high area coverage on the surface of the treatment plots relative to the chopped leaves of the *Pennisetum* mulch. This could have resulted to low exposure of the weeds to sunlight which they also need to carry out physiological functions such as photosynthesis, for growth and development.

Although weed biomass was not significantly influenced by the irrigation treatments, the trend in the significant effect of the irrigation rates on weed density in 2015/2016 and 2016/2017 is in line with the findings of Ather *et al*. (2007), who reported that irrigation rates of 50, 75, 100 and 125% cumulative pan evaporation had no significant effect on weed density and weed dry weight in 2002 – 2003 but significantly influenced both parameters in 2003 – 2004. The low weed density and weed biomass under 75% ET_c relative to CROPWAT and 100% ET_c water application rates in 2015/2016 and 2016/2017, could be attributed to the high levels of irrigation water applied per time under both treatments relative to 75% ET_c. This supports the findings of Maruthi (1988), who reported that weed density and dry matter decreased with decrease in irrigation water levels.

The growth and yield of okra under Raised bed and Ridge gave a clear indication of the potentials of these land preparation types for improving soil conditions for crop growth and yield during dry season okra cultivation. Although, Raised bed consistently had better okra growth and yield than Ridge and Flat, the varying influence of the land preparation types on crop growth and yield was shown by the results obtained under Ridge and Flat land preparation types. This is contrary to the findings of Aiyelari *et al*. (2002), who reported consistently high and low number of cassava leaves for Ridge and No-till (Flat) respectively, over two years of cropping.

In this study, the low number of leaves and plant height obtained for Ridge in relation to Flat in 2015/2016 could be attributed to high loss of water via evaporation, as this season was characterized by high solar radiation and temperature. This could have resulted to low soil water in Ridges, thus affecting its crop growth (Li and Gong, 2002), as Ridges could affect soil temperature and water content as well as soil water and solute movement compared with traditional Flat farming (Waddell and Weil, 2006). Licht and Al-Kaisi (2005) explained that no-tillage system (Flat) is perceived to have lower soil temperatures and wetter soil conditions compared to conservation tillage system such as Ridge. In an earlier study, Adams (1967) reported that rapid drying of soil moisture in Ridges resulted to poor crop growth performance. On the contrary, there was improved okra growth under Ridge than Flat in 2016/2017. Although, Ridge increases soil moisture evaporation and soil temperature, thereby reducing the amount of irrigation water supplied for plant use (Al-Kaisi and Hanna, 2002), the performance of Ridge in 2016/2017 could have been enhanced by the use of drip irrigation coupled with the mild temperature conditions. Drip irrigation has been reported to reduce irrigation loss via evaporation and deep percolation (Oshunsanya *et al*., 2016). Under these conditions, plants on Ridge can absorb water to meet their growth requirement (Chen *et al*., 2011). The poor okra growth under Flat could be due to low downward flow of water resulting to surface soil lateral flow which exposes more of the applied water to loss via evaporation, thereby not making sufficient amount of the applied water available for crop use. This is in agreement with the results of Chen *et al*. (2011) who reported that the profile water content in Ridge increased due to lateral and vertical infiltration, as opposed to decreased gravitational water in the profile of Flat land preparation during water redistribution. In an earlier study, Willis *et al*. (1963) attributed the performance of Ridge to deeper penetration of water and suppression of evaporation losses. Licht and Al-Kaisi (2005) explained that no-tillage (Flat) presents a unique challenge in poorly drained soils, in which certain surface soil properties are affected due to the absence of tillage as a corrective measure. Karlen *et al*. (1994) also reported the act of no-tillage system (Flat) in conserving soil moisture in the top 5 cm relative to other tillage systems.

The consistent high stem diameter values obtained from Ridge relative to Flat in 2015/2016 and 2016/2017 has earlier been reported by Aiyelari *et al*. (2002), who noted higher cassava stem girth values for Ridge over No-till. Although, the high okra plant height recorded by Ridge relative to Flat in 2016/2017 is in line with the results of Aiyelari *et al*. (2002), who reported Ridging treatment having taller plants than No-till and other tillage treatments, in this study, Raised bed had superior plant height than Ridge over two dry seasons of okra cultivation. The consistent high growth of okra under Raised bed over the two dry seasons could suggest it is an effective land preparation type that creates a favourable soil condition (soil moisture, temperature and penetration resistance) for plant emergence, plant development, and unimpeded root growth (Licht and Al-Kaisi, 2005). It could be inferred that Raised bed creates such soil condition by combining the benefits of Ridge and Flat land preparation types (Vyn and Raimbault, 1993).

The potentials of organic mulch materials in optimizing okra growth and yield under dry season conditions were also observed in this study. The improved growth and yield of okra plants under *Gliricidia* mulch and *Pennisetum* mulch over the control (Zero mulch), could be as a result of the influence of the mulch materials in modifying the soil conditions for plant growth. The low plant height, number of leaves, stem diameter under Zero mulch plots could due to soil moisture deficit resulting from the increased soil drying that was observed in 2015/2016 and 2016/2017, respectively. According to Rasmussen (1999), plant residues left as mulch on the surface in no tillage, lowered soil temperature and evapotranspiration, thus improving the plant available water content (Bhagat and Verma, 1991; Verma and Bhagat, 1992). Licht and Al-Kaisi (2005) reported that residue cover has a substantial effect on soil temperature and soil moisture. Similarly, Nasir *et al*. (2011) reported that mulching conserves soil moisture, which in turn results in increase in the plant growth. Thus, the more improved plant growth under *Gliricidia* mulch compared with *Pennisetum* mulch could have resulted to more reduced evaporation (Yang *et al*., 2006) under *Gliricidia* mulch. The *Gliricidia* mulch was observed to provide a good surface soil cover due to the fact that *Pennisetum* mulch leaves were easily displaced out of position more often in this study. This is as a result of the difference in their weights with respect to their respective moisture contents, as a leaf of *Gliricidia sepium* (having eight leaflets) and a blade of *Pennisetum purpureum* grass (mean length of 47.3 cm) had mean weights of 1.55 g and 1.22 g, respectively.

The high growth performance of okra under higher irrigation water level was shown throughout the study. In comparison with the daily application of 75% ET_c and CROPWAT irrigation rate, 100% ET_c produced taller plants, bigger plant stems and higher number of leaves in 2015/2016 and 2016/2017, respectively. Hosseini *et al*. (2009) reported higher plant growth under high irrigation water application (100% FC) than 75% FC in chickpea production. In South-west Nigeria, Ejieji and Adeniran (2010), reported high plant height for grain amaranth under 100% ET water application, while in Turkey, Cemek *et al*. (2011) reported that application of high ET water rate for lettuce production recorded high number of leaves, and Biswas *et al*. (2015) demonstrated that 100% ET_c produced taller tomato plants than 75% ET_c. However, several studies in literature have reported contradicting results. For example, Owusu-Sekyere and Annan (2010) reported better growth and yield of okra under 80% ET_c irrigation water application than 100% ET_c. Similarly, Babu *et al*. (2015) reported higher okra growth under drip irrigation at 80% ET_c than 100% ET_c. Cemek *et al*. (2011) explained that irrigating with high amount of high salinity water resulted to low plant height, low number of leaves, low yield, but high dry matter. The relatively low performance of okra under CROPWAT irrigation rates when compared to those under daily application of 100% ET_c and 75% ET_c in terms of growth and yield, could be due to the withdrawal of water application at certain period of the crop’s growth as applicable in the schedule. This would have resulted to some level of stress especially in 2015/2016 that was characterized by high solar radiation and temperature, thus affecting the plant’s growth and consequently, its yield. Davenport (1994) reported that drought stress on vegetables affects yield quality, while Calvache and Reichardt (1999) explained that water deficit during vegetative growth leads to decline in yield. This result supports the findings of Rashidi and Keshavarzpour (2011) who explained that low crop growth and yield values of CROPWAT irrigated plants could be due to infrequent irrigation water application. The improved growth and shoot production of okra under CROPWAT irrigation rates in 2016/2017 could be due to the milder and favourable weather conditions with less heat stress on the crops, which resulted from low solar radiation and more cloud cover as opposed to 2015/2016. Malekian *et al.* (2009), who also noted variations in CROPWAT performance in arid regions, explained that it was due to the difference in climatic conditions, such as hot winds and high temperature, of the region.

Consequently, the superior growth of okra grown on Raised bed relative to Ridge and Flat also culminated in high shoot production under Raised bed in 2015/2016 and 2016/2017, respectively. This result confirms the findings of an earlier study by Zhang *et al.* (2012) who reported high shoot production for maize plants grown on Raised bed compared with Flat. This is also in line with the findings of Bortolini and Bietresato (2016) who reported that the use of Raised beds to cultivate vegetables can improve crop performance. The low shoot values recorded under Flat corroborates the results of Lawson *et al.* (2008) who also reported low biomass production for Flat relative to Ridge and Mound types. Similar results were also reported by Sujatha (1992) and Aiyelari *et al.* (2002). Oussible *et al.* (1992) related low shoot production under Flat land preparation to the limitation of root growth and distribution under this land preparation. Contrary results in support of the high shoot production under Flat land preparation type in comparison to Ridge in 2015/2016 have also been reported in literature. For instance, Agbede and Ojeniyi (2009) reported that Zero tillage methods (Flat) increased sorghum grain and biomass yields by 15% compared with other tillage methods. The improved growth of okra under *Gliricidia* mulch and *Pennisetum* mulch translated to high shoot production under both mulch materials, relative to Zero mulch plots. This could have resulted from the insulating role played by the mulch materials, allowing for sufficient utilization of available soil moisture for growth and development (Yadav *et al*., 2005). Similarly, Norman *et al.* (2011) reported maximum dry upper plant biomass of okra plants under dry grass mulch when compared to plants under the control treatment. Gajri *et al.* (1994) explained that organic mulch keeps the surface layer wetter and helps to increase plant root growth, thus resulting to high shoot production. This was more pronounced in *Gliricidia* mulch plots which were superior to *Pennisetum* mulch in terms of shoot production. The superiority of *Gliricidia* mulch over *Pennisetum* mulch supports the findings of AdeOluwa *et al*. (2006) who reported that *Gliricidia sepium* pruning produced better growth and yield of *Solanum macrocapon* than other organic and mineral fertilizer sources. According to Venkanna (2008), the application of *Gliricidia* mulch resulted to higher dry matter production when compared to no mulch. The high growth performance of okra under 100% ET_c irrigation also resulted to high shoot production under this irrigation treatment, especially in 2015/2016. Similar results have been reported in several studies of irrigation water management for crop production (Hosseini *et al*., 2009; Ejieji and Adeniran, 2010; Biswas *et al*., 2015). The high shoot production under 100% ET_c over 75% ET_c supports the results of Hosseini *et al*. (2009) who reported that above ground biomass increased with increase in soil moisture, with 100% field capacity water application recording higher values than 75% field capacity.

In terms of okra yields, the superiority of Raised bed in creating soil conditions favourable for plant growth was also reflected in its superior yield production. Unlike the results of Aiyelari *et al*. (2002), there were significant variations in the yield characteristics of okra recorded among the land preparation types. The variation in okra growth between Ridge and Flat was also reflected in their okra yield production in 2015/2016 and 2016/2017, respectively. The variation in yield production between Ridge and Flat over the two dry seasons could be due to differences in water use efficiency for pod production under the prevailing weather conditions in 2015/2016 and 2016/2017, respectively. In comparison to Raised bed and Ridge land preparation types, the low number of pods and fresh pod weight recorded under Flat in 2015/2016 is in line with the low number of soybean pods obtained under Flat (143 pods plant^{-1}) relative to Ridge (189 pods plant^{-1}) and Mound (197 pods plant^{-1}) by Lawson *et al*. (2008). They further reported that this pod formation characteristic reflected in the grain yield of 6.14, 5.95, and 4.07 t ha^{-1} for Mound, Ridge and Flat, respectively. This result also supports those of Sujatha (1992) who reported that minor surface Ridge has been found to be effective in conserving moisture and increasing water use efficiency for yield production compared to Flat soil surface. According to Singh and Kaur (2012), yield of crops under Zero tillage (Flat) may be equivalent or somewhat lower than conventional tillage, even though it had lower cultivation costs. On the contrary, the high yield production of okra under Flat land preparation relative to Ridge in 2016/2017 confirms the result of McGarry *et al*. (2000) who associated increase in wheat grain to high plant available soil water in Flat. The high yield production of okra under Raised bed compared with Ridge and Flat could be due to its conservation and conductivity of water and nutrient for plant growth and yield (Gilliam, 2006; 2007). In an earlier study by Sujatha (1992), the high groundnut yields observed for Raised bed relative to Ridge and Flat was attributed to increase in soil moisture retention. This is consistent with the observation that maize growth and yield in Raised bed planting were higher than those of Flat (Zhang *et al*., 2012). They explained that Raised bed planting can enhance productivity in the summer relative to other land preparation types. Similar results were reported in other studies (Limon-Ortega *et al*., 2000, 2002; Marschner *et al*., 2004).

Consequently, the low okra growth under Zero mulch could have led to its low yield. This could be due to low conservation of soil moisture as a result of exposed soil surface to the high temperatures associated with the dry season periods of the study. Thus, the resulting soil moisture deficit scenarios would have resulted to periodic moisture stress on the plants under Zero mulch treatments. According to Yadav *et al*. (2005), soil moisture stress is a major constraint limiting crop productivity. The high okra yield recorded under *Gliricidia* mulch and *Pennisetum* mulch plots have also been reported by Aiyelari *et al*. (2011), who noted higher okra pod fresh weight under 10 t ha^{-1} organic mulch than those of 0 and 5 t ha^{-1} mulch levels, respectively. This could have been due to their influence on soil properties. According to Adetunji (1990), organic mulch reduces day time temperature, conserves moisture, and increases yield attributes of vegetables, while De Silva and Cook (2003) reported that mulch application is of benefit to crop yield by improving soil physical conditions, including improved stability in the topsoil.

The superior growth of okra under 100% ET_c did not translate to superior yield production over 75% ET_c, which had consistently higher okra yield than 100% ET_c and CROPWAT irrigated plants in 2015/2016 and 2016/2017, respectively. The high okra yield production under 75% ET_c irrigation water can be attributed to optimum soil conditions in terms of aeration and moisture availability (Owusu-Sekyere and Annan, 2010). According to Rashidi and Keshavarzpour (2011), the low okra yield recorded under 100% ET_c could be due to weed infestation under this treatment. In an earlier study, Konyeha and Alatise (2013) reported that irrigating okra at 75% ET_c of its water requirement gave the best yield. On the contrary, some previous studies have also reported high okra yield production under 100% ET_c irrigation water application (Ejieji and Adeniran, 2010; Babu *et al*., 2015).

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The results from this study showed that the highest crop water requirement occurred at flowering and pod formation stages (7 – 8 WAS) of okra life cycle. UI4-30 had superior growth and yield than NH47-4, while high irrigation water level of ET_o-N had highest plant growth and yield.

In relation to Flat, Ridge improved the water retention capacity by 0.21 – 0.16 m^3 m^{-3} at 0 to 1500 kPa in 2015/2016, while Raised bed had superior soil water retention capacity in 2016/2017. The mulch types did not significantly improve the soil water retention capacity, although, *Gliricidia* mulch and *Pennisetum* mulch increased the soil water content by 0.01 m^3 m^{-3} and 0.02 – 0.03 m^3 m^{-3} compared with Zero mulch at 0 to 1500 kPa in 2015/2016 and 2016/2017, respectively. Furthermore, superior soil moisture retention was recorded under CROPWAT irrigated plots, with higher soil moisture content in the ranges of 0.03 – 0.04 m^3 m^{-3} and 0.03 – 0.08 m^3 m^{-3} than daily application of 75% ET_c and 100% ET_c at 0 to 1500 kPa, respectively. The penetration resistance of the soil varied with depth and treatments applied. Plots with Ridge were superior to Raised bed in reducing soil penetration resistance by 0.27 – 0.25 MPa at 0 – 30 cm depth, relative to Flat. *Gliricidia* mulch and *Pennisetum* mulch did not significantly reduce the soil's resistance to penetration relative to the control (Zero mulch). However, in relation to Zero mulch, *Gliricidia* mulch was superior to *Pennisetum* mulch in reducing the soil penetration resistance by 0.12 – 0.13 MPa. The irrigation treatments did not significantly influence the soil's penetration resistance at 0–10 cm depth.

Although, Raised bed and Ridge reduced the clay dispersion index, they also reduced the percentage water stable aggregate, mean weight diameter, aggregated silt and clay and clay flocculation index of the soil relative to Flat land preparation. However, the structural stability index of the soil was improved under Ridge by 4.16 and 4.97 over Raised bed and Flat over the two seasons of study, respectively. In relation to Zero mulch, the application of *Gliricidia* mulch was superior in improving the soil structural stability index by 3.70 compared with *Pennisetum* mulch (1.02). Water stable aggregates were better enhanced by 3.61% under *Gliricidia* mulch than *Pennisetum* mulch (2.66%) when compared with Zero mulch over the two seasons. Although, *Pennisetum* mulch was not significantly more effective than *Gliricidia* mulch in improving the water stable aggregates and mean weight diameter in 2015/2016, *Gliricidia* mulch was more significantly effective than *Pennisetum* mulch in 2016/2017, and was also consistent in enhancing the structural stability and structural stability index of the soil over the two dry seasons. The application of irrigation water at 75% ET_c resulted to higher soil macro and micro aggregate stability relative to CROPWAT and 100% ET_c irrigation water applications, thus culminating in good structural stability of the soil.

Ridge was superior in reducing the soil bulk density by 0.08 Mg m^{-3} than Raised bed (0.07 Mg m^{-3}) in relation to Flat land preparation, while *Gliricidia* mulch and *Pennisetum* mulch resulted to a 0.03 Mg m^{-3} reduction in soil bulk density when compared with Zero mulch over the two dry seasons. The soil bulk density was 0.04 Mg m^{-3} lower under the CROPWAT and 75% ET_c irrigation water application than 100% ET_c irrigation water application. With respect to the land preparation types, saturated hydraulic conductivity was 3.44 and 0.97 cm hr^{-1} higher under Ridge than Flat and Raised bed, respectively, while *Pennisetum* mulch had higher saturated hydraulic conductivity of 3.84 and 1.13 cm hr^{-1} than Zero mulch and *Gliricidia* mulch, respectively. The soil saturated hydraulic conductivity was 4.12 and 3.85 cm hr^{-1} higher under 75% ET_c than CROPWAT and 100% ET_c irrigation water application, respectively. In relation to Flat, Ridge was superior in increasing the total porosity of the soil by 2.97% compared with Raised bed (2.96%) over the two dry seasons, while *Pennisetum* mulch increased the soil total porosity by 1.13 and 0.13% over Zero mulch and *Gliricidia* mulch over the two seasons, respectively. Total porosity was much enhanced by 1.42% and 0.20% under CROPWAT than 100% ET_c and 75% ET_c irrigation water application.

Furthermore, soil organic carbon was much improved under Ridge land preparation type, while the total nitrogen content of the soil was better improved by 0.15 g kg^{-1} under Raised bed and Ridge land preparation. However, the level of salinity in the Raised bed and Ridge land preparation types were higher by 31.1 and 72.7 µS cm^{-1} than Flat. In terms of mulch application, *Gliricidia* mulch was more effective in improving the total organic carbon, total nitrogen and available phosphorus of the soil, relative to *Pennisetum* mulch and Zero mulch. On the other hand, CROPWAT irrigated plots had consistently higher total organic carbon and total nitrogen content than 100% ET_c and 75% ET_c irrigated plots, respectively. However, there was no variation in the sodium content of the soil under the irrigation treatments, while CROPWAT irrigation rates resulted to low soil electrical conductivity.

With respect to the growth parameters, Raised bed consistently enhanced the growth of okra relative to Ridge and Flat, while *Gliricidia* mulch was also superior in terms of okra growth, when compared with *Pennisetum* mulch and Zero mulch. The reduction in irrigation water application from 100% ET_c to 75% ET_c significantly reduced the okra plant height and stem diameter at the latter stages of the crop growth. However, the number of leaves was not significantly reduced by the reduction in irrigation water from 100% ET_c to 75% ET_c in both seasons. It is also worthy to note that the crop response to 100% ET_c irrigation water application was similar to that of the CROPWAT irrigation rate, especially in 2016/2017.

Shoot weight of okra was higher under Flat than Ridge, while on the average, Raised bed consistently had higher shoot weight than Flat and Ridge, respectively. With respect to mulch application, *Gliricidia* mulch was superior in enhancing the shoot weight of okra than *Pennisetum* mulch in relation to Zero mulch, over the two dry seasons. The application of irrigation water at 75% ET_c relative to 100% ET_c consistently reduced the shoot weight of okra. The shoot weight was higher under CROPWAT irrigation rate than 75% ET_c and 100% ET_c water application, respectively.

In terms of the yield components of okra, the quantity and size of pods produced under Ridge land preparation type was not significantly different from those produced on Flat. Relatively, Raised bed produced significantly higher quantity of pods and bigger pods than Ridge. The application of *Gliricidia* mulch was superior to *Pennisetum* mulch in increasing the average number of pods produced by 0.8 pods per plant relative to Zero mulch. *Gliricidia* mulch also improved fresh pod weight by 5.88 and 3.11 g plant^{-1} relative to Zero mulch and *Pennisetum* mulch, respectively. The application of 75% ET_c irrigation water consistently increased the quantity and weight of fresh pods produced. In addition, the quantity of fresh pods produced under the daily application of 100% ET_c was not significantly different from those produced under CROPWAT irrigation rate.

6.2 Recommendations

From the results obtained from this study, the following findings are hereby recommended.

i. UI4-30 okra variety could be adopted for high pod yield production during dry season farming relative to NH47-4.

ii. The use of Raised beds is recommended for optimum soil conditions for high growth and yield production of okra during dry season farming.

iii. The application of *Gliricidia sepium* at 6 t ha^{-1} is recommended as a more effective mulch material for improving soil hydrological and soil structural properties during dry season farming.

iv. *Pennisetum purpureum* at 6 t ha^{-1} could be adopted as a more effective mulch material for reducing soil bulk density and enhancing total porosity and saturated hydraulic conductivity.

v. The application of *Gliricidia sepium* at 6 t ha^{-1} should be adopted as a more effective mulch material for improving the total organic carbon and major nutrient elements of the soil for dry season okra production, while *Pennisetum purpureum* could be adopted for counteracting the effect of poor quality irrigation water on soil salinity.

vi. The daily application of 75% ET_c is recommended as an effective irrigation water management strategy for optimizing the growth and yield of okra during dry season farming.

vii. On the average, UI4-30 okra variety should be cultivated on Raised beds, mulched with *Gliricidia sepium* leaves, and irrigated with 75% ET_c for effective soil and water management for high yield production during dry season farming.

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APPENDICES

Appendix 1: CROPWAT monthly mean daily irrigation rates for dry season okra production in Ibadan, Nigeria

Month	Decade	Stage	K_c	ET_c	ET_c	Effective rainfall	Irrigation requirement
				(mm day^{-1})	mm dec^{-1}		
November	2	Init	0.36	1.6	3.2	1.6	3.2
November	3	Init	0.36	1.63	16.3	6.2	10.2
December	1	Dev	0.41	1.89	18.9	4.7	14.2
December	2	Dev	0.57	2.61	26.1	1.0	25.1
December	3	Mid	0.72	3.7	40.7	1.6	39.1
January	1	Mid	0.79	4.55	45.5	1.9	43.6
January	2	Mid	0.79	4.96	49.6	1.6	48.0
January	3	Mid	0.79	4.77	52.4	5.2	47.2
February	1	Late	0.61	3.5	35.0	8.9	26.1
February	2	Late	0.22	1.24	7.4	7.2	1.4

K_c: Crop coefficient; ET_c: Crop evapotranspiration: Init: Initial growth stage, Dev: Developmental growth stage, Mid: Mid-season growth stage, Late: Late-season growth stage.

Appendix 2: Critical values of soil structural stability index

S < 5	Severe physical degradation
5 < S < 7	High hazards of physical degradation
7 < S < 9	Low hazards of physical degradation
9 < S	No physical degradation

Source: Pieri (1989)

Appendix 3: Okra yield as influenced by ET_o × variety interaction at first planting under screenhouse conditions

Treatment	Number of pods	Fresh pod weight	Dry pod weight	Pod length	Pod diameter	100 seed weight
	($plant^{-1}$)	g $plant^{-1}$		(cm pod^{-1} $plant^{-1}$)	(mm pod^{-1} $plant^{-1}$)	(g)
UI 4-30 + ET_o-M	3.7±0.33	10.22±0.17	1.87±0.24b	4.7±0.20	10.09±0.19	4.25±0.03
UI 4-30 + ET_o-I	2.7±0.33	7.97±1.31	1.24±0.03bc	3.9±0.38	8.60±1.15	4.17±0.03
UI 4-30 + ET_o-N	5.0±0.58	11.10±0.51	4.04±0.20a	5.3±0.26	10.38±0.13	4.48±0.11
NH47-4 + ET_o-M	2.3±0.33	9.23±0.34	1.14±0.09c	4.1±0.29	8.64±0.31	3.83±0.11
NH47-4 + ET_o-I	2.0±0.00	6.97±0.77	1.06±0.03c	4.0±0.79	6.89±0.64	3.95±0.02
NH47-4 + ET_o-N	3.0±0.58	10.14±0.30	1.81±0.38b	4.5±0.23	9.89±0.57	4.01±0.02
S.E.D	ns	ns	0.29	ns	ns	ns
CV (%)	22.7	12.8	19.0	16.1	11.6	2.9

Means with the same letter(s) are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation

Appendix 4: Okra yield as influenced by ET_o × variety interaction at second planting under screenhouse conditions

Treatment	Number of pods	Fresh pod weight	Dry pod weight	Pod length	Pod diameter	100 seed weight
	(plant^{-1})	g plant^{-1}		(cm pod^{-1} plant^{-1})	(mm pod^{-1} plant^{-1})	(g)
UI4-30 + ET_o-M	4.3±0.33b	10.56±0.59	4.20±0.14b	5.9±0.24	11.07±1.09	4.60±0.07ab
UI4-30 + ET_o-I	2.3±0.33c	9.60±1.22	2.23±0.16c	4.5±0.37	6.98±0.80	4.37±0.06b
UI4-30 + ET_o-N	7.0±0.58a	11.36±0.19	6.12±0.20a	6.7±0.45	10.85±0.64	4.74±0.04a
NH47-4 + ET_o-M	3.0±0.58bc	8.49±2.69	2.52±0.32c	4.3±0.72	10.58±2.49	3.82±0.11c
NH47-4 + ET_o-I	2.7±0.33c	8.94±1.72	2.52±0.18c	4.0±0.47	8.58±0.98	3.99±0.07c
NH47-4 + ET_o-N	3.7±0.67bc	10.06±0.21	4.05±0.50b	5.0±0.85	10.79±0.88	4.00±0.08c
S.E.D	0.69	ns	0.40	ns	ns	0.11
CV (%)	22.2	25.0	13.5	19.0	23.0	3.1

Means with the same letter(s) are not significantly different at $p = 0.05$, ns = not significantly different at $p = 0.05$, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation

Appendix 5: Okra shoot weight as influenced by ET_o × variety interaction at first planting of screenhouse study

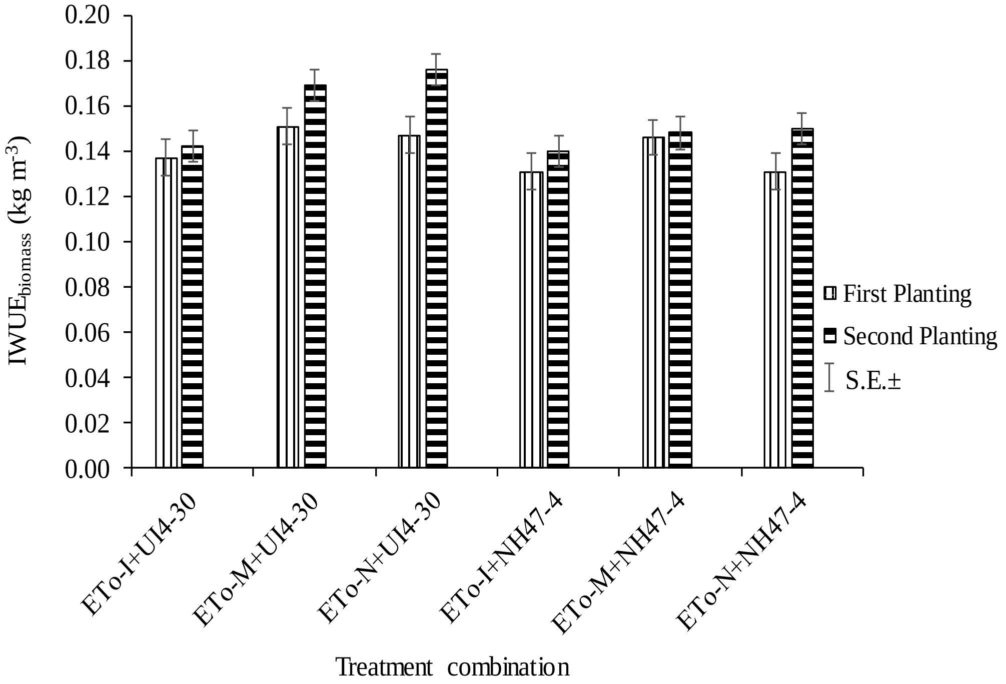
Treatment	Fresh shoot weight	Dry shoot weight
	g $plant^{-1}$	
UI 4-30 + ET_o-M	2.22±0.07	0.36±0.00
UI 4-30 + ET_o-I	1.71±0.05	0.25±0.02
UI 4-30 + ET_o-N	2.53±0.06	0.40±0.01
NH47-4 + ET_o-M	2.10±0.06	0.29±0.01
NH47-4 + ET_o-I	1.60±0.15	0.19±0.02
NH47-4 + ET_o-N	2.19±0.15	0.35±0.02
S.E.D	ns	ns
CV (%)	8.2	7.6

ns = not significantly different at p = 0.05, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation

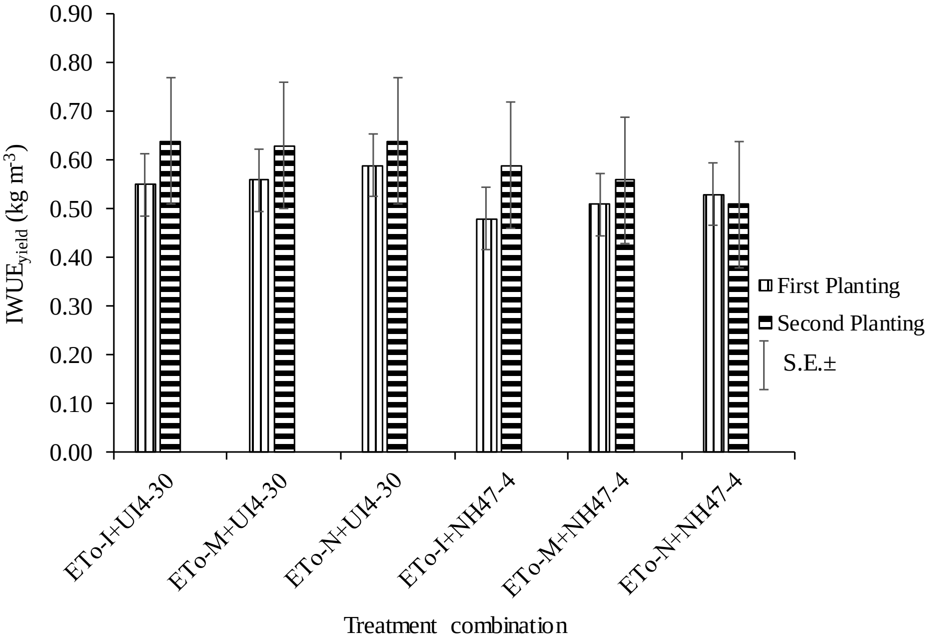
Appendix 6: Okra shoot weight as influenced by ET_o × variety interaction at second planting of screenhouse study

Treatment	Fresh shoot weight	Dry shoot weight
	g plant^{-1}	
UI4-30 + ET_o-M	2.50±0.09	0.37±0.01
UI4-30 + ET_o-I	1.79±0.04	0.28±0.01
UI4-30 + ET_o-N	2.64±0.03	0.40±0.01
NH47-4 + ET_o-M	2.05±0.07	0.32±0.02
NH47-4 + ET_o-I	1.78±0.07	0.28±0.01
NH47-4 + ET_o-N	2.19±0.17	0.38±0.02
S.E.D	ns	ns
CV (%)	7.3	6.2

ns = not significantly different at p = 0.05, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation



Appendix 7: Influence of ET$_o$ × variety interaction on the irrigation water use efficiency of okra for biomass production under screenhouse conditions



Appendix 8: Influence of ET$_o$ × variety interaction on the irrigation water use efficiency of okra for yield production under screenhouse conditions

Appendix 9: Irrigation rate × land preparation interaction on soil hydro-physical parameters in 2015/2016

Treatment	Bulk density ($Mg\ m^{-3}$)	Saturated hydraulic conductivity ($cm\ hr^{-1}$)	Total porosity	Macroporosity	Microporosity
				%	
100%ET_c+RB	1.54±0.02abc	21.37±2.03bc	42.08±0.85bcd	7.75±1.00bc	34.32±0.53c
100%ET_c+R	1.45±0.03cd	32.80±3.97a	45.12±1.14ab	9.34±1.16ab	35.77±0.54bc
100%ET_c+F	1.59±0.03a	24.82±3.06abc	39.85±1.10d	3.82±0.90d	36.03±0.90abc
75%ET_c+RB	1.40±0.04d	16.46±3.36c	47.33±1.46a	11.42±1.66a	35.91±0.53abc
75%ET_c+R	1.52±0.02abc	15.87±1.28c	42.47±0.87bcd	5.10±0.82cd	37.37±0.72ab
75%ET_c+F	1.59±0.02a	25.57±3.73abc	40.04±0.82d	4.99±0.90cd	35.05±0.66c
CROPWAT+RB	1.50±0.02bc	30.22±2.58ab	43.48±0.86bc	5.40±0.92cd	38.08±0.53a
CROPWAT+R	1.56±0.03ab	18.37±3.53c	41.28±1.16cd	3.54±0.90d	37.74±1.10ab
CROPWAT+F	1.60±0.03a	16.06±3.21c	39.79±1.07d	5.82±1.20cd	33.97±0.64c
S.E.D	0.04	3.53	1.52	1.43	0.84
CV (%)	3.5	19.3	4.8	28.7	3.0

Means with the same letter(s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 10: Irrigation rate × mulch interaction on soil hydro-physical parameters in 2015/2016

Treatment	Bulk density	Saturated hydraulic conductivity	Total porosity	Macroporosity	Microporosity
	(Mg m^{-3})	(cm hr^{-1})		%	
100%ET_c+GsM	1.56±0.03a	25.31±3.01	41.11±1.05b	6.59±0.92bc	34.52±0.62b
100%ET_c+PpM	1.51±0.02ab	29.95±3.74	43.17±0.93ab	7.17±1.00abc	36.00±0.83ab
100%ET_c+ZM	1.52±0.04ab	23.72±3.00	42.77±1.40ab	7.16±1.50abc	35.61±0.58ab
75%ET_c+GsM	1.43±0.04b	21.83±3.09	45.88±1.59a	10.50±1.56a	35.38±0.79ab
75%ET_c+PpM	1.50±0.03ab	24.01±3.94	43.35±1.19ab	8.00±1.10ab	35.35±0.49ab
75%ET_c+ZM	1.57±0.02a	12.08±0.74	40.61±0.64b	3.02±0.69d	37.59±0.58a
CROPWAT+GsM	1.56±0.03a	23.72±3.97	41.13±1.13b	3.77±0.94cd	37.36±0.77a
CROPWAT+PpM	1.53±0.03a	19.12±2.67	42.29±1.15b	6.36±1.15bcd	35.93±1.00ab
CROPWAT+ZM	1.56±0.03a	21.81±3.56	41.13±0.99b	4.63±0.92bcd	36.51±0.94ab
S.E.D	0.03	ns	1.20	1.49	ns
CV (%)	3.5	19.3	4.8	28.7	3.0

Means with the same letter(s) in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 11: Land preparation × mulch interaction on soil hydro-physical parameters in 2015/2016

Treatment	Bulk density	Saturated hydraulic conductivity	Total porosity	Macroporosity	Microporosity
	(Mg m^{-3})	(cm hr^{-1})	%		
RB+GsM	1.44±0.04	27.33±3.05	45.61±1.51	9.35±1.76	36.26±0.81
RB+PpM	1.46±0.03	20.15±2.98	44.92±1.07	9.73±1.15	35.18±0.56
RB+ZM	1.53±0.02	20.57±2.78	42.36±0.83	5.48±0.76	36.88±0.45
R+GsM	1.53±0.03	23.49±3.79	42.11±0.97	5.35±0.91	36.76±0.66
R+PpM	1.49±0.03	24.24±4.01	43.69±1.13	6.00±0.89	37.69±0.89
R+ZM	1.51±0.03	19.32±2.91	43.07±1.25	6.64±1.49	36.44±0.94
F+GsM	1.58±0.04	20.04±3.09	40.41±1.32	6.16±1.02	34.25±0.73
F+PpM	1.58±0.02	28.69±3.60	40.20±0.72	5.79±0.95	34.41±0.70
F+ZM	1.61±0.02	17.73±3.23	39.08±0.84	2.69±0.91	36.39±0.76
S.E.D	ns	ns	ns	ns	ns
CV (%)	3.5	19.3	4.8	28.7	3.0

ns = means in a column are not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 12: Irrigation rate × land preparation × mulch interaction on soil hydro-physical parameters in 2015/2016

Treatment	Bulk density (Mg m^{-3})	Saturated hydraulic conductivity (cm hr^{-1})	Total porosity	Macroporosity	Microporosity
				%	
100%ET_c+RB+GsM	1.54±0.03	21.65±2.60c-h	41.76±1.24	7.79±1.57	33.97±0.80
100%ET_c+RB+PpM	1.50±0.04	21.55±4.15c-h	43.46±1.54	9.56±2.03	33.90±1.24
100%ET_c+RB+ZM	1.56±0.05	20.91±4.22c-h	41.01±1.70	5.91±1.51	35.10±0.69
100%ET_c+R+GsM	1.53±0.04	35.37±6.78abc	42.33±1.36	7.84±1.75	34.48±0.56
100%ET_c+R+PpM	1.46±0.05	40.04±8.56ab	45.09±1.70	7.39±1.12	37.70±1.10
100%ET_c+R+ZM	1.38±0.15	22.98±3.29c-h	47.92±2.31	12.79±2.41	35.13±0.53
100%ET_c+F+GsM	1.61±0.07	18.92±2.98c-h	39.25±2.61	4.13±1.16	35.12±1.69
100%ET_c+F+PpM	1.57±0.04	28.27±4.11a-g	40.94±1.35	4.54±1.51	36.40±1.66
100%ET_c+F+ZM	1.61±0.05	27.28±7.69b-g	39.37±1.85	2.79±2.09	36.58±1.56
75%ET_c+RB+GsM	1.28±0.08	29.98±7.48a-e	51.60±2.97	16.30±3.51	35.30±1.45
75%ET_c+RB+PpM	1.38±0.05	7.78±1.53h	47.83±1.76	12.33±1.59	35.50±0.68
75%ET_c+RB+ZM	1.52±0.03	11.63±0.92gh	42.55±1.19	5.62±1.26	36.93±0.11
75%ET_c+R+GsM	1.49±0.05	15.31±2.31d-h	43.68±2.02	6.38±0.90	37.30±1.29
75%ET_c+R+PpM	1.50±0.04	20.39±1.93c-h	43.40±1.38	7.35±1.21	36.04±1.25
75%ET_c+R+ZM	1.58±0.02	11.92±0.72gh	40.35±0.64	1.57±0.82	38.78±1.13
75%ET_c+F+GsM	1.53±0.04	20.18±3.69c-h	42.36±1.68	8.81±1.00	33.55±1.09
75%ET_c+F+PpM	1.62±0.03	43.85±4.28a	38.84±1.16	4.32±1.35	34.52±0.39
75%ET_c+F+ZM	1.62±0.03	12.68±2.04fgh	38.93±1.03	1.86±0.75	37.08±1.32
CRW+RB+GsM	1.50±0.04	30.36±4.75a-e	43.46±1.34	3.96±1.01	39.50±0.83
CRW+RB+PpM	1.50±0.05	31.12±4.01a-d	43.46±1.92	7.31±2.10	36.15±0.82
CRW+RB+ZM	1.50±0.04	29.16±5.40a-f	43.52±1.45	4.92±1.41	38.60±0.56
CRW+R+GsM	1.58±0.04	19.79±7.14c-h	40.31±1.59	1.81±0.79	38.50±0.90
CRW+R+PpM	1.52±0.07	12.29±2.28gh	42.58±2.75	3.26±1.75	39.32±2.04
CRW+R+ZM	1.57±0.05	23.05±7.64c-h	40.94±1.78	5.54±1.75	35.40±2.40
CRW+F+GsM	1.60±0.07	21.00±8.61c-h	39.62±2.67	5.54±2.44	34.08±1.09
CRW+F+PpM	1.57±0.03	13.94±2.77e-h	40.82±1.25	8.50±1.71	32.32±0.65
CRW+F+ZM	1.62±0.04	13.23±3.95fgh	38.93±1.62	3.41±1.78	35.52±1.24
S.E.D	ns	6.55	ns	ns	ns
CV (%)	4.4	37.0	6.0	52.7	5.5

Means with the same letter(s) are not significantly different at p = 0.05, ns = means in a column are not significantly different at p = 0.05, CRW = CROPWAT, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 13: Irrigation rate × land preparation effect on soil hydro-physical parameters in 2016/2017

Treatment	Bulk density (Mg m^{-3})	Saturated hydraulic conductivity (cm hr^{-1})	Total porosity	Macroporosity	Microporosity
				%	
100%ET$_c$+RB	1.53±0.04	13.90±3.22	42.31±1.38	8.71±1.58	33.60±1.03
100%ET$_c$+R	1.51±0.02	16.63±2.36	43.02±0.73	9.19±1.57	33.83±1.30
100%ET$_c$+F	1.57±0.06	13.42±3.06	40.71±2.14	6.52±1.79	34.19±1.65
75%ET$_c$+RB	1.56±0.02	27.61±8.87	41.09±0.77	9.17±1.25	31.92±1.05
75%ET$_c$+R	1.43±0.02	39.54±3.27	45.87±0.70	11.98±1.46	33.89±1.17
75%ET$_c$+F	1.50±0.03	20.98±3.73	43.56±0.98	10.80±1.27	32.77±0.80
CROPWAT+RB	1.38±0.04	23.56±2.66	47.97±1.60	10.98±1.94	36.99±1.15
CROPWAT+R	1.42±0.04	15.67±2.59	46.54±1.35	11.96±1.95	34.58±1.57
CROPWAT+F	1.52±0.07	17.40±2.77	42.52±2.47	10.57±2.55	31.94±1.19
S.E.D	ns	ns	ns	ns	ns
CV (%)	5.7	33.0	7.3	33.8	6.9

Means with the same letter(s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 14: Irrigation rate × mulch interaction on soil hydro-physical parameters in 2016/2017

Treatment	Bulk density	Saturated hydraulic conductivity	Total porosity	Macroporosity	Microporosity
	(Mg m^{-3})	(cm hr^{-1})		%	
100%ET$_c$+GsM	1.52±0.04	15.92±2.48	42.77±1.35	8.56±0.77	34.21±1.55
100%ET$_c$+PpM	1.57±0.04	15.70±2.82	40.76±1.52	5.60±1.89	35.16±1.20
100%ET$_c$+ZM	1.52±0.05	12.32±3.31	42.52±1.70	10.26±1.76	32.26±1.06
75%ET$_c$+GsM	1.50±0.03	28.17±5.37	43.35±1.16	9.80±1.39	33.56±1.19
75%ET$_c$+PpM	1.46±0.03	29.70±8.65	44.91±1.06	12.71±1.34	32.20±0.95
75%ET$_c$+ZM	1.53±0.02	30.26±4.65	42.26±0.76	9.44±1.12	32.82±0.96
CROPWAT+GsM	1.44±0.04	18.29±2.25	45.83±1.58	10.83±1.15	35.00±1.53
CROPWAT+PpM	1.42±0.04	21.52±3.37	46.37±1.57	11.88±1.94	34.49±1.34
CROPWAT+ZM	1.46±0.07	16.81±2.80	44.82±2.73	10.80±3.01	34.02±1.61
S.E.D	ns	ns	ns	ns	ns
CV (%)	5.7	33.0	7.3	33.8	6.9

ns = not significantly different at p = 0.05, GsM = *Gliricidia sepium* mulch, PM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 15: Land preparation × mulch effect on soil hydro-physical parameters in 2016/2017

Treatment	Bulk density	Saturated hydraulic conductivity	Total porosity	Macroporosity	Microporosity
	(Mg m^{-3})	(cm hr^{-1})		%	
RB+GsM	1.50±0.04	16.51±2.48	43.52±1.47	9.50±1.36	34.02±1.25
RB+PpM	1.49±0.05	27.09±8.96	43.94±1.99	9.71±2.02	34.23±1.30
RB+ZM	1.49±0.04	21.47±3.91	43.90±1.51	9.64±1.51	34.26±1.37
R+GsM	1.48±0.03	25.73±5.34	44.23±1.17	10.39±1.05	33.84±1.41
R+PpM	1.45±0.02	21.48±3.00	45.45±0.91	10.83±1.99	34.62±1.45
R+ZM	1.44±0.03	24.63±5.47	45.74±1.17	11.91±1.95	33.83±1.20
F+GsM	1.48±0.04	20.14±3.25	44.19±1.66	9.29±1.07	34.90±1.64
F+PpM	1.52±0.04	18.36±3.52	42.64±1.66	9.65±2.18	32.99±0.87
F+ZM	1.59±0.06	13.30±2.90	39.96±2.35	8.95±2.61	31.01±0.87
S.E.D	ns	ns	ns	ns	ns
CV (%)	5.7	33.0	7.3	33.8	6.9

ns = means in a column are not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 16: Irrigation rate × land preparation × mulch interaction on soil hydro-physical parameters in 2016/2017

Treatment	Bulk density (Mg m^{-3})	Saturated hydraulic conductivity (cm hr^{-1})	Total porosity	Macroporosity	Microporosity
			%		
100%ET_c+RB+GsM	1.50±0.03	9.48±1.98	43.52±1.20	10.06±1.58	33.47±1.31
100%ET_c+RB+PpM	1.55±0.08	14.64±1.84	41.64±3.01	8.67±3.75	32.97±1.65
100%ET_c+RB+ZM	1.54±0.09	17.57±10.03	41.76±3.35	7.39±3.40	34.37±2.77
100%ET_c+R+GsM	1.55±0.05	21.84±3.72	41.51±1.70	9.31±0.70	32.20±1.00
100%ET_c+R+PpM	1.52±0.01	15.81±5.31	42.64±0.38	4.87±2.86	37.77±2.49
100%ET_c+R+ZM	1.46±0.02	12.24±1.14	44.91±0.58	13.37±1.71	31.53±1.17
100%ET_c+F+GsM	1.50±0.11	16.45±4.23	43.27±4.05	6.30±0.47	36.97±4.47
100%ET_c+F+PpM	1.64±0.09	16.66±7.93	37.99±3.54	3.25±3.60	34.73±1.53
100%ET_c+F+ZM	1.57±0.11	7.14±1.40	40.88±4.33	10.01±3.70	30.87±0.96
75%ET_c+RB+GsM	1.60±0.05	16.70±4.35	39.50±2.02	8.40±3.35	31.10±2.42
75%ET_c+RB+PpM	1.54±0.01	37.87±28.07	42.01±0.25	9.85±2.17	32.17±2.03
75%ET_c+RB+ZM	1.54±0.03	28.26±5.06	41.76±1.03	9.26±1.52	32.50±1.63
75%ET_c+R+GsM	1.44±0.02	45.40±0.91	45.79±0.67	11.59±3.02	34.20±2.38
75%ET_c+R+PpM	1.39±0.04	29.67±2.72	47.55±1.53	14.25±1.46	33.30±1.96
75%ET_c+R+ZM	1.48±0.02	43.55±6.82	44.28±0.67	10.11±3.13	34.17±2.60
75%ET_c+F+GsM	1.46±0.01	22.40±9.75	44.78±0.50	9.41±0.42	35.37±0.78
75%ET_c+F+PpM	1.45±0.05	21.56±5.97	45.16±1.83	14.02±2.92	31.13±1.33
75%ET_c+F+ZM	1.57±0.04	18.97±5.73	40.75±1.43	8.95±1.64	31.80±0.42
CRW+RB+GsM	1.39±0.06	23.34±1.66	47.55±2.08	10.05±2.72	37.50±0.82
CRW+RB+PpM	1.37±0.13	28.76±5.86	48.18±4.99	10.61±5.40	37.57±2.24
CRW+RB+ZM	1.37±0.03	18.57±4.70	48.18±1.20	12.28±2.73	35.90±3.03
CRW+R+GsM	1.45±0.07	9.96±1.31	45.41±2.72	10.28±1.55	35.13±3.85
CRW+R+PpM	1.43±0.03	18.96±4.44	46.16±0.98	13.36±3.27	32.80±2.78
CRW+R+ZM	1.38±0.09	18.09±5.87	48.05±3.41	12.25±5.50	35.80±2.11
CRW+F+GsM	1.47±0.11	21.57±1.90	44.53±3.96	12.16±2.17	32.37±2.45
CRW+F+PpM	1.46±0.02	16.85±6..49	44.78±0.88	11.68±1.88	33.10±1.29
CRW+F+ZM	1.64±0.17	13.78±5.56	38.24±6.60	7.87±8.03	30.37±2.71
S.E.D	ns	ns	ns	ns	ns
CV (%)	6.7	62.9	8.6	55.2	11.1

Means with the same letter(s) are not significantly different at p = 0.05, ns = means in a column are not significantly different at p = 0.05, CRW = CROPWAT, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 17: Irrigation rate × land preparation interaction on soil aggregate and structural stability in 2015/2016

Treatment	WSA (%)	MWD (mm)	ASC	CDI	CFI	DR	SS	S
			%					
100%ET_c+RB	59.37±1.97ab	1.06±0.04a	11.06±0.69d	90.03±18.31	90.83±18.61a	27.92±2.79	0.28±0.03	14.83±1.52a
100%ET_c+R	54.88±0.61c	0.87±0.08b	12.66±0.67cd	38.77±8.39	33.44±8.48b	25.05±2.72	0.22±0.01	19.59±1.80a
100%ET_c+F	55.46±0.97bc	0.99±0.03a	16.03±1.45abc	77.32±16.46	65.50±16.72ab	23.46±3.00	0.23±0.02	16.93±2.15a
75%ET_c+RB	60.15±2.22a	1.07±0.04a	19.21±1.10a	32.70±7.38	32.70±7.38b	11.85±1.85	0.30±0.03	18.32±2.02a
75%ET_c+R	61.09±0.62a	1.09±0.02a	15.54±1.42abc	45.23±11.75	44.19±11.79b	17.71±3.68	0.30±0.01	15.72±1.92a
75%ET_c+F	59.40±0.52ab	1.06±0.04a	17.78±0.78ab	45.56±9.29	44.47±9.29b	11.78±2.20	0.27±0.02	8.38±0.58b
CROPWAT+RB	55.62±2.02bc	0.99±0.04a	13.88±1.49bcd	38.19±9.00	28.78±5.42b	21.49±3.04	0.24±0.03	15.31±1.03a
CROPWAT+R	60.49±0.46a	1.08±0.03a	14.41±1.10bcd	33.23±7.30	33.23±7.30b	14.66±2.49	0.29±0.03	19.80±1.61a
CROPWAT+F	61.77±0.43a	1.10±0.02a	16.67±1.89ab	61.59±10.45	61.59±10.45ab	13.97±1.18	0.31±0.03	16.25±1.52a
S.E.D	0.53	0.04	1.22	ns	13.97	ns	ns	1.59
CV (%)	0.8	4.3	6.7	34.6	40.5	18.1	13.5	10.9

Means with the same letter(s) are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, WSA = Water stable aggregate, MWD = Mean weight diameter, ASC = Aggregated silt and clay, CDI = Clay dispersion index, CFI = Clay flocculation index, DR = Dispersion ration, SS = Soil structural stability, S = Soil structural stability index, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 18: Irrigation rate × mulch effect on soil aggregate and structural stability in 2015/2016

Treatment	WSA	MWD	ASC	CDI	CFI	DR	SS	S
	(%)	(mm)	%					
100%ET_c+GsM	57.52±1.15b	1.02±0.04a	13.96±1.12b	78.47±16.09	79.57±16.43a	25.50±2.60	0.25±0.02	19.39±2.32a
100%ET_c+PpM	58.91±1.64ab	1.05±0.03a	12.89±0.91b	63.71±14.99	63.71±14.99ab	22.48±2.74	0.28±0.02	17.88±1.43ab
100%ET_c+ZM	53.28±0.75c	0.84±0.07b	12.89±1.29b	63.95±16.37	46.49±16.36ab	28.46±3.08	0.21±0.02	14.07±1.55ab
75%ET_c+GsM	58.15±1.75ab	1.03±0.03a	18.12±1.37a	41.42±11.94	41.42±11.94b	11.14±2.88	0.27±0.03	15.72±2.80ab
75%ET_c+PpM	60.60±0.98ab	1.08±0.04a	18.33±1.05a	40.01±9.51	40.01±9.51b	11.24±2.23	0.29±0.02	13.48±1.34b
75%ET_c+ZM	61.88±0.92a	1.10±0.02a	16.07±1.03ab	42.06±7.21	39.93±7.21b	18.95±2.74	0.31±0.02	13.21±1.72b
CROPWAT+GsM	61.66±0.61ab	1.10±0.02a	13.58±0.92b	35.24±6.96	35.24±6.96b	18.41±2.11	0.31±0.04	19.35±1.61a
CROPWAT+PpM	58.77±1.59ab	1.05±0.04a	15.52±1.16ab	48.12±9.76	48.12±9.76ab	13.61±2.74	0.27±0.03	15.66±1.22ab
CROPWAT+ZM	57.46±1.75b	1.03±0.04a	15.86±2.21ab	49.65±10.93	40.24±8.96b	18.09±2.47	0.26±0.02	16.35±1.49ab
S.E.D	0.58	0.05	1.13	ns	8.51	ns	ns	0.79
CV (%)	0.8	4.3	6.7	34.6	40.5	18.1	13.5	10.9

Means with the same letter(s) are not significantly different at $p = 0.05$, ns = not significantly different at $p = 0.05$, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, WSA = Water stable aggregate, MWD = Mean weight diameter, ASC = Aggregated silt and clay, CDI = Clay dispersion index, CFI = Clay flocculation index, DR = Dispersion ration, SS = Soil structural stability, S = Soil structural stability index, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 19: Land preparation × mulch interaction on soil aggregate and structural stability in 2015/2016

Treatment	WSA	MWD	ASC	CDI	CFI	DR	SS	S
	(%)	(mm)	%					
RB+GsM	58.92±1.95	1.05±0.04	16.58±1.28ab	60.37±15.23	61.17±15.68ab	19.25±2.71abc	0.28±0.03	16.80±2.00abc
RB+PpM	60.43±1.99	1.08±0.04	13.99±1.13bc	48.01±7.80	48.01±7.80ab	19.02±2.77abc	0.30±0.03	16.68±0.89abc
RB+ZM	55.79±2.28	1.00±0.04	13.58±1.64bc	52.54±17.05	43.13±15.97ab	22.99±3.54ab	0.25±0.03	14.97±1.77abc
R+GsM	59.32±1.17	1.06±0.03	14.39±1.02bc	40.73±12.80	41.04±12.82ab	19.77±2.97abc	0.27±0.03	20.25±2.27a
R+PpM	57.91±1.21	1.03±0.03	16.39±1.20ab	31.37±5.79	31.37±5.79b	12.15±2.91c	0.26±0.01	17.86±1.65ab
R+ZM	59.23±0.96	0.95±0.09	11.83±0.90c	45.12±7.92	38.45±8.25ab	25.49±2.82a	0.27±0.01	17.00±1.45abc
F+GsM	59.09±0.90	1.05±0.03	14.69±1.38bc	54.02±10.32	54.02±10.32ab	16.03±2.99bc	0.27±0.03	17.41±2.62ab
F+PpM	59.94±0.74	1.07±0.04	16.36±1.09ab	72.46±16.82	72.46±16.82a	16.16±2.57bc	0.28±0.02	12.48±1.12bc
F+ZM	57.60±1.50	1.03±0.03	19.42±1.61a	57.99±9.76	45.08±8.78ab	17.02±2.06abc	0.26±0.02	11.66±1.22c
S.E.D	ns	ns	0.70	ns	11.49	2.82	ns	1.08
CV (%)	0.8	4.3	6.7	34.6	40.5	18.1	13.5	10.9

Means with the same letter(s) are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, WSA = Water stable aggregate, MWD = Mean weight diameter, ASC = Aggregated silt and clay, CDI = Clay dispersion index, CFI = Clay flocculation index, DR = Dispersion ration, SS = Soil structural stability, *S* = Soil structural stability index, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 20: Irrigation rate × land preparation × mulch interaction on soil aggregate and structural stability in 2015/2016

Treatment	WSA	MWD	ASC	CDI	CFI	DR	SS	S
	(%)	(mm)	%					
100%ET_c+RB+GsM	61.87±0.84cde	1.10±0.06a-e	13.13±1.10c-g	124.83±26.03a	127.20±27.49a	25.11±3.39	0.31±0.06a-d	15.27±2.08a-f
100%ET_c+RB+PpM	64.52±0.39ab	1.15±0.04ab	10.40±1.03fg	74.52±11.89ab	74.52±11.89ab	25.62±3.69	0.35±0.05ab	16.52±2.26a-f
100%ET_c+RB+ZM	51.73±0.54lm	0.92±0.04de	9.63±1.12g	70.75±47.28ab	70.75±47.28ab	33.05±6.80	0.19±0.01d	12.69±3.67b-f
100%ET_c+R+GsM	55.08±0.79jk	0.98±0.07a-e	13.63±1.24c-g	32.98±19.47b	33.91±19.66b	27.55±2.77	0.22±0.02bcd	19.53±4.56abc
100%ET_c+R+PpM	53.53±1.31kl	0.95±0.05b-e	13.88±0.78c-g	27.84±12.73b	27.84±12.73b	19.87±5.74	0.21±0.01cd	20.76±3.45ab
100%ET_c+R+ZM	56.02±0.76j	0.67±0.18f	10.47±0.99fg	55.50±9.47ab	38.58±13.15b	27.73±5.19	0.23±0.02a-d	18.47±1.47a-d
100%ET_c+F+GsM	55.60±0.41j	0.99±0.06a-e	15.10±3.12c-g	77.60±27.22ab	77.60±27.22ab	23.84±6.96	0.23±0.01a-d	23.38±4.82a
100%ET_c+F+PpM	58.69±0.08hi	1.05±0.01a-e	14.40±2.19c-g	88.76±39.78ab	88.76±39.78ab	21.95±5.15	0.27±0.01a-d	16.35±1.18a-f
100%ET_c+F+ZM	52.08±0.46lm	0.93±0.04de	18.58±2.22a-e	65.59±19.62b	30.13±11.77b	24.60±4.04	0.20±0.06d	11.05±0.85c-f
75%ET_c+RB+GsM	51.32±0.58m	0.91±0.01e	22.70±1.34a	35.79±17.52b	35.79±17.52b	9.52±2.50	0.19±0.02d	18.07±6.09a-e
75%ET_c+RB+PpM	64.26±0.43ab	1.15±0.02ab	19.43±0.78abc	42.97±9.92b	42.97±9.92b	10.17±2.28	0.35±0.01ab	16.57±1.65a-f
75%ET_c+RB+ZM	64.86±0.22a	1.16±0.02a	15.50±2.17b-g	19.33±9.53b	19.33±9.53b	15.85±4.33	0.36±0.05a	20.30±1.71abc
75%ET_c+R+GsM	61.95±1.08cde	1.10±0.03a-e	12.60±2.50d-g	64.33±31.21ab	64.33±31.21ab	17.34±7.80	0.31±0.03a-d	19.96±4.88abc
75%ET_c+R+PpM	59.11±0.70ghi	1.05±0.05a-e	19.20±2.42a-d	19.99±3.33b	19.99±3.33b	7.21±3.28	0.27±0.02a-d	15.30±2.13a-f
75%ET_c+R+ZM	62.20±0.20cde	1.11±0.02a-e	14.82±1.98c-g	51.37±14.67b	48.26±15.22b	28.58±4.55	0.31±0.01a-d	11.89±1.03b-f
75%ET_c+F+GsM	61.17±0.21def	1.09±0.04a-e	19.07±0.82a-d	24.14±1.59b	24.14±1.59b	6.57±2.27	0.30±0.06a-d	9.12±1.75d-f
75%ET_c+F+PpM	58.43±0.83i	1.04±0.12a-e	16.37±1.92a-g	57.08±25.94b	57.08±25.94b	16.34±5.13	0.26±0.02a-d	8.57±0.28e-f
75%ET_c+F+ZM	58.59±0.41hi	1.04±0.01a-e	17.90±1.04a-e	55.47±8.18b	52.19±8.85b	12.43±2.83	0.26±0.01a-d	7.44±0.30f
CRW+RB+GsM	63.57±0.77abc	1.13±0.06abc	13.92±1.52c-g	20.50±10.64b	20.50±10.64b	23.13±5.32	0.34±0.01abc	17.06±1.08a-e
CRW+RB+PpM	52.51±0.24lm	0.94±0.01cde	12.13±1.46efg	26.53±11.96b	26.53±11.96b	21.27±5.85	0.20±0.06d	16.95±0.94a-e
CRW+RB+ZM	50.79±0.36m	0.91±0.05e	15.60±4.11b-g	67.54±17.57ab	39.31±2.44b	20.07±5.57	0.19±0.01d	11.93±1.95b-f
CRW+R+GsM	60.92±0.94d-g	1.09±0.01a-e	16.93±0.90a-f	24.89±12.02b	24.89±12.02b	14.43±1.61	0.29±0.10a-d	21.26±10.55ab
CRW+R+PpM	61.09±0.05d-g	1.09±0.05a-e	16.10±2.34b-g	46.28±9.80b	46.28±9.80b	9.37±4.91	0.30±0.001a-d	17.50±2.89a-e
CRW+R+ZM	59.46±0.92f-i	1.06±0.09a-e	10.20±0.84fg	28.50±15.84b	28.50±15.84b	20.16±5.00	0.27±0.02a-d	20.63±2.50abc
CRW+F+GsM	60.49±0.48e-h	1.08±0.03a-e	9.90±0.75g	60.33±6.78ab	60.33±6.78b	17.68±2.58	0.29±0.06a-d	19.72±3.59abc
CRW+F+PpM	62.71±0.29bcd	1.12±0.06a-d	18.32±1.48a-e	71.54±23.01ab	71.54±23.01ab	10.20±0.80	0.32±0.07a-d	12.53±1.51b-f
CRW+F+ZM	62.12±0.76cde	1.11±0.01a-e	21.78±4.32ab	52.90±22.42b	52.90±22.42b	14.04±1.14	0.31±0.01a-d	16.50±1.31a-f
S.E.D	0.88	0.08	1.50	18.60	18.34	ns	0.06	1.72
CV (%)	1.8	10.2	8.5	36.3	36.9	32.3	26.2	5.0

Means with the same letter(s) are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, WSA = Water stable aggregate, MWD = Mean weight diameter, ASC = Aggregated silt and clay, CDI = Clay dispersion index, CFI = Clay flocculation index, DR = Dispersion ration, SS = Soil structural stability, S = Soil structural stability index, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 21: Irrigation rate × land preparation interaction on soil aggregate and structural stability in 2016/2017

Treatment	WSA	MWD	ASC	CDI	CFI	DR	SS	S
	(%)	(mm)	%					
100%ET_c+RB	54.00±1.55b	0.95±0.03bc	2.57±0.24ab	68.70±5.41	31.30±5.41	69.78±2.61ab	0.21±0.04ab	39.72±1.24
100%ET_c+R	55.99±1.06b	0.99±0.02ab	3.37±0.15a	73.16±3.05	26.84±3.05	62.50±0.92b	0.29±0.03a	33.92±1.32
100%ET_c+F	53.22±1.03b	0.91±0.03c	3.40±0.35a	68.61±1.55	31.39±1.55	62.28±2.44b	0.14±0.04b	40.38±2.22
75%ET_c+RB	55.93±1.16b	1.00±0.04ab	3.73±0.21a	67.07±2.48	32.93±2.48	59.87±2.20b	0.23±0.03ab	34.53±1.53
75%ET_c+R	56.31±1.36ab	1.00±0.02ab	1.77±0.75b	64.96±1.23	35.04±1.23	86.16±11.28a	0.24±0.02ab	49.65±7.31
75%ET_c+F	59.80±0.76a	1.07±0.01a	3.57±0.33a	67.44±1.64	32.56±1.64	63.01±2.54b	0.28±0.03a	38.22±3.18
CROPWAT+RB	54.66±1.67b	0.97±0.03bc	3.78±0.39a	75.22±4.18	24.78±4.18	61.37±3.05b	0.22±0.04ab	41.50±0.91
CROPWAT+R	53.93±0.82b	0.96±0.01bc	3.08±0.67ab	67.22±3.15	32.78±3.15	71.94±8.96ab	0.15±0.03b	50.47±5.87
CROPWAT+F	56.72±1.07ab	1.01±0.02ab	2.55±0.50ab	77.57±6.73	22.43±6.73	72.47±4.85ab	0.30±0.02a	39.18±3.34
S.E.D	0.70	0.02	0.38	ns	ns	5.61	0.03	ns
CV (%)	1.5	3.5	14.9	8.1	18.8	10.9	20.0	13.5

Means with the same letter(s) are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, WSA = Water stable aggregate, MWD = Mean weight diameter, ASC = Aggregated silt and clay, CDI = Clay dispersion index, CFI = Clay flocculation index, DR = Dispersion ration, SS = Soil structural stability, S = Soil structural stability index, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 22: Irrigation rate × mulch effect on soil aggregate and structural stability in 2016/2017

Treatment	WSA (%)	MWD (mm)	ASC	CDI	CFI	DR	SS	S
			%					
100%ET_c+GsM	57.00±1.25	1.00±0.03	3.38±0.32ab	65.09±1.84	34.91±1.84	62.30±2.25bc	0.23±0.06	40.57±1.97
100%ET_c+PpM	54.37±1.10	0.94±0.03	3.23±0.29ab	67.73±3.87	32.28±3.87	64.15±2.92bc	0.22±0.04	36.76±1.69
100%ET_c+ZM	51.84±0.82	0.91±0.01	2.72±0.19ab	77.66±3.65	22.34±3.65	68.11±1.53abc	0.20±0.02	36.70±1.85
75%ET_c+GsM	59.85±0.13	1.07±0.02	2.07±0.67b	68.44±1.40	31.56±1.40	82.50±10.61a	0.28±0.01	45.55±5.47
75%ET_c+PpM	58.31±0.90	1.04±0.04	3.05±0.56ab	63.70±1.02	36.31±1.02	67.66±6.24abc	0.26±0.03	43.19±6.27
75%ET_c+ZM	53.88±1.29	0.96±0.02	3.95±0.17a	67.33±2.50	32.67±2.50	58.88±1.69c	0.21±0.03	33.66±1.51
CROPWAT+GsM	57.77±1.31	1.03±0.02	3.65±0.25a	68.75±3.22	31.25±3.22	61.91±1.80bc	0.24±0.06	43.07±2.64
CROPWAT+PpM	55.29±1.11	0.99±0.02	3.15±0.44ab	77.29±4.23	22.71±4.23	66.40±3.21abc	0.23±0.03	40.62±2.21
CROPWAT+ZM	52.25±0.52	0.93±0.01	2.62±0.79ab	73.97±6.87	26.03±6.87	77.47±9.66ab	0.20±0.02	47.46±6.36
S.E.D	ns	ns	0.49	ns	ns	5.85	ns	ns
CV (%)	1.5	3.5	14.9	8.1	18.8	10.9	20.0	13.5

Means with the same letter(s) are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, WSA = Water stable aggregate, MWD = Mean weight diameter, ASC = Aggregated silt and clay, CDI = Clay dispersion index, CFI = Clay flocculation index, DR = Dispersion ration, SS = Soil structural stability, S = Soil structural stability index, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 23: Land preparation × mulch effect on soil aggregate and structural stability in 2016/2017

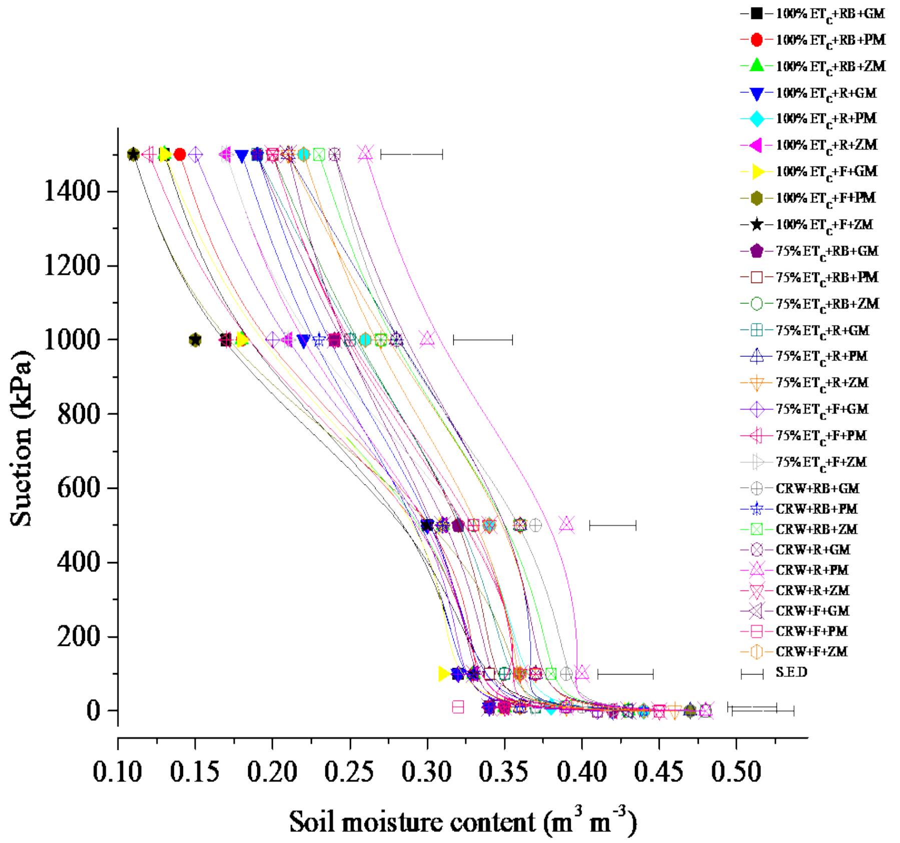
Treatment	WSA	MWD	ASC	CDI	CFI	DR	SS	S
	(%)	(mm)	%					
RB+GsM	60.18±0.81a	1.07±0.13a	3.23±0.28	66.74±3.04	33.26±3.04	65.12±2.21	0.27±0.05	38.28±2.15
RB+PpM	52.89±0.83de	0.94±0.04cd	3.08±0.32	67.97±5.07	32.03±5.07	65.23±3.46	0.21±0.02	38.29±1.60
RB+ZM	51.52±0.14e	0.91±0.01d	3.77±0.39	76.27±3.98	23.73±3.98	60.66±3.09	0.18±0.02	39.18±0.86
R+GsM	57.13±1.05bc	1.02±0.02ab	2.17±0.66	70.31±1.89	29.69±1.89	80.02±10.93	0.24±0.05	49.52±4.44
R+PpM	57.35±0.45bc	1.03±0.01ab	3.12±0.57	67.64±2.88	32.36±2.88	68.64±5.96	0.25±0.02	43.19±6.25
R+ZM	51.75±0.48e	0.91±0.01d	2.93±0.63	67.39±3.57	32.61±3.57	71.94±8.96	0.19±0.02	41.33±6.93
F+GsM	57.31±1.17bc	1.01±0.03abc	3.70±0.36	65.23±1.48	34.77±1.48	61.56±2.72	0.24±0.05	41.38±3.09
F+PpM	57.73±1.26ab	1.00±0.04abc	3.23±0.40	73.09±3.13	26.91±3.13	64.34±3.13	0.25±0.05	39.09±2.52
F+ZM	54.69±1.37cd	0.98±0.02bcd	2.58±0.43	75.30±6.25	24.70±6.25	71.86±4.45	0.23±0.03	37.31±3.09
S.E.D	0.88	0.03	ns	ns	ns	ns	ns	ns
CV (%)	1.5	3.5	14.9	8.1	18.8	10.9	20.0	13.5

Means with the same letter(s) are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, WSA = Water stable aggregate, MWD = Mean weight diameter, ASC = Aggregated silt and clay, CDI = Clay dispersion index, CFI = Clay flocculation index, DR = Dispersion ration, SS = Soil structural stability, S = Soil structural stability index, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 24: Irrigation rate × land preparation × mulch interaction on soil aggregate and structural stability in 2016/2017

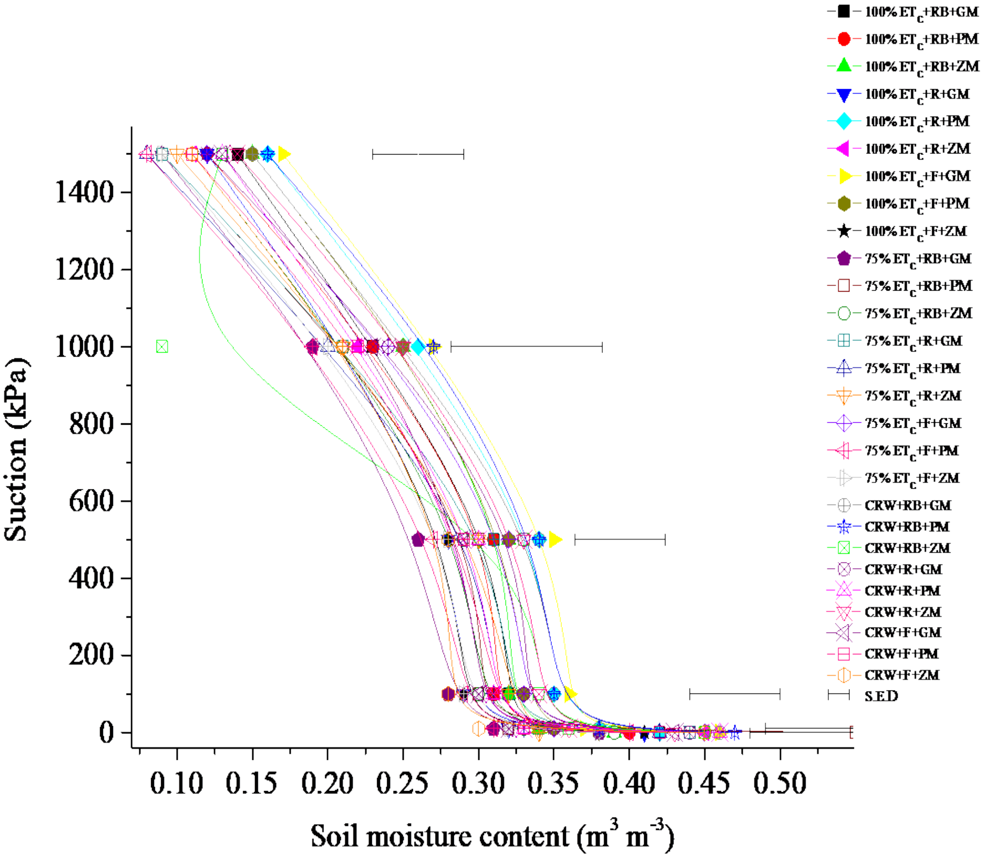
Treatment	WSA	MWD	ASC	CDI	CFI	DR	SS	S
	(%)	(mm)	%					
100%ET_c+RB+GsM	59.67±2.06abc	1.06±0.03	2.75±0.49b-g	62.55±4.40efg	37.45±4.40abc	66.99±4.03cde	0.24±0.12	44.14±0.54
100%ET_c+RB+PpM	51.24±0.68g	0.90±0.02	2.50±0.64b-g	56.56±6.13g	43.44±6.13a	70.87±7.63cde	0.20±0.05	37.05±1.06
100%ET_c+RB+ZM	51.10±0.32g	0.88±0.01	2.45±0.09b-g	86.99±5.81ab	13.01±5.81fg	71.49±1.19cde	0.17±0.01	37.98±1.50
100%ET_c+R+GsM	58.33±0.35abc	1.03±0.01	3.10±0.29a-g	66.05±4.02c-g	33.95±4.02a-e	63.75±2.17cde	0.36±0.02	36.94±3.29
100%ET_c+R+PpM	57.59±0.83a-d	1.04±0.01	3.70±0.06a-d	73.29±6.54a-g	26.71±6.54a-g	60.41±0.24de	0.30±0.04	33.57±1.26
100%ET_c+R+ZM	52.04±0.88g	0.90±0.04	3.30±0.29a-f	80.13±1.85a-e	19.87±1.85c-g	63.34±1.45cde	0.20±0.02	31.24±0.56
100%ET_c+F+GsM	53.01±1.45efg	0.91±0.05	4.30±0.52abc	66.66±0.29c-g	33.34±0.29a-e	56.15±3.01e	0.07±0.05	40.62±4.74
100%ET_c+F+PpM	54.26±1.78d-g	0.87±0.07	3.50±0.46a-e	73.33±2.36a-g	26.67±2.36a-g	61.17±3.17de	0.14±0.08	39.65±4.71
100%ET_c+F+ZM	52.37±2.58fg	0.94±0.02	2.40±0.29c-g	65.86±2.49c-g	34.14±2.49a-e	69.52±2.57cde	0.22±0.08	40.87±3.75
75%ET_c+RB+GsM	59.87±0.04ab	1.07±0.03	3.35±0.43a-f	67.05±4.59c-g	32.95±4.59a-e	64.74±4.56cde	0.28±0.03	30.39±0.39
75%ET_c+RB+PpM	56.11±0.06b-e	1.00±0.12	3.90±0.17a-d	63.63±1.21efg	36.37±1.21abc	56.92±1.78e	0.23±0.03	34.27±2.43
75%ET_c+RB+ZM	51.82±0.10g	0.92±0.01	3.95±0.43a-d	70.53±6.25b-g	29.47±6.25a-f	57.94±3.98de	0.18±0.06	38.93±1.92
75%ET_c+R+GsM	59.54±0.31abc	1.06±0.00	0.00±1.10h	68.91±0.73c-g	31.09±0.73a-e	114.13±23.18a	0.28±0.03	60.37±8.77
75%ET_c+R+PpM	58.43±0.48abc	1.04±0.02	1.15±0.89gh	64.20±2.08efg	35.80±2.08abc	87.78±12.19bc	0.26±0.02	57.24±17.56
75%ET_c+R+ZM	50.96±0.02g	0.91±0.00	4.15±0.32a-d	61.76±0.13fg	38.24±0.13ab	56.57±3.19e	0.19±0.01	31.33±1.20
75%ET_c+F+GsM	60.14±0.08a	1.07±0.04	2.85±0.84a-g	69.37±0.46b-g	30.63±0.46a-f	68.63±6.23cde	0.28±0.00	45.90±7.53
75%ET_c+F+PpM	60.40±2.19a	1.08±0.00	4.10±0.46a-d	63.26±2.56efg	36.74±2.56abc	58.28±3.38de	0.28±0.10	38.05±2.36
75%ET_c+F+ZM	58.85±1.17abc	1.05±0.02	3.75±0.09a-d	69.70±3.50b-g	30.30±3.50a-f	62.12±0.01cde	0.27±0.06	30.72±1.22
CRW+RB+GsM	61.01±1.74a	1.09±0.00	3.60±0.58a-e	70.61±7.34b-g	29.39±7.34a-f	63.65±4.31cde	0.28±0.11	40.32±2.17
CRW+RB+PpM	51.32±0.18g	0.91±0.01	2.85±0.55a-g	83.74±8.38abc	16.26±8.38efg	67.90±5.32cde	0.19±0.05	43.54±1.01
CRW+RB+ZM	51.65±0.03g	0.92±0.01	4.90±0.29a	71.30±5.57b-g	28.70±5.57a-f	52.55±1.47e	0.19±0.00	40.62±1.02
CRW+R+GsM	53.53±1.71efg	0.95±0.03	3.40±0.58a-f	75.96±0.56a-f	24.04±0.56b-g	62.17±4.08cde	0.09±0.06	51.26±3.02
CRW+R+PpM	56.02±0.01c-f	1.00±0.00	4.50±0.12ab	65.44±5.30d-g	34.56±5.30a-d	57.74±1.20de	0.18±0.00	38.74±1.86
CRW+R+ZM	52.24±1.23g	0.93±0.02	1.35±1.59fgh	60.27±5.17fg	39.73±5.17ab	95.92±22.56ab	0.18±0.06	61.41±16.50
CRW+F+GsM	58.77±0.04abc	1.05±0.00	3.95±0.09a-d	59.66±1.02fg	40.34±1.02ab	59.91±0.53de	0.37±0.01	37.63±4.22
CRW+F+PpM	58.52±1.15abc	1.04±0.01	2.10±0.69d-g	82.69±3.33a-d	17.31±3.33d-g	73.57±5.45b-e	0.32±0.01	39.57±6.90
CRW+F+ZM	52.86±1.17efg	0.94±0.02	1.60±0.98e-h	90.34±16.63a	9.66±16.63g	83.93±10.37bcd	0.22±0.01	40.35±8.17
S.E.D	1.52	ns	0.84	7.38	7.38	10.57	ns	ns
CV (%)	3.6	6.1	36.4	13.5	31.4	19.9	40.4	24.3

Means with the same letter(s) are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, WSA = Water stable aggregate, MWD = Mean weight diameter, ASC = Aggregated silt and clay, CDI = Clay dispersion index, CFI = Clay flocculation index, DR = Dispersion ration, SS = Soil structural stability, S = Soil structural stability index, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.



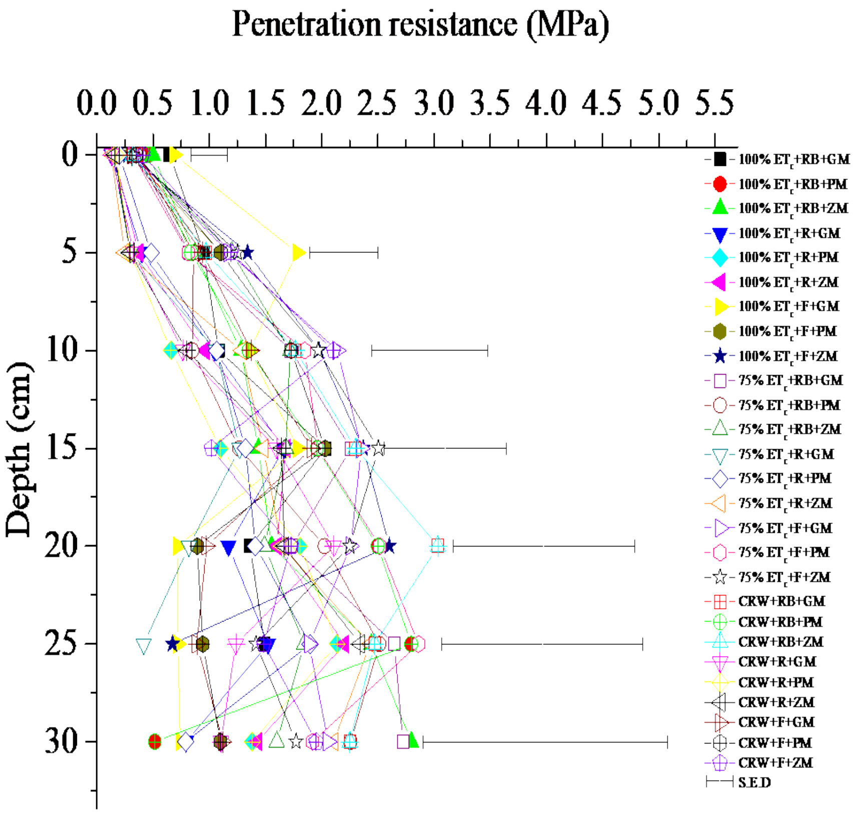
Appendix 25: Irrigation rate × land preparation × mulch interaction on soil water retention characteristics in 2015/2016

Note: RB = Raised bed, R = Ridge, F = Flat, GM = *Gliricidia* mulch, PM = *Pennisetum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means



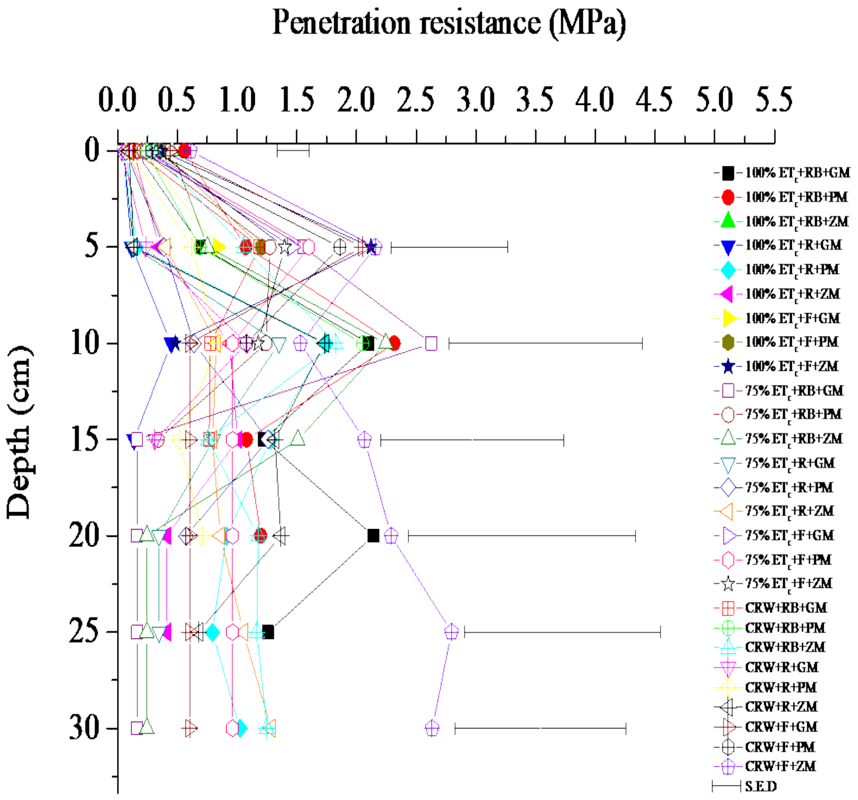
Appendix 26: Irrigation rate × land preparation × mulch interaction on soil water retention characteristics in 2016/2017

Note: RB = Raised bed, R = Ridge, F = Flat, GM = *Gliricidia* mulch, PM = *Pennisetum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means



Appendix 27: Irrigation rate × land preparation × mulch effect on soil water retention characteristics in 2015/2016

Note: RB = Raised bed, R = Ridge, F = Flat, GM = *Gliricidia* mulch, PM = *Pennisetum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means



Appendix 28: Effect of irrigation rate × land preparation × mulch on soil water retention characteristics in 2016/2017

Note: RB = Raised bed, R = Ridge, F = Flat, GM = *Gliricidia* mulch, PM = *Pennisetum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means

Appendix 29: Effect of irrigation rate × land preparation on soil chemical properties in 2015/2016

Treatment	pH	TOC	TN	Avail P	Mn	Fe	Cu	Zn	Pb	K	Ca	Mg	Na	Ex. Acidity	EC
		g kg^{-1}		mg kg^{-1}						cmol kg^{-1}					(µS cm^{-1})
100%ET$_c$+RB	5.9±0.31	12.4±1.11cd	1.3±0.12cd	16.2±1.61a	364.7±10.85cd	356.8±22.75bc	4.5±0.15e	7.9±0.87a	15.0±0.98ab	0.8±0.09	0.31±0.04c	1.1±0.08ab	0.3±0.03	0.4±0.05	146.2±4.83ef
100%ET$_c$+R	6.0±0.25	17.7±0.99ab	1.9±0.13ab	12.6±1.15ab	345.2±10.52de	335.8±24.65bc	6.9±0.27c	5.4±0.31b	16.3±1.31a	0.9±0.05	1.59±0.40a	0.9±0.08bc	0.3±0.03	0.3±0.04	342.5±45.93d
100%ET$_c$+F	5.9±0.25	17.7±0.67ab	1.8±0.07ab	17.4±3.98a	326.8±7.05e	245.8±25.20de	5.8±0.17d	5.1±0.30b	12.4±0.99bcd	0.7±0.06	0.23±0.04c	1.1±0.07ab	0.3±0.02	0.4±0.04	115.7±4.62f
75%ET$_c$+RB	6.3±0.32	21.0±2.14a	2.1±0.18a	15.4±2.96ab	380.5±11.10bc	349.0±50.50bc	8.1±0.12b	8.7±0.70a	13.2±0.94bcd	0.9±0.05	0.97±0.30b	0.9±0.07bc	0.4±0.03	0.3±0.04	543.0±40.50b
75%ET$_c$+R	6.2±0.44	16.5±0.77b	1.7±0.14ab	14.1±1.12ab	415.7±11.75a	218.5±8.37de	9.0±0.16a	8.7±0.40a	11.5±0.89d	0.8±0.05	0.39±0.05c	0.8±0.05c	0.3±0.02	0.5±0.06	610.2±18.68a
75%ET$_c$+F	6.1±0.23	9.8±0.76d	1.1±0.11d	8.9±1.12b	342.3±8.15de	198.8±9.33e	8.7±0.11a	8.6±0.92a	10.7±0.89d	0.9±0.18	0.30±0.04c	0.5±0.05d	0.3±0.02	0.5±0.06	425.7±8.99c
CROPWAT+RB	6.2±0.38	15.5±0.81bc	1.7±0.12ab	12.2±1.87ab	381.2±7.30bc	304.2±27.17cd	3.5±0.16f	3.5±1.07b	12.6±0.69bcd	0.7±0.07	0.51±0.09bc	1.3±0.04a	0.3±0.03	0.4±0.06	200.0±13.67e
CROPWAT+R	6.1±0.25	18.9±1.14ab	1.8±0.11ab	16.5±2.50a	409.0±8.63ab	412.5±23.24ab	4.1±0.11e	5.0±1.39b	11.7±1.05cd	0.8±0.04	0.47±0.07bc	1.2±0.05a	0.3±0.03	0.4±0.05	187.8±9.65e
CROPWAT+F	6.0±0.26	16.2±1.64b	1.6±0.07bc	11.1±1.37ab	432.0±17.30a	445.2±46.59a	3.4±0.15f	8.8±0.42a	14.6±0.77abc	0.8±0.06	0.64±0.06bc	1.1±0.15ab	0.3±0.02	0.4±0.05	164.8±8.51ef
S.E.D	ns	1.51	0.16	2.43	12.61	41.44	0.18	0.87	1.20	ns	0.15	0.10	ns	ns	21.55
CV (%)	10.7	13.7	14.1	22.4	4.7	21.8	4.9	13.5	14.9	18.9	36.4	13.4	17.3	30.5	10.0

Means with the same letter(s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 30: Effect of irrigation rate × mulch on soil chemical properties in 2015/2016

Treatment	pH	TOC	TN	Avail P	Mn	Fe	Cu	Zn	Pb	K	Ca	Mg	Na	Ex. Acidity	EC
		g kg^{-1}		mg kg^{-1}						cmol kg^{-1}					(µS cm^{-1})
100%ET_c+GsM	6.0±0.26	18.0±1.01	1.8±0.08	14.6±2.42ab	359.0±8.53	292.0±25.69	6.2±0.40b	6.6±1.01	16.8±1.41a	0.8±0.05	1.1±0.37a	1.0±0.09	0.4±0.02	0.4±0.04	248.8±50.64
100%ET_c+PpM	5.9±0.26	16.5±1.10	1.6±0.18	18.6±3.59a	327.7±10.40	344.2±26.66	5.2±0.26c	5.6±0.50	12.1±0.83bc	0.9±0.09	0.2±0.03c	1.0±0.05	0.3±0.02	0.4±0.05	151.3±10.54
100%ET_c+ZM	5.9±0.30	13.3±1.05	1.6±0.11	12.9±0.78ab	350.0±10.72	302.3±29.72	5.8±0.35bc	6.1±0.29	14.8±0.83ab	0.7±0.06	0.7±0.30abc	1.2±0.08	0.3±0.03	0.3±0.05	204.2±42.45
75%ET_c+GsM	6.2±0.31	17.2±2.61	1.7±0.22	10.9±1.02b	376.8±12.92	280.2±52.21	8.5±0.13a	8.6±0.59	10.5±0.98c	0.8±0.05	0.3±0.02c	0.7±0.08	0.3±0.03	0.5±0.07	529.3±37.22
75%ET_c+PpM	6.1±0.21	16.1±1.55	1.6±0.14	11.9±1.77ab	359.7±6.98	263.5±30.41	8.4±0.16a	7.8±0.49	12.1±0.90bc	1.0±0.17	1.1±0.28a	0.7±0.06	0.4±0.02	0.4±0.05	518.5±35.39
75%ET_c+ZM	6.2±0.45	14.0±1.37	1.6±0.20	15.5±2.86ab	402.0±16.55	222.7±10.41	8.8±0.19a	9.6±0.87	12.8±0.86bc	0.8±0.06	0.3±0.05c	0.8±0.08	0.3±0.02	0.4±0.06	531.0±31.77
CROPWAT+GsM	6.1±0.26	18.4±1.54	1.9±0.08	16.5±2.55ab	408.8±16.12	342.0±27.71	3.7±0.11d	6.9±1.39	12.0±0.95bc	0.8±0.05	0.5±0.07abc	1.1±0.09	0.4±0.03	0.4±0.05	175.0±5.08
CROPWAT+PpM	6.1±0.29	15.7±0.81	1.8±0.11	12.0±1.97ab	412.2±15.35	411.0±48.71	3.4±0.21d	5.7±1.10	12.6±1.01bc	0.8±0.06	0.6±0.07abc	1.3±0.11	0.3±0.02	0.4±0.06	193.5±13.57
CROPWAT+ZM	6.1±0.35	16.5±1.36	1.4±0.07	11.2±1.13b	401.2±6.59	408.8±31.93	3.9±0.12d	4.7±1.13	14.3±0.63ab	0.8±0.06	0.5±0.08bc	1.2±0.06	0.3±0.03	0.5±0.05	184.2±13.60
S.E.D	ns	ns	ns	2.80	ns	ns	0.14	ns	1.04	ns	0.14	ns	ns	ns	ns
CV (%)	10.7	13.7	14.1	22.4	4.7	21.8	4.9	13.5	14.9	18.9	36.4	13.4	17.3	30.5	10.0

Means with the same letter(s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, GsM = *Gliricidia sepium* mulch, PM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 31: Effect of land preparation × mulch on soil chemical properties in 2015/2016

Treatment	pH	TOC	TN	Avail P	Mn	Fe	Cu	Zn	Pb	K	Ca	Mg	Na	Ex. Acidity	EC
		g kg^{-1}		mg kg^{-1}						cmol kg^{-1}					(µS cm^{-1})
RB+GsM	6.1±0.25	18.9±2.30	1.9±0.19a	15.2±1.34	368.7±9.03	356.3±51.68	5.6±0.61	6.7±1.50abc	13.8±1.27ab	0.8±0.06	0.3±0.02c	1.1±0.08ab	0.4±0.03	0.3±0.03bc	307.2±68.71
RB+PpM	6.2±0.36	16.1±1.19	1.6±0.17ab	13.6±2.48	365.0±9.57	331.7±25.83	5.0±0.65	7.9±0.63ab	13.6±0.83ab	0.8±0.09	1.1±0.28ab	1.0±0.09abc	0.4±0.02	0.4±0.06abc	275.5±41.23
RB+ZM	6.1±0.39	13.9±1.45	1.6±0.13ab	14.9±2.75	392.7±9.79	322.0±23.62	5.5±0.56	5.4±0.95bc	13.4±0.55abc	0.8±0.07	0.3±0.04c	1.2±0.06a	0.3±0.03	0.4±0.06abc	306.5±61.61
R+GsM	6.2±0.29	19.5±1.13	1.7±0.10ab	15.1±2.50	405.5±9.12	325.2±22.40	6.8±0.68	8.5±0.70a	13.5±1.59ab	0.9±0.04	1.3±0.34a	0.9±0.08bc	0.4±0.03	0.5±0.06a	412.0±50.32
R+PpM	6.0±0.20	18.5±0.83	2.0±0.11a	14.6±1.33	370.7±14.24	346.8±40.31	6.4±0.54	4.3±0.85c	10.2±0.69c	0.8±0.05	0.4±0.03c	1.1±0.07ab	0.3±0.02	0.4±0.05abc	363.7±67.24
R+ZM	6.1±0.44	15.0±0.42	1.7±0.15ab	13.5±1.18	393.7±15.99	294.8±26.51	6.8±0.66	6.3±0.98abc	15.7±0.72a	0.8±0.05	0.7±0.30bc	0.9±0.06abc	0.3±0.03	0.4±0.05abc	364.8±60.52
F+GsM	6.0±0.30	15.2±1.64	1.8±0.12ab	11.8±2.47	370.5±19.30	232.7±20.61	6.1±0.58	6.9±0.78abc	12.0±1.22bc	0.8±0.05	0.4±0.06c	0.8±0.12c	0.3±0.02	0.4±0.06abc	234.0±40.27
F+PpM	5.9±0.15	13.7±1.07	1.4±0.09ab	14.3±3.82	363.8±20.66	340.2±51.93	5.6±0.70	6.9±0.51abc	13.0±0.88abc	1.0±0.18	0.4±0.06c	0.9±0.14bc	0.3±0.02	0.3±0.04bc	224.2±41.98
F+ZM	6.1±0.27	14.8±1.73	1.3±0.11b	11.3±1.15	366.8±14.15	317.0±47.95	6.3±0.68	8.7±0.94a	12.8±0.87abc	0.7±0.05	0.4±0.08c	1.1±0.11ab	0.3±0.02	0.5±0.04a	248.0±42.56
S.E.D	Ns	ns	0.14	ns	ns	ns	ns	0.73	1.25	ns	0.14	0.10	ns	0.07	ns
CV (%)	10.7	13.7	14.1	22.4	4.7	21.8	4.9	13.5	14.9	18.9	36.4	13.4	17.3	30.5	10.0

Means with the same letter(s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 32: Irrigation rate × land preparation × mulch interaction on soil chemical properties in 2015/2016

Treatment	pH	TOC	TN	Avail P	Mn	Fe	Cu	Zn	Pb	K	Ca	Mg	Na	Ex. Acidity	EC
		g kg^{-1}		mg kg^{-1}						cmol kg^{-1}					($\mu S\ cm^{-1}$)
100%ET_c+RB+GsM	6.0±0.21	15.3±1.79	1.7±0.17b-e	16.7±2.68	353.0±16.87	336.5±56.96b-h	4.9±0.33hi	10.1±2.02abc	18.0±0.91	0.8±0.08	0.4±0.02de	1.2±0.13	0.3±0.06	0.3±0.04	149.5±12.28f
100%ET_c+RB+PpM	6.0±0.82	12.4±0.74	1.0±0.16gh	18.2±3.99	348.0±17.38	371.5±37.36b-e	4.2±0.07jk	7.1±1.22c-i	13.3±2.22	0.9±0.26	0.2±0.07e	0.9±0.09	0.4±0.03	0.5±0.10	145.0±7.94f
100%ET_c+RB+ZM	5.8±0.57	9.6±2.10	1.3±0.10e-h	13.6±1.32	393.0±17.38	362.5±28.87b-g	4.3±0.15ijk	6.4±0.57d-i	13.8±0.45	0.7±0.07	0.3±0.08de	1.3±0.10	0.3±0.05	0.3±0.09	144.0±6.06f
100%ET_c+R+GsM	6.1±0.41	18.3±1.85	1.6±0.03b-f	11.2±2.22	381.0±10.21	336.5±6.34b-h	7.8±0.38e	5.5±0.74e-i	19.4±2.84	0.8±0.06	2.9±0.14a	0.7±0.07	0.4±0.04	0.5±0.06	484.0±13.03cd
100%ET_c+R+PpM	5.8±0.08	19.7±1.82	2.2±0.27ab	14.0±2.33	323.5±20.76	386.5±17.08b-e	6.2±0.21fg	5.0±0.18f-i	11.9±0.44	1.0±0.06	0.3±0.06de	1.2±0.06	0.3±0.03	0.3±0.06	192.0±13.93f
100%ET_c+R+ZM	6.0±0.69	15.0±0.42	1.9±0.22a-e	12.7±1.72	331.0±5.45	284.5±67.97d-h	6.8±0.41f	5.5±0.65e-i	17.5±0.78	0.8±0.14	1.6±0.79c	0.9±0.13	0.4±0.09	0.3±0.06	351.5±92.68e
100%ET_c+F+GsM	5.9±0.71	20.4±0.26	2.0±0.07abc	15.9±6.81	343.0±12.36	203.0±3.51gh	6.0±0.20g	4.2±0.31hij	13.0±2.32	0.8±0.12	0.2±0.06e	1.1±0.16	0.4±0.02	0.3±0.09	113.0±2.92f
100%ET_c+F+PpM	5.9±0.16	17.3±0.44	1.7±0.10b-f	23.7±10.21	311.5±15.02	274.5±60.56d-h	5.2±0.04h	4.7±0.20ghi	11.3±1.30	0.8±0.09	0.2±0.02e	0.9±0.02	0.3±0.06	0.4±0.05	117.0±2.48f
100%ET_c+F+ZM	5.9±0.42	15.4±0.67	1.6±0.08b-f	12.5±1.33	326.0±1.63	260.0±48.53d-h	6.3±0.17fg	6.3±0.05d-i	13.1±1.73	0.6±0.05	0.3±0.09de	1.3±0.06	0.3±0.03	0.5±0.09	117.0±14.73f
75%ET_c+RB+GsM	6.5±0.58	23.3±6.58	2.4±0.47a	13.6±1.23	389.5±17.93	419.5±140.59a-d	8.3±0.27cde	9.4±1.40a-d	12.5±2.44	0.8±0.10	0.3±0.02e	0.8±0.14	0.4±0.04	0.4±0.05	599.50±94.44ab
75%ET_c+RB+PpM	6.1±0.41	20.6±1.76	1.7±0.23b-e	10.5±4.36	357.0±3.70	398.5±10.24a-d	7.9±0.10e	8.2±1.48a-f	12.8±1.11	0.8±0.07	2.4±0.18b	0.8±0.09	0.4±0.03	0.3±0.06	460.5±18.70d
75%ET_c+RB+ZM	6.3±0.77	19.2±0.94	2.1±0.09ab	22.0±7.22	395.0±27.18	229.0±30.18e-h	8.1±0.21de	8.4±0.96a-e	14.2±1.42	1.0±0.11	0.3±0.04de	1.0±0.09	0.2±0.02	0.3±0.12	569.0±72.22bc
75%ET_c+R+GsM	6.2±0.65	17.4±0.89	1.4±0.08c-g	11.6±1.35	416.0±3.11	231.5±14.31e-h	8.9±0.15abc	9.4±0.48a-d	10.5±1.20	0.9±0.08	0.3±0.06de	0.7±0.06	0.3±0.07	0.6±0.15	569.0±8.35bc
75%ET_c+R+PpM	6.2±0.43	18.0±1.39	1.9±0.14a-d	16.4±1.79	373.5±14.91	190.0±7.82h	8.6±0.38bcd	7.4±0.21b-h	10.1±1.44	0.8±0.11	0.4±0.05de	0.8±0.05	0.3±0.04	0.5±0.11	675.5±25.72a
75%ET_c+R+ZM	6.2±1.23	14.2±1.06	1.9±0.38a-e	14.3±2.22	457.5±10.51	234.0±9.87e-h	9.4±0.07a	9.4±0.75a-d	13.8±1.54	0.8±0.04	0.4±0.12de	0.9±0.13	0.3±0.02	0.5±0.09	586.0±30.40ab
75%ET_c+F+GsM	6.1±0.54	11.0±2.23	1.4±0.26d-h	7.6±1.32	325.0±6.76	189.5±4.11h	8.4±0.20b-e	7.1±0.68c-i	8.4±0.60	0.7±0.07	0.3±0.03e	0.4±0.08	0.3±0.02	0.6±0.10	419.5±7.85de
75%ET_c+F+PpM	6.0±0.38	9.8±0.66	1.1±0.08fgh	8.7±1.21	348.5±13.87	202.0±29.52gh	8.6±0.08bcd	7.8±0.51a-g	13.4±1.90	1.3±0.52	0.4±0.04de	0.4±0.06	0.4±0.02	0.4±0.10	419.5±12.80de
75%ET_c+F+ZM	6.3±0.35	8.6±0.09	0.9±0.02h	10.3±3.04	353.5±18.37	205.0±4.85fgh	9.0±0.21ab	11.0±2.40a	10.3±0.75	0.7±0.09	0.3±0.09e	0.6±0.11	0.4±0.05	0.5±0.10	438.0±24.24de
CRW+RB+GsM	6.0±0.49	18.0±0.48	1.7±0.14b-f	15.3±3.10	363.5±7.44	313.0±65.47c-h	3.7±0.18kl	0.6±0.14k	10.9±1.35	0.7±0.13	0.3±0.04e	1.2±0.08	0.4±0.02	0.3±0.05	172.5±6.18f
CRW+RB+PpM	6.6±0.74	15.4±0.83	2.1±0.14ab	12.0±4.65	390.0±19.11	225.0±5.45e-h	2.8±0.03n	8.3±0.60a-f	14.8±0.78	0.7±0.08	0.9±0.06d	1.4±0.05	0.3±0.03	0.5±0.15	221.0±14.38f
CRW+RB+ZM	6.0±0.86	12.9±1.44	1.3±0.12d-h	9.1±0.91	390.0±2.97	374.5±6.55b-e	4.0±0.05jkl	1.5±0.53jk	12.0±0.46	0.7±0.16	0.4±0.10de	1.3±0.07	0.3±0.05	0.6±0.09	206.5±37.38f
CRW+R+GsM	6.2±0.57	22.9±2.02	2.2±0.07ab	22.5±5.91	419.5±22.35	407.5±6.89a-d	3.7±0.23jkl	10.5±0.14ab	10.7±1.10	0.9±0.08	0.8±0.06de	1.2±0.09	0.3±0.05	0.5±0.08	183.0±13.53f
CRW+R+PpM	5.9±0.50	17.8±1.24	1.8±0.16a-e	13.5±3.04	415.0±13.31	464.0±65.00abc	4.4±0.08ij	0.6±0.10k	8.7±1.10	0.8±0.09	0.4±0.07de	1.3±0.08	0.3±0.06	0.4±0.06	223.5±9.24f
CRW+R+ZM	6.1±0.31	15.9±0.41	1.4±0.16c-g	13.6±2.67	392.5±1.71	366.0±7.33b-f	4.2±0.08jk	4.0±2.12ij	15.8±0.74	0.8±0.08	0.2±0.05e	1.1±0.03	0.3±0.03	0.3±0.08	157.0±2.48f
CRW+F+GsM	6.0±0.41	14.3±3.05	1.9±0.08a-e	11.8±2.69	443.5±34.37	305.5±44.26c-h	3.8±0.23jkl	9.6±1.13a-d	14.5±1.99	0.8±0.07	0.6±0.07de	0.8±0.22	0.3±0.05	0.3±0.08	169.5±5.36f
CRW+F+PpM	5.9±0.25	13.9±1.54	1.4±0.10c-g	10.6±3.22	431.5±41.94	544.0±58.95a	3.0±0.13mn	8.2±0.25a-f	14.5±1.22	0.8±0.15	0.5±0.13de	1.2±0.35	0.3±0.03	0.3±0.09	136.0±8.83f
CRW+F+ZM	6.2±0.70	20.5±2.94	1.6±0.03b-g	11.0±1.67	421.0±16.36	486.0±90.14ab	3.5±0.24lm	8.7±0.56a-e	15.0±1.02	0.8±0.10	0.8±0.07de	1.3±0.14	0.3±0.06	0.6±0.05	189.0±14.51f
S.E.D	ns	ns	0.24	ns	ns	65.88	0.29	1.39	ns	ns	0.24	ns	ns	ns	46.59
CV (%)	19.7	21.7	18.1	49.2	9.7	27.8	6.4	27.3	22.0	35.1	51.4	24.9	24.9	41.0	23.5

Means with the same letter(s) under the same category in a column are not significantly different at $p = 0.05$, ns = not significantly different at $p = 0.05$, CRW = CROPWAT, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 33: Effect of irrigation rate × land preparation on soil chemical properties in 2016/2017

Treatment	pH	TOC	TN	Avail P	Mn	Fe	Cu	Zn	Pb	K	Ca	Mg	Na	Ex. Acidity	EC
		g kg^{-1}		mg kg^{-1}						cmol kg^{-1}					µS cm^{-1}
100%ET$_c$+RB	6.8±0.03ab	19.5±0.53bcd	1.8±0.09cd	5.4±0.88b	92.0±2.26b	14.8±0.67bc	1.4±0.07	8.2±0.02bc	1.4±0.19b	0.2±0.04b	3.1±0.03a	0.9±0.04c	0.9±0.02	0.3±0.03ab	222.0±6.69bc
100%ET$_c$+R	6.8±0.01ab	17.5±0.62d	1.8±0.06cd	15.4±2.68a	85.9±1.15bc	19.5±3.85b	1.3±0.04	13.2±2.64a	1.5±0.12ab	0.2±0.03b	2.8±0.16abc	0.9±0.03c	0.8±0.01	0.3±0.03ab	220.0±6.87bc
100%ET$_c$+F	6.7±0.02bc	20.4±0.88b	2.0±0.14bcd	10.5±1.19ab	88.5±1.04b	24.8±3.35a	1.1±0.05	12.5±1.43a	1.5±0.21ab	0.2±0.01b	2.6±0.16c	1.0±0.04bc	0.9±0.01	0.2±0.00b	255.0±10.38a
75%ET$_c$+RB	6.8±0.03ab	18.6±0.77bcd	1.9±0.07bcd	15.9±3.23a	98.8±2.75a	8.0±0.52d	1.1±0.06	8.2±0.29bc	0.7±0.14d	0.2±0.01b	2.3±0.03d	1.2±0.04a	0.9±0.01	0.3±0.03ab	230.0±9.13bc
75%ET$_c$+R	6.8±0.01ab	18.0±0.91bcd	1.9±0.06bcd	10.8±1.32ab	80.8±2.23c	9.4±0.27cd	1.0±0.05	6.6±0.29bc	1.9±0.07a	0.2±0.01b	2.6±0.09c	1.1±0.02ab	0.9±0.01	0.2±0.02b	218.3±3.33bc
75%ET$_c$+F	6.8±0.01ab	20.3±0.76bc	2.1±0.08abc	10.0±1.38ab	81.1±0.91c	7.8±0.28d	0.9±0.12	5.4±0.06c	1.7±0.09ab	0.2±0.01b	2.8±0.04abc	1.1±0.02ab	0.9±0.03	0.3±0.03ab	211.7±8.29c
CROPWAT+RB	6.7±0.07bc	23.0±0.50a	2.3±0.04a	10.7±2.00ab	85.9±3.50bc	9.1±0.50d	1.1±0.05	9.2±0.11b	1.3±0.07bc	0.2±0.01b	3.1±0.08a	1.2±0.05a	0.9±0.02	0.4±0.02a	230.0±6.61bc
CROPWAT+R	6.7±0.02bc	23.7±0.80a	2.2±0.07ab	11.7±1.47a	92.7±2.46ab	12.0±1.02cd	1.2±0.03	8.7±0.16b	1.3±0.13bc	0.3±0.02a	3.0±0.07ab	1.1±0.04ab	0.8±0.02	0.3±0.03ab	241.7±7.45ab
CROPWAT+F	6.9±0.02a	17.9±1.12cd	1.7±0.12d	9.9±1.33ab	89.7±2.03b	11.2±0.83cd	1.2±0.03	8.4±0.08bc	1.0±0.08cd	0.2±0.03b	2.8±0.06abc	1.1±0.05ab	0.8±0.02	0.3±0.03ab	211.7±6.46c
S.E.D	0.04	0.67	0.06	2.18	3.32	1.73	ns	0.41	0.10	0.02	0.13	0.07	ns	0.02	8.06
CV (%)	0.6	4.5	4.5	26.5	5.0	17.7	9.8	6.8	10.1	11.5	6.3	6.1	3.2	6.9	5.2

Means with the same letter (s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 34: Irrigation rate × mulch interaction on soil chemical properties in 2016/2017

Treatment	pH	TOC	TN	Avail P	Mn	Fe	Cu	Zn	Pb	K	Ca	Mg	Na	Ex. Acidity	EC
		g kg^{-1}		mg kg^{-1}						cmol kg^{-1}					µS cm^{-1}
100%ET$_c$+GsM	6.7±0.04b	20.5±0.87	2.1±0.09	10.3±1.63	91.4±2.11	19.3±3.47ab	1.3±0.04a	10.9±1.43ab	1.9±0.08a	0.3±0.03a	2.8±0.08bc	0.9±0.02c	0.9±0.01a	0.3±.0.03	240.3±9.03a
100%ET$_c$+PpM	6.8±0.02a	19.0±0.62	1.8±0.10	13.8±2.80	87.4±1.17	15.6±2.77bc	1.2±0.10ab	9.8±1.03bc	1.4±0.16bc	0.2±0.03b	3.1±0.15a	1.0±0.03b	0.9±0.02a	0.3±0.03	235.0±12.02a
100%ET$_c$+ZM	6.8±0.02a	17.8±0.62	1.7±0.08	7.3±1.56	87.6±1.64	24.2±2.88a	1.2±0.05ab	13.1±2.65a	1.1±0.14c	0.2±0.02b	2.6±0.14bcd	0.9±0.04c	0.9±0.01a	0.2±0.02	221.7±6.87ab
75%ET$_c$+GsM	6.8±0.01a	18.8±0.90	2.0±0.09	12.4±1.06	88.9±3.84	9.0±0.35d	1.2±0.04ab	6.6±0.50c	1.2±0.25bc	0.2±0.01b	2.5±0.08cd	1.1±0.02ab	0.8±0.02b	0.3±0.03	226.7±6.18ab
75%ET$_c$+PpM	6.8±0.02a	19.4±1.02	1.9±0.08	15.3±3.36	87.2±3.44	8.5±0.49d	1.1±0.06ab	6.9±0.53c	1.6±0.22ab	0.2±0.01b	2.5±0.10cd	1.2±0.04a	0.9±0.02a	0.3±0.03	225.0±10.41ab
75%ET$_c$+ZM	6.8±0.02a	18.7±0.67	2.0±0.06	9.0±1.33	84.6±3.52	7.8±0.39d	0.8±0.10c	6.7±0.39c	1.5±0.09abc	0.2±0.01b	2.6±0.08bcd	1.1±0.03ab	0.9±0.01a	0.2±0.00	208.3±3.54b
CROPWAT+GsM	6.7±0.03b	23.4±0.93	2.2±0.08	10.7±1.44	91.7±2.73	12.1±1.01cd	1.2±0.02ab	8.6±0.11bc	1.4±0.12bc	0.2±0.03b	2.9±0.03ab	1.1±0.05ab	0.8±0.02b	0.3±0.03	228.3±4.00ab
CROPWAT+PpM	6.7±0.08b	20.6±1.29	2.1±0.08	10.7±1.91	88.9±3.72	9.5±0.33d	1.0±0.04b	8.9±0.18bc	1.2±0.07bc	0.2±0.01b	3.2±0.08a	1.1±0.05ab	0.9±0.02a	0.3±0.03	215.0±5.65ab
CROPWAT+ZM	6.8±0.02a	20.6±1.22	1.9±0.14	10.9±1.55	87.7±1.73	10.8±1.00cd	1.2±0.02ab	8.7±0.17bc	1.1±0.12c	0.2±0.01b	2.8±0.07bc	1.2±0.05a	0.8±0.01b	0.3±0.03	240.0±10.54a
S.E.D	0.03	ns	ns	ns	ns	1.41	0.04	0.40	0.10	0.01	0.08	0.05	0.02	ns	6.97
CV (%)	0.6	4.5	4.5	26.5	5.0	17.7	9.8	6.8	10.1	11.5	6.3	6.1	3.2	6.9	5.2

Means with the same letter (s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 35: Effect of land preparation × mulch on soil chemical properties in 2016/2017

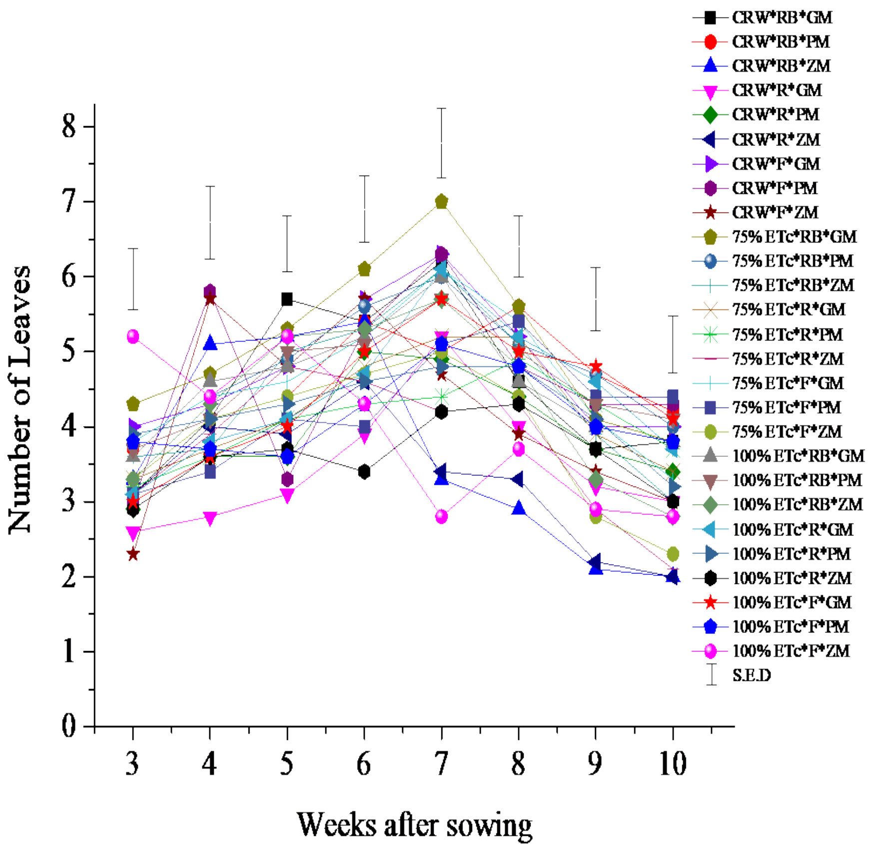
Treatment	pH	TOC	TN	Avail P	Mn	Fe	Cu	Zn	Pb	K	Ca	Mg	Na	Ex. Acidity	EC
		g kg^{-1}		mg kg^{-1}						cmol kg^{-1}					(μS cm^{-1})
RB+GsM	6.8±0.02a	20.1±0.93abc	2.0±0.06ab	8.5±1.24bc	97.1±2.75a	11.0±0.78ab	1.2±0.02ab	8.5±0.11b	1.2±0.27bcd	0.2±0.02b	2.7±0.12ab	1.0±0.04b	0.8±0.01b	0.3±0.03	227.0±5.33
RB+PpM	6.7±0.08b	19.6±0.76abc	2.0±0.11ab	15.6±3.66a	90.9±4.28ab	10.8±1.23ab	1.3±0.09a	8.9±0.18b	1.0±0.08d	0.2±0.02b	2.9±0.17a	1.2±0.06a	0.9±0.01a	0.3±0.03	231.7±9.86
RB+ZM	6.8±0.02a	21.4±0.91a	2.1±0.11ab	8.0±1.64c	88.7±2.18b	10.1±1.46b	1.2±0.08ab	8.2±0.31b	1.3±0.12a-d	0.2±0.02b	2.9±0.12a	1.1±0.10ab	0.9±0.01a	0.3±0.03	223.3±6.87
R+GsM	6.8±0.03a	20.6±1.41ab	2.0±0.10ab	13.4±1.14abc	90.6±2.92ab	12.1±1.04ab	1.3±0.03a	7.4±0.36b	1.7±0.08a	0.3±0.03a	2.8±0.06ab	1.0±0.06b	0.8±0.02b	0.3±0.03	233.3±4.17
R+PpM	6.8±0.00a	20.3±1.28abc	1.9±0.09b	14.6±2.57ab	86.0±1.74b	10.7±0.50ab	1.1±0.04abc	7.8±0.43b	1.8±0.13a	0.2±0.01b	3.0±0.18a	1.1±0.03ab	0.8±0.01b	0.3±0.03	216.7±4.08
R+ZM	6.8±0.02a	18.2±0.83bc	1.9±0.05b	9.9±1.79abc	82.9±2.45b	18.2±4.18a	1.1±0.06abc	13.3±2.60a	1.3±0.13bcd	0.2±0.02b	2.6±0.07b	1.0±0.03b	0.9±0.01a	0.3±0.03	230.0±10.1
F+GsM	6.7±0.03b	21.9±0.83a	2.2±0.10a	11.5±1.34abc	84.4±0.99b	17.3±3.96ab	1.2±0.05ab	10.2±1.68ab	1.6±0.15ab	0.2±0.02b	2.7±0.07ab	1.1±0.05ab	0.8±0.02b	0.3±0.03	235.0±9.97
F+PpM	6.8±0.02a	19.1±0.97abc	1.9±0.08b	9.7±1.29abc	86.6±2.02b	12.0±3.12ab	1.0±0.04c	9.0±1.27b	1.5±0.18abc	0.2±0.01b	2.9±0.11a	1.1±0.04ab	0.9±0.02a	0.3±0.03	226.7±13.46
F+ZM	6.8±0.02a	17.4±0.44c	1.6±0.08c	9.2±1.13bc	88.4±2.33b	14.4±2.23ab	1.0±0.12c	7.1±0.47b	1.1±0.14cd	0.2±0.02b	2.6±0.08b	1.1±0.04ab	0.9±0.02a	0.2±0.00	216.7±8.54
														0.3±0.01	
S.E.D	0.03	0.89	0.10	1.95	2.87	1.58	0.06	0.48	0.11	0.02	0.11	0.04	0.02	ns	ns
CV (%)	0.6	4.5	4.5	26.5	5.0	17.7	9.8	6.8	10.1	11.5	6.3	6.1	3.2	6.9	5.2

Means with the same letter (s) under the same category in a column are not significantly different at $p = 0.05$, ns = not significantly different at $p = 0.05$, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 36: Irrigation rate × land preparation × mulch effect on soil chemical properties in 2016/2017

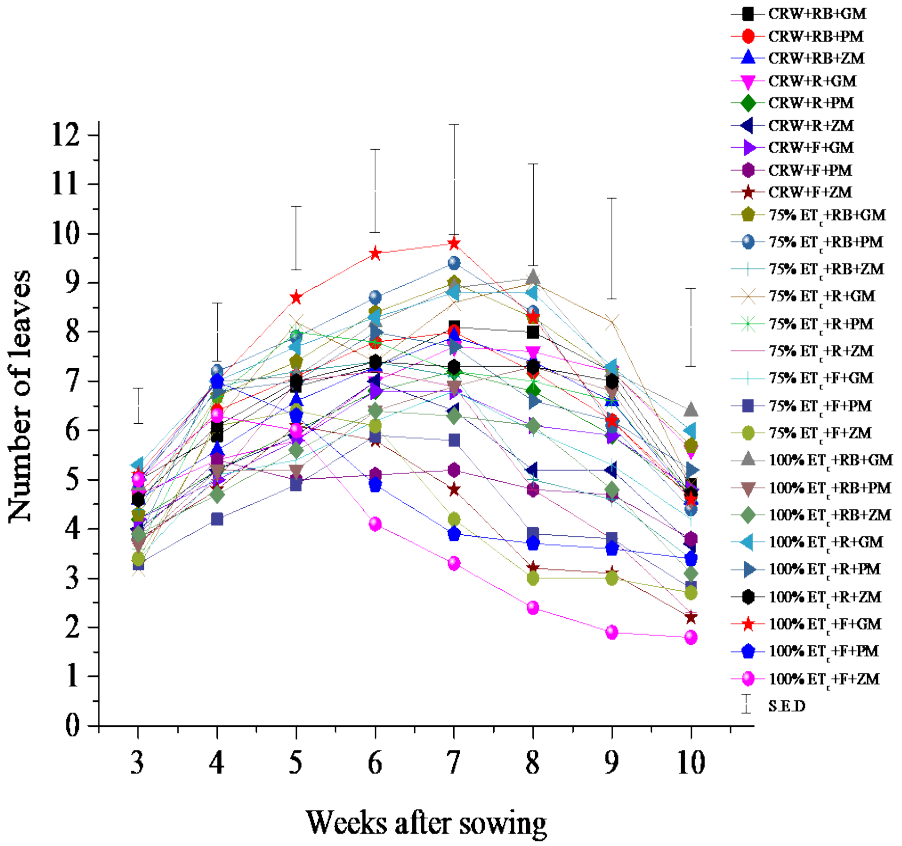
Treatment	pH	TOC	TN	Avail P	Mn	Fe	Cu	Zn	Pb	K	Ca	Mg	Na	Ex. Acidity	EC
		g kg^{-1}		mg kg^{-1}						cmol kg^{-1}					(µS cm^{-1})
100%ET$_c$+RB+GsM	6.7±0.06b	20.8±1.00	2.0±0.02	7.1±1.82de	99.3±1.30ab	13.7±0.95c-g	1.2±0.03bcd	8.2±0.04de	2.0±0.01ab	0.3±0.02a	3.0±0.02b-e	0.9±0.02de	0.8±0.01ab	0.3±0.06	226.0±15.01
100%ET$_c$+RB+PpM	6.9±0.03a	18.6±0.72	1.7±0.21	6.3±0.27de	90.3±1.88a-f	15.3±0.72c-f	1.6±0.07a	8.2±0.01de	0.9±0.13jk	0.1±0.05b	3.1±0.01abc	0.9±0.01de	0.9±0.02a	0.3±0.06	220.0±17.32
100%ET$_c$+RB+ZM	6.9±0.03a	18.9±0.62	1.7±0.16	2.8±0.78e	86.4±3.52g-g	15.6±1.70cde	1.4±0.06ab	8.1±0.02de	1.4±0.36e-i	0.3±0.03a	3.1±0.05abc	0.7±0.05f	0.9±0.02a	0.3±0.06	220.0±0.00
100%ET$_c$+R+GsM	6.9±0.03a	18.1±1.00	1.8±0.03	14.9±3.37a-d	88.3±1.30b-g	11.3±0.26d-h	1.4±0.03ab	8.0±0.17de	1.8±0.02a-e	0.3±0.03a	2.9±0.04b-f	0.8±0.02ef	0.9±0.02a	0.3±0.06	240.0±11.55
100%ET$_c$+R+PpM	6.8±0.00ab	18.2±1.08	1.8±0.14	21.6±5.61ab	84.6±2.08c-g	12.4±0.52d-h	1.2±0.04bcd	8.0±0.10de	1.7±0.16b-e	0.2±0.02ab	3.2±0.38ab	1.0±0.03cde	0.8±0.01ab	0.3±0.06	210.0±11.55
100%ET$_c$+R+ZM	6.8±0.00ab	16.2±1.08	1.7±0.12	9.6±2.73cde	85.0±2.43c-g	34.9±0.49a	1.3±0.06bcd	23.5±1.85a	1.1±0.07ijk	0.2±0.01ab	2.4±0.04e-i	0.9±0.04de	0.9±0.03a	0.2±0.00	210.0±0.00
100%ET$_c$+F+GsM	6.7±0.03b	22.6±1.43	2.4±0.14	8.7±0.40cde	86.8±1.88c-g	33.1±0.23a	1.3±0.03bcd	16.6±0.84b	2.0±0.22ab	0.2±0.01ab	2.5±0.06d-i	0.9±0.04de	0.9±0.02a	0.2±0.00	255.0±20.21
100%ET$_c$+F+PpM	6.8±0.03ab	20.2±1.36	1.9±0.20	13.5±1.91bcd	87.4±0.78c-g	19.0±8.95bc	0.9±0.07ef	13.3±1.97c	1.7±0.26b-e	0.2±0.02ab	3.1±0.35abc	1.1±0.07abc	0.9±0.03a	0.2±0.00	275.0±8.66
100%ET$_c$+F+ZM	6.8±0.03ab	18.4±1.01	1.7±0.18	9.4±2.52cde	91.5±1.44a-f	22.3±0.43b	1.1±0.01cde	7.7±0.23def	0.8±0.01k	0.2±0.01ab	2.3±0.04i	0.9±0.05de	0.8±0.01ab	0.2±0.00	235.0±20.21
75%ET$_c$+RB+GsM	6.8±0.00ab	16.7±0.22	1.8±0.03	10.9±0.52cde	100.8±7.94a	9.8±0.61d-h	1.2±0.03bcd	8.6±0.20de	0.2±0.04l	0.2±0.01ab	2.2±0.02i	1.1±0.06abc	0.9±0.01a	0.3±0.06	230.0±5.77
75%ET$_c$+RB+PpM	6.9±0.00a	18.0±1.22	1.9±0.14	23.3±9.03a	100.0±4.00a	7.2±0.62h	1.3±0.03bcd	9.0±0.03de	0.8±0.01k	0.2±0.01ab	2.3±0.05i	1.3±0.06a	0.9±0.03a	0.3±0.06	250.0±23.09
75%ET$_c$+RB+ZM	6.7±0.00b	21.1±0.72	2.2±0.09	13.6±0.83bcd	95.8±2.17abc	7.1±0.43h	0.9±0.12ef	7.1±0.12efg	1.2±0.01g-k	0.2±0.01ab	2.4±0.04e-i	1.2±0.06ab	0.9±0.01a	0.2±0.00	210.0±5.77
75%ET$_c$+R+GsM	6.8±0.03ab	17.8±1.26	1.9±0.13	13.0±0.83bcd	82.3±2.17d-g	9.0±0.34fgh	1.2±0.02bcd	6.0±0.10fgh	1.8±0.08a-e	0.2±0.01ab	2.6±0.15c-i	1.1±0.04abc	0.9±0.01a	0.3±0.06	225.0±2.89
75%ET$_c$+R+PpM	6.8±0.00ab	18.8±2.71	1.8±0.13	13.4±0.89bcd	81.8±0.14efg	10.1±0.53d-h	0.9±0.04ef	6.2±0.15fgh	2.2±0.02a	0.2±0.01ab	2.5±0.17d-i	1.1±0.05abc	0.8±0.03ab	0.2±0.00	220.0±5.77
75%ET$_c$+R+ZM	6.8±0.00ab	17.4±0.72	2.0±0.02	6.0±1.39de	78.3±7.07g	9.1±0.29fgh	0.9±0.08ef	7.7±0.33def	1.8±0.02a-e	0.2±0.01ab	2.7±0.16c-h	1.0±0.04cde	0.9±0.01a	0.2±0.00	210.0±5.77
75%ET$_c$+F+GsM	6.8±0.03ab	21.8±1.03	2.3±0.09	13.4±3.27bcd	83.8±1.88d-g	8.2±0.61gh	1.1±0.13cde	5.3±0.09h	1.5±0.16d-i	0.2±0.02ab	2.6±0.04d-i	1.1±0.04abc	0.8±0.02ab	0.3±0.06	225.0±20.21
75%ET$_c$+F+PpM	6.8±0.00ab	21.4±0.63	2.1±0.07	9.2±0.78cde	79.8±1.01fg	8.1±0.14gh	1.1±0.08cde	5.5±0.12gh	1.9±0.11a-d	0.2±0.03ab	2.8±0.07b-g	1.1±0.03abc	0.9±0.04a	0.3±0.06	205.0±14.43
75%ET$_c$+F+ZM	6.8±0.00ab	17.6±0.29	1.8±0.02	7.34±1.39de	79.8±0.14fg	7.2±0.49h	0.6±0.27g	5.2±0.03h	1.6±0.04c-h	0.2±0.02ab	2.8±0.03b-g	1.1±0.04abc	0.9±0.01a	0.2±0.00	205.0±8.66
CRW+RB+GsM	6.8±0.03ab	22.7±0.21	2.2±0.01	7.5±3.27cde	91.3±0.43a-f	9.6±0.81e-h	1.2±0.05bcd	8.8±0.16de	1.3±0.17e-j	0.2±0.03ab	2.9±0.07b-f	1.1±0.08abc	0.8±0.01ab	0.3±0.06	225.0±8.66
CRW+RB+PpM	6.5±0.14c	22.1±0.14	2.3±0.01	17.0±2.22abc	82.6±11.11d-g	10.1±0.87d-h	1.0±0.09def	9.4±0.08d	1.2±0.04f-j	0.2±0.00ab	3.4±0.01a	1.3±0.01a	0.9±0.03a	0.4±0.00	225.0±8.66
CRW+RB+ZM	6.8±0.00ab	24.3±1.29	2.3±0.13	7.5±1.28cde	84.0±1.07c-g	7.8±0.43gh	1.2±0.03bcd	9.2±0.09d	1.5±0.15d-i	0.2±0.02ab	3.1±0.05a-d	1.3±0.06a	0.8±0.04ab	0.4±0.00	240.0±17.32
CRW+R+GsM	6.7±0.03b	26.0±0.19	2.4±0.01	12.2±1.32b-e	101.3±1.30a	15.9±0.64cd	1.2±0.03bcd	8.2±0.03de	1.7±0.26b-e	0.3±0.02a	2.9±0.04b-f	1.1±0.13abc	0.7±0.02b	0.3±0.06	235.0±2.89
CRW+R+PpM	6.8±0.00ab	23.9±1.21	2.2±0.05	8.7±2.13cde	91.5±2.60a-f	9.5±0.29e-h	1.1±0.05cde	9.1±0.02d	1.4±0.03e-i	0.2±0.01ab	3.2±0.02ab	1.1±0.07abc	0.8±0.03ab	0.3±0.06	220.0±0.00
CRW+R+ZM	6.7±0.00b	21.1±0.29	1.9±0.03	14.1±3.50bcd	85.4±0.38c-g	10.7±0.66d-h	1.1±0.02cde	8.8±0.30de	0.9±0.02jk	0.3±0.02a	2.8±0.04b-g	1.1±0.04abc	0.9±0.01a	0.4±0.00	270.0±0.00
CRW+F+GsM	6.8±0.00ab	21.5±2.22	2.1±0.23	12.3±2.20b-e	82.6±0.26d-g	10.8±0.14d-h	1.3±0.03bcd	8.7±0.14de	1.2±0.12g-k	0.1±0.04b	3.0±0.05b-e	1.2±0.08ab	0.8±0.04ab	0.3±0.06	225.0±8.66
CRW+F+PpM	6.9±0.00a	15.8±0.21	1.8±0.03	6.4±1.65de	92.8±2.17a-e	9.0±0.46fgh	1.1±0.01cde	8.3±0.05de	0.9±0.02jk	0.2±0.01ab	2.9±0.05b-f	1.0±0.08cde	0.9±0.02a	0.3±0.06	200.0±11.55
CRW+F+ZM	6.9±0.03a	16.4±0.43	1.4±0.03	11.0±1.91cde	93.9±2.40a-d	13.9±1.39c-g	1.2±0.02bcd	8.2±0.01de	**0.8**±0.07k	0.2±0.03ab	2.6±0.04c-i	1.1±0.08abc	0.8±0.01ab	0.2±0.00	210.0±11.55
S.E.D	0.05	ns	ns	3.22	4.78	2.65	0.09	0.79	0.19	0.03	0.17	0.07	0.03	ns	ns
CV (%)	0.8	10.3	11.4	31.9	5.8	23.2	6.8	11.3	17.4	16.7	6.1	4.9	2.8	31.7	7.8

Means with the same letter(s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, CRW = CROPWAT, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.



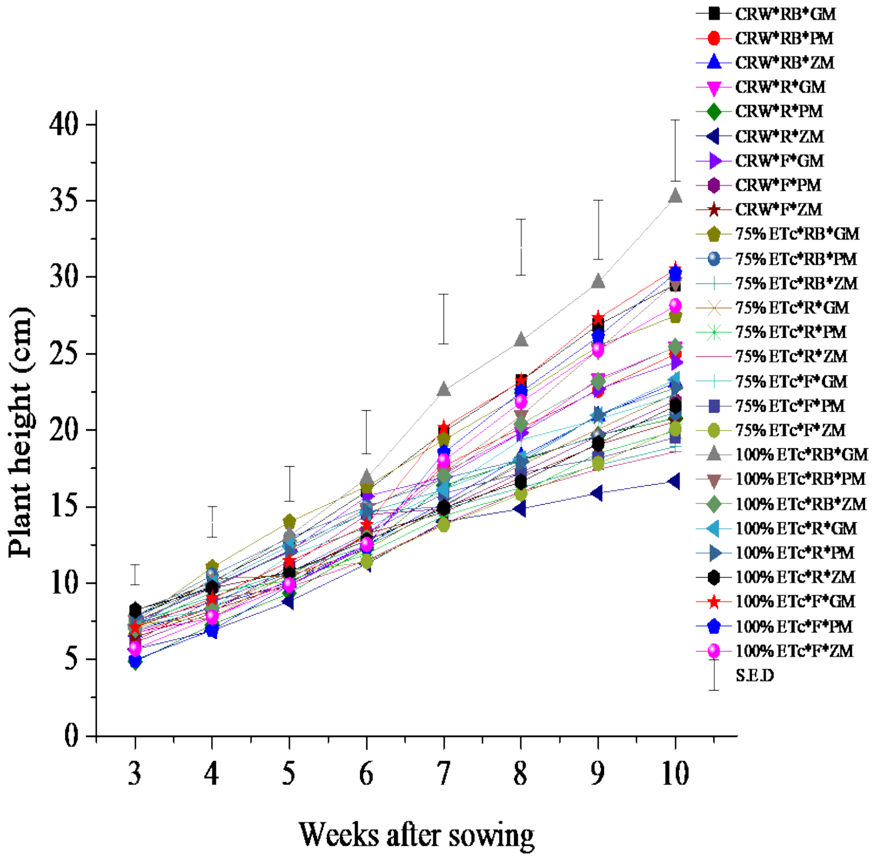
Appendix 37: Effect of irrigation rate × land preparation × mulch on okra number of leaves in 2015/2016

Note: RB = Raised bed, R = Ridge, F = Flat, GM = *Gliricidia* mulch, PM = *Pennisetum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means



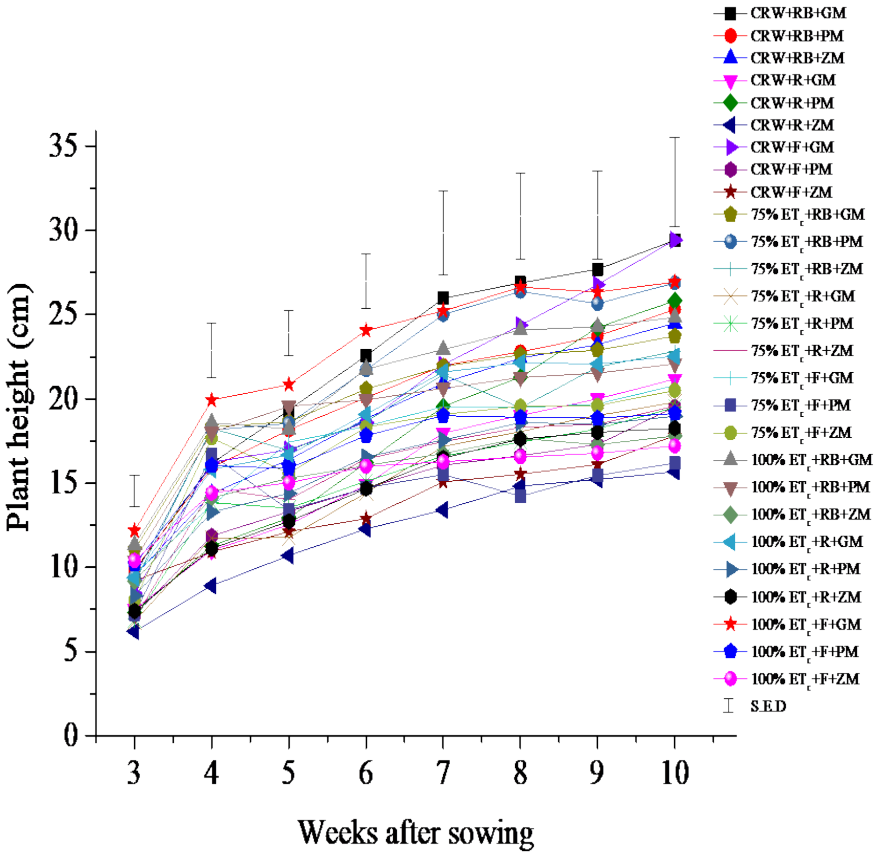
Appendix 38: Effect of irrigation rate × land preparation × mulch on okra number of leaves in 2016/2017

Note: RB = Raised bed, R = Ridge, F = Flat, GM = *Gliricidia* mulch, PM = *Pennisetum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means



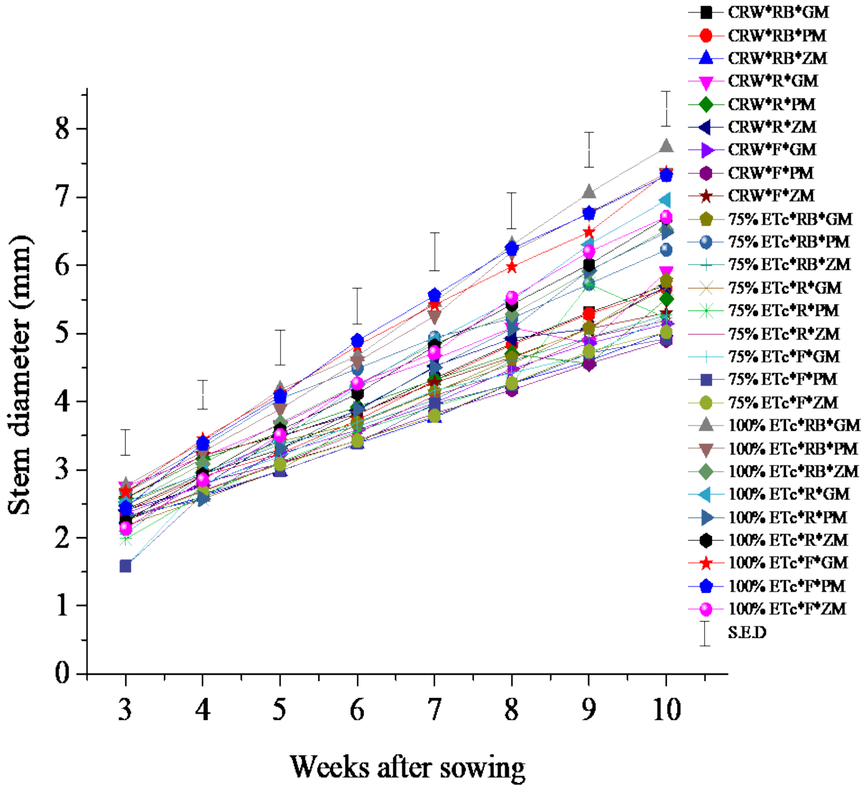
Appendix 39: Irrigation rate × land preparation × mulch effect on plant height of okra in 2015/2016

Note: RB = Raised bed, R = Ridge, F = Flat, GM = *Gliricidia* mulch, PM = *Pennisetum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means



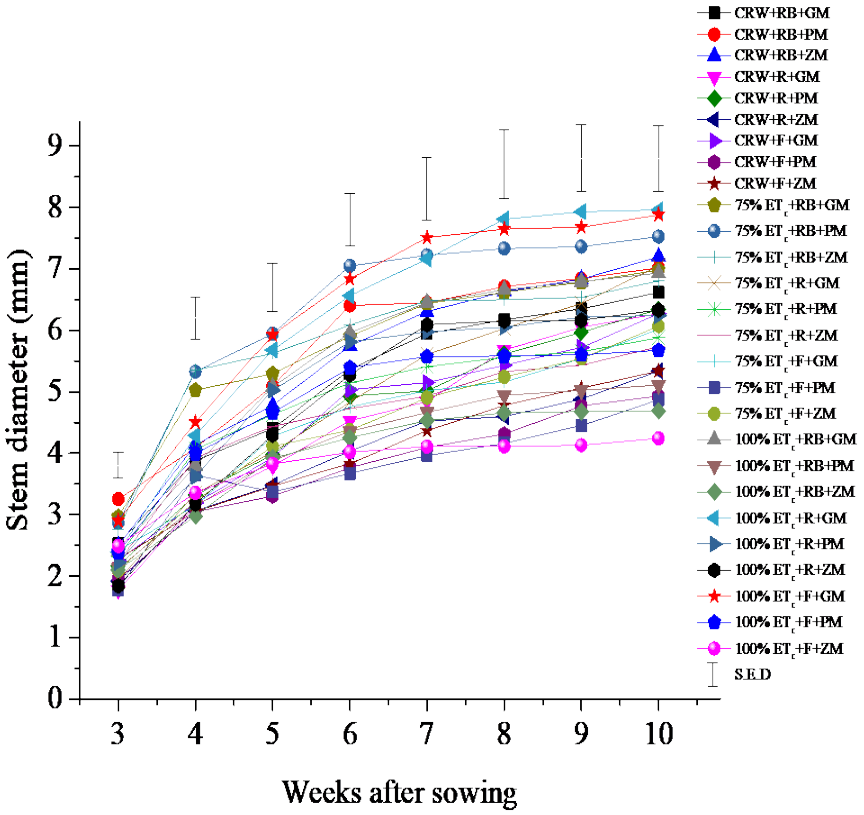
Appendix 40: Irrigation rate × land preparation × mulch effect on plant height of okra in 2016/2017

Note: RB = Raised bed, R = Ridge, F = Flat, GM = *Gliricidia* mulch, PM = *Pennisetum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means



Appendix 41: Effect of irrigation rate × land preparation × mulch on stem diameter of okra in 2015/2016

Note: RB = Raised bed, R = Ridge, F = Flat, GM = *Gliricidia* mulch, PM = *Pennisetum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means



Appendix 42: Effect of irrigation rate × land preparation × mulch on stem diameter of okra in 2016/2017

Note: RB = Raised bed, R = Ridge, F = Flat, GM = *Gliricidia* mulch, PM = *Pennisetum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means

Appendix 43: Irrigation rate × land preparation effect on okra shoot weight in 2015/2016

Treatment	Fresh shoot weight	Dry shoot weight
	g plant^{-1}	
100%ET_c+RB	2.11±0.16bc	0.52±0.04d
100%ET_c+R	3.00±0.36a	1.08±0.17a
100%ET_c+F	1.94±0.17bc	0.50±0.03d
75%ET_c+RB	2.71±0.40ab	0.76±0.09bcd
75%ET_c+R	0.92±0.16d	0.24±0.04e
75%ET_c+F	2.38±0.35ab	0.67±0.09cd
CROPWAT+RB	2.25±0.30abc	0.85±0.09abc
CROPWAT+R	1.48±0.14cd	0.60±0.07cd
CROPWAT+F	2.72±0.28ab	0.95±0.07ab
S.E.D	0.27	0.13
CV (%)	15.4	25.9

Means with the same letter(s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 44: Irrigation rate × mulch effect on okra shoot weight in 2015/2016

Treatment	Fresh shoot weight	Dry shoot weight
	g plant^{-1}	
100%ET$_c$+GsM	2.86±0.30	0.97±0.16a
100%ET$_c$+PpM	2.18±0.28	0.64±0.08bc
100%ET$_c$+ZM	2.01±0.18	0.49±0.06cd
75%ET$_c$+GsM	2.24±0.42	0.65±0.10bc
75%ET$_c$+PpM	2.42±0.38	0.73±0.10abc
75%ET$_c$+ZM	1.35±0.16	0.29±0.02d
CROPWAT+GsM	2.59±0.34	0.88±0.09ab
CROPWAT+PpM	2.19±0.22	0.88±0.08ab
CROPWAT+ZM	1.67±0.18	0.65±0.06bc
S.E.D	ns	0.10
CV (%)	15.4	25.9

Means with the same letter(s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 45: Land preparation × mulch effect on okra shoot weight in 2015/2016

Treatment	Fresh shoot weight	Dry shoot weight
	g plant^{-1}	
RB+GsM	2.95±0.37	0.89±0.09
RB+PpM	2.49±0.28	0.74±0.08
RB+ZM	1.63±0.18	0.50±0.06
R+GsM	2.04±0.39	0.84±0.18
R+PpM	1.66±0.26	0.66±0.10
R+ZM	1.70±0.21	0.42±0.07
F+GsM	2.69±0.29	0.76±0.08
F+PpM	2.65±0.33	0.85±0.08
F+ZM	1.71±0.16	0.50±0.05
S.E.D	ns	ns
CV (%)	15.4	25.9

Means with the same letter(s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 46: Irrigation rate × land preparation × mulch effect on okra shoot weight in 2015/2016

Treatment	Fresh shoot weight	Dry shoot weight
	g plant^{-1}	
100%ET_c+RB+GsM	2.33±0.20	0.63±0.07c-i
100%ET_c+RB+PpM	2.16±0.36	0.56±0.08e-j
100%ET_c+RB+ZM	1.83±0.28	0.37±0.06f-j
100%ET_c+R+GsM	4.17±0.66	1.76±0.36a
100%ET_c+R+PpM	2.33±0.63	0.79±0.23b-g
100%ET_c+R+ZM	2.51±0.43	0.69±0.15b-h
100%ET_c+F+GsM	2.07±0.22	0.51±0.06e-j
100%ET_c+F+PpM	2.07±0.46	0.57±0.08e-j
100%ET_c+F+ZM	1.70±0.15	0.41±0.03f-j
75%ET_c+RB+GsM	3.54±0.85	1.09±0.15b
75%ET_c+RB+PpM	2.96±0.66	0.80±0.14b-g
75%ET_c+RB+ZM	1.62±0.37	0.40±0.03f-j
75%ET_c+R+GsM	0.48±0.05	0.16±0.03j
75%ET_c+R+PpM	1.04±0.32	0.36±0.11g-j
75%ET_c+R+ZM	1.23±0.33	0.20±0.05ij
75%ET_c+F+GsM	2.69±0.63	0.70±0.13b-h
75%ET_c+F+PpM	3.26±0.72	1.04±0.16bcd
75%ET_c+F+ZM	1.20±0.04	0.26±0.01hij
CRW+RB+GsM	2.98±0.70	0.94±0.19b-e
CRW+RB+PpM	2.34±0.37	0.88±0.17b-e
CRW+RB+ZM	1.42±0.29	0.73±0.13b-g
CRW+R+GsM	1.48±0.35	0.60±0.14d-j
CRW+R+PpM	1.60±0.22	0.83±0.09b-f
CRW+R+ZM	1.35±0.12	0.38±0.04f-j
CRW+F+GsM	3.30±0.53	1.08±0.11bc
CRW+F+PpM	2.62±0.49	0.95±0.13b-e
CRW+F+ZM	2.23±0.41	0.82±0.09b-f
S.E.D	ns	0.19
CV (%)	33.8	30.5

Means with the same letter(s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, CRW = CROPWAT, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 47: Irrigation rate × land preparation effect on okra shoot weight in 2016/2017

Treatment	Fresh shoot weight	Dry shoot weight
	g plant^{-1}	
100%ET$_c$+RB	3.22±0.60abc	1.39±0.11c
100%ET$_c$+R	4.38±0.55abc	1.98±0.11ab
100%ET$_c$+F	4.43±1.15abc	1.54±0.26bc
75%ET$_c$+RB	5.16±1.08ab	2.22±0.15a
75%ET$_c$+R	2.67±0.42bc	1.32±0.04c
75%ET$_c$+F	2.40±0.29c	1.08±0.03c
CROPWAT+RB	5.80±0.94a	2.31±0.23a
CROPWAT+R	4.63±1.11abc	1.90±0.22ab
CROPWAT+F	4.10±0.84abc	1.17±0.10c
S.E.D	0.89	0.14
CV (%)	25.4	9.7

Means with the same letter(s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 48: Irrigation rate × mulch effect on okra shoot weight in 2016/2017

Treatment	Fresh shoot weight	Dry shoot weight
	g plant^{-1}	
100%ET$_c$+GsM	7.09±0.95a	2.55±0.10a
100%ET$_c$+PpM	2.74±0.33c	1.24±0.06c
100%ET$_c$+ZM	2.19±0.39c	1.13±0.12c
75%ET$_c$+GsM	3.02±0.39c	1.33±0.08c
75%ET$_c$+PpM	4.49±1.14bc	1.88±0.21b
75%ET$_c$+ZM	2.71±0.37c	1.40±0.08c
CROPWAT+GsM	6.36±1.06ab	2.05±0.10b
CROPWAT+PpM	5.50±1.07ab	2.29±0.28ab
CROPWAT+ZM	2.66±0.44c	1.04±0.10c
S.E.D	0.95	0.15
CV (%)	25.4	9.7

Means with the same letter (s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, FBGB = Fresh below-ground biomass, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 49: Land preparation × mulch effect on okra shoot weight in 2016/2017

Treatment	Fresh shoot weight	Dry shoot weight
	g plant^{-1}	
RB+GsM	5.31±0.88ab	2.03±0.06ab
RB+PpM	5.55±1.21ab	2.39±0.29a
RB+ZM	3.31±0.44bcd	1.51±0.08cd
R+GsM	4.74±0.75abc	2.00±0.15ab
R+PpM	4.46±0.97abc	1.98±0.15ab
R+ZM	2.47±0.39cd	1.22±0.10de
F+GsM	6.41±1.15a	1.90±0.21bc
F+PpM	2.72±0.34cd	1.05±0.01e
F+ZM	1.78±0.29d	0.84±0.07e
S.E.D	0.91	0.14
CV (%)	25.4	9.7

Means with the same letter(s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 50: Irrigation rate × land preparation × mulch effect on okra shoot weight in 2016/2017

Treatment	Fresh shoot weight	Dry shoot weight
	g $plant^{-1}$	
100%ET_c+RB+GsM	5.32±1.42	2.01±0.01de
100%ET_c+RB+PpM	2.30±0.27	1.10±0.06hij
100%ET_c+RB+ZM	2.03±0.48	1.07±0.02hij
100%ET_c+R+GsM	6.06±0.98	2.60±0.05bc
100%ET_c+R+PpM	3.44±0.85	1.59±0.03fg
100%ET_c+R+ZM	3.63±0.70	1.76±0.02ef
100%ET_c+F+GsM	9.90±1.98	3.04±0.01a
100%ET_c+F+PpM	2.47±0.44	1.02±0.01hij
100%ET_c+F+ZM	0.90±0.24	0.55±0.01k
75%ET_c+RB+GsM	4.58±0.73	1.74±0.01ef
75%ET_c+RB+PpM	7.86±2.90	3.07±0.02a
75%ET_c+RB+ZM	3.04±0.69	1.86±0.01ef
75%ET_c+R+GsM	2.33±0.45	1.33±0.03gh
75%ET_c+R+PpM	3.23±1.01	1.51±0.01fg
75%ET_c+R+ZM	2.44±0.67	1.11±0.04hij
75%ET_c+F+GsM	2.15±0.31	0.92±0.01ijk
75%ET_c+F+PpM	2.39±0.54	1.07±0.02hij
75%ET_c+F+ZM	2.65±0.67	1.24±0.01ghi
CRW+RB+GsM	6.05±2.26	2.35±0.03cd
CRW+RB+PpM	6.50±1.78	2.99±0.58a
CRW+RB+ZM	4.85±0.66	1.60±0.05fg
CRW+R+GsM	5.84±1.69	2.07±0.24de
CRW+R+PpM	6.70±2.53	2.83±0.02ab
CRW+R+ZM	1.34±0.22	0.79±0.03jk
CRW+F+GsM	7.20±1.83	1.73±0.02ef
CRW+F+PpM	3.31±0.79	1.05±0.01hij
CRW+F+ZM	1.79±0.26	0.74±0.05jk
S.E.D	ns	0.25
CV (%)	48.6	19.0

Means with the same letter (s) under the same category in a column are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, CRW = CROPWAT, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation.

Appendix 51: Irrigation rate × land preparation effect on okra yield parameters in 2015/2016

Treatment	No. of pods (plant^{-1})	Fresh pod weight (g plant^{-1})	Pod diameter (mm pod^{-1} plant^{-1})	Pod length (cm pod^{-1} plant^{-1})	Dry pod weight (g plant^{-1})
100%ET$_c$+RB	4.3±0.27cde	8.71±0.36bcd	14.09±0.52a	5.1±0.14a	4.58±0.46bc
100%ET$_c$+R	6.6±0.69b	20.03±2.55a	12.04±0.58bc	4.1±0.16c	3.09±0.51def
100%ET$_c$+F	3.7±0.23de	7.79±0.49cd	10.28±0.51d	3.5±0.21d	2.45±0.46ef
75%ET$_c$+RB	7.8±0.53a	24.04±2.72a	14.16±0.55a	5.1±0.19a	6.97±0.46a
75%ET$_c$+R	3.6±0.20de	9.52±1.20bcd	13.26±0.66ab	4.5±0.23bc	3.84±0.27bcd
75%ET$_c$+F	5.0±0.38c	11.87±0.90bc	10.44±0.51cd	3.4±0.17d	3.71±0.33cde
CROPWAT+RB	4.7±0.38cd	13.01±1.21b	13.36±0.56ab	4.8±0.21ab	5.02±0.43b
CROPWAT+R	3.3±0.19f	7.02±0.36d	9.67±0.55d	3.4±0.17d	2.22±0.46f
CROPWAT+F	4.7±0.30cd	9.70±0.74bcd	12.65±0.74ab	4.6±0.18abc	3.24±0.37def
S.E.D	0.40	1.79	0.77	0.26	0.68
CV (%)	7.4	18.9	8.6	8.4	22.6

Means with the same letter(s) are not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation

Appendix 52: Irrigation rate × mulch effect on okra yield parameters in 2015/2016

Treatment	No. of pods (plant^{-1})	Fresh pod weight (g plant^{-1})	Pod diameter (mm pod^{-1} plant^{-1})	Pod length (cm pod^{-1} plant^{-1})	Dry pod weight (g plant^{-1})
100%ET$_c$+GsM	5.0±0.34abc	13.35±1.55a-d	13.12±0.52	4.3±0.23	3.96±0.55
100%ET$_c$+PpM	4.0±0.28cd	8.96±0.32de	11.80±0.50	4.1±0.18	3.50±0.49
100%ET$_c$+ZM	5.5±0.74ab	16.83±2.80ab	11.50±0.75	4.3±0.25	4.19±0.46
75%ET$_c$+GsM	5.9±0.61a	18.24±3.17a	12.86±0.60	4.3±0.24	5.21±0.59
75%ET$_c$+PpM	5.4±0.44abc	14.44±1.17abc	12.83±0.70	4.4±0.25	4.36±0.25
75%ET$_c$+ZM	5.0±0.48abc	10.16±1.01cde	12.17±0.65	4.4±0.23	4.95±0.49
CROPWAT+GsM	4.3±0.30bcd	10.15±0.70cde	12.44±0.56	4.2±0.18	3.21±0.42
CROPWAT+PpM	5.1±0.37abc	12.34±1.33b-e	12.09±0.68	4.5±0.25	3.07±0.51
CROPWAT+ZM	3.3±0.21d	7.25±0.29e	11.15±0.80	4.1±0.23	2.66±0.45
S.E.D	0.50	1.72	ns	ns	ns
CV (%)	7.4	18.9	8.6	8.4	22.6

Means with the same letter(s) are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation

Appendix 53: Effect of land preparation × mulch on okra yield parameters in 2015/2016

Treatment	No. of pods (plant^{-1})	Fresh pod weight (g plant^{-1})	Pod diameter (mm pod^{-1} plant^{-1})	Pod length (cm pod^{-1} plant^{-1})	Dry pod weight (g plant^{-1})
RB+GsM	6.3±0.53a	16.37±2.77ab	14.16±0.51	4.9±0.20	3.92±0.34
RB+PpM	5.4±0.46ab	14.93±1.12abc	13.88±0.52	5.2±0.15	5.05±0.42
RB+ZM	5.0±0.49a-d	10.45±0.97cd	13.57±0.60	5.0±0.19	4.46±0.43
R+GsM	4.4±0.36bcd	12.69±1.60bc	11.80±0.59	3.8±0.15	4.70±0.68
R+PpM	3.9±0.27cd	9.65±1.20cd	12.01±0.64	4.0±0.23	3.62±0.40
R+ZM	5.2±0.76abc	18.25±3.16a	11.14±0.74	4.2±0.24	4.98±0.57
F+GsM	4.4±0.34bcd	11.26±0.88cd	12.45±0.49	4.1±0.23	3.77±0.56
F+PpM	5.3±0.34abc	11.16±0.76cd	10.82±0.60	3.9±0.22	2.36±0.31
F+ZM	3.7±0.21d	6.94±0.30d	10.10±0.69	3.5±0.17	2.25±0.34
S.E.D	0.42	1.86	ns	ns	ns
CV (%)	7.4	18.9	8.6	8.4	22.6

Means with the same letter(s) are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation

Appendix 54: Irrigation rate × land preparation × mulch effect on okra yield parameters in 2015/2016

Treatment	No. of pods (plant^{-1})	Fresh pod weight (g plant^{-1})	Pod diameter (mm pod^{-1} plant^{-1})	Pod length (cm pod^{-1} plant^{-1})	Dry pod weight (g plant^{-1})
100%ET_c+RB+GsM	4.9±0.48b-e	8.32±0.63hi	14.89±0.78	5.4±0.15	4.49±0.53
100%ET_c+RB+PpM	4.0±0.44cde	9.99±0.47f-i	13.58±0.72	4.9±0.17	5.56±0.86
100%ET_c+RB+ZM	4.0±0.44cde	7.83±0.56hi	13.79±1.16	5.1±0.34	3.68±0.92
100%ET_c+R+GsM	6.0±0.69bc	22.52±2.45c	12.67±1.04	4.0±0.15	3.66±1.12
100%ET_c+R+PpM	4.3±0.67b-e	8.75±0.50ghi	11.82±0.86	3.8±0.24	2.69±0.65
100%ET_c+R+ZM	9.4±1.42a	40.87±1.02a	11.63±1.18	4.6±0.37	2.91±0.87
100%ET_c+F+GsM	4.2±0.49cde	9.21±1.09ghi	11.80±0.55	3.6±0.48	3.73±1.14
100%ET_c+F+PpM	3.8±0.32de	8.14±0.54hi	9.99±0.63	3.6±0.32	2.24±0.61
100%ET_c+F+ZM	3.0±0.29e	6.02±0.44i	9.07±1.15	3.2±0.32	1.38±0.14
75%ET_c+RB+GsM	9.0±0.90a	28.84±6.59b	15.33±0.70	5.4±0.37	2.95±0.44
75%ET_c+RB+PpM	6.2±1.08b	15.22±1.59def	14.14±0.92	5.1±0.25	4.85±0.43
75%ET_c+RB+ZM	8.1±0.51a	16.04±1.66de	13.03±1.14	4.9±0.36	3.71±0.32
75%ET_c+R+GsM	3.6±0.38de	7.54±0.53i	11.91±1.22	3.9±0.36	8.04±0.88
75%ET_c+R+PpM	4.1±0.31cde	13.63±3.21e-h	14.63±0.91	4.8±0.43	4.58±0.45
75%ET_c+R+ZM	3.0±0.29e	7.40±0.58i	13.23±1.19	4.8±0.38	8.29±0.10
75%ET_c+F+GsM	5.0±0.85b-e	14.11±1.64efg	11.34±0.64	3.6±0.25	4.63±0.84
75%ET_c+F+PpM	6.0±0.58bc	14.48±0.67d-g	9.71±1.12	3.2±0.37	3.65±0.35
75%ET_c+F+ZM	4.0±0.29cde	7.03±0.53i	10.27±0.83	3.4±0.28	2.85±0.23
CRW+RB+GsM	5.1±0.63bcd	11.97±1.01e-i	12.26±0.84	4.0±0.23	4.31±0.68
CRW+RB+PpM	6.0±0.58bc	19.58±1.94cd	13.93±1.13	5.5±0.34	4.75±0.85
CRW+RB+ZM	3.0±0.29e	7.49±0.53i	13.90±0.93	5.1±0.32	5.98±0.63
CRW+R+GsM	3.6±0.41de	8.02±0.83hi	10.83±0.74	3.5±0.26	2.38±0.47
CRW+R+PpM	3.2±0.28de	6.57±0.36i	9.59±0.91	3.2±0.35	3.58±0.83
CRW+R+ZM	3.0±0.29e	6.47±0.47i	8.58±1.10	3.3±0.32	3.75±0.56
CRW+F+GsM	4.1±0.35cde	10.46±1.45e-i	14.23±1.03	5.0±0.24	2.94±0.91
CRW+F+PpM	6.0±0.50bc	10.86±1.52e-i	12.75±1.07	4.9±0.21	0.87±0.38
CRW+F+ZM	4.0±0.41cde	7.77±0.45hi	10.96±1.55	3.8±0.29	2.84±0.84
S.E.D	0.77	3.14	ns	ns	ns
CV (%)	20.5	31.3	11.6	14.7	40.7

Means with the same letter(s) are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation

Appendix 55: Irrigation rate × land preparation effect on okra yield parameters in 2016/2017

Treatment	No. of pods (plant^{-1})	Fresh pod weight (g plant^{-1})	Pod diameter (mm pod^{-1} plant^{-1})	Pod length (cm pod^{-1} plant^{-1})	Dry pod weight (g plant^{-1})
100%ET$_c$+RB	10.0±1.61	56.24±8.56	19.14±0.45a	5.5±0.13a	7.68±1.07
100%ET$_c$+R	7.6±1.01	33.94±4.76	17.10±0.45b	4.5±0.16c	3.94±0.53
100%ET$_c$+F	8.5±1.21	26.36±4.52	15.34±0.48c	3.8±0.21d	3.30±0.48
75%ET$_c$+RB	12.2±1.42	69.89±7.92	19.22±0.49a	5.4±0.18a	8.63±0.78
75%ET$_c$+R	6.6±0.93	33.30±3.27	18.31±0.51ab	4.8±0.22bc	4.24±0.43
75%ET$_c$+F	8.2±1.25	21.51±2.83	15.50±0.41c	3.8±0.16d	3.02±0.47
CROPWAT+RB	11.5±1.23	54.69±5.50	18.42±0.49ab	5.2±0.20ab	6.78±0.67
CROPWAT+R	5.0±0.58	16.16±1.97	14.72±0.47c	3.7±0.18d	2.09±0.31
CROPWAT+F	9.9±1.36	43.89±6.31	17.70±0.52b	4.9±0.17abc	6.92±0.87
S.E.D	ns	ns	0.77	0.26	ns
CV (%)	29.3	31.6	6.1	7.8	34.9

Means with the same letter(s) are not significantly different at p = 0.05, ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation

Appendix 56: Irrigation rate × mulch effect on okra yield parameters in 2016/2017

Treatment	No. of pods (plant^{-1})	Fresh pod weight (g plant^{-1})	Pod diameter (mm pod^{-1} plant^{-1})	Pod length (cm pod^{-1} plant^{-1})	Dry pod weight (g plant^{-1})
100%ET$_c$+GsM	9.8±1.44	47.13±6.93	18.17±0.50	4.7±0.23	6.35±0.97
100%ET$_c$+PpM	9.2±1.51	40.20±7.78	16.85±0.47	4.5±0.18	4.90±0.87
100%ET$_c$+ZM	7.1±0.83	29.21±4.49	16.55±0.62	4.6±0.24	3.68±0.50
75%ET$_c$+GsM	9.7±1.35	46.33±8.06	17.91±0.55	4.6±0.23	5.95±0.91
75%ET$_c$+PpM	7.3±1.12	38.35±6.74	17.88±0.62	4.7±0.25	4.49±0.73
75%ET$_c$+ZM	10.0±1.35	40.01±4.31	17.23±0.50	4.7±0.22	5.45±0.53
CROPWAT+GsM	9.0±1.35	40.19±6.17	17.50±0.45	4.5±0.17	5.63±0.83
CROPWAT+PpM	9.2±1.35	40.83±6.55	17.14±0.60	4.9±0.25	5.81±0.84
CROPWAT+ZM	8.2±0.94	33.72±4.71	16.21±0.65	4.4±0.22	4.35±0.67
S.E.D	ns	ns	ns	ns	ns
CV (%)	29.3	31.6	6.1	7.8	34.9

ns = not significantly different at p = 0.05, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation

Appendix 57: Land preparation × mulch effect on okra yield parameters in 2016/2017

Treatment	No. of pods (plant^{-1})	Fresh pod weight (g plant^{-1})	Pod diameter (mm pod^{-1} plant^{-1})	Pod length (cm pod^{-1} plant^{-1})	Dry pod weight (g plant^{-1})
RB+GsM	10.4±1.59	59.30±8.75	19.22±0.44	5.2±0.19	8.04±1.06
RB+PpM	12.2±1.62	67.65±8.76	18.94±0.48	5.5±0.15	8.12±0.89
RB+ZM	11.0±1.02	53.87±3.84	18.63±0.51	5.4±0.18	6.93±0.56
R+GsM	6.9±0.83	29.93±3.80	16.86±0.45	4.2±0.15	3.71±0.46
R+PpM	6.4±0.87	26.92±3.53	17.07±0.62	4.3±0.23	3.35±0.42
R+ZM	5.9±0.93	26.56±4.23	16.20±0.57	4.6±0.23	3.21±0.53
F+GsM	11.2±1.46	44.42±6.69	17.51±0.50	4.4±0.23	6.17±0.88
F+PpM	7.0±1.15	24.81±3.86	15.87±0.44	4.3±0.22	3.74±0.72
F+ZM	8.4±1.08	22.52±2.87	15.16±0.50	3.8±0.17	3.33±0.32
S.E.D	ns	ns	ns	ns	ns
CV (%)	29.3	31.6	6.1	7.8	34.9

ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation

Appendix 58: Irrigation rate × land preparation × mulch effect on okra yield parameters in 2016/2017

Treatment	No. of pods (plant^{-1})	Fresh pod weight (g plant^{-1})	Pod diameter (mm pod^{-1} plant^{-1})	Pod length (cm pod^{-1} plant^{-1})	Dry pod weight (g plant^{-1})
100%ET$_c$+RB+GsM	10.7±2.92	63.67±13.69	19.95±0.58	5.7±0.14	9.96±1.96
100%ET$_c$+RB+PpM	12.0±3.61	64.78±20.37	18.63±0.67	5.3±0.15	8.07±2.14
100%ET$_c$+RB+ZM	7.2±1.52	40.28±8.07	18.85±1.02	5.4±0.35	5.03±1.06
100%ET$_c$+R+GsM	9.3±1.89	41.28±9.15	17.72±0.67	4.3±0.16	4.52±1.18
100%ET$_c$+R+PpM	6.4±1.33	29.44±6.16	16.88±0.68	4.2±0.25	3.55±0.70
100%ET$_c$+R+ZM	7.1±1.98	31.11±9.44	16.68±1.00	4.9±0.34	3.77±0.91
100%ET$_c$+F+GsM	9.4±2.83	36.44±12.03	16.85±0.99	3.9±0.47	4.58±1.19
100%ET$_c$+F+PpM	9.0±2.33	26.39±4.85	15.05±0.68	4.0±0.31	3.09±0.67
100%ET$_c$+F+ZM	7.0±0.71	16.25±2.39	14.12±0.59	3.5±0.31	2.23±0.07
75%ET$_c$+RB+GsM	14.2±2.94	85.50±17.48	20.38±0.67	5.7±0.37	10.83±1.57
75%ET$_c$+RB+PpM	10.0±2.33	66.17±14.70	19.19±0.91	5.4±0.27	7.46±1.48
75%ET$_c$+RB+ZM	12.2±2.11	58.00±6.31	18.08±0.83	5.2±0.33	7.60±0.63
75%ET$_c$+R+GsM	5.0±0.82	26.17±4.36	16.96±0.90	4.2±0.33	3.24±0.50
75%ET$_c$+R+PpM	7.4±2.06	35.33±6.81	19.69±0.88	5.2±0.41	4.43±0.84
75%ET$_c$+R+ZM	7.2±1.74	38.39±5.33	18.29±0.66	5.1±0.36	5.05±0.81
75%ET$_c$+F+GsM	9.9±1.76	27.32±4.59	16.40±0.74	4.0±0.23	3.77±0.92
75%ET$_c$+F+PpM	4.3±0.73	13.56±2.40	14.77±0.59	3.6±0.35	1.58±0.36
75%ET$_c$+F+ZM	10.4±2.95	23.65±6.22	15.32±0.76	3.8±0.27	3.70±0.86
CRW+RB+GsM	6.3±1.87	28.72±6.92	17.32±0.64	4.3±0.17	3.34±0.60
CRW+RB+PpM	14.6±2.37	72.00±10.66	18.98±0.98	5.8±0.34	8.83±0.93
CRW+RB+ZM	13.6±0.73	63.33±1.45	18.96±0.86	5.4±0.30	8.17±0.93
CRW+R+GsM	6.4±1.13	22.33±3.56	15.89±0.73	3.9±0.25	3.39±0.53
CRW+R+PpM	5.4±1.06	15.98±3.54	14.64±0.96	3.6±0.36	2.06±0.43
CRW+R+ZM	3.2±0.40	10.17±1.86	13.64±0.60	3.6±0.34	0.82±0.22
CRW+F+GsM	14.1±2.82	69.50±12.13	19.28±0.54	5.4±0.23	10.16±1.47
CRW+F+PpM	7.7±2.33	34.50±9.38	17.80±0.62	5.3±0.20	6.55±1.70
CRW+F+ZM	7.9±0.11	27.67±5.25	16.02±1.15	4.1±0.27	4.05±0.19
S.E.D	ns	ns	ns	ns	ns
CV (%)	44.8	49.8	8.2	13.6	54.8

ns = not significantly different at p = 0.05, RB = Raised bed, R = Ridge, F = Flat, GsM = *Gliricidia sepium* mulch, PpM = *Pennisetum purpureum* mulch, ZM = Zero mulch, S.E.D = Standard error of differences of means, CV (%) = Coefficient of variation

Appendix 59: Assessment of irrigation water quality based on electrical conductivity

Salinity-hazard class	Specific conductance[†] (µS cm^{-1})	Characteristics	Samples
Low	0 – 250	Low-salinity water can be used for irrigation on most soil with minimal likelihood that soil salinity will develop.	
Medium	251 – 750	Medium-salinity water can be used for irrigation if a moderate amount of drainage occurs.	I_1, I_2, and I_3
High	751 – 2, 250	High-salinity water is not suitable for use on soil with restricted drainage. Even with adequate drainage, special management for salinity control may be required.	
Very high	More than 2, 250	Very high-salinity water is not suitable for irrigation under normal conditions.	

[†] µS cm^{-1} = microsiemens per centimeter at 25 degrees Celsius, Note: I_1 = Irrigation water for Screenhouse experiment, I_2 = Irrigation water used for 2015/2016 experiment, I_3 = Irrigation water used for 2016/2017 experiment.

Source: Tank and Chandel (2010)

Appendix 60: Sodium adsorption ratio classes for water suitability for irrigation

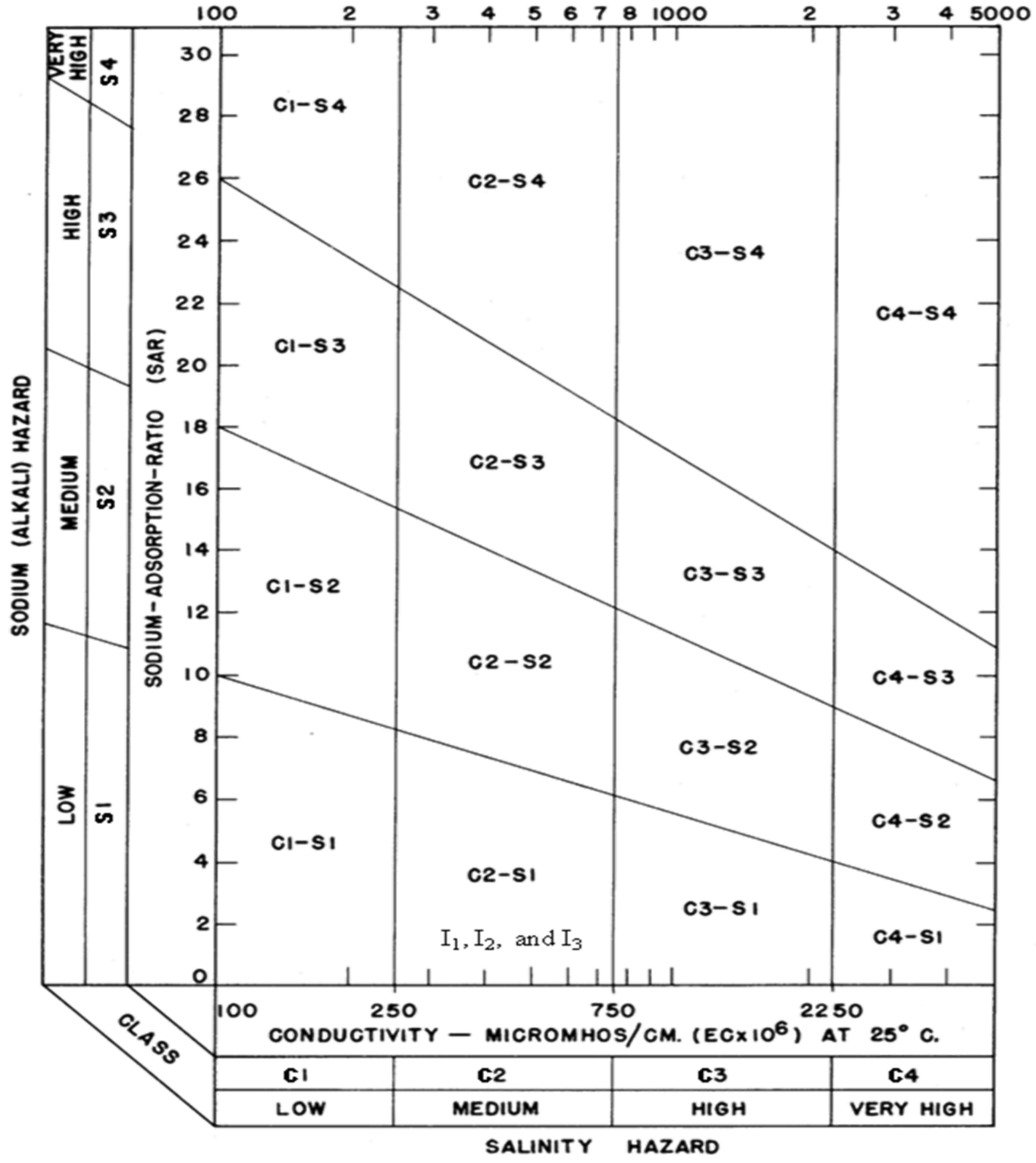
SAR	Water-suitability for irrigation
0-10	Suitable for all types of soils except for those crops which are highly sensitive to sodium.
10-18	Suitable for coarse textured or organic soil with good permeability. Relatively unsuitable in fine textured soil.
18-26	Harmful for almost all types of soils. Requires good drainage, high leaching and gypsum addition.
> 26	Unsuitable for irrigation.

Source: Tank and Chandel (2010)

Appendix 61: Assessment of irrigation water quality based on % Sodium

% Na	Class of water	Quality of water	Sample
< 20%	1	Excellent	Nil
20-40%	2	Good	1 (2015/2016 field experiment)
40-60%	3	Permissible	2 (Screen-house and 2016/2017 field experiment)
60-80%	4	Doubtful	Nil
> 80%	5	Unsuitable	Nil

Source: Tank and Chandel (2010)



Appendix 62: Irrigation water classification using United States salinity diagram

Note: I_1 = Irrigation water for screenhouse experiment, I_2 = Irrigation water used for 2015/2016 experiment, I_3 = Irrigation water used for 2016/2017 experiment