# WEED MANAGEMENT IN CASSAVA (*Manihot esculenta* Crantz) WITH SELECTED PRE- AND POST-EMERGENCE HERBICIDES UNDER ALTERNATIVE APPLICATION SEQUENCE

**By**

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# CERTIFICATION

We certify that this work was carried out by Miss. Mariam Adenike ALABI in the Department of Crop and Horticultural Sciences, the University of Ibadan under our supervision.

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## DEDICATION

I dedicate this work to the Father, Son and the Holy Spirit, the Qualifier of the unqualified. He is the custodian of wisdom, knowledge and understanding.

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## ABSTRACT

Cassava is a major crop in Africa, but weed management at its early growth stage is a problem. Pre-emergence Herbicides (PrH), often supplemented with Post-emergence Herbicides (PoH), are used for Weed Management (WM) in cassava. Delayed application of PrH could necessitate the use of PoH before PrH. There is a dearth of information on the effects of application of PoH before PrH as a WM strategy in cassava. Therefore, this study was conducted to evaluate some PrH and PoH and their alternative application sequences on WM, growth and yield of cassava.

Three PrH: sulfentrazone, flumiosaxin+pyroxasulfone and indaziflam+isoxaflutole at 0.6, 0.11+0.14 and 0.068+0.20 kg a.i./ha, respectively and three PoH: clethodim+lactofen (0.21+0.41 kg a.i./ha), trifloysulfuron-sodium (5.25 g a.i./ha) and carfentrazone-ethyl (5.84 g a.i./ha) were evaluated in cassava (TMEB419) plots planted at 1x0.8 $m^2$. The PrH were evaluated in plots laid in a Randomised Complete Block Design (RCBD). Plots treated with atrazine+S-metolachlor (0.73+1.30 kg a.i./ha) plus 2-Hoe-Weeding (ASm+2HW), weed-free and a weedy-check served as controls. Cassava Plant Height (CPH)-cm, stand count and Weed Dry Weight (WDW)-g/$m^2$ per plot were measured at eight Weeks After Planting (WAP). In another experiment, two spray methods (banded and broadcast) of the PoH at two WAP were evaluated on sprouted cassava in a split-plot design. Spray methods and PoH were the main and sub-plots, respectively. Crop injury (%) and Weed Control Efficacy (WCE)-% were assessed. Thereafter, two sequences of application of PrH and PoH (PrH-PoH and PoH-PrH) were evaluated using split-plot arrangements in RCBD. The PrH or banded PoH were either the main or sub-plots in the sequences. Data were collected on WCE and cassava Storage Root Yield-SRY (t/ha). All experiments were replicated three times. Data were analyzed using descriptive statistics and ANOVA at $\alpha_{0.05}$.

The CPH ranged from 38.0±1.2 (sulfentrazone) to 53.2±1.3 (weed-free). Stand count ranged from 10471.3±0.0 (indaziflam+isoxaflutole) to 11976.1±0.0 (weed-free). Significant reduction (%) in WDW relative to the maximum from weedy-check (110 g/$m^2$) was in the order: 76.4 (sulfentrazone) <82.1 (flumioxazin+pyroxasulfone) <87.3 (indaziflam+isoxaflutole) <89.1 (ASm+2HW) <91.8 (weed-free). Broadcast spray caused 55.19 ±10.7% crop injury which was significantly higher than 7.4 ±7.0% in banding. Crop injury of 92.2±10.7% (carfentrazone-ethyl), 54.8±10.7% (trifloysulfuron-sodium) and 19.0±7.1% (clethodim+lactofen) due to broadcast-spraying were significantly higher than 6.3±7.0%, 7.8±7.0% and 8.2±7.0%, respectively in band-spraying. The WCE at 79.0±0.6% (carfentrazone-ethyl) was significantly lower than 88.4±0.6% (trifloysulfuron-sodium) and 97.0±0.6% (clethodim+lactofen). The WCE in PrH-PoH was significantly higher than in PoH-PrH. The WCE involving PrH-PoH application was 38.0% (sulfentrazone), 29.4% (flumioxazin+pyroxasulfone), 28.1% (carfentrazone-ethyl) and 22.3% (trifloysulfuron-sodium) significantly higher than those of their PoH-PrH. However, those of indaziflam+isoxaflutole (7.0%) and clethodim+lactofen (6.3%) were not significantly different. The SRY of 14.0±1.9 (sulfentrazone) was significantly lower than 28.7±1.9 (flumioxazin+pyroxasulfone) and 31.5±2.0 (indaziflam+isoxaflutole) across the PoH, while 22.7±1.9 (carfentrazone-ethyl), 23.9±1.9 (trifloysulfuron-sodium) and 26.7±1.9 (clethodim+lactofen) across the PrH were comparable.

Indaziflam+isoxaflutole and flumiosaxin+pyroxasulfone, and banded spray of trifloysulfuron-sodium and clethodim+lactofen enhanced cassava growth and weed control efficacy. Sequences involving clethodim+lactofen before or after indaziflam+isoxaflutole improved weed control efficacy and yield of cassava.

**Keywords:** Cassava storage root, Herbicide spray method, Herbicide application sequence, Weed control efficacy

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# CHAPTER 1
# INTRODUCTION

## 1.1 Background to the study

Cassava (*Manihot esculenta* Crantz) is a perennial woody plant with storage roots that thrives in tropical and subtropical climates of the world. Cassava plant is one of the members in the Euphorbiaceae family and it is considered as a crop of high value in the tropics. It is used to feed both humans and animals (Viana *et al.,* 2001). The leaves, stalks and residue of cassava plant serve as source of animal feed, fertilizer and pest control materials (Alves *et al*., 2009; IBGE, 2010). It is grown mostly for its storage roots in underdeveloped nations, but its leaves are also eaten in some parts of Africa, including Nigeria, and used as animal feed in other parts of Asia. A large portion of cassava storage roots produced in Nigeria (90%) is for human consumption (IITA, 2010; FAO, 2018). Nigeria delicacies such as 'fufu', 'amala', 'abacha', 'garri', starch, cassava bread and snacks are products of cassava. It is a food source on which the people of the country rely to meet a portion of their daily dietary energy and total calorie requirements (Ezulike *et al.*, 2006). It benefits industries such as pharmaceuticals, textiles, cosmetics, and biopolymers, to name a few (FAO, 2018). The most cost-effective feedstocks for gasoline ethanol production in Nigeria are cassava, sugarcane, and sweet sorghum, however cassava is the most extensively grown. (Anonymous, 2011). Ziska *et al*. (2009) remarked that cassava was a potential carbohydrate source for ethanol production while FAO (2018) observed a consistent rise in its use as a feedstock in processing biofuel.

Nigeria is ranked to be the largest producer of cassava in the world (FAO, 2018). The world production of cassava storage root was 278 million tonnes, of which Africa accounted for 61.2% while Nigeria contributed 35.3% to Africa's production (FAO, 2018; FAOSTAT, 2019). However, the productivity of cassava in Nigeria is low despite the first position it occupies in world production. In 2018, Nigeria's estimated harvest yield was 9.1 t/ha compared to 20 t/ha in Ghana and 24 t/ha in Indonesia (Ikuemonisan, 2020). In spite of the availability of high yielding cassava genotypes, weed control methods adopted as a part of agronomic practices most times are not suitable for production (FAO, 2013).

Cardoso (2013) emphasized the reasons for a low productive index of cassava as competition with weeds and poor acceptance of modern innovations in the farming *system among other factors. The manual method of weed control is mainly practiced by subsistent farmers in Africa (Ojo and Adebayo, 2012).

Weed infestation reduces crop yield, and in Nigeria cost of weed control have been identified as the most expensive part of crop production (Agahiu *et al*., 2012; Iyagba, 2013). Farmers' inability to do necessary weeding during critical periods of weed interference contributed to a huge reduction of harvest yield among Africa farmers due to crop failure (Vissoh *et al.,* 2004). Herbicides are reported as effective invention for weed management since they may kill weeds on a vast scale before or during emergence with low impact on crops or soils and it does not require a lot of human labour (Akobundu, 1987). As a result, chemical weed control is becoming the most important aspect of modern crop production which could supplement conventional method.

## 1.2 Statement of the Problem

Conventionally, Nigerian farmers remove weeds for more than two times in cassava during its early growing period (Ekeleme *et al*., 2019). Although hand-weeding greatly limits the size of the field that a farmer can cultivate, it is the standard method of weed control in developing countries (Ekeleme, 2013). Ekeleme (2013) further emphasized that weeding needs precise scheduling, which farmers frequently fail to adhere to due to conflicting household labour demands. Herbicides could be a better option however, among many challenges that farmers face in using herbicides in Nigeria are the scarcity of different active ingredients in the market, literacy of strategic combination of active ingredients for optimum weed control, and inferior herbicides application methods.

Primextra® or other trade names of the active ingredients (atrazine + s-metolachlor) in varying proportions and the respective single active ingredients, which are pre-emergence herbicides and glyphosate as well as paraquat, are among the few herbicides used to control weeds in cassava, leaving little or no alternatives in the choice of chemical to use. Atrazine and its derivatives have been commonly identified in soils, surface water, and groundwater as a result of its wide adoption during the last three decades (Silva *et al.,* 2009). Weed resistance in crop cultivation has been connected to repeated or excessive use of the same active components; thus, there is a need to reduce reliance on herbicides with the same mode of action (Jablonkai, 2015). A frequent way of herbicide application among a few farmers is to apply a pre-emergence herbicide at planting, which is later supplemented with hoe-weeding. Agahiu *et al*. (2012) stated that 66% and 30% use manual weeding and herbicide application, respectively, on cassava farms by Kogi farmers. He also observed that herbicides commonly used include the active ingredient: atrazine and s-metolachlor, with different product names as Primextra, Extraforce, Extravest when the active ingredients were formulated together or as atraz, atraforce and metaforce etc when they are respectively presented as single active ingredients. Those containing glyphosate as active ingredients had common trade names such as sarosate, delsate, touchdown, forceup, roundup to mention a few. The broadcast method is used to apply pre-emergence herbicides. However, foliar applied herbicides could either be done by broadcasting or directed to weeds (band spraying). There may be a need to choose the right application method when the herbicides are not selective to minimize phytotoxicity to crop.

However, the application of pre-emergence herbicides after weeds have emerged could reduce its efficiency; hence, post-emergence herbicides are required. The use of post-emergence herbicides at this stage, when cassava plants are tender, could pose a challenge as most of the available products are not selective. Lack of appropriate understanding of right applications and specificity on crop usually has adverse effects on yield quality (Osundare, 2007; Silva *et al*., 2013). Glyphosate, a non-selective systemic herbicide, and paraquat, a non-selective contact herbicide, are two of the most extensively used post-emergence herbicides in Nigeria for cassava weed management. They are employed for weed suppression in land preparation, as well as under cassava canopy. However, the use of paraquat has been discontinued in many countries due to high risks to applicators. Extra care and training are required to use glyphosate under the cassava canopy to prevent severe injury to cassava because of its systemic property. Availability of herbicides registered for cassava cultivation, especially for use in post-emergence situations are restricted (Biffe *et al*., 2010; Silva *et al*., 2011).

Non-selectivity of most post-emergence herbicides causes injury to cultivated crops. As a result, control of already emerged weed seedlings, especially when the cassava plant is young, becomes difficult. According to Oliveira *et al*. (1994), cassava plant response to herbicide application could be selective, or significant damage due to phytotoxicity caused by some products noticed. The capacity of an herbicide to eliminate weeds in a crop while causing minimum or no damage to the crop's development and yield is referred to as selectivity. (Scariot *et al.*, 2013).

According to Sieczka and Creighton (1984), effective weed management programmes among other methods require the application of pre-emergence and/or post-emergence herbicides. Studies have indicated that herbicides increase the productivity of cassava cultivation (Enyong *et al*., 2013). Therefore, the proper sequence of soil and foliar applied herbicides could be a weed control strategy that can be incorporated into weed control programmes for better weed management and higher crop productivity. Two or more herbicides could be or are often applied by tank-mixing or in sequence and it is a good practice that is extensively used in intensive agriculture to broaden the spectrum of weed control; to provide long term weed control; to improve the efficacy of the combined herbicides (synergistic reactions); to delay herbicide resistance development in weeds; to reduce herbicide rates and consequently to reduce the cost of weed control (Damalas, 2004). However, tank-mixing of herbicides could create antagonistic reactions which often reduce the efficacy of their application (Robert *et al*., 2006).

## 1.3 Justification

The practice of hoe-weeding to manage weeds in cassava leads to drudgery which consequently affects the quality of life of farmers' families while other competing household and farm operations influence the timing of weeding. In addition, it has been observed that the pre-emergence herbicides available for weed management in cassava in Nigeria are becoming limited as several active ingredients are being withdrawn from markets either due to their reduced efficacy or concern for environmental pollution (Ojo, 2016). Similarly, the post-emergence herbicides in cassava cultivation have also been limited to glyphosate and paraquat which have been extensively used and are non-selective herbicides. All of these result in poor weed control and low efficiencies of production. Therefore, there is the need to evaluate herbicides with different active ingredients for their selectivity and weed control in cassava.

Also, the conventional method that involves the spray of soil-applied herbicides in addition with post-emergence herbicides or with other supplementary weed control; may be reviewed by alternating the sequence of application of post-emergence herbicide with pre-emergence herbicides as a follow up.

## 1.4 Aim and Objectives of the Study

The aim of the study is to increase herbicide options with different sites of action for use in cassava during the period of canopy closure. Regardless of when pre-emergence herbicides are used, the order in which they are applied may improve their effectiveness. This research work was therefore conceived with the objectives of:

i) evaluating the effects of selected new pre-emergence herbicides followed-up with foliar-applied herbicides on cassava and weeds,

ii) determining the selectivity of three post-emergence herbicides using banded and broadcast spray methods in cassava, and

iii) comparing application of post-emergence herbicides followed by pre-emergence herbicides to the conventional pre-post sequence as a weed management strategy in cassava.

### 1.5 Significance of Study

Weed management in cassava especially during its early period of establishment has always been demanding. The removal of weed manually is one of the factors identified to limit productivity. Although a few herbicides have been evaluated in the past most of these herbicides have been withdrawn from the market as a result of environmental pollution or health issues among other reasons. Investigations from this study identified new herbicides that suppressed weed longer than the ones commonly used by cassava farmers. Other post-emergence herbicides aside from glyphosate which is mostly patronized by farmers were discovered. In addition, applications of the herbicides in sequence effectively managed weed during the first three to four months which is critical for cassava. Furthermore, alternative application sequence with some of the herbicides where post-emergence herbicides is applied before pre-emergence could suppressed already emerged weed seedlings and consequently enhance the effectiveness of pre-emergence herbicides as a follow-up. Appropriate application of these herbicides could improve the quality of life of farmers and cassava productivity in Nigeria.

### 1.6 Scope of the Study

The research work evaluated selected herbicides which included three new pre-emergence herbicides: sulfentrazone, flumioxazin + pyroxasulfone, and indaziflam + isoxaflutole and three post-emergence herbicides: clethodim+lactofen, trifloysulfuron-sodium and carfentrazone-ethyl on cassava and weeds. Also, their sequential application was explored. Soil properties of the trial fields were determined before planting. The investigation covered from planting till harvesting and it was a one location experiments (International Institute of Tropical Agriculture), Idi-Ose. The research trials were established in the planting seasons of 2015 through 2018. The profitability of the herbicides was ascertained through economic analysis.

# CHAPTER 2
# LITERATURE REVIEW
## 2.1 Agronomic Practices for Cassava in Nigeria

In Nigeria, primitive methods of production of cassava are primarily employed by small-holder farmers. Nweke (2004) believed these farmers engage in subsistence farming of the crop mainly to process the roots and prepare it for home consumption while the remaining harvest is sold in village markets or transported to urban areas. Cassava is perceived as a hardy crop that is tolerant of extreme environmental conditions and could even thrive well on impoverished soils (Carvalho *et al*., 2007). However, cassava grows best on light, sandy loams or loamy sands, moist, fertile and deep (Onwueme, 1978).

The crop, according to literature, prefers a warm, humid atmosphere. Temperature is necessary for its survival and it is the reason why it is mainly grown in areas that are not affected by frost. The highest storage root production can be expected in the tropical lowlands below an altitude of 150 m where temperature average 25 to 29°C. Some other varieties could grow at an altitude of 1500 m. The plant thrives in areas where the yearly rainfall is at least 1000 mm. (Hauser *et al*., 2014) but it can be grown where the annual rainfall is as low as 500 mm but well distributed and as high as 5000 mm. It is a crop that withstands prolonged periods of drought in which most other food crops would not survive. This makes it valuable in regions where annual rainfall is low or where seasonal distribution is irregular. Onwueme (1978) reported that cassava could be profitably grown in areas where the annual rainfall is as low as 50 cm.

Planted cassava stakes are from 8 - 18 months old plants and angle planting are recommended for heavy soils and wet conditions, while horizontal is accepted for well-prepared soil (Williams *et al*., 1979). Recommended number of plants per hectare is 10000-15000 and the yield varies among different varieties which could be within the range of 5-60 tonnes/ha (William *et al*., 1979). According to Eze and Ugwuoke (2010), the quality of cassava planting material and the agronomic procedures used, determines the storage root production. Recently, IITA recommended non-branching, high yielding variety TME (Tropical *Manihot esculenta*) 419 in South-west and South-south Nigeria. Although, the crop varieties mature at different time, the storage root can be harvested at six months to three years and harvesting can be done throughout the year.

## 2.2 Weed, a Constraint to Cassava Production

Weeds are the major constraints to cassava cultivation in Nigeria and other cassava growing areas (Ravindran and Ravi, 2009; Hauser *et al.*, 2015). They are the most common pests of crops globally, especially in the tropics (Akinyosoye, 1999). Weeds have been identified as the primary problem that farmers face in 25 of the 30 most frequent crops cultivated (Ayeni, 1991). IITA (2020) opined that weed competition in cassava especially in the first three months significantly reduced storage root yield. Khanthavong *et al*. (2016) reported that weed competition in cassava accounted for 46 to 95% storage root yield loss. Small-scale farmers reckon that weeds contributed to poor yield mostly obtained at harvest (Vissoh *et al.*, 2004). Cardoso (2013) also added that poor technological adoption in the farming system, low yielding varieties, and, most importantly, weed competition are among the key reasons for the crop's low productivity index.

Weed competition is severe on young crops as they are denied of adequate supply of water, nutrients, light, carbon dioxide and space thereby lowering crop yields (Van Heemst, 1985). Competition from weed in cassava significantly influences canopy development and yield components such as the number of storage roots, storage roots length and weight per plant. The quality of cassava roots is depreciated by weed as they feed on soil resources available for plant roots and storage roots development. Pests and diseases easily attacked weed-infested cassava. The Influence of weed infestation is severe in cassava due to its slow-growing pattern during the early stage of cultivation (Olasantan, 2001, 2007).

The significant effect of poor weed control has been reported in many African nations. For example, the loss of cassava yields due to weed infestation was reported to vary from about 40% in Nigeria (Akobundu, 1980) to 94% in Columbia (Doll and Piedraluta, 1973). In Kenya in 2004, inadequate weed control in cassava fields resulted in a 5 tonne/ha yield difference on average, limiting production by 11.6 tonnes/ha (Fermont *et al.*, 2009). In Zambia, many farms recorded low yield. Indeed, excessive weed infestation has resulted in the loss of entire crops for several farmers. (Kabwe, 2014; Vissoh *et al.,* 2004). According to Nyam (2005), crop losses on crop fields might be as high as 100% due to a lack of weed control. As a result of the negative effects of weeds, reducing weed infestation in crop production is vital, particularly during the critical growth period, so as to attain optimum crop output. (Agahiu *et al*., 2011).

Farmers in Kogi state, Nigeria identified grasses as the major weed species on their cassava fields, according to a study by Agahiu *et al.* (2012) on the perception of weed infestation and measures used by cassava farmers. The common weeds of cassava in Nigeria include *Panicum maximum* Jacq, *Imperata cylindrica* (L.) *Beauv, Chromolaena odorata* L., *Mimosa invisa* Mart., *Cynodon dactylon* (L.) *Pers.* (Melifonwu *et al*., 2000), *Talinum fruticosum* (L.) Juss, *Ageratum conyzoides* L, *Euphorbia heterophylla* L, *Digitaria horizontalis* (Jacq.) Willd, *Tridax procumbens* L (Melifonwu *et al*., 1994, 2000) among others. Ekeleme *et al*. (2019) identified *Digitaria horizontalis* Wild, *Rottboellia cochinchinensis* Lour., *Chromolaena odorata* L, *Aspilia africana* Pers., *Commelina benghalensis* L., *Euphorbia heterophylla* Linn. as troublesome weeds in cassava.

### 2.3 Weed Control Measures in Cassava

Weed control in the humid tropics is always a challenge, but weed control in cassava systems is much more demanding than most other field crops. The crop is in the field for a long time and is planted at a wide spacing which gives room for weed competition. In cassava, weeds are suppressed by hand weeding or other cultural approaches, even though chemical weed control could be used (Hauser *et al*., 2015). Mechanical weed control makes use of simple tools, animal-drawn implements or modern implements such as a tractor. Cultural weed control is achieved by selecting adapted cultivars, high-quality stakes, correct planting density, mulching, tillage, burning and crop rotation. A more holistic approach to weed management would be preferable. This entails combining available tools, knowledge, and management abilities with the most recent innovations. Pre-plant herbicide application, tillage, and ridging; cultivation, crop rotation and the use of pre-emergence and/or foliar herbicides are expected for effective weed management strategies (Sieczka and Creighton 1984). Weed management has traditionally been done with a cutlass and hoe, and farmers favour it because of low income and interest in multiple cropping practices.

### 2.3.1 Hoe-weeding and its challenges

Small-scale farmers in cassava agriculture still use hoe-weeding as a weed management approach (Agahui *et al.*, 2012). However, the life of drudgery associated with this method (Ekeleme, 2019), makes it practically impossible for it to be used to manage weeds on large-scale production systems. Johnson (1995) reported that despite a significant amount of energy put in, optimum yield is never achieved because of untimely removal of weeds, limited cash to hire labour and unavailability of able hands during critical periods of weed interference. Ekeleme (2013) expressed that though hoe-weeding is still common among African farmers, it is expensive and require proper timing, which farmers do not follow due to other competing household labour. In addition, it was revealed that farmers could suffer ill-health during critical times which could be detrimental to cultivation (Orr, 2002).

The International Fund for Agricultural Development (1998) opined that as long as hoes continued to be the tool for weed control, cultivation will continue to be at subsistence level. Ukekje *et al*. (2004) remarked that women supply over 90% of the hand-weeding labour for most crop. More than 50% of farmers' children between the ages of 5 - 14 are engaged on farms at the expense of their academics, especially at the crucial period of weeding. For cassava, this period is during the first 3 to 4 months after planting. Weeds are a menace in crop production that farmers continually combat with and the cost of manual weeding create a gap between potential and actual yield and profit. Ekeleme *et al.* (2003) emphasized the adoption of weed management practices that can reduce the amount of labour required which will, in turn, lower the cost of food production.

### 2.3.2 Chemical weed control in cassava

Weed management with chemicals has become a necessary aspect of modern crop cultivation. This is because herbicides are more effective in controlling weeds on a large scale with none or minimal effect on crops and soils (Akobundu, 1987). Ekeleme (2013) reported that several studies have indicated herbicides control weeds better in cassava with higher yields and income at less cost. Chikoye *et al*. (2001) found chemical weeding in cassava to be 30 to 50% less expensive than the cost of hand weeding three times, especially if applied timely and correctly. Tahir *et al.* (2009) expressed that using chemical is faster, more effective, and saves time and labor than previous methods. Several herbicides have been screened for weed control in cassava and other root crops in time past. Herbicides recommended for weed control in cassava included alachlor 2-

3, atrazine + metolachlor 2.5, fluometuron 2-3, fluometuron + metolachlor 2 + 2, fluometuron + pendimethalin 2 + 2 (kg a.i./ha) for broad-spectrum control of weeds, and diuron + paraquat at 2.8 kg applied as early post for control of annual weeds (Akobundu, 1987; Iyagba, 2003). Presently, in Nigeria, few herbicides are available for use in cassava with atrazine and glyphosate being widely used. Also, the method of weed control in cassava is the supplementary use of manual weeding following a pre-emergence herbicide application. Glyphosate and paraquat, both non-selective herbicides, have been mostly sprayed in cases where post-emergence herbicides have been used, with glyphosate being widely used worldwide (Leyva-Soto *et al*., 2018). Velmurugan *et al*. (2017) reported that oxyfluorfen (150 g/ha) + hoe-weeding at 3 months after planting and hoe-weeding twice followed by glyphosate three months after was found effective in cassava. In an experiment conducted on weed control in maize and cassava intercrop, s-metolachlor + atrazine and metolachlor + metobromuron at 250 g each gave satisfactory control of weed only up to 6 weeks after planting (Olorunmaiye and Olorunmaiye, 2009). Better results were recorded when atrazine + s-metolachlor was supplemented with two times how-weeding. They reported significant lower weed biomass of 42.9 g/m$^2$ and yields (kg/ha) of 1,135 (maize) and 10,027 (cassava), compared to weed biomass of 80.4 g/m$^2$ and yields of 678 and 1801 for maize and cassava respectively when using atrazine + s-metolachlor alone. Quee *et al*. (2016) discovered that the application of terbulor at 4 L/ha + two-time hoe-weeding gave significant cassava storage root yield of 91% and lower weed biomass compared to yield from un-weeded plots.

Recently in Brazil, new herbicides are made available for weed control in cassava. Clomazone + ametryn (1,080 + 2,000 g a.i./ha), clomazone + metribuzin (1,080 + 480 g a.i./ha), clomazone + flumioxazin (1,080 + 80 g a.i./ha), isoxaflutole + ametryn (93.7 + 2,000 g a.i./ha), isoxaflutole + metribuzin (93.7 + 480 g a.i./ha), isoxaflutole + flumioxazin (93.7 + 80 g a.i./ha) were found selective. In addition, metribuzin-containing herbicide combinations were found to have poor weed suppression than herbicide combinations including clomazone or isoxaflutole (Santiago *et al.*, 2018).

Akobundu (1987) addressed the fact that herbicide application (pre-emergence) gives early weed control. Some products quickly lose their efficacy which allows late-emerging and vigorous growing weeds to gain ground. Indication from studies shows available or most pre-emergence herbicides need to be supplemented with other means of controlling subsequent weed flush after the effect of pre-emergence herbicides applied dissipated (Adigun and Lagoke, 2003). Appropriate post-emergence herbicides could later be introduced to take care of subsequent weeds that emerged before canopy closure or till the critical period ends.

## 2.4 Herbicides in Crop Production

### 2.4.1 Herbicide adoption in Africa

Herbicides are rarely used by smallholder farmers in Africa; less than 5% have been documented (Mavudzi, 2001; Overfield *et al.*, 2001). There are reports of poor acceptance of herbicide use in some states in Nigeria, and these included Niger, Rivers and Bayelsa states (Kolo *et al*., 2004). A similar observation was made in some other parts of Africa: herbicides are used on 5-10% of cotton acres in Zambia and Zimbabwe, whereas 4 % of groundnut growers in Ghana use herbicides, according to a survey by ICAC in 2005 (Boifrey-Arku *et al.*, 2006). Despite research proving that this strategy was cost-effective and provided a higher return than conventional methods, herbicide technologies were not adopted on small-scale farms due to a lack of diffusion of knowledge from research efforts (Muthamia *et al.*, 2001). Herbicide technology required skill which may be lacking among most African farmer as a result of probably low level of education. Among the solution Chikoye (2000) proffered were training of farmer on proper sprayer calibration and possibility of expressing recommendation in local language for ease of access by farmers.

Herbicide use has risen in recent years in global agricultural production. Philip-McDougall (2013) remarked that between 2002 and 2011, the global herbicide market rose by 39%, with the expectation that it would grow by another 11% in 2016. Pingali and Gerpacio (1997) emphasized that the inadequacy of non-chemical controls of weed and the rising opportunity of jobs that the use of herbicide avails will encourage its acceptability. In Nigeria, the usage of pesticides for weed management has increased dramatically in the recent decade (Agahiu *et al*., 2012; Iyagba, 2013).

### 2.4.2 Types of herbicides

Herbicides are classified and applied as foliar and soil-applied (Anwar *et al*., 2013). While the foliar herbicides are classified under post-emergence herbicides the soil-applied herbicides are known as pre-emergence herbicides. Pre-emergence herbicides are systemic, while post-emergence herbicide could either be systemic or contact herbicide. Pre-emergence herbicides are incorporated by cultivation, rainfall or irrigation (Haskins, 2012) also, when there is adequate soil moisture at the time of application. Farmers in Nigeria have a higher dependence on pre-emergence herbicides than post-emergence herbicides except glyphosate which is incorporated in the land preparation process. However, Qasem (2007) and Zand *et al*. (2010) suggested that post-emergence herbicides application could increase yield and significantly reduce weed population.

Bond and Griffin (2005) identified weather conditions, amount of precipitation, time of application, among others, as factors that could affect herbicide's potency. The need of applying post-emergence herbicides at the right time in proportion to the size of the weeds was emphasized, with a decreased efficiency on already established weeds (Jordan, 1993 and Loux *et al*., 2008).

### 2.4.3 Herbicide selectivity

Herbicide selectivity, according to Rao (2000), is a phenomenon in which a chemical injures or kill only susceptible plant species in a plant community while causing no harm or only minor effects to the other plants. Filho *et al*. (2018) opined that young plants are more vulnerable to herbicides than older plants, this is as a result of the presence of more meristematic tissues in the young plant. Filho *et al*. (2018) stressed that selective herbicides are imperative for successful operation with chemical control. According to Varshney (2012), herbicide selectivity or non-selectivity is determined by a variety of parameters including environment, soil topography, plant physiology, application time, rate, and technique. Selectivity can also be influenced by differential absorption, translocation and sequestration in plants at sub-cellular levels, differences in-active site, sensitivity, and the rate of metabolism, which was rated to be the major factor in selection action (Rao, 2000; Jablonkai, 2015). Selectivity could be affected by physical means through spray and the correct choice of spraying equipment especially for non-selective post-emergence herbicides. Physical mean to force selectivity could be achieved by band-application where herbicides are directed to weeds alone and chances of drifting minimized through the use of knapsack spray shield or sprayhood and nozzles of appropriate bandwidths. Band application of herbicides is one of the integrated weed management tactics (Eadie *et al*., 2004).

According to Akobundu (1981) plant responses to herbicide interactions can be assessed using stand reduction or a variety of growth measures. Although chemical weed control has the ability to minimize labour needs, cutting production costs, non-selective types may have a negative influence on crop growth and output due to damage to particular plant components (Akobundu, 1987; Galon *et al*., 2009). Some may induce a substantial rise in phytotoxicity, while others may have no effect or create a low amount of phytotoxicity. Filho *et al*. (2018) tested five post-emergence herbicides (mesotrione, carfentrazone-ethyl, chlorimuron-ethyl, nicosulfuron and imazethapyr) in a greenhouse applied at 30 and 45 DAP. They reported that mesotrione and chlorimuron were not toxic to cassava. However, differences in tolerance level of the rest of herbicide active ingredients by cassava plants varied with application time and more damages noticed at 30 DAP. Cafetrazone-ethyl, nicosulfuron and imazethapyr caused higher reductions in root dry matter (Filho *et al*., 2018). An experiment was conducted where six herbicides metolachlor, diuron, oryzalin, tetrafluron, alachlor, and fluometuron were applied alone or in combinations to control weed in cassava. It was discovered that diuron was not phytotoxic while others showed slight symptoms (Quinones and Moreno, 1995). Because of the interactions of some herbicides within the plant, they can provide effective weed control at much lower concentrations than are commonly employed in single applications. Cassava is susceptible to atrazine, although the atrazine components in the primextra formulation are 1.0 kg a.i./ha, which are tolerated by cassava in a 2.5 kg a.i./ha mixture.  The result of previously evaluated herbicides for their selectivity is shown in Table 2.1 (CIAT 1976).

#### 2.4.4 Effects of herbicides and their application methods on yield of cassava

Herbicides are applied as part of agronomic practices in crop production to manage weeds and achieve optimum yield (Doll and Pedrahita, 1976). There are reports on improved yield with herbicides. For example, storage root yields that doubled the average yield of 8.76 t/ha in Nigeria were reported by Ekeleme *et al*. (2020) using indaziflam + isoxaflutole, S-metolachlor + atrazine and terbuthylazine + S-metolachlor, aclonifen + isoxaflutole, acetochlor + atrazine + terbuthylazine, diflufenican + flufenacet + flurtamone, flumioxazin + pyroxasulfone. In another study, a combination

Table 2.1: Pre-emergence and pre-planting incorporated herbicides selectivity in cassava

| Highly selective | moderately selective | Non-selective |
|---|---|---|
| Alachlor | Ametryn | Atrazine |
| Benthiocarb | Butylate | Bromacil |
| Bifenox | Chlorbromuron | EPTC |
| Butachlor | Diuron | Karbutilate |
| Chloramben | DPX-6774 | Tebuthiuron |
| Oyanazine | Fluometuron | Vernolate |
| Dinitramine | Linuron | |
| DNBP | Methabenzithiazuron | |
| Fluorodifen | Metribuzin | |
| H-22234 | Oxadiazon | |
| Methazole | Prometryn | |
| Napropamide | Terbutryn | |
| Nitrofen | | |
| Norea | | |
| Perfluidone | | |
| Pronamide | | |
| S-2846 | | |
| Trifluralin | | |

Source: Centro International de Agricultura Tropical (CIAT) 1976 of flumioxazin + clomazone at 2,160 + 160 g/ha resulted in a greater accumulation of dry shoot weight and root yield of cassava than the lower rate (540 + 40 g/ha) of the same herbicide (Santiago *et al*., 2020). According to Meister (1992), two major methods of herbicide application are band and broadcast applications. Several authors have reported the influence of the two application methods on crop yield. Uremis *et al*. (2004), in their research work observed that banding was as effective as a broadcast application with selective herbicide application. They also recorded that flat fan nozzles of different bandwidths gave similar weed control and maize yields. In addition, Swanton *et al*. (2002) reported that band herbicide application provided comparable weed control, maize and soybean yields, and gross return to broadcast herbicide application. The effect of several herbicide application methods and cultivation on yield and weed control of maize (*Zea mays*) was evaluated in a study, and it was reported that both band and broadcast spraying had no influence on yield and offered excellent weed control (Niazmand *et al*., 2008).

The quality and quantity of crop could be affected by herbicides, mainly when they are not correctly applied (Doll and Pedrahita, 1976). Nedunchezhiyan *et al*. (2017) worked on the storage root of cassava yield and starch content as affected by weed control methods; they reported that application of oxyfluorfen + two hoe-weeding and two hoe-weeding + with application of glyphosate at 3 MAP resulted in an insignificant reduction 9.6 and 10.1% in the storage root yield compared to weed control using a ground cover with mat mulching. They also reported that there was maximum dry matter partitioning efficiency in cassava under weed control of ground cover, but there was no adverse effect on the starch content of storage root of cassava in glyphosate
treated plots. In another study, Filho *et al*. 2018 conducted green-house research on the selectivity of cassava crop in post-emergence application and reported that nicosulfuron and imazethapyr, which affected the early stages of stem growth, had an effect on stem diameter. They expressed that this effect could implicate the quality of planting material as well as subsequent cultivation. According to them chlorimuron did not result in substantial decrease in dry shoot matter of cassava plants among the herbicides they tested, but carfentrazone-ethyl, nicosulfuron and imazethapyr resulted in higher reductions. This implies that nicosulfuron and imazethapyr probably will negatively affect yield as the photosynthesis process is disturbed because of their effect on shoot growth (Viana *et al*., 2001).

## 2.5 Weed Spectrum in Herbicide Weed Control

Weeds of different types depend on basic necessities as water, nutrients, space, sunlight for survival hence they compete with crops for them. Weeds are mainly grouped into grass, broadleaf and sedge (Melifonwu *et al*., 2000). They are further classified into annual, biennial and perennial weeds. These identities given to weeds help understand their survival mechanism in ecology, and the knowledge about the proper use of herbicides is crucial to the development of strategies to manage or control them (Singh *et al*., 1996). Abuse of herbicides application as a result of ignorance could lead to more difficulties in weed control. There could be the development of weed resistance and weed shift, to mention a few. It was opined that herbicide application among other agronomic practices could give rise to a change in weed flora where another replaces the removal of one weed species or group, and this thereby determine the weed flora that is established and persist in a particular agricultural site (Swanton *et al*., 1993). Weed shift could be of a disadvantage if the change produced higher percentage of grass weeds and sedge or more noxious broadleaf weeds. Annual weeds could also be replaced with perennial ones (Kandasamy, 1997). Bergkvist and Ledin (1997) observed that the reduction of perennial weeds in a willow (*Salix* spp) plantation often result in a flush growth of annual weeds as glyphosate and terbuthylazine were the major herbicides used to control predominant *Elymus repens* (L. Gould) and *Circium* species in the plantation. Rana and Rana (2015) opined that to break the chain of predominant weeds in particular cropland, crop and weed management diversity practices may be adopted. Despite the challenges associated with the methods of weed control, several weed types and species have been successfully suppressed in crop production through appropriate herbicide applications.

An investigation on the use of herbicide GF-2581 (penoxsulam + florasulam) to control broadleaf weeds in olive was carried out and Travos *et al*. (2014) reported that penoxsulam + florasulam kept the plantation free from *Stellaria media* (L). Villi, *Conyza canadensi* L. and *Sonchus oleraceous* L. for a long time. They observed that the control efficacy of this herbicide was significantly higher than flumioxazin. Travlos and Chachalis (2012) further stated that *Sonchus* spp and *Conyza* spp are prolific seed producers, so controlling them is crucial. The authors also observed that *Sonchus media* L. could be easier to manage with most herbicides while *Sonchus oleraceous* L. and *Conyza canadensis* L. are more competitive of which they suggested mixing or sequential strategic application of penosulam and florasulam with glyphosate or diquat.

Qasem (2007) reported that diphenamid 7.5 kg/ha and pronomide 2.5 kg/ha reduced weed growth, crop shoot dry weight and weed biomass in cauliflower while oxyfluorfen at 2.5 L/ha applied pre-planting produced the best weed reduction.

In a greenhouse and field experiment, Beck *et al*. (2020) investigated the efficacy of various herbicides on perennial *Plantago spp*. and their effect on Alfafa damage and yield; they discovered that saflufenacil alone and in combination with imazethapyr or imazamox only temporarily controlled two species of plantago. In another experiment, where clodinafop was used for weed control in wheat *Poa annua* L. made up the weed vegetation. Rana and Rana, 2015 indicated that atrazine use in maize resulted in the emergence of *Commelina benghalensis, Bracharia ramose* (L.) Stapf., and *Ageratum conyzoides* L. despite the fact that atrazine is expected to manage broadleaf and grasses weeds according to Obermeier and Kapusta, (1996).

Mehmeti *et al*. (2019) evaluated different herbicides to manage weeds in maize. They reported that the predominant weed *Amaranthus retroflexus* L. and *Chenopodium album* L. among other 14 weed species were effectively controlled by isoxaflutole applied as pre and post (Markovic *et al*., 2008). Metribuzin is a chemical substance introduced for broadleaf and grass weed management in potato (Robinson *et al*., 1996). However, weed species; *Chenopodium album* L. and *Amaranthus retroflexus* L. were resistant to its application (Eberlein *et al*., 1994). Nicosulfuron and rimsulfuron are used to control grasses in maize (Mekki and Leroux, 1994) and they were effective against grass weed spp; *Sorghum halepense* L. Pers and *Setaria faberi* Herm (Thompson *et al*., 2009). Alebrahim *et al*. (2012), in another study reported effective control of *Amarathus retroflexus* L. by trifluralin applied PRE, rimusulfuron applied PRE or POST while oxadiargyl applied POST and pendimethalin applied PRE controlled *Chenopodium album* L. Singh *et al*. (2001) reported the efficacy of control of *Cyperus rotundus* L. *Cyperus campestris* Schrad. Ex Nees, *Eleusine aegyptiacum, Eleusine indica, Ipomoea hispioda* and *Vicia indica* L in sugarcane by metribuzin at 1.4 kg a.i/ha on problematic weeds. Knezevic *et al*. (2003) reported that sulfonylurea (50 and 30 %) recommended rates of prosulfuron and primisulfuron-methyl at 16 g a.i/ha and 20% and 30% recommended rate of atrazine and metolachlor (0.9 and 0.6 L a.i/ ha) applied Pre successfully suppressed annual broadleaf weeds but not perennial weeds.

Glyphosate is a frequently used post-emergence herbicide that is efficient against a wide range of broadleaf and grass weeds (Franz *et al*., 1997). Still, Shaw and Arnold, (2002) reported that it was ineffective against Ipomoea species, *Commelina diffusa* (Brum.) F. and *Cyperus* spp. Arregui *et al.* (2000), in an attempt to control *Solanum sisymbrifolium* Lam., *Parietaria debilis* Nutt., *Commelina erecta* L and *Sida rhombifolia* L. in glypghosate-tolerance soybean, they applied metribuzin, imazaquin and post-emergence herbicide imazethapyr and glyphosate. They reported that these herbicides were effective against *Solanum sisymbrifolium* Lam., *Commelina erecta* L and *Sida rhombifolia* L.

Zand *et al*. (2007) identified problematic broadleaf weeds in wheat as *Descurani asophia* (L.) Webb, *Galium* spp, *Sinapis arvensis* L, *Cirsium arvense* (L) Scop., *Convolvulus arvensis* L, *Glycyrrhiza glabra* L, *Alhagi persarum* Boiss and Buhse and *Acroptilon repens* L. This led them to investigate the efficacy of diflufenican +MCPA at 0.5, 1 and 1.5 L/ ha; clopyralid 1.5 L/ha + 2,4-D 2 L/ha and fluroxypr, tribenuronmethyl, 2,4-D + MCPA, clopyralid + MCPA and dicholoprop-p + mecoprop-p + MCPA. They reported broadleaf weeds were controlled by diflufenican + MCPA, clopyralid + 2,4-D and fluroxypr while fluroxypr at 2.5 L/ha reduced weed population and biomass significantly.

### 2.6 Weed Resistance to Herbicide Application

Weed resistance to herbicide application can be a menace in a production system if the appropriate measure is not considered (Yu and Powles, 2014). To avoid or delay this menace an integrated weed management approach is essential. This may include herbicide use of the different mechanism of action, herbicide rotation and a mixture of active ingredients. These techniques could hinder weed to develop resistance to selected pesticides. The use of herbicides of different mode or site of action could prevent target-site resistance among susceptible plants as variation at point of attachment is achieved. Herbicide resistance is the ability of a plant to survive and reproduce following exposure to a dose of herbicide that will generally be lethal. The development is an evolutionary process when weeds respond to repeated treatment with a particular class or family of herbicides; weed, populations change in genetic composition such that the frequency of resistance alleles or resistance individuals’ increases (Green and Owen, 2011). In this way, weed populations become adapted to the intense selection pressure imposed by herbicides (Rao, 2000). In a plant, resistance may be natural or induced. In a modern farming system, spraying of herbicides of similar mechanism of action, has contributed to the problem of weed resistance. Herbicide resistance in weeds threatens cropping system sustainability in many areas around the globe (Harker, 2013). It is a rapidly expanding phenomenon resulting in higher production cost due to the more significant weed impact (Owen and Zelaya, 2005; Jeanmart *et al*., 2016). In addition, weed resistance to herbicides leads to indiscriminate use and consequently cause injury to non-target plants and groundwater contamination (Sherwani *et al*., 2015). According to some estimates, there are 183 herbicide-resistant plants worldwide, including monocots and dicots (Heap, 2011). Furthermore, the issue of weed resistance in herbicide application could create a serious challenge in weed management; hence, introducing new herbicides of different mode of action is a pre-requisite to arrest and delay the problem of weed resistance.

Herbicides of varying chemical families and mechanisms of action must be used at separate times on the same crop, according to Vencilli *et al.* (2012), to avoid difficulty of resistance. Presently, herbicides of varying active ingredients, chemical family, site and mechanisms of action are being evaluated for use in cassava and some other crops (Ekeleme *et al*., 2019).

### 2.7 Herbicide Groups

Classification of herbicide is essential for understanding and managing herbicide resistance (Duke, 1990; Torrens and Castellano, 2014). The chemical family, mode of action, and target specificity are used for herbicide classification (Fonne-Pfister *et al*., 1996; Tresch *et al*., 2008). According to Duke (1990) and Varshney (2012), herbicides can be classified into different aspects as chemical family, time of application, selectivity, translocation, site of action and mode of action. Herbicide’s mode of action includes contact, absorption, movement, toxicity, and plant death, which can be accomplished by inhibiting the normal processes required for proper plant growth and development (Sherwani *et al*., 2015).

#### 2.7.1 Acetyl-Coenzyme A Carboxylase inhibitors group

These are primarily used for grass control in broadleaf crops. They are absorbed through the foliage and translocated in the phloem to the growing point where they inhibit meristematic activities. They inhibit the enzyme Acetyl-Coenzyme A Carboxylase (ACCase) or lipid biosynthesis which catalyses the first step in fatty acid synthesis which is important for membrane synthesis (Yang *et al*., 2010). Symptoms include chlorosis of newly formed leaves with reddishness or purpling of older leaves, necrosis, bleaching, leaf distortion and crinkling. According to Kukorelli *et al*. (2013), their selectivity is mainly because they block the eukaryote-type ACCase enzyme of Poaceae. Clethodim [(EE)-(±)-2-[1-[[(3-Chloro-2propenyl) oxy] imino] propyl]-5-[2(ethylthio) propyl]-3-hydroxy-2-cyclohexen-1-one] is an ACCase inhibitor and belongs to the cyclohexanedione family. They are group 1 member according to the WSSA table (Burton, 1991) with 34 weed species found to be resistant to this particular group (Heap, 2011). They are applied post-emergence for effective control of annual and perennial grasses (Devine and Shimabukuro, 1994), and they are both systemic and selective (Vidah, 2007).

It was discovered by Chevron Chemical (Tomlin, 2006) and its herbicidal spectrum was almost similar to sethoxydim but the application rate is lower. This group of herbicides actually target the ACCase (Secor and Cseke, 1988; Rendina *et al*., 1990; Burton *et al*., 1991), catalyses the first step in fatty acid biosynthesis. These herbicides are weak acids as their pKa are usually less than 5. They ionize quickly, but it is in protonated form that the herbicide is able to penetrate the plant cuticle (Kukorreli *et al*., 2013). They could be easily influenced by pH in terms of solubility and partition properties. They are easily decomposed by sunlight radiation and pH variations.

### 2.7.2 Proto Portophyrinogen Oxidase (PPO) inhibitors group

They are cell membrane disrupters and they mainly target protoporphyrinogen oxidase (protox) in the porphyrin biosynthetic pathway (Jacobs and Jacobs, 1987; Witkowski and Halling, 1989). The enzyme is the last common step before branching the pathway for chlorophyll II and heme synthesis. Members of PPO inhibitors include: Lactofen, carfentrazone-ethyl, sulfentrazone and flumioxazine. Lactofen {2-ethoxy-1-methyl-2-oxoethyl5-[2-chloro-4-(trifluoromethyl) phenoxy]-2-nitrobenzoate} is a contact herbicide and belong to diphenylether chemical family and it is a group 14 member. Only two weed species are recorded to resist group 14 herbicide (Heap, 2011). Carfentrazone-ethyl and sulfentrazone are phenyltriazolinone family (Theodoridis *et al*., 1992). Carfentrazone (α,2-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-l-yl]-4-fluorobenzene-propanoic acid, ethyl ester) is used in cereals, and some leguminous crops as foliar-applied herbicide for control of broadleaf weeds (IIango, 2003). Carfentrazone-ethyl is also used to manage aquatic floating and emergent weeds. It acts on the foliage and is quickly broken down into metabolites like carfentrazone acid. Carfentrazone-ethyl is a contact herbicide that has an immediate negative effect on plants and kills them within a few days of treatment (WSSA, 2007). According to WSSA (2007), it is a non-mobile herbicide which get quickly degraded by microbes.

Sulfentrazone is suitable for applications in pre-emergence (Dayan *et al*., 1996). It is reported for use in agricultural and non-agricultural areas. It controls weeds in coffee, sugarcane, citrus and soy (Dayan *et al*., 1996). Sulfentrazone solubility in soil is moderate and it is 490 mg $L^{-1}$ soluble in water with a vapour pressure of 1 x $10^{-9}$ mm $Hg^{-1}$ at $25^oC$. It has a half-life of 180 days as it is fed on by microbes (Rodrigues and Almeida, 2011). Sulfentrazone shows greater adsorption in soils with high clay and organic matter content due to its large specific surface and high retention capacity and ion exchanges, compared to sandy textured soils (Polubesova *et al*., 2003).

Flumioxazin[N-(7-fluoro-3,4-dihydro-3-oxo-4-prop-2-ynyl-2H-1,4-benzoxazin-6-yl) cyclohex-1-ene-1,2-dicarboxamide is part of the N-phenylphthalimide chemical family (Yoshida *et al*., 1991; Hartzler, 2004). It is used pre-emergence for broadleaf weed control in soybean, cotton, peanut and several other crops. It is also used as a selective herbicide in industrial vegetative management and non-cropland areas. It is a contact herbicide and its mobility is limited to treated leaves. Flumioxazin can be classified as volatile with vapour pressure 3.2 mPA (25°C), moderately mobile: soil mobility potential (mean $K_{oc}$= 557) (USEPA, 2010). It has a short half-life ($t_{1/2}$<18 days) and water solubility of 1.79 mg L-1. They are light-dependent peroxidising herbicides (LDPH) that inhibit plant development by inhibiting heme and chlorophyll biosynthesis, causing phytotoxic porphyrins to accumulate in plant and animal tissues (USEPA, 2010). Alister *et al*. (2009) reported that both leaves and roots take up the active ingredient with longer persistence in the soil. Symptoms include lipid membrane peroxidation leading to a rapid loss of turgidity and foliar burns.

#### 2.7.3 The 4-hydroxyPhenylPyruvate De-oygenase (HPPD) inhibitors group

They inhibit carotenoid biosynthesis and pigment formation (Qin *et al*., 2007) where diterpene synthesis takes place in plants. Carotene levels in susceptible plants are altered, resulting in the formation of free lipid radicals that obstruct fatty acid and lipid uptake. Lipid peroxidation is caused by the presence of radicals, which has a deleterious impact on chlorophyll II, other cell membrane lipids, and some proteins (Sherwani *et al*., 2015). Isoxaflutole[(5-cyclopropyl-1, 2-oxazol-4-yl alpha alpha-trifluoro-2-mesyl-p-tolyl ketone, belongs in this class, and it is a member of the isoxazole chemical family of group 27 and only one weed species is resistant to this family (Heap, 2011).

Members in this group are being recommended for use in maize cultivation. They control broadleaf and grassy weeds. They could be sprayed before planting, before emergence, or after emergence. It is a systemic herbicide with a half-life of 8 to 18 days, metabolism and herbicide intensity beyond 100 days were generally low (Papiernik *et al*., 2007). It has a high adsorption with solubility of 6,200 mg/L in water at a temperature of 20°C (Sims *et al*., 2009). The herbicide inhibits hydroxyphenyl-pyruvate dehydrogenase which is an essential enzyme. Isoxazoles show characteristic symptoms in susceptible species, leaf bleaching, followed by standstill growth and plant death. The typical feature of carotenoid synthesis inhibitor herbicides includes a reduction in leaf colouration, or white leaf colouration which is promoted by oxidative stress resulting from chlorophyll photooxidation caused by the presence of light and absence of carotenoids action.

### 2.7.4 Aceto-Lactate Synthase (ALS) or Aceto-Hydroxy Acid Synthase (AHAS) inhibitors group

They impede amino acid synthesis (leucine and valine) (Whitcomb, 1999). This is achieved by inhibiting the ALS enzyme, which eventually leads to wilting and death of the plant. An example of ALS is trifloxysulfuron-sodium [N-(4, 6-Dimethoxy-2-pyrimidi-nyl)-3-(2,2,2-trifluoroethoxy)-pyridin-2-sulfonamide sodium salt], with a trade name: Envoke. The active ingredient in Envoke® is a new broad-spectrum, low-rate technology herbicide for over-the-top post-emergence application, developed for use in sugarcane and cotton. It is selective and systemic in action. Trifloysulfuron-sodium is an ALS inhibitor that belongs to the sulfonylurea family and group 2 (Hudetz *et al*., 2000). The Surfonyl-Ureas (SUs) are weak acids and their solubility is influenced by pH. Their poor solubility especially, in neutral and alkaline solution affect their absorption and translocation into plants leaves consequently affect their efficacy as the remains of the herbicides on plants leaves could be washed off by rainfall. However, they hydrolyse faster in acidic solution (Sarmah and Sabadie, 2002). This could explain why the herbicides are formulated as dry materials since their effectiveness could be improved by dissolving them in appropriate medium. Surfonyl-Ureas (SUs) affect the production of valine, leucine, and isoleucine in plants. These essential amino acids are produced by ALS enzymes which is the target of the herbicide. The application of the herbicides is at a small dose with less environmental impact as they degrade primarily by abiotic hydrolysis, which increases with increasing temperature and in acidic pH condition (Hudetz *et al*., 2000; Matocha and Senseman, 2007).

### 2.7.5 Photosystem II inhibitor

The PSN inhibitors herbicides cause the disruption of the photosynthetic and biochemical pathway which are important for plants growth and development (Santabarbara, 2006; Lambreda *et al*., 2014; Roch and Krieger-Liszkay, 2014). Atrazine 2-Chloro-4-ethylamino-6-isopropylamino-s-triazine is an herbicide of the triazine family of group 5. It is used for pre- and post-emergence control of broadleaf weeds in crops. Atrazine is a photosynthetic inhibitor (mobile l). Application of atrazine in susceptible plants move from the roots through the xylem to the site of action (photosystem II) to distrupt the photosynthetic pathway. However, it is not effective on tolerant crop. Although, the average half-life of atrazine is 60 days, it persists longer in soils with pH of above 7.2. Degradation of atrazine is by microbial activity and this is greater in soils with pH of 5.5 to 6.5 (WSSA, 2007). It could also be broken down by photodegredation especially when rainfall is not adequate. Some weeds have developed resistance to herbicides in this family as a result of their misuse, particularly atrazine and metribuzine and about 24 weed species are identified (Heap, 2011).

### 2.7.6 Very Long-Chain Fatty Acid Elongases (VLCFAE) inhibitors group

These are seedling shoot growth inhibitors. They are designed to be applied as part of soil preparation and acts effectively before grass and broadleaf weeds emerge. The site of action is at the VLCFAE located in the cell membrane (Trenkamp *et al*., 2004; Qin *et al*., 2007). Pyroxasulfone3-[[[5-(difluoromethoxy)-1-methyl-3-(trifluoromethyl)-1H-pyrazol-4-yl]methy]sulfonyl]-4,5-dihydro-5,5-dimethyl: isoxazole belongs to chloroacetamide family of group 15 and it is relatively new (Anonymous, 2011). It is classified as a k3 herbicide by the Herbicide Resistance Action Committee. Shaner (2014) remarked that pyroxasulfone is not readily soluble in water hence its potential to leach into the soil is reduced. It is mobile, being a systemic herbicide and it is selective in action. This group is reported to have very low weed resistance (Heap, 2014). Pyroxasulfone is a new herbicide for pre-emergence control of grass and broadleaf weeds in corn, soybeans, and wheat. Pyroxasulfone works on susceptible weeds when applied pre-emergence or early-post-emergence at up to 230 g a.i $ha^{-1}$ (Knezevic *et al*., 2009). Weed control with pyroxasulfone is achieved with a little dose and gives a broader spectrum of weed control. It stays longer in the soil. It could be considered environmentally friendly as its pollution is insignificant compared to S-metolachlor. (Westra, 2012). Metolachlor is a broad-spectrum (systemic and selective) herbicide that controls grasses, grass-like weeds and broadleaved weeds. It inhibits very long fatty acids. It interferes with the cell division and inhibits seedling development and shoot growth. Soil characteristics influence the chemical properties. It is moderately mobile with $K_d$ values ranging from 0.11 to 44.8 and $K_{oc}$ from 21.6 to 367 (Janaki *et al*., 2015). It is degraded by microbes (aerobic soil metabolism $t_{1/2}$ = 13.9 to 66 days; anaerobic takes 81 days while photo-degradation takes 70 days in water and 8 days in soil.

### 2.7.7 Cellulose inhibitor or cell wall biosynthesis inhibitor group

Cellulose is synthesized in the plasma membrane by a multi-protein complex known as cellulose synthase complex which is responsible for converting Uridine diphosphate (UDP)-glucose to cellulose (Tateno *et al*., 2016). They exhibit characteristic symptomology of stunted growth, radical swelling, rapidly expanding tissue, ectopic lignification and reduced cellulose content in a dose and inhibit the incorporation of $^{14}$C-glucose into cellulose fraction of cell walls (Tateno *et al*., 2016). Indaziflam(N-[(1R,2S)-2,3-dihydro-2,6-dimethyl-1H-inden-1-yl]-6-[(1R)-1 fluoroethyl]-1,3,5-triazine-2,4-diamine) is a new alkylazine herbicide that inhibits cellulose biosynthesis in the plant cell wall. It is an alkylazine family of group 29. It is manufactured by Bayer Crop Science and can be applied pre-emergence with broad-spectrum control. Indaziflam is labelled to control broadleaves and grasses and it is used for annual weed control in various agricultural systems, residential and commercial areas (Brosnan *et al*., 2011). Its mode of control is systemic and selective, it affects emerging seedlings meristematic areas. (Brabham *et al*., 2014). It is moderately mobile in the soil; however, its breakdown products (indaziflam-carboxylicacid, fluoroethyl ldiaminotriazine and fluoroethyltriazinanedione) are more mobile. It provides long-lasting residual activity at low application rates, due to its long persistence in soil ($t_{1/2}$ = 150 days) (Brosnan *et al*., 2011). The water solubility of indaziflam is 0.0028 g/L at 20°C and its organic carbon sorption coefficient ($K_{oc}$) is <1,000 mL/g. It is dissipated through degradation and leaching. There are no reports of resistance to this group of herbicides.

## 2.8 Tank-mixing and Application of Herbicides in Sequence

Tank-mixing typically is done for soil and foliar-applied herbicides and it is done to effect broad-spectrum control of weeds. However, among factors that influence the efficacy of foliar-applied herbicides, tank-mixed application of two or more active ingredients are marked (Mcwhorter, 1982). There are reports that mixing certain active ingredients may result in the modified activity of the herbicides in the mixture due to interactions that often occur prior, during or after application of the mixtures. In addition, antagonism is generally observed more than synergism and it occurs more frequently in grass weeds than broadleaf weeds especially where the companion herbicides belong to different chemical families (Damalas, 2004). The prediction of reactions that occur with tank-mixing could be problematic. For example, it was reported by Robert *et al.* (2006) that tank mixing of clethodim + 2, 4-D and quaizalofop-p + 2,4-D led to antagonistic reactions. In addition, a commercial mixture of thifensulfuron + tribenuron reduced the efficacy of clethodim. Damalas (2004) confirmed that when herbicides are tank-mixed, the conditions under which each herbicide has the most excellent effectiveness can differ. However, tank-mixing of herbicides saves time and reduced application cost; however, their efficacy may become reduced or null (Merritt *et al*., 2020).

Application is made in sequence as weed control strategy could yield a long-term effect and consistency in weed control (Lockhart and Howatt, 2004). Studies have indicated that sequential herbicide applications could result in effective weed control and protect very sensitive crops (Boutsalis *et al.*, 2010; Goodrich *et al.*, 2018). Harper (1974), reported successful application of paraquat at 0.2 to 0.4 kg/ha in a directed inter-row spray post application for weed control in cassava when the plant was 15 – 20 cm. The application was in sequence and repeated spray was carried out 10 – 14 days later. A further spray was made 6 MAP until harvesting. It was concluded that plant growth and yields were not different when hoe-weeding treatment was compared with paraquat, but the cost of weed control was considerably reduced with paraquat treatment (Harper, 1974). There are reports of advantageous applications in sequence over a single application even when the same herbicide rates are used (Mathiassen and Kudsk, 2016). Previous research demonstrated sequential pyroxasulfone applications of 75 g/ha followed by 25 g/ha controlled trifluralin-resistant annual ryegrass *Lolium rigidum* Goudin relative to a single application of 100 g/ha (Boutsalis *et al.*, 2010). Mohammed and Addisu (2016) worked on sequential application of four post-emergence herbicides with all possible combinations: 2, 4-D (1 L/ ha) and flurasulam + flumelsulam (0.06 L/ ha) applied at 28 days after crop emergence (DAE) and pyroxsulam (0.45 L/ ha) and mesosulfuron methyl + iodosulfuronmethysodium (1 L/ ha) applied at 35 DAE. They reported that sequential applications of 2, 4-D and pyroxsulam followed by flurasulam

+ flumelsulam recorded maximum grain yield of durum wheat (2,849 and 2,818 kg/ ha), and weed suppression was higher with pyroxsulam followed by 2, 4-D and twice hoe-weeding and flurasulam + flumelsulam followed by pyroxsulam herbicides. Gupta *et al.* (2018) reported that sequential applications of pendimenthalin (1 kg/ha) pre-emergence at sowing of maize grain followed by atrazine 750 + 2,4-D (750 + 400 g/ha) as POST at 25 days after sowing was comparable to hand-weeding performed at 20 and 40 DAS in reduction of weed density of grasses, sedge and broadleaf weeds and weed dry weight. Also, they found out that crop growth and yield attributes and grain (6.47 t/ha) of hybrid maize from hand-weeding was comparable to sequential application of atrazine at 1 kg/ha pre-emergence at sowing followed by tembotrione at 120 g/ha post-emergence at 25 DAS (6.74 t/ha). Taylor-Lovell *et al.* (2002) evaluated pre-emergence herbicide flumioxazin and pendimethalin and post-emergence herbicide systems for weed control in soybean. They discovered that sequential herbicide applications with a pre-emergence herbicide gave up to 25% more control than post-emergence alone treatments. Soybean yields were also higher in most treatments that included both pre- and post-applications rather than just post-applications. Iyagba and Ayeni (2007) applied bentazon at 2 kg/ha and followed it sequentially with grass herbicides; sethoxydim, haloxyfop-ethoxyethyl and flauzifob-butyl at 0.25, 0.5 and 0.75 kg/ha respectively for weed control in cassava. They noticed higher phytotoxicity on cassava plants with a post-emergence application made at 14 days than at 21 days after planting even though better weed control was achieved 14 days after planting. They could record cassava storage root yield that was not significantly different when bentazon at 2 kg/ha followed by flauzifob-butyl (0.25, 0.5 and 0.75 kg a.i./ha) compared with hoe-weeded plots. Furthermore, Banerjee *et al.* (2006) reported that trifloysulfuron (27.8 g/ha) + ametryn (1097.3g/ha) applied at 15 DAP increased sugarcane productivity by 23%, 17.2% and 22% in comparison to trifloysulfuron, atrazine and 2, 4-D in a single application. Liu *et al.* (1982) evaluated weed control of glyphosate in cassava. They reported that glyphosate pre-plant plus post-emergence application provided better and sustained weed control than a single pre-plant application but it recorded more cassava crop injury. Ekeleme *et al*., 2019, screened nineteen pre-emergence herbicides (in g/l): aclonifen (600), aclonifen + isoxaflutole (500 + 75), acetochlor + atrazine +terbuthylazine (250 + 225 + 225), clomazone + metribuzin (60 + 233), clomazone + pendimenthalin (30 + 333), diflufenican + flufenacet + flurtamone (60 + 240 +120), diflufenican + flufenacet + flurtamone (90 + 240 + 120), diflufenican + flufenacet + flurtamone (120 + 120 + 120), dimethenamid-P

+ pendimenthalin (212.5 +250), flumioxazin + pyroxasulfone (33.5 + 42.5), indaziflam + metribuzin (37.5 + 480), indaziflam + isoxaflutole (150 + 450), isoxaflutole (75), isoxaflutole + cyprosulfamide (240 + 240), metribuzin (480), mesotrione (480), oxyfluorfen (480), prometryn + S-metolachlor (250 + 162.5), S-metolachlor + atrazine (290 + 370), sulfentrazone (480) and terbuthylazine + S-metolachlor (187.5 + 312.5) and reported that their single applications was not sufficient for three to four months, which is the period that is critical for weed control in cassava.

# CHAPTER 3
# MATERIALS AND METHODS

## 3.1 Experimental Location

The field location was at International Institute of Tropical Agriculture (IITA), Idi-Ose, Oyo Road, Ibadan North in Oyo State (7°30'N, 3°55'E). Rainfall in the area is bimodal. The meteorological data for the site during the period of the experiments were obtained from IITA meteorological station. The vegetation is Derived Savanna and the soils are in the Alfisols group.

## 3.2 Land Preparation

Before the ploughing of the experimental field, glyphosate was sprayed, and the field was left for 14 days. The land was ploughed to a depth of 15 - 30 cm, and later disc harrowed to 10 cm before ridging with tractor-mounted implements at second and fourth weeks, respectively. Debris of weed root was hand-picked.

## 3.3 Soil Sampling and Soil Analysis

With a soil auger, soil samples were taken at five separate sites from the experimental plots at a depth of 0–15 cm in the second week of July; 2015, 2016 and 2017 before land preparation. Debris and stones were removed with a 2 mm sieve after the soil samples were compacted and air-dried at room temperature. Soil analysis was carried out to determine the physical and chemical properties of the soil. Soil sample pH was determined in soil-water suspension (1:1) using a glass electrode pH meter as described by Mclean (1982). The titration method was used to determine the exchangeable acidity (H+). The particle size distribution was carried out using Bouyoucous hydrometer in which 0.5 N sodium hexametaphosphate was used as a dispersant (Landor, 1991). Organic carbon was determined using the wet oxidation method of Walkey and Black (Walkey and Black, 1947), while organic matter (OM) per cent was calculated as OM = TOC (%) x 1.724; TOC = Total Organic Carbon. Soil available phosphorus (mg/kg) was extracted by the Bray-1 procedure (Bray and Kurtz, 1945) and analysed using the molybdate blue method described by Murphy and Riley (1962). Soil N (g/kg) was determined by wet acid digestion (Buondonno *et al.*, 1995) and analysed colorimetrically (Anderson and Ingram, 1993). Exchangeable Ca, Mg, Na and K (cmol $kg^{-1}$) were extracted using 1 M ammonium acetate and read from atomic absorption spectrophotometer (AAS).

## 3.4 Experiment 1: Effects of Selected Pre-emergence Herbicides Supplemented with Selected Post-emergence Herbicides on Weed Control and Growth and Yield of Cassava

### 3.4.1 Experimental Design, Treatments and Procedure

Field trials were conducted in July 2015/2016, 2016/2017 and 2017/2018 to determine the response of cassava plants growth, the storage root yield, and weed to three pre-emergence herbicides which were follow–up with three post-emergence herbicides. The selected herbicides, their active ingredients and the rates of application are presented in Table 3.1. Three pre-emergence herbicides: sulfentrazone, flumioxazin + pyroxasulfone, and indaziflam + isoxaflutole at 0.6, 0.11+ 0.14 and 0.068 + 0.20 kg/ha respectively were applied at planting and followed by post-emergence herbicides trifloysulfuron-sodium (5.25 g/ha), clethodim + lactofen (0.21 + 0.41 kg/ha) and carfentrazone-ethyl (5.84 g/ha) at 8 WAP as supplementary weed control. These were compared with atrazine + s-metolachlor at 0.73 + 1.30 kg/ha followed by two hoe-weedings at 8 and 12 WAP, weed-free (hoe-weeding at 4, 8 and 12 WAP) and weedy check. There were 12 treatment combinations laid in a Randomized Complete Block Design (RCBD) and replicated three times. The field layout and treatment combinations are presented in Figure 3.1 and Table 3.2. Blanket application of N.P.K 15:15:15 fertilizer was made at the rate of 125 kg/ha at 8 WAP (ACAI, 2020). The method of fertilizer application was by ringing; with the rings made at 10 cm radius round the plants. Unit plot size measured 4 m x 4 m (16 $m^2$). Each plot was separated from the next by a 1 m border, and a 2 m border separated the blocks. Cassava variety TMEB 419 cuttings of 20 - 25 cm long were planted after land preparation at the inter-row and intra-row spacing of 1 m x 0.8 m giving a plant population of 12,500 plants/ha (Hauser *et al.,* 2014). The variety, TMEB 419, was chosen because of its popularity among farmers, its high starch content and yield among other factors (Adetunji *et al.,* 2020). In addition, it is a non-branching variety, as branching could confound the effects of the herbicides on its weed control efficacies. Pre-emergence herbicides were applied by broadcast spraying at planting with the use of hand-pumped CP 15 (COOPER PEGLER) knapsack sprayer of 110º spray standard flat fan cooper pegler propolijet nozzle ANI.2 Green (EXEL GSA, ZI NORS ARNAS-BP 30424, 69653) calibrated to deliver 250 L/ha of water at 240 kpa. In addition, flumioxazin + pyroxasulfone and trifloysulfuron-sodium herbicides in granules of small recommended doses were measured with METTLER PJ 3600 Delta Ranger$^{R}$ and dissolved in small amount of measuring before filling up the sprayer.

### 3.4.2 Data collection

#### 3.4.2.1 Cassava

Parameters taken were cassava plant count; plant vigour assessed by visual rating on a scale of 1-5 (1 = very poor; 5 = very vigorous) at 2 weeks interval; plant height measured in centimetres at 4 weeks interval with a measuring tape from the base of the plant to the tip of the top shoot. In addition, numbers of plants and stems were counted at harvest (12 months after planting, (MAP) while weights of the stems, top shoots and cassava storage root yields were measured using Electronic weighing balance (KERN, DE 60K1DL) at harvest.

#### 3.4.2.2 Weed

Weed control efficacy was scored for broadleaves, sedges and grass weeds on a 0-100% scale, with 0 as no control and total control rated 100%. A 1 $m^2$ quadrat was laid diagonally in each plot, weed species within the quadrants were identified and counted, uprooted, enveloped and oven-dried at 70$^{\circ}$C for 48 hours to determine weed dry weight (Sartorious ED820128650571 weighing balance). Relative density (RWD) was determined using the formula of Tabib *et al.* (2014) as presented below.

$$\text{RWD (\%)} = \frac{\text{Density of individual weed species from each treatment plot}}{\text{Total density of all weed species in the treatment plot}} \times 100$$

### 3.4.3 Data analysis

Data collected over three years were combined and subjected to ANOVA in Linear Mixed Model procedure (SAS Institute, 2016), means separation was done with SAS LSMEANS test (pair-wise t-test comparisons at P = 0.05). Repeated statement (for year effect) and Satterthwaite adjustment were incorporated in the ANOVA model to adjust for the possible presence of heterogeneity of error of variances among trial years (Satterthwaite, 1946; Searle *et al.*, 1992; Little *et al.*, 1996; Little *et al.*, 2000; So and Edward, 2009). Also, replicates (nested in year) and replicates interactions with

**Table 3.1.** Formulation, rate of application and manufacturers of the selected herbicides used for the experiments

| Trade name | Technical name (a.i) | Formulation | Application rate (kg/ha) | Mechanism of action | Manufacturer |
|---|---|---|---|---|---|
| Pre-emergence | | | | | |
| Authority | Sulfentrazone | 480 SC | 0.60 | PPO inhibitor | FMC Corporation Market Street, PA. USA |
| Fierce | Flumioxazin+ Pyroxasulfone | 33.5,42.5 % G | 0.11 + 0.14 | PPO + cell division inhibitor | Valent U.S.A. |
| Merlin Total | Indaziflam + Isoxaflutole | 150, 450 SC | 0.068 + 0.20 | Cellulose-biosynthesis + HPPD inhibitor | Bayer Crop Science, Alfred-Nobel-Str. 50, Monheim. |
| Primextra Gold | Atrazine+s-metolachlor | 290, 370 SC | 0.73 + 1.30 | Photosynthetic + cell division inhibitor | SyngentaCrop ProtectionAG, Basel, Switzerland |
| Post-emergence | | | | | |
| Envoke | Trifloysulfuron-sodium | 75% G | 5.25 g/ha | ALS inhibitor | Syngenta |
| Select Max | Clethodim | 120.6 % SC | 0.21 | ACCase inhibitor | Valent U.S.A. |
| Cobra | Lactofen | 240 SC | 0.22 | PPO inhibitor | Valent U.S.A. |
| Shark EW | Carfentrazone-ethyl | 40 EC | 5.84 g/ha | PPO inhibitor | FMC Corporation Philadelphia, PA |

PPO: Proto Porphyrinogenn Oxidase
HPPD: 4-hydroxy PhenylPyruvate Deoxygenase
ALS: Aceto-Lactate Synthase
ACCase: Acetyl-Coenzyme A Carboxylase
SC: Soluble concentrate
EC: Emulsifiable concentrate
G: granule

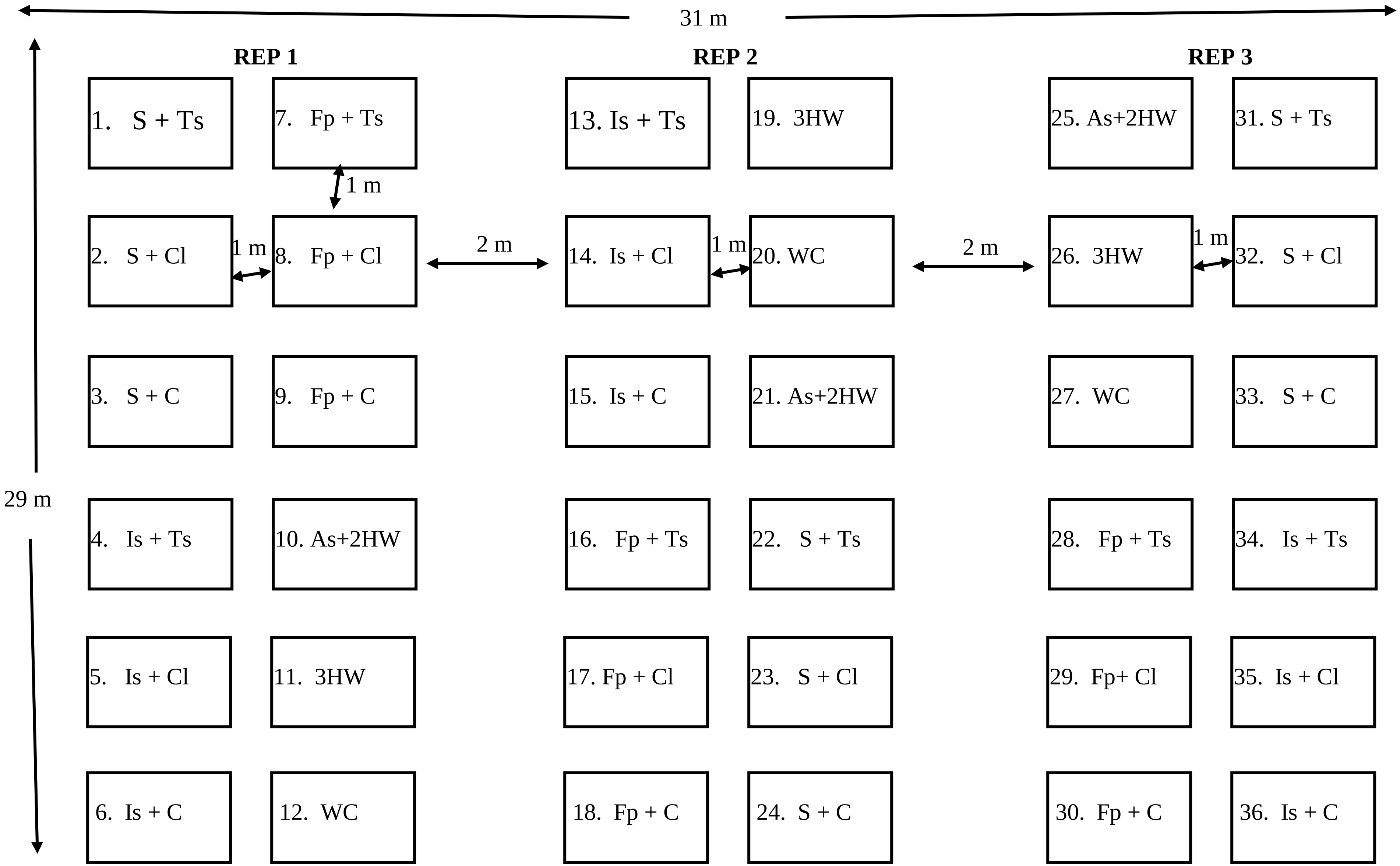


**Figure 3.1: Experiment 1 field layout**

S = Sulfentrazone
Cl = Clethodim + lactofen
Ts = Tnfloysulfuron – sodium
C = Cafertrazone-ethyl
Fp = Flumioxazine + pyroxasulfone
Is = Indaziflam + Isoxaflutole
As = Atrazine + S– metolachlor
2Hw = Two – Time – hoe-weeding
3Hw = Three – Time – hoe-weeding
WC = Weedy check

**Table 3.2: Pre- and post-emergence herbicides treatment combinations and controls for experiment 1**

| S/N | Pre-emergence | Post-emergence follow-up |
|---|---|---|
| 1 | Sulfentrazone + | Trifloysulfuron-sodium |
| 2 | + | Clethodim + Lactofen |
| 3 | + | Carfentrazone-ethyl |
| 4 | Flumioxazin + Pyroxasulfone + | Trifloysulfuron-sodium |
| 5 | + | Clethodim + Lactofen |
| 6 | + | Carfentrazone-ethyl |
| 7 | Indaziflam + Isoxaflutole + | Trifloysulfuron-sodium |
| 8 | + | Clethodim + Lactofen |
| 9 | + | Carfentrazone-ethyl |
| 10 | Atrazine + s-metolachlor + | 2-times-hoe-weeding |
| 11 | 3-times-hoe-weeding | |
| 12 | Weedy-check | |

treatments are regarded as random effects in the ANOVA Model. Where two-way interaction or higher-order interaction effects were significant ($p \leq 0.05$), simple effect differences were evaluated among treatment factors to understand the nature of the interactions. All count data were $\log_{10}(x+1)$ transformed before analysis to stabilize the variance and normalize the data (Gomez and Gomez, 1984).

## 3.5 Experiment 2: Evaluation of Three Post-emergence Herbicides Supplemented with Pre-emergence Herbicides for Their Selectivity in Cassava

### 3.5.1 Experimental Design, Treatments and Procedure

The trials were conducted from 2015 – 2018 to evaluate the tolerance of cassava to three post-emergence herbicides. It was a split-plot experiment design fitted into RCBD. Two spray methods: broadcast and banded were the main plots and the post-emergence herbicides: trifloysulfuron-sodium (5.25 g/ha), clethodim + lactofen (0.21 + 0.41 kg/ha) and carfentrazone-ethyl (5.84 g/ha) applied at 2 WAP followed by pre-emergence herbicides at 4 WAP: sulfentrazone, flumioxazin + pyroxasulfone, and indaziflam + isoxaflutole at 0.6, 0.11+ 0.14 and 0.068 + 0.20 kg/ha respectively were the sub-plot treatments. The eighteen (18) treatment combinations were compared with atrazine + s-metolachlor at 0.73 + 1.30 kg/ha followed by two hoe-weeding at 8 and 12 WAP and a weed-free and no-weeding as controls. The treatment combinations which were replicated three times are presented in Table 3.3. The experiment field layout is presented in Figure 3.2. The application was done with the sprayer used in experiment one. The 110$^{o}$ spray standard flat fan and 80$^{o}$ spray angle even flat fan nozzle was used for broadcast and band application. In the band application, spraying was done with a plastic shield and the nozzle was pointed between rows with care to avoid contact with the growing cassava plant shoots. The experimental plot size, planting spacing and cassava variety was the same as in experiment one. Fertilizer application was done as in the previous experiment.

**Table 3.3: Spray methods, pre- and post-emergence herbicide treatment combinations and controls for experiment 2**

| S/N | Spray methods | Post-emergence | | Pre-emergence follow-up |
|---|---|---|---|---|
| 1 | Broadcast spray | Trifloysulfuron-sodium | + | Sulfentrazone |
| 2 | | | + | Flumioxazin + Pyroxasulfone |
| 3 | | | + | Indaziflam + Isoxaflutole |
| 4 | | Clethodim + Lactofen | + | Sulfentrazone |
| 5 | | | | Flumioxazin + Pyroxasulfone |
| 6 | | | | Indaziflam + Isoxaflutole |
| 7 | | Carfentrazone-ethyl | + | Sulfentrazone |
| 8 | | | | Flumioxazin + Pyroxasulfone |
| 9 | | | | Indaziflam + Isoxaflutole |
| 10 | Banded spray | Trifloysulfuron-sodium | + | Sulfentrazone |
| 11 | | | + | Flumioxazin + Pyroxasulfone |
| 12 | | | + | Indaziflam + Isoxaflutole |
| 13 | | Clethodim + Lactofen | + | Sulfentrazone |
| 14 | | | + | Flumioxazin + Pyroxasulfone |
| 15 | | | + | Indaziflam + Isoxaflutole |
| 16 | | Carfentrazone-ethyl | + | Sulfentrazone |
| 17 | | | + | Flumioxazin + Pyroxasulfone |
| 18 | | | + | Indaziflam + Isoxaflutole |
| 19 | Atrazine + s-metolachlor followed by 2-times-hoe-weeding | | | |
| 20 | 3-times-hoe-weeding | | | |
| 21 | Weedy-check | | | |

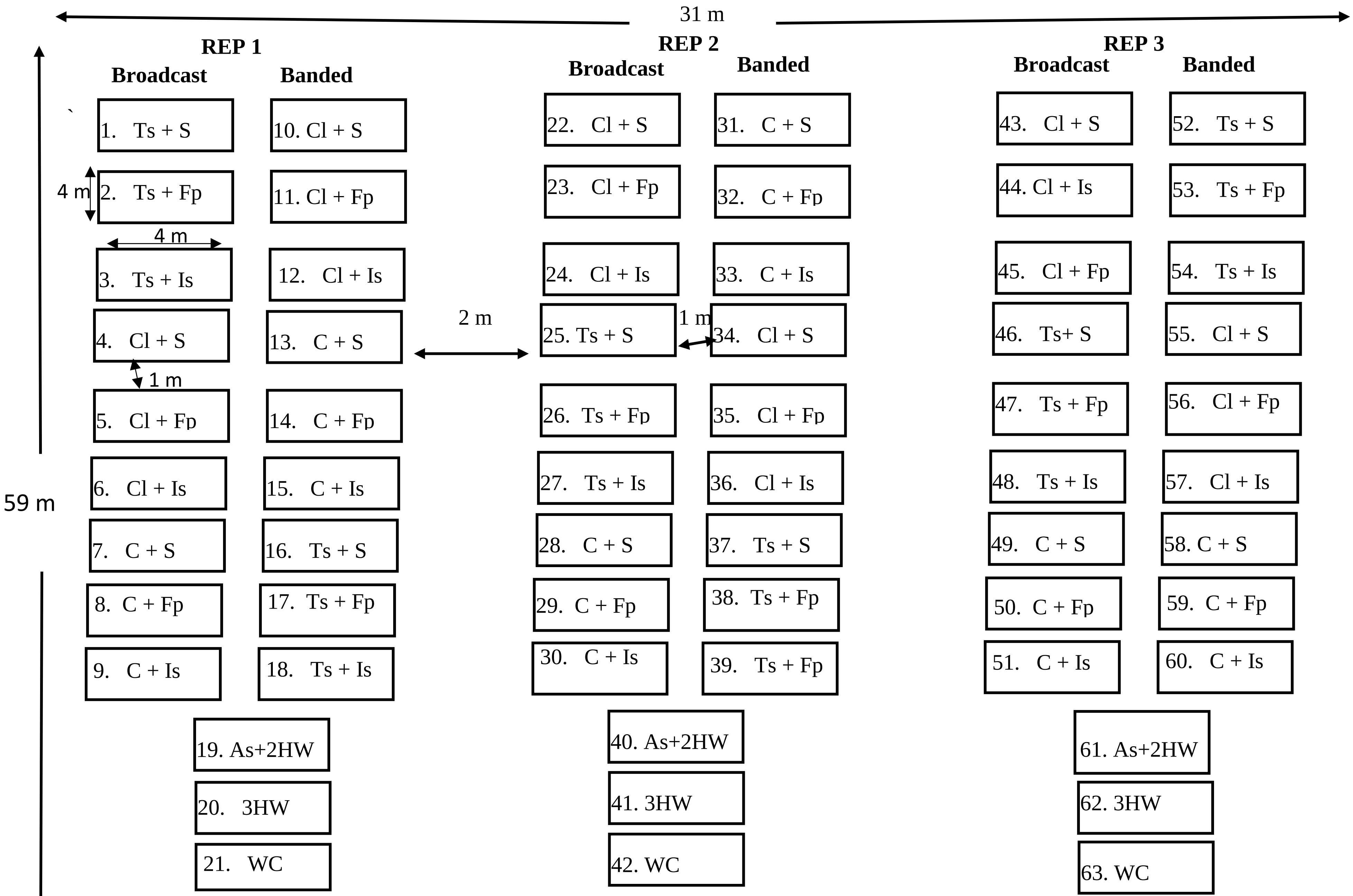


**Figure 3.2: Experiment 2 field layout**

S = Sulfentrazone
Cl = Clethodim + lactofen
Ts = Tnfloysulfuron – sodium
C = Cafertrazone-ethyl
Fp = Flumioxazine + pyroxasulfone
Is = Indaziflam + Isoxaflutole
As = Atrazine + S– metolachlor
2Hw = Two – Time – hoe-weeding
3Hw = Three – Time – hoe-weeding
WC = Weedy check

### 3.5.2 Data collection and analysis

Data were collected and analyzed as in experiment 1, but relative density was not determined Additionally, injury rating was observed on a scale of 0 – 10, where 0 = no phytotoxicity and 10 = total plant death. The scores were expressed in percentages.

### 3.5.3 Economic analysis of cassava production with selected pre- and post-emergence herbicides

Economic analyses of cassava production under the pre-post and post-pre sequences of application of herbicides were done according to Wesley *et al*. (1993). The budgets developed for each treatment combinations were estimated based on what was obtainable from 2015 to 2021. The costs of the herbicides and hoe-weeding were sourced online and from farmers respectively. The operational costs are obtainable to produce cassava on one hectare of land in Ibadan, the south-western part of Nigeria. Total variable costs (TVC) sum up operational costs and weed control costs (herbicides and hoe-weeding). Farmgate price (FGP), price of 1 tonne of cassava storage root; Total gross return (TGR), the product of yield in tonnes/ha and FGP; Net benefit (NB), the difference between TGR and TVC. The Marginal Rate of Return (MRR) was determined using the relationship of Wesley *et al*. (1993) as presented below.

$$\text{MRR}(\%) = \frac{\text{Marginal benefit from weed control}}{\text{Marginal investment on weed control}} \times 100$$

## 3.6 Experiment 3: Alternative Sequence of Application of Pre- and Post-emergence Herbicides

### 3.6.1 Experimental design, treatments and procedure

The experiment set up in 2016/2017 and 2017/2018 at IITA involved evaluation of two sequential orders of herbicide application. The first sequence involved the conventional application of pre-emergence herbicides at planting followed by post-emergence herbicides at 8 WAP (pre-post). In the second sequence, post-emergence herbicides application was at 2 WAP which was followed up by application of pre-emergence herbicides at 4 WAP (post-pre). In the post-pre sequence of application, post-emergence herbicides were sprayed by band application. The sequences of the herbicide combinations were laid in a split-plot arrangement in RCBD and these were replicated three times. The pre- or post-emergence herbicides were either the main or the sub-plots in the sequences. The three pre-emergence herbicides sulfentrazone, flumioxazin +

pyroxasulfone, and indaziflam + isoxaflutole at 0.6, 0.11+ 0.14 and 0.068 + 0.20 kg/ha respectively, and three post-emergence herbicides trifloysulfuron-sodium (5.25 g/ha), clethodim + lactofen (0.21 + 0.41 kg/ha) and carfentrazone-ethyl (5.84 g/ha) which were evaluated in the previous experiments were used in the experiment. The field layout and treatment combinations are presented in Figure 3.3 and Table 3.4 respectively. Planting and other arrangements and procedures were as in the previous experiments.

### 3.6.2 Data collection

This was as in experiment 1 apart from relative density. Data collection on weed dry weight was done at 14 WAP and this was used to determine the weed control efficiency (WCE) according to Kumar *et al*. (2017).

$$\text{WCE}(\%) = \frac{\text{dry weight of weeds in unweeded control} - \text{dry weight in treatment plot}}{\text{dry weight of weeds in unweeded control}} \times 100$$

### 3.6.3 Data analysis

Data analysis was the same as in the previous experiments. However, within the ANOVA model, contrasts or comparisons were set up to test the significance of the pre-post and post-pre sequences of the herbicide application.

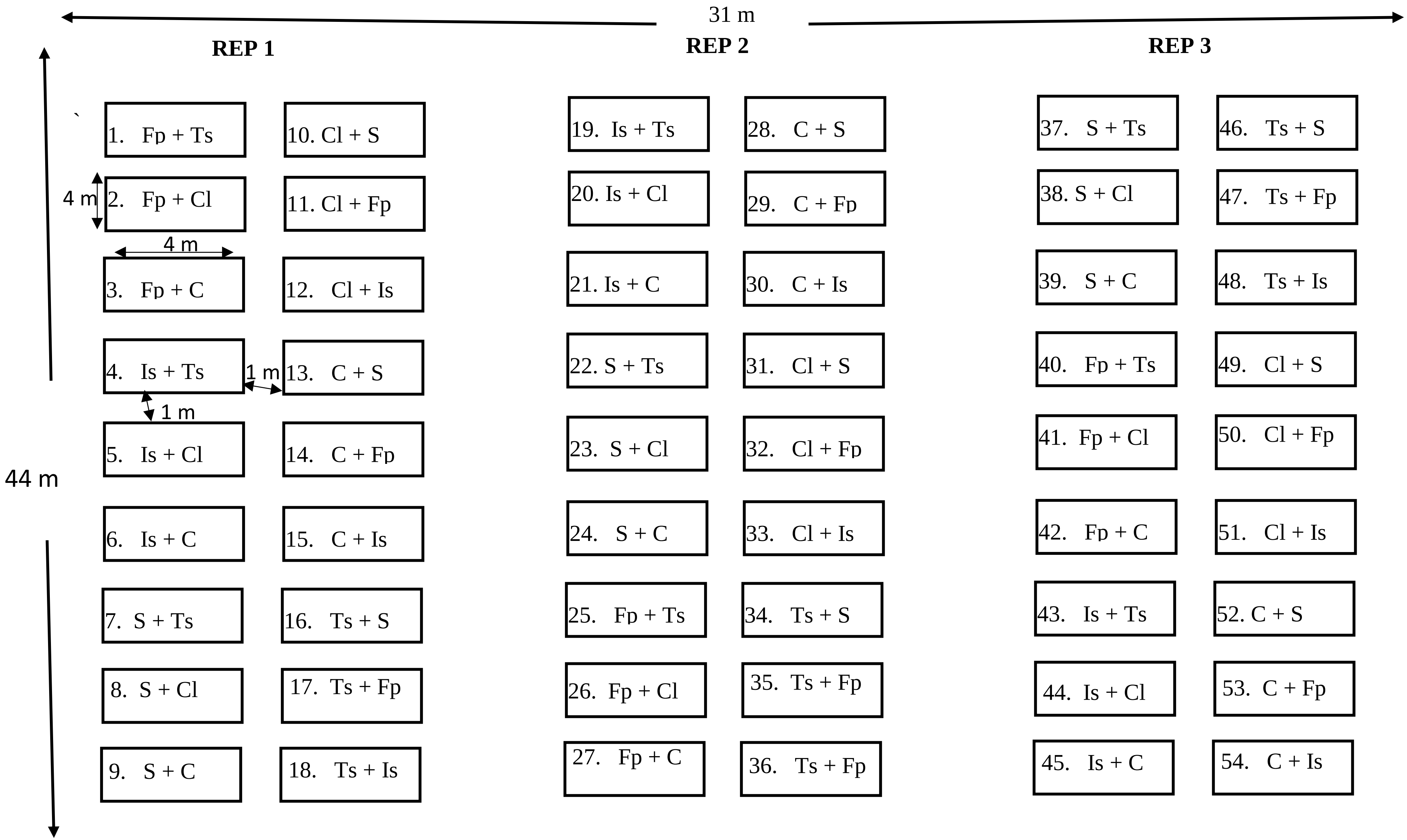


**Figure 3.3: Experiment 3 field layout**

S = Sulfentrazone
C = Cafertrazone-ethyl
As = Atrazine + S– metolachlor
WC = Weedy check
Cl = Clethodim + lactofen
Fp = Flumioxazine + pyroxasulfone
2Hw = Two – Time – hoe-weeding
Ts = Tnfloysulfuron – sodium
Is = Indaziflam + Isoxaflutole
3Hw = Three – Time – hoe-weeding

**Table 3.4: Pre- and post-emergence herbicide treatment combinations for Experiment 3**

| S/N | Herbicides | |
|---|---|---|
| | Pre-post | |
| 1 | Sulfentrazone | + Trifloysulfuron-sodium |
| 2 | | + Clethodim + Lactofen |
| 3 | | + Carfentrazone-ethyl |
| 4 | Flumioxazin + Pyroxasulfone | + Trifloysulfuron-sodium |
| 5 | | + Clethodim + Lactofen |
| 6 | | + Carfentrazone-ethyl |
| 7 | Indaziflam + Isoxaflutole | + Trifloysulfuron-sodium |
| 8 | | + Clethodim + Lactofen |
| 9 | | + Carfentrazone-ethyl |
| | Post-pre | |
| 10 | Trifloysulfuron-sodium | + Sulfentrazone |
| 11 | | + Flumioxazin + Pyroxasulfone |
| 12 | | + Indaziflam + Isoxaflutole |
| 13 | Clethodim + Lactofen | + Sulfentrazone |
| 14 | | + Flumioxazin + Pyroxasulfone |
| 15 | | + Indaziflam + Isoxaflutole |
| 16 | Carfentrazone-ethyl | + Sulfentrazone |
| 17 | | + Flumioxazin + Pyroxasulfone |
| 18 | | + Indaziflam + Isoxaflutole |

# CHAPTER 4
# RESULTS

## 4.1 Soil properties and weather data of the experiment location

The results of the physical and chemical properties of the soils of the experimental sites before cultivation are presented in Table 4.1. The soils of the experimental fields were moderately acidic with a pH of 5.5, 5.9 and 6.2 respectively. Available phosphorus was average in the second and third experimental fields but sufficient in the first. Soil organic matter content of plots was sufficient (1.26, 1.45 and 1.57%) and the particle size distribution showed the soils were sandy loam. The weather data during the trial is presented in Figure 4.1.

## 4.2 Effects of pre-emergence herbicides supplemented with post-emergence herbicides on growth and yield of cassava and weed control

### 4.2.1 Cassava plant count, vigour and height

The effect of pre-emergence herbicides and year on cassava plant count, vigour and height is presented in Table 4.2. The plant count on plots treated with indaziflam + isoxaflutole was 7244, which was significantly lower than the number of plants on plots treated with other treatments (9120 to 10471 plants/ha) at 2 WAP. Flumioxazin + pyroxasulfone (4.96) treated plot had the best cassava vigour and was comparable to hoe-weeded plots (4.85) and atrazine + s-metolachlor followed by hoe-weeded (4.67) at 8 WAP. Sulfentrazone application resulted in poorer crop vigour (3.76) than weedy-check (4.17) and reduced height of cassava (38.0 cm) which was not significantly different from those produced in weedy-check plots (38.5cm). There was significant interaction among the treatments and year for crop vigour score ($P \leq .0001$) and plant count of cassava ($P=0.0049$). In 2017, plant count and vigour were significantly higher than in the previous years (Table 4.2). The year by pre-emergence herbicides interaction is shown in Table 4.3. At 8 WAP, sulfentrazone effect on cassava vigour in 2015 and 2016 was not significantly different with a score of 3.56 and 3.33, respectively however, cassava vigour score was significantly lower than what was recorded in 2017 (4.39). The plant count as influenced by the three pre-emergence herbicides in 2015 and 2016 was similar but significantly lower than that of 2017. Flumioxazin + pyroxasulfone had plant

**Table 4.1: Physical and chemical properties of the soil before planting in 2015-2017**

| | pH ($H_20$) | OM | N | P | K | Ca | Mg | Sand | Silt | Clay | Textural class (USDA) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | g/kg | | mg/kg | c mol $kg^{-1}$ | | | g/kg | | | |
| 2015 | 5.5 | 15.7 | 1.0 | 15 | 0.11 | 0.56 | 0.51 | 650 | 120 | 230 | Sandy clay loam |
| 2016 | 6.2 | 12.6 | 1.1 | 10 | 0.09 | 0.45 | 0.45 | 740 | 80 | 180 | Sandy loam |
| 2017 | 5.9 | 14.5 | 1.1 | 12 | 0.13 | 0.39 | 0.49 | 790 | 70 | 140 | Loamy sand |
| Critical values | 4.5-7* | 20-40* | | 10-14* | 0.10-0.15* | | | | | | |

* (Howeler, 2002)

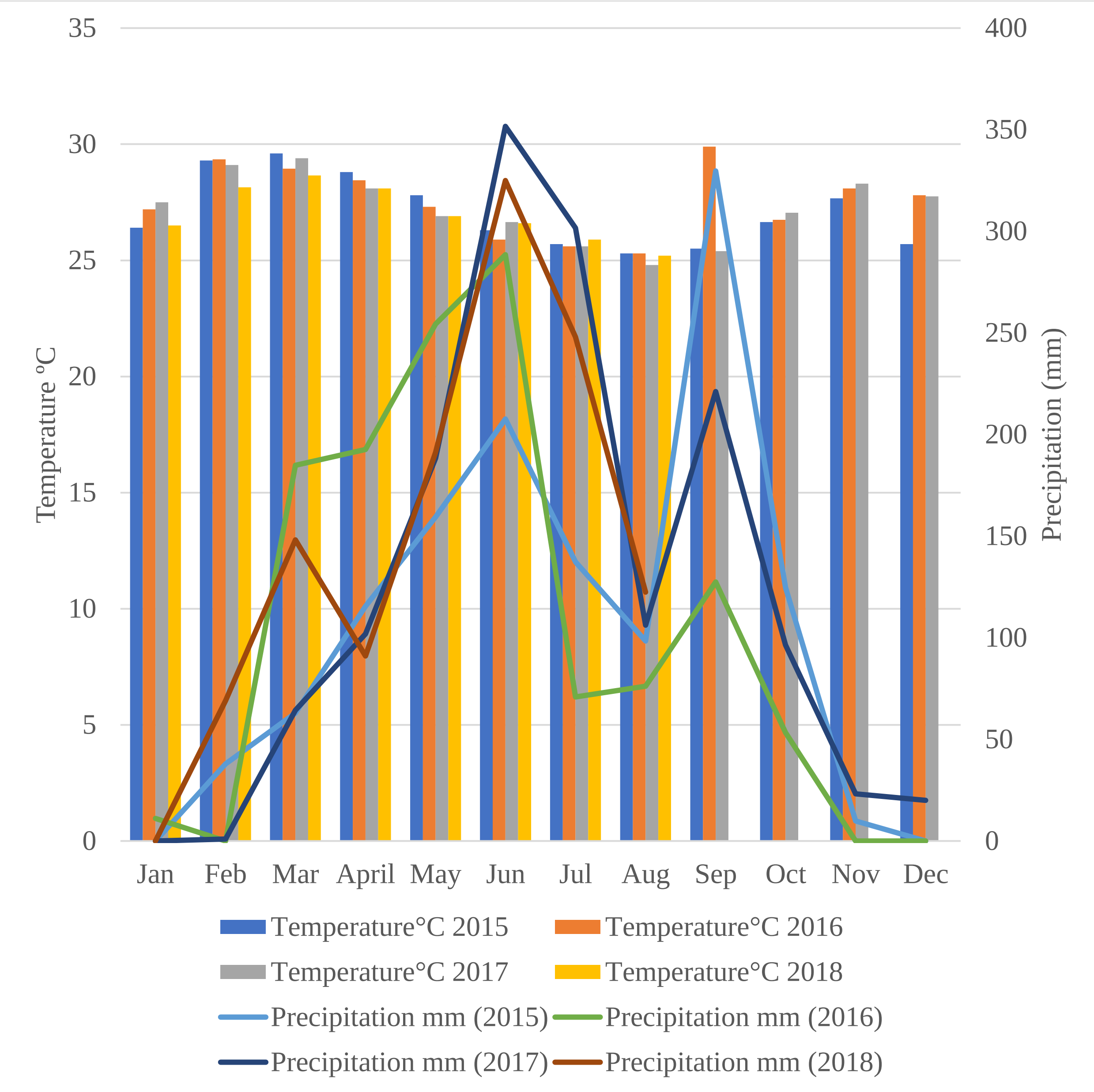


Figure 4.1. Mean rainfall pattern and average temperature during the field trial at International Institute of Tropical Agriculture, Ibadan in 2015 to 2018

**Table 4.2: Cassava plant count, vigour and height as influenced by pre-emergence herbicides**

| | Plant count (plants/ ha) | | | Vigour | | | Height (cm) | |
|---|---|---|---|---|---|---|---|---|
| | Weeks after planting | | | | | | | |
| **Treatment** | 2 | 6 | 8 | 4 | 6 | 8 | 4 | 8 |
| Sulfentrazone | 9120b | 10760b | 11015c | 3.78b | 3.89c | 3.76c | 22.3c | 38.0b |
| Flumioxazin + Pyroxasulfone | 10233a | 11511a | 11604b | 4.13a | 4.81a | 4.96a | 31.3a | 53.4a |
| Indaziflam + Isoxaflutole | 7244c | 10028c | 10471d | 3.81b | 4.54b | 4.80a | 29.7b | 51.9a |
| Atraz + s-met fb 2HW | 9550ab | 11682a | 11896ab | 4.22a | 4.67ab | 4.83a | 28.7b | 51.0a |
| Hoe-weeded (3ce) | 10471a | 12045a | 11976ab | 4.28a | 4.72ab | 4.85a | 31.6a | 53.2a |
| Weedy-check | 10471a | 12348a | 12348a | 4.22a | 4.67ab | 4.17b | 23.1c | 38.5b |
| **Year** | | | | | | | | |
| 2015 | 10000a | 10730b | 10812c | 3.74b | 4.22b | 4.27b | 26.9a | 47.9a |
| 2016 | 7762b | 11220b | 11527b | 3.76b | 4.61a | 4.63a | 27.9a | 46.1a |
| 2017 | 10715a | 12198a | 12314a | 4.72a | 4.81a | 4.75a | 28.4a | 47.1a |
| Year x treatment | * | ns | * | ns | * | * | ns | ns |

Means in a column followed by a similar letter(s) did not differ significantly at probability level of 5%.
Plant count data for statistical analyses were logarithm transformed to stabilize variances but de-transformed values are presented ns, not significant; *significant at p≤0.05; Atraz + s-met fb 2HW, Atrazine + s-metolachlor followed by two hoe-weeding

**Table 4.3: Year x pre-emergence herbicides interaction on cassava plant count and vigour as influenced by pre-emergence herbicides**

| Year | PRE herbicides | Plant count (plants/ha) | | Vigour | |
|---|---|---|---|---|---|
| | | Weeks after planting | | | |
| | | 6 | 8 | 6 | 8 |
| 2015 | Sulfentrazone | 9550b | 10106c | 3.64d | 3.56c |
| | Flumioxazin + Pyroxasulfone | 10000ab | 10641c | 4.61bc | 4.94a |
| | Indaziflam + Isoxaflutole | 8128c | 9858c | 4.11c | 4.50b |
| 2016 | Sulfentrazone | 6918d | 10641c | 3.50d | 3.33c |
| | Flumioxazin + Pyroxasulfone | 9772ab | 11896ab | 4.83ab | 4.94a |
| | Indaziflam + Isoxaflutole | 5888d | 9842c | 4.67b | 4.94a |
| 2017 | Sulfentrazone | 11220a | 12428a | 4.22c | 4.39b |
| | Flumioxazin + Pyroxasulfone | 10965a | 12348a | 5. 00a | 5. 00a |
| | Indaziflam + Isoxaflutole | 7943cd | 11836b | 4.83ab | 4.98a |

Means within a column with the same letter(s) are not significantly different ($p \leq 0.05$). Plant count data for statistical analyses were logarithm transformed to stabilize variances, but de-transformed values are presented, WAP, Weeks after planting count which was comparable to those of the other two herbicides in 2017.

The effects of the three selected pre-emergence herbicides each supplemented with each of the three selected post-emergence herbicides: trifloysulfuron-sodium, clethodim + lactofen and carfentrazone-ethyl on cassava plant count, crop vigour and plant height are presented in Table 4.4. Regardless of the post-emergence herbicides used as supplementary, the plant count, crop vigour score and height observed at 12 WAP were similar to the observations at 8 WAP. The highest cassava vigour score was recorded in treatment combinations of indaziflam + isoxaflutole and flumioxazin followed up with carfentrazone-ethyl. The effect of year by herbicide was not significant on plant count and plant height. Year by herbicide treatments interaction on crop vigour is presented in Table 4.5. Crop vigour as influenced by the three post-emergence herbicides following sulfentrazone was comparable in 2015 and 2016 but significantly lower than that of 2017. The three post-emergence herbicides following indaziflam + isoxaflutole and flumioxazin + pyroxasulfone had similar crop vigour in the three years.

### 4.2.2 Yield and yield components of cassava at 12 months after planting (MAP)

The effect of the three pre-emergence herbicides followed by each of the three post-emergence herbicides over three years on yield components and yield of cassava at harvest are presented in Table 4.6. The weed control treatments significantly influenced all the yield components and yield. Atrazine + s-metolachlor and all the other herbicide treatments except sulfentrazone followed by any of the three post-emergence herbicides and indaziflam + isoxaflutole followed by carfentrazone-ethyl produced number of stands that were comparable to the highest number in hoe-weeded control, (12006 plants/ha). The plants count of the combinations involving sulfentrazone and the three post-emergence herbicides and indaziflam + isoxaflutole followed by carfentrazone-ethyl were comparable to other combinations and the weedy-check. Plants reduction owning to the use of sulfentrazone

**Table 4.4: Effect of pre-emergence herbicides supplemented with post-emergence herbicides on cassava plant count, vigour and height at 12 WAP**

| **Treatment** | | Plant count (no of plants/ha) | Vigour | Height (cm) |
|---|---|---|---|---|
| PRE herbicides + POST herbicides | | | | |
| Sulfentrazone | Trifloysulfuron-sodium | 11355bc | 4.28b | 99. 0c |
| | Clethodim + Lactofen | 11564b | 4.11b | 102.5c |
| | Carfentrazone-ethyl | 11421bc | 4. 00b | 97.7c |
| Flumioxazin + Pyroxasulfone | Trifloysulfuron-sodium | 12196ab | 4.89a | 143.3ab |
| | Clethodim + Lactofen | 11749ab | 4.94a | 140.2ab |
| | Carfentrazone-ethyl | 12045ab | 5. 00a | 146.5a |
| Indaziflam + Isoxaflutole | Trifloysulfuron-sodium | 10829c | 5. 00a | 139.1ab |
| | Clethodim + Lactofen | 11084bc | 5. 00a | 134.1b |
| | Carfentrazone-ethyl | 11355bc | 5. 00a | 134. 0b |
| Control | | | | |
| Atraz + s-met fb 2HW | | 12045ab | 4.83a | 131.7b |
| Hoe-weeded (3ce) | | 11976ab | 4.72a | 135.9b |
| Weedy | | 12500a | 4.06b | 105.4c |
| **Year** | | | | |
| 2015 | | 11043b | 4.61a | 126.3 |
| 2016 | | 12120a | 4.56a | 123.9 |
| 2017 | | 12379a | 4.69a | 125.8 |
| Year x treatment | | ns | * | ns |

Means in a column followed by a similar letter(s) are not significantly different at probability level of 5%. Plant and stem count data for statistical analyses were logarithm transformed to stabilize variances, but de-transformed values are presented, WAP, week after planting; ns, not significant; *significant at $p \leq 0.05$; no, number, Atraz + s-met fb 2HW, Atrazine + s-metolachlor followed by two hoe-weeding

**Table 4.5: Year x herbicide treatments interaction on vigour at 12 WAP as influenced by pre- and post-emergence herbicides**

| **Year** | **PRE herbicides + POST herbicides** | | Vigour |
|---|---|---|---|
| 2015 | Sulfentrazone | Trifloysulfuron-sodium | 4.17b |
| | | Clethodim + Lactofen | 4.00b |
| | | Carfentrazone-ethyl | 3.67b |
| | Flumioxazin + Pyroxasulfone | Trifloysulfuron-sodium | 4.83a |
| | | Clethodim + Lactofen | 4.83a |
| | | Carfentrazone-ethyl | 5.00a |
| | Indaziflam + Isoxaflutole | Trifloysulfuron-sodium | 5.00a |
| | | Clethodim + Lactofen | 5.00a |
| | | Carfentrazone-ethyl | 5.00a |
| 2016 | Sulfentrazone | Trifloysulfuron-sodium | 4.00b |
| | | Clethodim + Lactofen | 3.67b |
| | | Carfentrazone-ethyl | 3.67b |
| | Flumioxazin + Pyroxasulfone | Trifloysulfuron-sodium | 4.83a |
| | | Clethodim + Lactofen | 5.00a |
| | | Carfentrazone-ethyl | 5.00a |
| | Indaziflam + Isoxaflutole | Trifloysulfuron-sodium | 5.00a |
| | | Clethodim + Lactofen | 5.00a |
| | | Carfentrazone-ethyl | 5.00a |
| 2017 | Sulfentrazone | Trifloysulfuron-sodium | 4.67a |
| | | Clethodim + Lactofen | 4.67a |
| | | Carfentrazone-ethyl | 4.67a |
| | Flumioxazin + Pyroxasulfone | Trifloysulfuron-sodium | 5.00a |
| | | Clethodim + Lactofen | 5.00a |
| | | Carfentrazone-ethyl | 5.00a |
| | Indaziflam + Isoxaflutole | Trifloysulfuron-sodium | 5.00a |
| | | Clethodim + Lactofen | 5.00a |
| | | Carfentrazone-ethyl | 5.00a |

Means within a column followed by a similar letter(s) are not significantly different ($p \leq 0.05$). WAP, week after planting

**Table 4.6: Cassava plant count, number of stems, top shoot and storage root yield at 12 MAP as influenced by pre- and post-emergence herbicides**

| **Treatments** | | Plants | Stem | Top shoot | Stem | Storage root |
|---|---|---|---|---|---|---|
| | | Count (plants /ha) | | Weight (tonnes/ha) | | |
| Sulfentrazone | Trifloysulfuron-sodium | 9598b | 27868a | 2.19c | 5.63cd | 12.46b |
| | Clethodim + Lactofen | 9676b | 27384a | 1.84c | 5.14d | 13.07b |
| | Carfentrazone-ethyl | 9752b | 28458a | 1.75c | 5.18d | 12.87b |
| Flumioxazin + Pyroxasulfone | Trifloysulfuron-sodium | 10457ab | 18302bc | 3.74ab | 12.6ab | 30.14a |
| | Clethodim + Lactofen | 10641ab | 18707bc | 3.16b | 11.52b | 28.65a |
| | Carfentrazone-ethyl | 11220ab | 19656b | 3.27b | 12.32ab | 30.11a |
| Indaziflam + Isoxaflutole | Trifloysulfuron-sodium | 10450ab | 19249b | 3.89ab | 12.26ab | 30.67a |
| | Clethodim + Lactofen | 10725ab | 19041bc | 3.84ab | 14.16a | 32.86a |
| | Carfentrazone-ethyl | 10278b | 16611c | 3.23b | 13.32ab | 32.25a |
| Atraz + s-met fb 2HW | | 11476ab | 18442bc | 4.01a | 11.96ab | 30.46a |
| Hoe-weeded (3ce) | | 12006a | 19539b | 3.51ab | 12.14ab | 30.54a |
| Weedy | | 10474ab | 15209c | 2.99b | 7.77c | 14.81b |
| **Year** | | | | | | |
| 2015 | | 9977b | 18510a | 2.21b | 10.51a | 21.89b |
| 2016 | | 10767ab | 18876a | 2.85b | 11.06a | 24.26ab |
| 2017 | | 11687a | 18218a | 4.68a | 9.72a | 28.93a |
| Year x treatments | | ns | * | ns | ns | ns |

Means within a column followed by a similar letter(s) are not significantly different ($p \leq 0.05$). Atraz + s-met fb 2HW, Atrazine + s-metolachlor followed by two hoe-weeding; MAP, month after planting; ns, not significant; *significant at $p \leq 0.05$; No, number; fb, followed by; Plant and stem count data for statistical analyses were logarithm transformed to stabilize variances but de-transformed values are presented.

followed by the three post-emergence herbicides averaged 19.4% relative to the hoe-weeded control. The combination involving sulfentrazone and the three post-emergence herbicides produced the maximum number of stems (averaged 27903/ha) which was significantly higher than the number of stems obtained from all other treatments: 15209 to 19656 stems/ha. The maximum weight of top shoot was obtained on the plots treated with atrazine + s-metolachlor followed by hoe-weeded (4.01 t/ha). This was however, not significantly different from those produced from flumioxazin + pyroxasulfone followed by trifloysulfuron-sodium, indaziflam + isoxaflutole followed by each of trifloysulfuron-sodium and clethodim + lactofen as well as those of hoe-weeded control. The top shoot weight produced by the combinations involving sulfentrazone and the three post-emergence herbicides was significantly lower than that produced by the other plots. Flumioxazin + pyroxasulfone and indaziflam + isoxaflutole supplemented with each of the three post-emergence herbicides as well as atrazine + s-metolachlor followed by hoe-weeding and hoe-weeding three times had comparable stem weight that ranged from 11.52 to 14.61 tonnes/ha. The highest top shoot weight was measured in indaziflam + isoxaflutole treated plot. Combinations involving sulfentrazone (5.14, 5.18) resulted in significantly lower stem weight (tonnes/ha) than weedy-check (7.77) except when sulfentrazone was followed by trifloysulfuron-sodium (5.63). All herbicide treatment combinations and hoe-weeded control resulted in significantly higher storage root yield than combinations involving sulfentrazone and weedy-check.

The treatments involving sulfentrazone as pre-emergence herbicide resulted in 58% storage root yield reduction in cassava while uncontrolled weed infestation resulted in 52% yield loss (Table 4.6). The highest storage root weight was recorded in indaziflam + isoxaflutole/clethodim + lactofen. Yield and yield components were significantly different in the three years. Higher values for the number of plants, stems, the weight of top shoot, stem and storage root were recorded in 2017 than for 2015 but were not significantly different from 2016 except for the weight of top shoot. The values of 2016 were not significantly different from those of 2015. Interaction of year by treatments was not significant for the yield and yield components except number of stems (Table 4.6). Year by herbicide interaction was significant for number of stems. Highest number of stems was produced in 2016 with the application of sulfentrazone followed by clethodim + lactofen (Table 4.7). This was closely followed by sulfentrazone + trifloysulfuron- sodium both of produced in 2016 with the application of sulfentrazone

**Table 4.7: Year x herbicide treatments interaction on number of stems at 12 MAP as influenced by pre- and post-emergence herbicides**

| Year | PRE herbicides + POST herbicides | | No of stems (plants/ha) |
|---|---|---|---|
| 2015 | Sulfentrazone | Trifloysulfuron-sodium | 27606ab |
| | | Clethodim + Lactofen | 25433b |
| | | Carfentrazone-ethyl | 27040ab |
| | Flumioxazin + Pyroxasulfone | Trifloysulfuron-sodium | 20716c |
| | | Clethodim + Lactofen | 22182bc |
| | | Carfentrazone-ethyl | 22646bc |
| | Indaziflam + Isoxaflutole | Trifloysulfuron-sodium | 19539cd |
| | | Clethodim + Lactofen | 18902cd |
| | | Carfentrazone-ethyl | 16990d |
| 2016 | Sulfentrazone | Trifloysulfuron-sodium | 32696a |
| | | Clethodim + Lactofen | 33783a |
| | | Carfentrazone-ethyl | 31297ab |
| | Flumioxazin + Pyroxasulfone | Trifloysulfuron-sodium | 14672d |
| | | Clethodim + Lactofen | 17515cd |
| | | Carfentrazone-ethyl | 15955d |
| | Indaziflam + Isoxaflutole | Trifloysulfuron-sodium | 19670cd |
| | | Clethodim + Lactofen | 17943cd |
| | | Carfentrazone-ethyl | 16504d |
| 2017 | Sulfentrazone | Trifloysulfuron-sodium | 23977bc |
| | | Clethodim + Lactofen | 23895bc |
| | | Carfentrazone-ethyl | 27227ab |
| | Flumioxazin + Pyroxasulfone | Trifloysulfuron-sodium | 20170cd |
| | | Clethodim + Lactofen | 16850d |
| | | Carfentrazone-ethyl | 21018bc |
| | Indaziflam + Isoxaflutole | Trifloysulfuron-sodium | 18557cd |
| | | Clethodim + Lactofen | 20361cd |
| | | Carfentrazone-ethyl | 16346d |

Means within a column with similar letter(s) are not significantly different ($p \leq 0.05$).

followed by clethodim + lactofen (Table 4.7). This was closely followed by sulfentrazone + trifloysulfuron-sodium both of which were significantly higher than the other treatment combinations across the years except sulfentrazone treatment followed bytrifloysulfuron-sodium in 2015 and sulfentrazone followed by carfentrazone-ethyl in both 2015 and 2016.

### 4.2.3 Relationships among cassava yield and yield components under three pre-emergence herbicides

The relationship among the yield and yield components as influenced by herbicide treatments are presented in Table 4.8. The number and weight of stems were not significantly correlated across the pre-emergence herbicides. Although sulfentrazone treated plots produced a greater number of stems (27384 to 28458 stems/ ha) compared to other herbicides (16611 to 19656 stems/ ha), it did not result in a commensurate increase in fresh storage root weight. All the cassava plots treated with the three pre-emergence herbicides indaziflam+ isoxaflutole, flumioxazin + pyroxasulfone and sulfentrazone showed a significant positive correlation between the number of stems and top shoot weight (r = 0.279, 0.289 and 0.449) respectively. There was no significant correlation between the number of stems and fresh root weight. Stem weight was significantly correlated with root weight but not with top shoot weight. Observation made under the three pre-emergence herbicides revealed a positive correlation between top shoot weight and root weight (Table 4.8).

### 4 .2.4 Broadleaf, sedges and grass weed control and weed dry weight at 8 WAP

Control of grass, sedge and broadleaf weeds observed throughout three years trial was similar (Table 4.9). All weed control treatments controlled weed groups up to 95 to 99% compared to uncontrolled plots (85 to 89%) at four weeks after treatment (Table 4.9). Indaziflam + isoxaflutole gave 95% grass control which was not significantly different from the grass weed control rating observed from the plots treated with atrazine + s-metolachlor followed by hoe-weeding (98%) and those of the plots that were hoe-weeded (98%). The grass weed control rating of 85 and 83% obtained from the plots that were treated with sulfentrazone and flumioxazin + pyroxasulfone respectively were significantly lower than 95% from indaziflam + isoxaflutole. The weed dry weight of 8.2, 10.9, and 12.7% relative to the weedy-check as a result of the application of hoe-weeding, atrazine+ s-metolachlor followed by hoe-weeding and indaziflam+isoxaflutole

**Table 4.8: Pearson correlation coefficient values of yield components of cassava under different pre-emergence herbicides**

| Parameters | Sulfentrazone | Flumioxazin + Pyroxasulfone | Indaziflam + Isoxaflutole |
|---|---|---|---|
| Number and weight of stems | 0.052 | 0.232 | 0.067 |
| Number of stems and weight of top shoot | 0.449* | 0.289* | 0.279* |
| Number of stems and weight of storage root | 0.089 | 0.014 | 0.156 |
| weight of stem and top shoot | 0.096 | 0.033 | 0.052 |
| Weight of stem and storage root | 0.374* | 0.561* | 0.652* |
| Weight of top shoot and storage root | 0.334* | 0.443* | 0.538* |

*Significant ($P \leq 0.05$); n = 54

**Table 4.9: Effect of selected pre-emergence herbicides and other weed control treatments on weed types and weed dry weight**

| | Broadleaf | | Grasses | | Sedges | | Weed dry weight |
|---|---|---|---|---|---|---|---|
| | % | | | | | | ($g/m^2$) |
| | Weeks after planting | | | | | | |
| **Treatment** | 4 | 8 | 4 | 8 | 4 | 8 | 8 |
| Sulfentrazone | 98a | 90a | 99a | 85b | 95a | 98a | 26b |
| Flumioxazin + Pyroxasulfone | 99a | 90a | 99a | 83b | 99a | 97a | 20c |
| Indaziflam + Isoxaflutole | 99a | 95a | 99a | 95a | 98a | 96a | 14d |
| Atrazin + s-met fb 2HW | 98a | 97a | 98a | 98a | 98a | 98a | 12d |
| Hoe-weeded (4,8, 12WAP) | 98a | 98a | 99a | 98a | 98a | 98a | 9d |
| Weedy | 85b | 64b | 86b | 63c | 89b | 71b | 110a |
| **Year** | | | | | | | |
| 2015 | 96 | 89 | 96 | 85 | 95 | 92 | 60a |
| 2016 | 96 | 88 | 97 | 87 | 96 | 92 | 52a |
| 2017 | 96 | 90 | 96 | 87 | 96 | 93 | 22b |
| Year x treatment | ns | ns | ns | ns | ns | ns | * |

Means in a column followed by similar letter(s) did not differ significantly ($p \leq 0.05$). *significant at $p \leq 0.05$; ns, not significant; Atraz + s-met fb 2HW, Atrazine + S-metolachlor followed by two hoe-weeding were comparable however, significantly lower than 18.2% obtained from flumioxazin + pyroxasulfone which was significantly lower than 23.6% obtained from sulfentrazone treated plots. In the three years, weed dry weight (22 g / m²) in 2017 was significantly lower than those of 2015 (52 g / m²) and 2016 (60 g / m²) which were comparable. There was a significant interaction between year and pre-emergence herbicides treatment on weed dry weight at 8 WAP (Table 4.10). Weed dry weight was significantly lower in 2017 than in 2015 and 2016. Indaziflam + isoxaflutole in the three years produced significantly lower weed dry weight than sulfentrazone. Flumioxazin + pyroxalsulfone resulted in weed dry weight, significantly higher than those of indaziflam + isoxaflutole (except in 2016) but comparable to those of sulfentrazone in both years (2015 and 2016). The influence of the pre-emergence herbicides on cassava and weed at 8 WAP is shown in Plate 4.1.

### 4.2.5 Influence of sulfentrazone, indaziflam + isoxaflutole and flumioxazin + pyroxasulfone on weed species

In 2015 at 8 WAP, 24 weed species were identified in weedy-check plots of which the relative density for *Calopogonium mucunoides*. was 13.7% of the 197 total weeds counted (Table 4.11). Sedge was 9.4 while *Talinum fruticosm*, *Passiflora foetida*, *Panicum maximum*, *Gomphrena celosioides*, *Digitaria horizontalis*, and *Tridax procumbens* were within the range of 7 to 7.4. The rest of the weed species were < 4. Pre-emergence herbicides had varying effects on weed species: in sulfentrazone treated plots, the relative density of *T. procumbens* and *D. horizontalis* was 22.3 of the total 55 weeds counted followed by *P. foetida* (12.1) and *Cleome rutidosperma* (10). Other weed species were within the range of < 10. The highest relative density was calculated for sedges (40) in indaziflam+isoxaflutole treated plots from 38 weeds counted. This was followed by *C. rutidosperma* (20), *D. horizontalis* (20) and other weed species that were < 5. *T. procumbens* in flumioxazin+pyroxasulfone treated plots had relative density of 34.3 followed by *D. horizontalis* (29), *T. procumbens* (14.3) and the rest weed species were < 10 of the total 87 weed species counted (Table 4.11). Sulfentrazone, indaziflam+isoxaflutole and flumioxazin+ pyroxasulfone totally hindered the emergence of *Calopogonium mucunoides*, *Chromolaena odorata*, *Spigelia anthelmia*, *Ipomoea mauritiana*, *Talinum fruticosm.*, *Oldenlandia corymbosa*, *Commelina diffusa*, *Portulaca quadrifida*, *Mitracarpus villosus* and *Ageratum conyzoides*. Indaziflam + isoxaflutole and flumioxazin + pyroxasulfone completely suppressed *Spermacoce*

**Table 4.10: Year x pre-emergence herbicides interaction on weed dry weight at 8 WAP as influenced by pre-emergence herbicide treatments**

| Year | PRE herbicides | Weed dry weight (g/ $m^2$) |
|---|---|---|
| 2015 | Sulfentrazone | 46a |
| | Flumioxazin + Pyroxasulfone | 37a |
| | Indaziflam + Isoxaflutole | 24b |
| 2016 | Sulfentrazone | 27b |
| | Flumioxazin + Pyroxasulfone | 25b |
| | Indaziflam + Isoxaflutole | 15bc |
| 2017 | Sulfentrazone | 6c |
| | Flumioxazin + Pyroxasulfone | 4c |
| | Indaziflam + Isoxaflutole | 2c |

Means within a column followed by a similar letter(s) are not significantly different ($p \leq 0.05$)

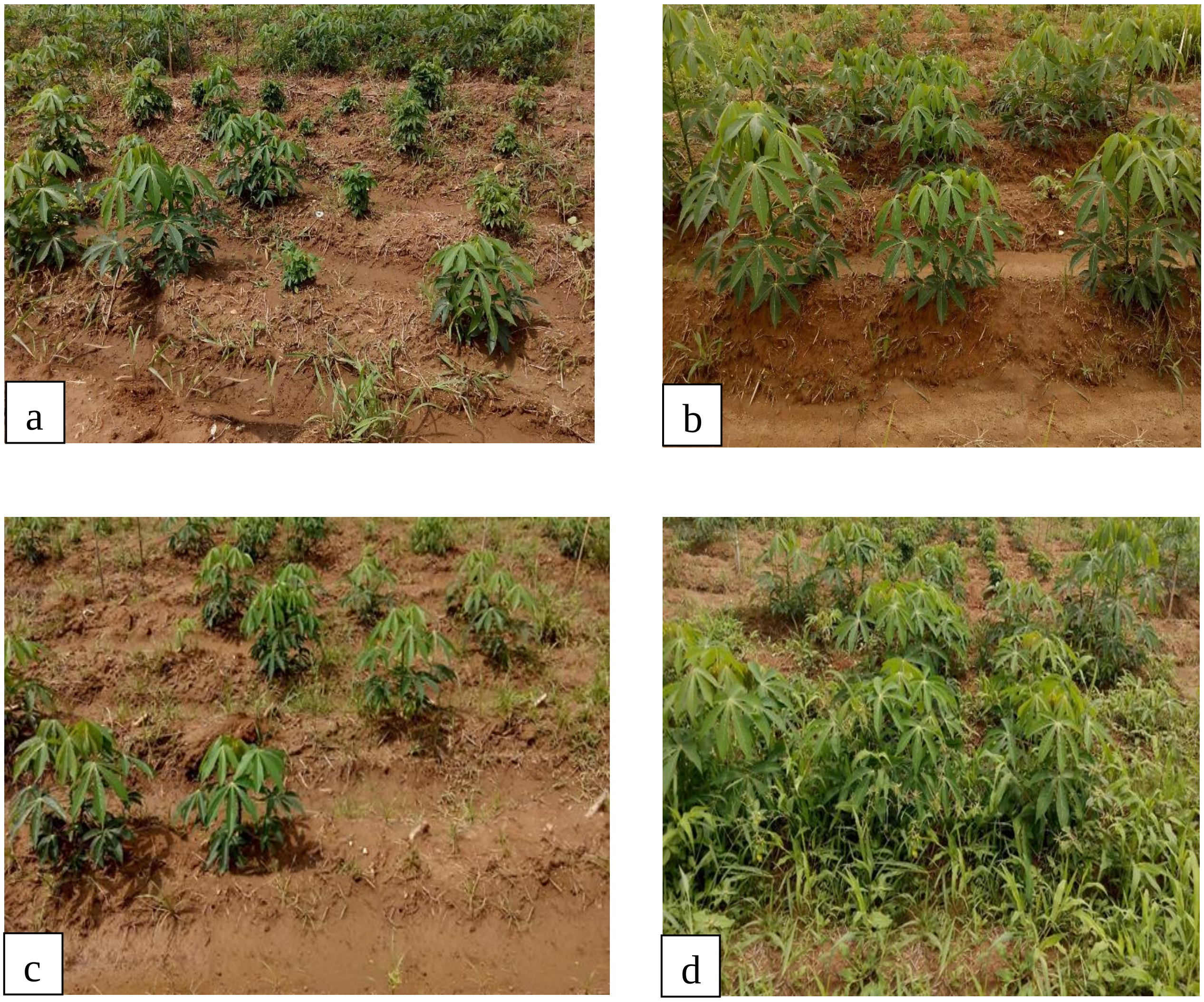


Plate 4.1: Influence of (a) sulfentrazone (b) flumioxazin + pyroxasulfone (c) indaziflam + isoxaflutole (d) atrazine + s-metolachlor at 8 WAP on cassava plants and weed

**Table 4.11: Flora composition (number/ m$^2$) and weed relative density (%) as influenced by three pre-emergence herbicides at 8 WAP in 2015.**

| Flora composition | Relative density (%) Untreated plot | St | In+If | Fl+Py |
|---|---|---|---|---|
| Broadleaf | | | | |
| *Calopogonium mucunoides* Desv. | 13.7 | nil | nil | nil |
| *Tridax procumbens* Linn. | 7.0 | 22.3 | 3.9 | 34.3 |
| *Cleome rutidosperma* D.C. | 6.4 | 10.8 | 20.1 | 2.9 |
| *Ipomoea involucrata* P. Beauv. | 0.8 | 1.8 | 3.5 | nil |
| *Chromolaena odorata* L. R M King and Robinson | 0.5 | nil | nil | nil |
| *Spigelia anthelmia* Linn. | 3.6 | nil | nil | nil |
| *Gomphrena celosioides* Mart. | 7.0 | 7.8 | 3.5 | 7.7 |
| *Spemacoce verticillata* Linn. | 3.4 | 5.4 | nil | nil |
| *Portulaca quadrifida* Linn. | 3.6 | 3.6 | nil | nil |
| *Ipomoea mauritiana* Jacq. | 1.5 | nil | nil | nil |
| *Phyllanthus amarus Var. (L) Juss* | 1.0 | nil | nil | 2.7 |
| *Talinum fruticosm* | 7.3 | nil | nil | nil |
| *Euphorbia hirta* Linn. | 0.5 | 5.4 | nil | 2.7 |
| *Oldenlandia corymbosa* Linn. | 1.9 | nil | nil | nil |
| *Acmella grandiflora* Turcz. | 0.8 | nil | nil | 2.3 |
| *Commelina di*ffusa Burm. | 0.5 | nil | nil | nil |
| *Desmodium scorpiurus* (Sw.) Desv. | 1.8 | 3.6 | nil | 2.3 |
| *Portulaca oleracea* Linn. | 3.0 | nil | nil | nil |
| *Mitracarpus villosus* (Sw.) DC. | 2.5 | nil | nil | nil |
| *Ageratum conyzoides* Linn. | 2.0 | nil | nil | nil |
| *Commelina benghalensis* L. | nil | nil | 2.6 | nil |
| Grass | | | | |
| *Panicum maximum* Jacq. | 7.4 | 2.4 | 2.6 | nil |
| *Digitaria horizontalis* Willd. | 7.1 | 22.3 | 20.1 | 28.9 |
| *Passiflora foetida* Linn. | 7.3 | 12.1 | 3.5 | 1.9 |
| Sedges | 9.4 | 2.4 | 40.2 | 14.3 |
| Total weed count/treatment | 196.9 | 55.3 | 38.2 | 86.5 |

St, sulfentrazone; In+If, indaziflam+isoxaflutole; Fl+Py,Flumioxazin+pyroxasulfone

*verticullata* and *Portulaca quadrifida*. Sulfentrazone and indaziflam + isoxaflutole suppressed *Phyllanthus amarus* and *Acmella grandiflora*. Indaziflam + isoxaflutole hindered *Euphorbia hirta* and *Desmodium scorpiurus* while flumioxazin+pyroxasulfone suppressed *Panicum maximum* Jacq. (Table 4.11).

Weed floral composition in 2016 at 8 WAP totaled 18 species (Table 4.12) with relative density of *A. grandiflora*, *Euphorbia hirta*, and *O. corymbosa*. ranging from 10 to < 20. *Calopogonium mucunoides*, Sedge, *T. procumbens*, *P. foetida*, *S. anthelmia*, *Gomphrena celosioides*, *Phyllanthus amarus*, *C. diffusa*, *A. conyzoides*, *Boerhavia ereta*, *Paspalum orbiculare* and *Rottboellia cochinchinensis* were < 10 of the total 126 weeds counted in un-weeded plots. Relative weed densities of species in sulfentrazone treated plots were 10.2 (*Panicum maximum*), 13.5 (*B. ereta*), 16.2 (*P. foetida*) and 21 for *T. procumbens*, *C. mucunoides*, Sedge, *G. celosioides*, *Euphorbia hirta*, *Euphorbia heterophylla*, *Celosia laxa*, *Paspalum orbiculare* and *R. cochinchinensis* were < 10 of the total 133 weeds counted. The total number of weeds counted in indaziflam + isoxaflutole sprayed plots were 79 of which 40% were sedge, 11.3% *B. ereta*, 13.9% *P. maximum*. and the rest species present were < 10%. Flumioxazin + pyroxasulfone sprayed plots accounted for 48 counted weeds of which 16% were E. heterophylla, 15% *P. orbiculare*. and *E. hirta*, 13% Sedge and *P. maximum*. *C. mucunoides*, *T. procumbens*, *P. foetida*, *S. anthelmia*, *B. ereta*. and *R. cochinchinensis* were < 10%. Sulfentrazone, indaziflam + isoxaflutole and flumioxazin + pyroxasulfone totally hindered the emergence of *Acmella grandiflora*, *P. amarus*, *Commelina diffusa* and *Oldenlandia corymbosa*. Sulfentrazone and indaziflam + isoxaflutole suppressed *Spigelia anthelmia* while sulfentrazone and flumioxazin + pyroxasulfone hindered *Ageratum conyzoides*. Indaziflam + isoxaflutole and flumioxazin + pyroxasulfone suppressed *Celosia laxa* and *G. celosioides*, while indaziflam + isoxaflutole hindered the emergence of *P. foetida* (Table 4.12).

Grass and broadleaf weed species identified in 2017 were 4 and 19, respectively and the total number of weeds counted in untreated plots was 173 (Table 4.13). Sedge was 15.9% while other weed species were < 10%. *A. grandiflora* and *C. mucunoides* accounted for 28 and 25% respectively in sulfentrazone treated plots while *T. procumbens, C rutidosperma*, *P. foetida*, *P. maximum*, *G. celosioides*, *E. heterophylla*. and *A. conyzoides*. were < 10% of the 31 weeds counted. Sedge was 16.5% in indaziflam + isoxaflutole sprayed plots, *P. foetida*. was 35.3, *S. anthelmia* 14.1 and *C. diffusa* 11 of

**Table 4.12: Flora composition (number/ m²) and weed relative density (%) as influenced by three pre-emergence herbicides at 8 WAP in 2016**

| Flora composition | Relative density (%) | | | |
|---|---|---|---|---|
| | Untreated plot | St | In+If | Fl+Py |
| Broadleaf | | | | |
| *Calopogonium mucunoides* Desv. | 3.2 | 7.2 | 8 | 4.2 |
| *Tridax procumbens* Linn. | 4.0 | 21.0 | 5 | 9.0 |
| *Passiflora foetida* Linn. | 2.6 | 16.2 | nil | 2.1 |
| *Spigelia anthelmia* Linn. | 8.3 | nil | nil | 7.6 |
| *Gomphrena celosioides* Mart. | 4.7 | 7.7 | nil | nil |
| *Phyllanthus amarus Var. (L) Juss* | 1.8 | nil | nil | nil |
| *Euphorbia hirta* Linn. | Nil | 3.7 | 1.3 | 14.5 |
| *Acmella grandiflora Turcz.* | 14.2 | nil | nil | nil |
| *Commelina di*ffusa Burm. | 1.6 | nil | nil | nil |
| *Euphorbia heterophylla* Linn. | 16.2 | 3.7 | 8.2 | 15.6 |
| *Oldenlandia corymbosa* Linn. | 10.0 | nil | nil | nil |
| *Ageratum conyzoides* Linn. | 1.8 | nil | 1.9 | nil |
| *Celosia laxa* Schum &Thonn | Nil | 8.2 | nil | nil |
| *Boerhavia ereta* Linn. | 5.5 | 13.5 | 11.3 | 6.2 |
| Grass | | | | |
| *Panicum maximum* Jacq. | 10.9 | 10.2 | 13.9 | 13.1 |
| *Paspalum orbiculare* Forst. | 4.7 | 6.7 | 1.3 | 14.5 |
| *Rottboellia cochinchinensis* Lour. | 2.8 | 9.8 | 8.8 | 4.2 |
| Sedges | 7.6 | 1.5 | 40.3 | 13.1 |
| Total weed count/treatment | 126.4 | 133.3 | 79.3 | 48.2 |

St, sulfentrazone; In+If, indaziflam+isoxaflutole; Fl+Py,Flumioxazin+pyroxasulfone

the total 14 weeds counted. *A. conyzoides*, *P. maximum* and *C. mucunoides* were < 10%. In flumioxazin + pyroxasulfone treated plots, *Acmella grandiflora* was 29%, *Panicum maximum* 28, *Calopogonium mucunoides* 11 Sedge and *Paspalum orbiculare* 10% while *Bracharia deflexa*, *Ageratum conyzoides*, *Euphorbia heterophylla*, *Euphorbia hirta*, *Gomphrena celosioides* and *Spigelia anthelmia* were less than 10% of the total 39 weeds counted. Sulfentrazone, indaziflam + isoxaflutole and flumioxazin + pyroxasulfone completely hindered the emergence of *Chromolaena odorata*, *Phyllanthus amarus*, *Talinum fruticosm*, *Oldenlandia corymbosa*, *Amaranthus spinosus*, *Mitracarpus villosus*, *Sida acuta*, *Rottboellia cochinchinensis* and *Vernonia cinerea*. Sulfentrazone and indaziflam + isoxaflutole suppressed *Euphorbia hirta*, *Paspalum orbiculare* and *Bracharia deflexa* while sulfentrazone and flumioxazin + pyroxasulfone suppressed *Commelina diffusa*. Indaziflam + isoxaflutole and flumioxazin + pyroxasulfone hindered *Tridax procumbens*; sulfentrazone completely suppressed sedge, *Spigelia anthelmia*; indaziflam + isoxaflutole suppressed *Gomphrena celosioides*, *Acmella grandiflora.* and *Euphorbia heterophylla*. Flumioxazin + pyroxasulfone suppressed *Passiflora foetida* (Table 4.13).

### 4.2.6 Broadleaf, sedge and grass weed control (12 WAP) and weed dry weight (14 WAP)

The weed control efficacy of pre- and post-emergence herbicides on broadleaf, sedge and grassy weeds and weed dry weight was significantly different across the three years (Table 4.14). The broadleaf and sedge weeds control as influenced by all the weed control treatments (95 to 98%) and (91 to 98%) were similar and significantly higher than weedy check (46%) and (65%), respectively. The grass weed control influenced by sulfentrazone and flumioxazin + pyroxasulfone each supplemented with carfentrazone-ethyl (80-82%) was significantly lower than those of other treatment combinations (95 to 98%), but significantly higher than the weedy-check treatment (44%). Weed dry weight was significantly lower in all of the treatments except in the weedy-check. Weed dry weight reduction due to the supplementary application of clethodim + lactofen to indaziflam + isoxaflutole was 90%. This however, was not significantly different from 85 to 89% reduction obtained from the plots where clethodim + lactofen followed each of sulfentrazone and flumioxazin + pyroxasulfone; where trifloysulfuron-sodium followed each of sulfentrazone and indaziflam + isoxaflutole; where carfentrazone-ethyl

**Table 4.13: Flora composition (number/ m²) and weed relative density (%) as influenced by three pre-emergence herbicides at 8 WAP in 2017**

| | Relative density (%) | | | |
|---|---|---|---|---|
| Flora composition | Untreated plot | St | In + If | Fl + Py |
| *Calopogonium mucunoides* Desv. | 2.2 | 25.0 | 9.39 | 11.2 |
| *Tridax procumbens* Linn. | 4.4 | 3.3 | nil | nil |
| *Cleome rutidosperma* D.C. | 3 | 6.5 | nil | nil |
| *Passiflora foetida* Linn. | 2 | 9.8 | 35.3 | nil |
| *Chromolaena odorata* L. | 5.8 | nil | nil | nil |
| *Spigelia anthelmia* Linn. | 2.9 | nil | 14.1 | 5.2 |
| *Gomphrena celosiodes* Mart. | 2.9 | 6.5 | nil | 2.6 |
| *Phyllanthus amarus Var. (L) Juss* | 1.4 | nil | nil | nil |
| *Talinum fruticosm*. | 2.9 | nil | nil | nil |
| *Euphorbia hirta* Linn. | 2.3 | nil | nil | 2.6 |
| *Oldenlandia corymbosa* Linn. | 5.5 | nil | nil | nil |
| *Acmella grandiflora Turcz.* | 6.2 | 27.7 | nil | 29.2 |
| *Amaranthus spinosus* Linn. | 3.5 | nil | nil | nil |
| *Commelina di*ffusa Burm. | 4.1 | nil | 10.6 | nil |
| *Mitracarpus villosus* (Sw.) DC. | 7.1 | nil | nil | nil |
| *Euphorbia heterophylla* Linn. | Nil | 9.8 | nil | 2.6 |
| *Ageratum conyzoides* Linn. | 4.5 | 6.5 | 7.1 | 3.9 |
| *Sida acuta* Burn. f. | 2 | nil | nil | nil |
| *Vernonia cinerea* Linn | 2.6 | nil | nil | nil |
| Grass | | | | |
| *Paspalum orbiculare* Forst. | 4.5 | nil | nil | 10.3 |
| *Panicum maximum* Jacq. | 4.1 | 4.9 | 7.1 | 19.8 |
| *Bracharia deflexa* Schumach | 6.7 | nil | nil | 2.6 |
| *Rottboellia cochinchinensis* Lour. | 3.5 | nil | nil | Nil |
| Sedges | 15.9 | nil | 16.45 | 10.3 |
| Total weed count/treatment | 172.6 | 30.7 | 14.2 | 38.8 |

St, sulfentrazone; In+If, indaziflam+isoxaflutole; Fl+Py,Flumioxazin+pyroxasulfone

**Table 4.14: Weed control efficacy of broadleaf, grasses, sedge (12 WAP) and weed dry weight (14 WAP) as influenced by pre- and post-emergence herbicide treatments**

| | | Broadleaf | Grass | Sedge | Weed dry weight |
|---|---|---|---|---|---|
| **Treatment** | | | % | | g / $m^2$ |
| PRE herbicides + POST herbicides | | | | | |
| Sulfentrazone | Trifloysulfuron-sodium | 97a | 96a | 98a | 21de |
| | Clethodim + Lactofen | 98a | 97a | 98a | 18de |
| | Carfentrazone-ethyl | 95a | 82b | 97a | 42b |
| Flumioxazin + Pyroxasulfone | Trifloysulfuron-sodium | 97a | 96a | 97a | 22d |
| | Clethodim + Lactofen | 97a | 96a | 95a | 19de |
| | Carfentrazone-ethyl | 95a | 80b | 95a | 35bc |
| Indaziflam + Isoxaflutole | Trifloysulfuron-sodium | 98a | 97a | 97a | 16de |
| | Clethodim + Lactofen | 98a | 98a | 97a | 14e |
| | Carfentrazone-ethyl | 98a | 95a | 97a | 18de |
| Atraz + s-met fb 2HW | | 97a | 98a | 91a | 31c |
| Hoe-weeded (3ce) | | 97a | 98a | 92a | 19de |
| Weedy | | 46b | 44c | 65b | 140a |
| **Year** | | | | | |
| 2015 | | 89b | 87b | 88b | 48b |
| 2016 | | 85c | 85c | 86c | 55a |
| 2017 | | 92ab | 92a | 94a | 36c |
| Year x treatment | | ns | * | * | * |

Means within a column followed by similar letter(s) are not significantly different (p≤0.05). WAP, week after planting; No, number; ns, not significant; *significant at p≤0.05; Atraz + s-met fb 2HW, Atrazine + s-metolachlor followed by two hoe-weeding follow indaziflam + isoxaflutole and the hoe-weeded control. The 84% reduction obtained from plots treated with flumioxazin + pyroxasulfone supplemented with trifloysulfuron-sodium was not significantly different from the herbicide combinations mention above but significantly higher than 78% from the plots where atrazine + s-metolachlor was followed by hoe-weeding. This was significantly higher than 70% obtained on the plots where sulfentrazone was supplemented with carfentrazone-ethyl. Weed control efficacy was higher in 2017 than the other two years. Consequently, weed dry weight was lower in 2017 than in 2015 and 2016.

Year by treatment interaction was significant for grasses, sedges and weed dry weight (Tables 4.15). In 2017, each of the three pre-emergence herbicides followed by each of the three post-emergence herbicides had similar grass weed control of 98% while in 2016, the results revealed flumioxazin + pyroxasulfone followed by carfentrazone-ethyl gave grass control of 86% which was significantly lower than other herbicide treatments (93 to 96%) except sulfentrazone supplemented with carfentrazone-ethyl (79%). Sulfentrazone supplemented with carfentrazone-ethyl control of grasses in 2015 (96%) was significantly lower than when indaziflam + isoxaflutole was followed by either clethodim + lactofen and carfentrazone-ethyl (99%) which gave the best control of grasses. However, other treatment combinations were not significantly different from indaziflam + isoxaflutole follow by clethodim + lactofen and carfentrazone-ethyl (97 to 98%). All the herbicide treatments (98%) suppressed sedges similarly in 2015, however in 2016, flumioxazin + pyroxasulone followed by carfentrazone-ethyl gave a sedge control efficacy of 89%. This was significantly lower than when sulfentrazone was supplemented with carfentrazon-ethyl (94%), flumioxazin + pyroxsulfone supplemented with trifoysulfuron-sodium (94%) and indaziflam + isoxaflutole supplemented with clethodim + lactofen (94%) and these were significantly lower than sulfentrazone followed by clethodim + lactofen (98%). Efficacy control of sedge was 92% with flumioxazin + pyroxasulfone followed by clethodim in 2015. This was comparable to the control in 2016 but significantly lower than the result of some treatments in 2017. Weed dry weight in sulfentrazone, flumioxazin + pyroxasulfone (2015); sulfentrazone, flumioxazin + pyroxasulfone (2016) sulfentrazone, flumioxazin + pyroxasulfone (2017) each supplemented with carfentrazone-ethyl and flumioxazin + pyroxasulfone followed by trifloysulfuron-sodium in 2016 were comparable and this ranged from 25.63 to 57.28 g/ $m^2$. These were significantly greater than the other treatment combinations (11.87 to

**Table 4.15: Year x herbicide treatments interaction on weed control efficacy of grass, sedge (12 WAP) and weed dry weight (g/ $m^2$) at 14 WAP as influenced by pre- and post-emergence herbicide treatments**

| **Year** | **PRE herbicides + POST herbicides** | | Grass | Sedge | WDW |
|---|---|---|---|---|---|
| 2015 | Sulfentrazone | Trifloysulfuron-sodium | 97ab | 99a | 22.07cd |
| | | Clethodim + Lactofen | 97ab | 99a | 17.8d |
| | | Carfentrazone-ethyl | 96b | 98a | 30.07bc |
| | Flumioxazin + Pyroxasulfone | Trifloysulfuron-sodium | 98ab | 98a | 22.15cd |
| | | Clethodim + Lactofen | 98ab | 98a | 15.98d |
| | | Carfentrazone-ethyl | 97ab | 98a | 25.63c |
| | Indaziflam + Isoxaflutole | Trifloysulfuron-sodium | 98ab | 98a | 15.43d |
| | | Clethodim + Lactofen | 99a | 98a | 12.85d |
| | | Carfentrazone-ethyl | 99a | 98a | 19.72cd |
| 2016 | Sulfentrazone | Trifloysulfuron-sodium | 93b | 97ab | 22.55cd |
| | | Clethodim + Lactofen | 95b | 98a | 16.75d |
| | | Carfentrazone-ethyl | 79d | 94b | 57.28a |
| | Flumioxazin + Pyroxasulfone | Trifloysulfuron-sodium | 93b | 94b | 28bc |
| | | Clethodim + Lactofen | 94b | 95ab | 19.57cd |
| | | Carfentrazone-ethyl | 86c | 89c | 46.05ab |
| | Indaziflam + Isoxaflutole | Trifloysulfuron-sodium | 96b | 96ab | 14.82d |
| | | Clethodim + Lactofen | 96b | 94b | 16.48d |
| | | Carfentrazone-ethyl | 96b | 95ab | 21.45cd |
| 2017 | Sulfentrazone | Trifloysulfuron-sodium | 98ab | 98a | 16.97d |
| | | Clethodim + Lactofen | 98ab | 98a | 20.77cd |
| | | Carfentrazone-ethyl | 98ab | 98a | 39.37b |
| | Flumioxazin + Pyroxasulfone | Trifloysulfuron-sodium | 98ab | 98a | 16.77d |
| | | Clethodim + Lactofen | 98ab | 92bc | 20.65cd |
| | | Carfentrazone-ethyl | 98ab | 98a | 34.3bc |
| | Indaziflam + Isoxaflutole | Trifloysulfuron-sodium | 98ab | 98a | 18.68cd |
| | | Clethodim + Lactofen | 98ab | 98a | 11.98d |
| | | Carfentrazone-ethyl | 98ab | 98a | 11.87d |

Means in the same column followed by a similar letter(s) did not differ significantly ($p \leq 0.05$). WDW, Weed Dry Weight; WAP, weeks after planting

22.55 g/ $m^2$) in other years (Table 4.15). Overall, combination of sulfentrazone / trifloysufone-sodium and clethodim + lactofen had the highest sedge control efficacy, indaziflam + isoxaflutole / clethodim + lactofen and carfentrazone-ethyl had the highest grass control efficacy and lowest weed dry weight.

### 4.2.7 Economic analysis of cassava production under pre- and post-emergence herbicides (pre-post) application for weed control

Budget analysis for cassava production on one hectare is presented in Table 4.16. Total Variable Cost (TVC) for three times hoe-weeding was ₦291,000 which was higher than other treatments considered. This was followed by atrazine + s-metolachlor (₦258,500) and other treatment combinations ranged from ₦ (185807 to 223002) while the TVC for the plots without any weed control treatment was ₦141,000. The difference between the total variable cost of the weedy check plots and each of the other treatment combinations was the cost of weed control which also varied among the various herbicide treatment combinations.

The MRR (%) as a result of hoe-weeding control and that of the Atrazine-S-metolachlor + 2-Hoe-weeding were 324 and 488 while those of the herbicide treatment combinations, other than those involving sulfentrazone ranged from 623 (flumioxazin-pyroxasulfone + clethodin-lactofen) to 1669 (indaziflam-isoxaflutole + cafertrazone-ethyl). The combinations involving sulfentrazone as pre-emergence herbicide resulted in negative MRR.

## 4. 3 Selectivity of three post-emergence herbicides supplemented with pre-emergence herbicides on cassava and their effects on weed.

Influences of spray methods and post-emergence herbicides on cassava plant count, vigour, injury ratings as influenced by spray methods and selected post-emergence herbicides are presented below:

### 4.3.1 Cassava plants count, vigour and injury as influenced by spray methods, post-emergence herbicides and their interactions at 2 WAT

Cassava plant count, vigour and injury or phytotoxicity as influenced by spray methods and post-emergence herbicides are presented in Tables 4.17 and 4.18.

**Table 4.16: Economic analysis for cassava production with the application of herbicides in sequence (pre-post) for weed control on 1-hectare land during 2015-2018 cropping year**

| Treatment combinations | Yield (t/ha) (Y) | Stem (t/ha) (ST) | Stem (bundles /ha) (STB) | Cost of weed control (₦) (CWC) | Total Variable Cost (₦) (TVC) | Total Gross Return (₦) (TGR) | Net Benefit (₦) (NB) | Marginal Rate of Return (%) (MRR) |
|---|---|---|---|---|---|---|---|---|
| Sulfentrazone + Trifloysulfuron-sodium | 12.46 | 5.63 | 179 | 22701 | 187701 | 365170 | 177469 | -296.4 |
| Sulfentrazone + Clethodin-Lactofen | 13.07 | 5.14 | 163 | 44842 | 209842 | 375749 | 165907 | -209.8 |
| Sulfentrazone + Cafertrazone-ethyl | 12.87 | 5.18 | 165 | 21263 | 186263 | 371130 | 184867 | -288.3 |
| Flumioxazin-Pyroxasulfone +Trifloysulfuron-sodium | 30.14 | 12.6 | 1001 | 35861 | 200861 | 1053783 | 852922 | 1040.0 |
| Flumioxazin-Pyroxasulfone + Clethodin-Lactofen | 28.65 | 11.52 | 915 | 58002 | 223002 | 990795 | 767793 | 622.8 |
| Flumioxazin-Pyroxasulfone + Cafertrazone-ethyl | 30.11 | 12.32 | 979 | 34423 | 199423 | 1046360 | 846937 | 1057.3 |
| Indaziflam-Isoxaflutole + Trifloysulfuron-sodium | 30.67 | 12.26 | 974 | 22245 | 187245 | 1058930 | 871685 | 1442.5 |
| Indaziflam-Isoxaflutole + Clethodin-Lactofen | 32.86 | 14.16 | 1125 | 44386 | 209386 | 1158961 | 949575 | 1052.9 |
| Indaziflam-Isoxaflutole + Cafertrazone-ethyl | 32.25 | 13.32 | 1058 | 20807 | 185807 | 1123692 | 937885 | 1668.9 |
| Atrazine-S-metolachlor + 2-Hoe-weeding | 30.46 | 11.96 | 950 | 117500 | 258500 | 1046531 | 788031 | 412.5 |
| 3-Hoe-weeding | 30.54 | 12.14 | 964 | 150000 | 291000 | 1052820 | 761820 | 323.7 |
| Weedy | 14.81 | 7.77 | 247 | nil | 141000 | 444320 | 303320 | nil |

TVC= CWC + operational cost; TGR= Y × Farm Gate Price (FGP) of storage root + STB × FGP of bundle of stem; NB = TGR – TVC; where FGP cassava storage root = ₦25000/t and stem bundle = ₦300

#### 4.3.1.1 Influence of spray methods

The methods of spraying of the selected post-emergence herbicides did not significantly affect cassava plant counts (Table 4.17). The effect on cassava crop vigour was however significant. Broadcast application of the herbicides resulted in crops that were significantly less vigorous than crops that received banded spray. Similarly, broadcast application caused the injury of 55.2% which was significantly higher than the injury score of 7.4% obtained in banded spray.

#### 4.3.1.2 Influence of the post-emergence herbicides

Treatments with post-emergence herbicides had no significant effect on the number of plants per hectare. (Table 4.17). The vigour score of cassava and the injury caused by the selected post-emergence herbicides were significant. The plots that received carfentrazone-ethyl had cassava plants that were significantly less vigorous than those of all other post-emergence herbicides and those of the plots that were not treated with post-emergence herbicides. The treatment with hoe-weeding and atrazine + s-metolachlor followed by hoe- weeding had significantly more vigorous plants than other treatments except those that received clethodim + lactofen or with uncontrolled weed, which in turn was not significantly different from those that were sprayed with trifloysulfuron-sodium.

Carfentrazone-ethyl caused up to 50% of crop injury. This was significantly higher than the injury score of 31% recorded from the plots that were sprayed with trifloysulfuron-sodium, which was also significantly different from 12% from clethodim + lactofen treated plants.

**Table 4.17: Cassava plant count, vigour and injury as influenced by methods of spray of selected post-emergence herbicides at 2 WAT**

| Treatment combinations | Plant count (plants/ha) | Vigour (Scale 1-5) | Injury (%) |
|---|---|---|---|
| **Spray method (S)** | | | |
| Broadcast | 11733 | 3.72b | 55.19a |
| Banded | 11825 | 4.47a | 7.41b |
| **POST (P)** | | | |
| Trifloysulfuron-sodium | 11882 | 4.28a | 31.48b |
| Clethodim + Lactofen | 11776 | 4.46a | 12.41c |
| Carfentrazone-ethyl | 11682 | 3.54b | 50.00a |
| **Year (Y)** | | | |
| 2015 | 11174b | 3.94c | 12.87a |
| 2016 | 12170a | 4.48b | 19.72a |
| 2017 | 12391a | 4.75a | 15.74a |
| S x P | Ns | * | * |
| Y x P | Ns | * | ns |
| Y x S | ns | * | ns |

Means within a column followed by a similar letter(s) are not significantly different ($p \leq 0.05$). ns, not significant; *significant at $p \leq 0.05$; Atraz + s-met fb 2HW, Atrazine + s-metolachlor followed by two hoe-weeding

Across the treatments, the numbers of cassava plants were significantly higher in 2016 and 2017 than in 2015. Cassava plants were more vigorous in 2017 than in 2016 and 2015. The interactions among the years, spray methods and the post-emergence not significant on cassava plant count but crop vigour was significantly influenced. Only spray methods by post-emergence herbicides interaction was significant on crop injury (Table 4.17).

#### 4.3.1.3 Interactions among spray methods, post-emergence herbicides and year of application

The interactions among the methods of spray, influence of post-emergence herbicides and the years of application on crop vigour and cassava injury score are presented in Table 4.18. Cassava crop vigour was significantly reduced under the broadcast spray of trifloysulfuron-sodium and carfentrazone-ethyl compared to the banded spray of the herbicides. In contrast, the reduction in crop vigour was not significant with clethodim + Lactofen. Crop injury was significantly more severe with a broadcast spray of the three herbicides compared to their banded spray with carfentrazone-ethyl causing significantly higher injury (92%) than the two other herbicides. Similarly, treatment with trifloysulfuron-sodium caused 55% injury which was significantly higher than that caused by clethodim + Lactofen (19%). However, in the banded application of these post- emergence herbicides, the injury caused was minor and the treatments were not significantly influenced. The injury caused by the post-emergence herbicides under banded application ranged from 6.3 to 8.2%. The effect of the banded spray of the three post- emergence herbicides on vigour score was significant only in 2017: Cassava vigour was significantly higher under band application of the post-emergence herbicides. The broadcast application of the same herbicides across the years showed that there was a significant difference in cassava vigour with a higher score observed in 2017 than 2016 and the lowest in 2015. Response of cassava vigour to the three post-emergence herbicides in the three years varied with significant higher vigour score reported in 2017, followed by 2016 and 2015 except for clethodim + lactofen whose cassava vigour score of 2017 and 2015 were not different but the vigour score in 2017 was significantly better compared to vigour in 2016.

**Table 4.18: Interaction of year, spray methods and post-emergence herbicides on cassava vigour and injury at 2 WAT**

| **Main factor** | **Sub factor** | Vigour | Injury (%) |
|---|---|---|---|
| **Spray method** | **POST herbicides** | | |
| Broadcast | Trifloysulfuron-sodium | 4.04b | 54.81b |
| | Clethodim + Lactofen | 4.33ab | 18.52c |
| | Carfentrazone-ethyl | 2.78c | 92.22a |
| Banded | Trifloysulfuron-sodium | 4.52a | 7.78d |
| | Clethodim + Lactofen | 4.59a | 6.30d |
| | Carfentrazone-ethyl | 4.3ab | 8.15d |
| **Year** | **Spray method** | | |
| 2015 | Broadcast | 2.96d | 49.63a |
| | Band-spray | 4.33b | 1.85b |
| 2016 | Broadcast | 3.93c | 61.11a |
| | Band-spray | 4.22bc | 12.22b |
| 2017 | Broadcast | 4.26b | 54.81a |
| | Band-spray | 4.85a | 8.15b |
| **Year** | **POST herbicides** | | |
| 2015 | Trifloysulfuron-sodium | 3.78c | 26.11b |
| | Clethodim + Lactofen | 4.61ab | 7.22c |
| | Carfentrazone-ethyl | 2.56d | 43.89a |
| 2016 | Trifloysulfuron-sodium | 4.33b | 33.89b |
| | Clethodim + Lactofen | 4.11bc | 22.22c |
| | Carfentrazone-ethyl | 3.78c | 53.89a |
| 2017 | Trifloysulfuron-sodium | 4.72a | 34.44b |
| | Clethodim + Lactofen | 4.67a | 7.78c |
| | Carfentrazone-ethyl | 4.28b | 52.22a |

Means within a column followed by a similar letter(s) are not significantly different ($p \leq 0.05$).

### 4.3.2 Cassava plants count, vigour and height at 8 and 12 WAP

Effect of spray methods, post-emergence herbicides supplemented with pre-emergence herbicides over three years on the number of plants, crop vigour and height, are presented in Table 4.19. The number of plants was not significantly influenced by spray methods and the herbicide treatments. The vigour and height of cassava at 8 WAP were affected significantly by the spray method, with higher values observed in the banded application method. However, by the twelfth week, the differences observed between broadcast and band-spray for vigour score and height were insignificant (Table 4.19). Some cassava plants in various plots treated with broadcast and banded application of the selected post-emergence herbicides supplemented with pre-emergence herbicides are shown in Plates 2 to 4.

Averaged over the pre-emergence supplementary weed control treatments, the crop vigour score and cassava plant heights respectively at 8 WAP were: 4.8 and 51.8 (control) > 4.5 and 47.8 (clethodim + lactofen) > 4.3 and 46.5 (tryfloysulfuron-sodium) > 3.87 and 43.1 (carfentrazone-ethyl) respectively. The weedy-check had the vigour of 4.1 and plant height of 39.5 cm (Table 4.19). This trend was also observed at 12 WAP with crop vigour scores and plant heights of 4.8 and 133.8 (control) > 4.7 and 123.9 (clethodim + lactofen) > 4.3 and 117.3 (tryfloysulfuron-sodium) > 3.9 and 106.3 (carfentrazone-ethyl). The vigour score and the measured plant height for cassava in the weedy-check plot were 4.1 and 105.4 cm. Measurements and observations among the treatment combinations showed that vigour scores at 12 WAP was poorer when carfentrazone-ethyl was followed by sulfentrazone (3.5) and trifloysulfuron- sodium followed by sulfentrazone (3.61). The best vigour score was recorded for cassava plants in plots treated with clethodim + lactofen followed by flumioxazin + pyroxasulfone (4.83) and in atrazine + s-metolachlor followed by hoe-weeding (4.83) but they did not differ significantly from plant vigour in plots hoe-weeded, trifloysulfuron-sodium followed by flumioxazin + pyroxasulfone, clethodim + lactofen followed by indaziflam + isoxaflutole, trifloysulfuron-sodium followed by indaziflam + isoxaflutole, and clethodim + lactofen followed by sulfentrazone. Cassava plants were taller in hoe-weeded plots (135.9 cm) but were not significantly different from clethodim + lactofen followed by flumioxazin + pyroxasulfone treated plots plants (128.1 cm).

**Table 4.19: Effect of spray methods and herbicide treatments on cassava sprout count, vigour and height**

| | | Plant count (/ha) | | Vigour | | Height (cm) | |
|---|---|---|---|---|---|---|---|
| | | Weeks after planting | | | | | |
| **Spray method (S)** | | 8 | 12 | 8 | 12 | 8 | 12 |
| Broadcast | | 11880 | 11886 | 3.88b | 4.65 | 43.0b | 114.2 |
| Banded | | 11888 | 11878 | 4.56a | 4.73 | 48.6a | 117.4 |
| **POST herbicides + PRE herbicides (T)** | | | | | | | |
| Trifloysulfuron-sodium | Sulfentrazone | 11896 | 12196 | 3.94c | 3.61cd | 43.7c | 108.5c |
| | Flumioxazin + Pyroxasulfone | 12045 | 12365 | 4.5b | 4.72a | 48.3b | 123.2b |
| | Indaziflam + Isoxaflutole | 11855 | 12196 | 4.33bc | 4.5ab | 47.4b | 120.2b |
| Clethodim + Lactofen | Sulfentrazone | 11828 | 12246 | 4.33bc | 4.5ab | 46.3bc | 118b |
| | Flumioxazin + Pyroxasulfone | 11896 | 12061 | 4.72ab | 4.83a | 48.6b | 128.1ab |
| | Indaziflam + Isoxaflutole | 11896 | 12061 | 4.5b | 4.67a | 48.6b | 125.6b |
| Carfentrazone-ethyl | Sulfentrazone | 11612 | 12148 | 3.72d | 3.5d | 41.9c | 104.8c |
| | Flumioxazin + Pyroxasulfone | 12045 | 12028 | 4.17c | 4.28b | 44.2c | 106.3c |
| | Indaziflam + Isoxaflutole | 11896 | 12196 | 3.72d | 3.89c | 43.3c | 107.7c |
| Control | | | | | | | |
| Atraz + s-met fb 2HW | | 11900 | 12122 | 4.75ab | 4.83a | 51.4ab | 131.7ab |
| Hoe-weeded (3ce) | | 12022 | 12130 | 4.88a | 4.72a | 54.1a | 135.9a |
| Weedy-check | | 12396 | 12252 | 4.08c | 4.06bc | 39.5d | 105.4c |
| **Year** | | | | | | | |
| 2015 | | 11290b | 11308b | 4.06b | 4.61a | 48.2a | 122.4a |
| 2016 | | 12246a | 12321a | 4.54a | 4.54a | 46.7a | 121.9a |
| 2017 | | 12428a | 12430a | 4.61a | 4.69a | 44.1a | 116.0a |
| S x T | | ns | ns | * | * | * | * |
| S x Y | | ns | ns | ns | ns | * | * |
| Y x T | | ns | ns | ns | ns | ns | ns |

Means within a column followed by a similar letter(s) are not significantly different ($p \leq 0.05$). ns, not significant; *significant at $p \leq 0.05$; Atraz + s-met fb 2HW, Atrazine + s-metolachlor followed by two hoe-weeding

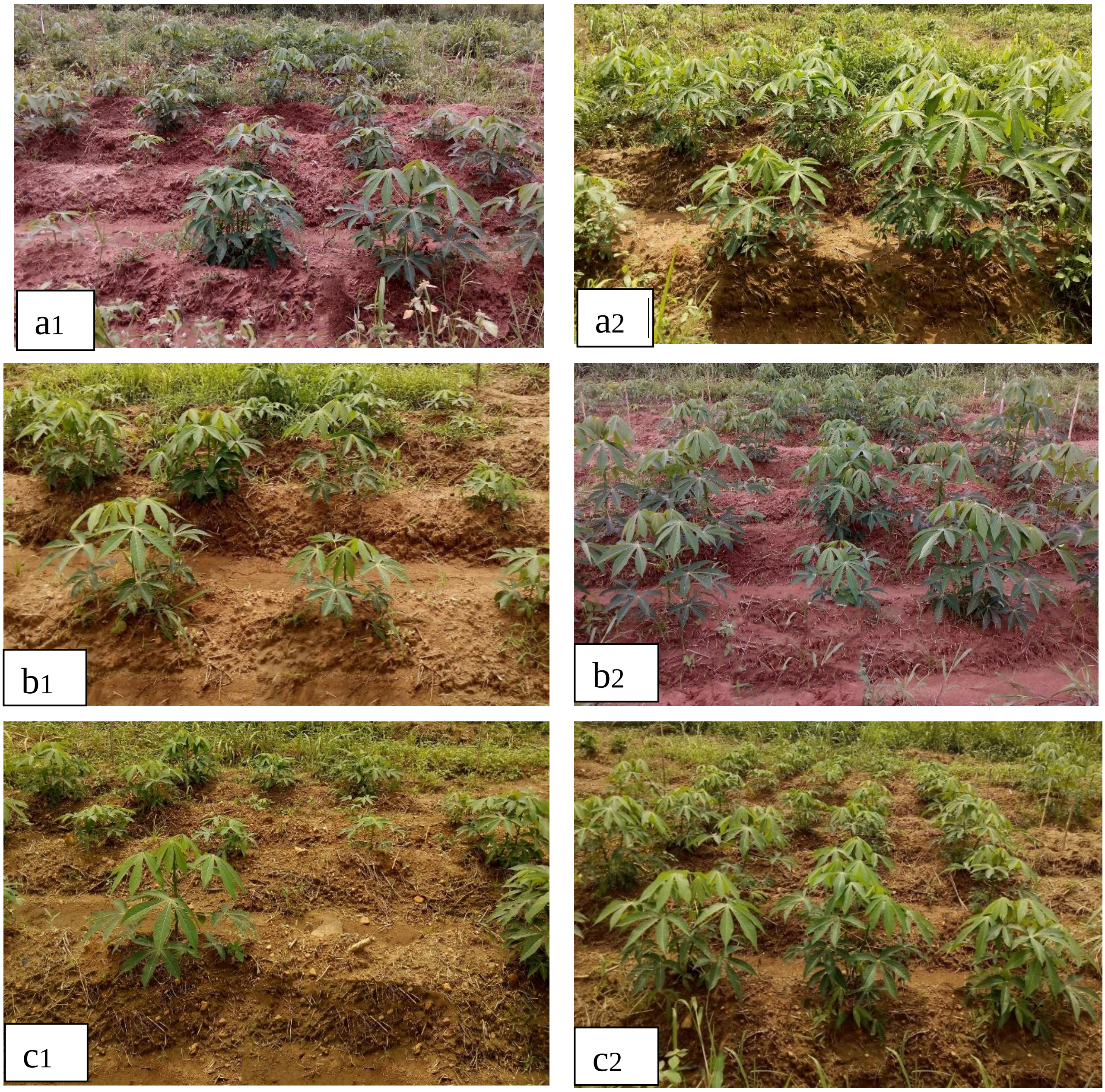


Plate 4.2: Influence of broadcast and banded application of: carfentrazone-ethyl (a1 and 2), trifloysulfuron-sodium (b1 and 2) and clethodim + lactofen (c1 and 2) at 2WAP each followed by flumioxazin + pyroxasulfone at 4 WAP on cassava and weed

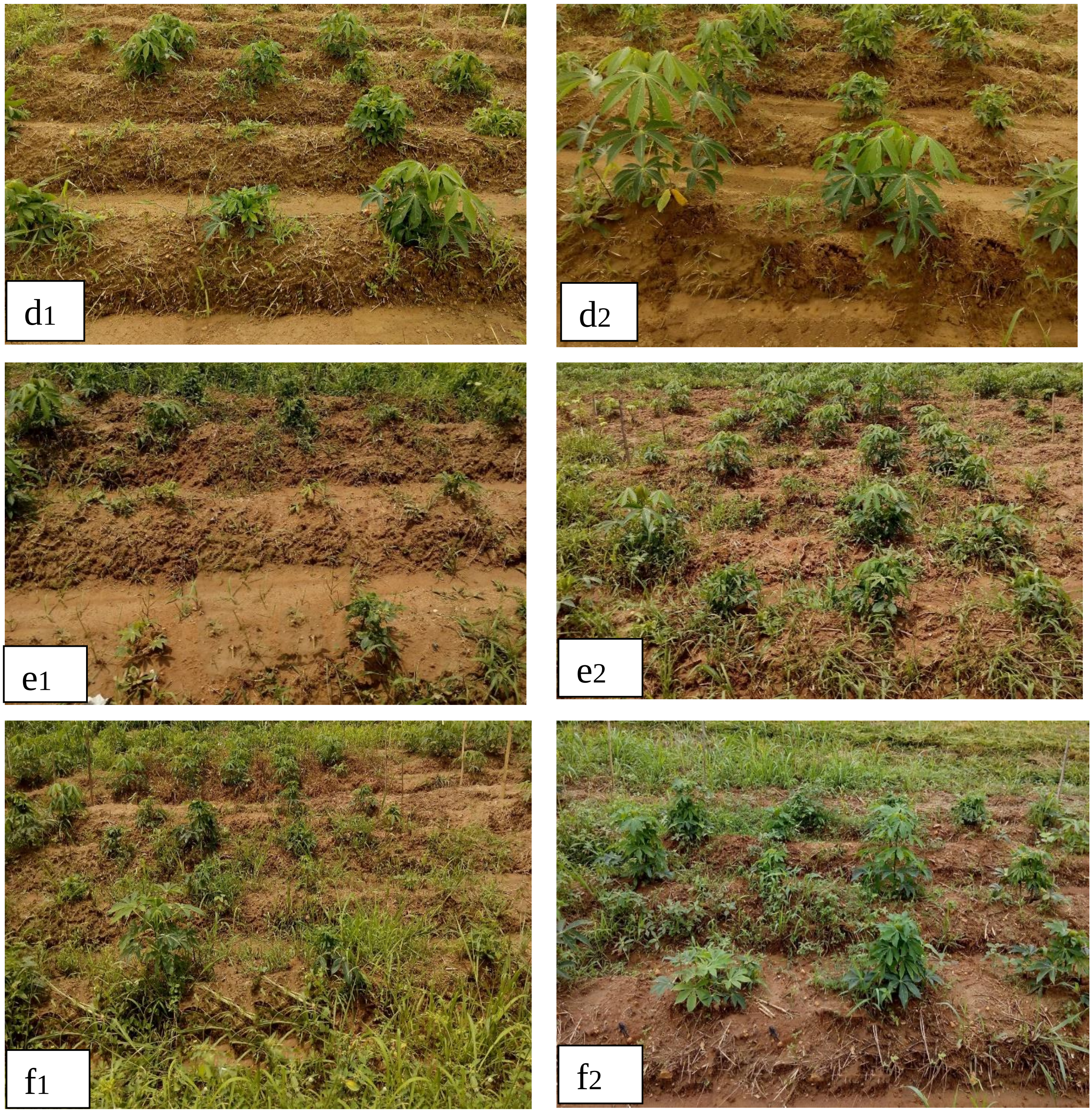


Plate 4.3: Influence of broadcast and banded application of: clethodim + lactofen (d1 and 2), carfentrazone-ethyl (e1 and 2) and trifloysulfuron-sodium (f1 and 2) at 2WAP each followed by sulfentrazone at 4 WAP on cassava and weed

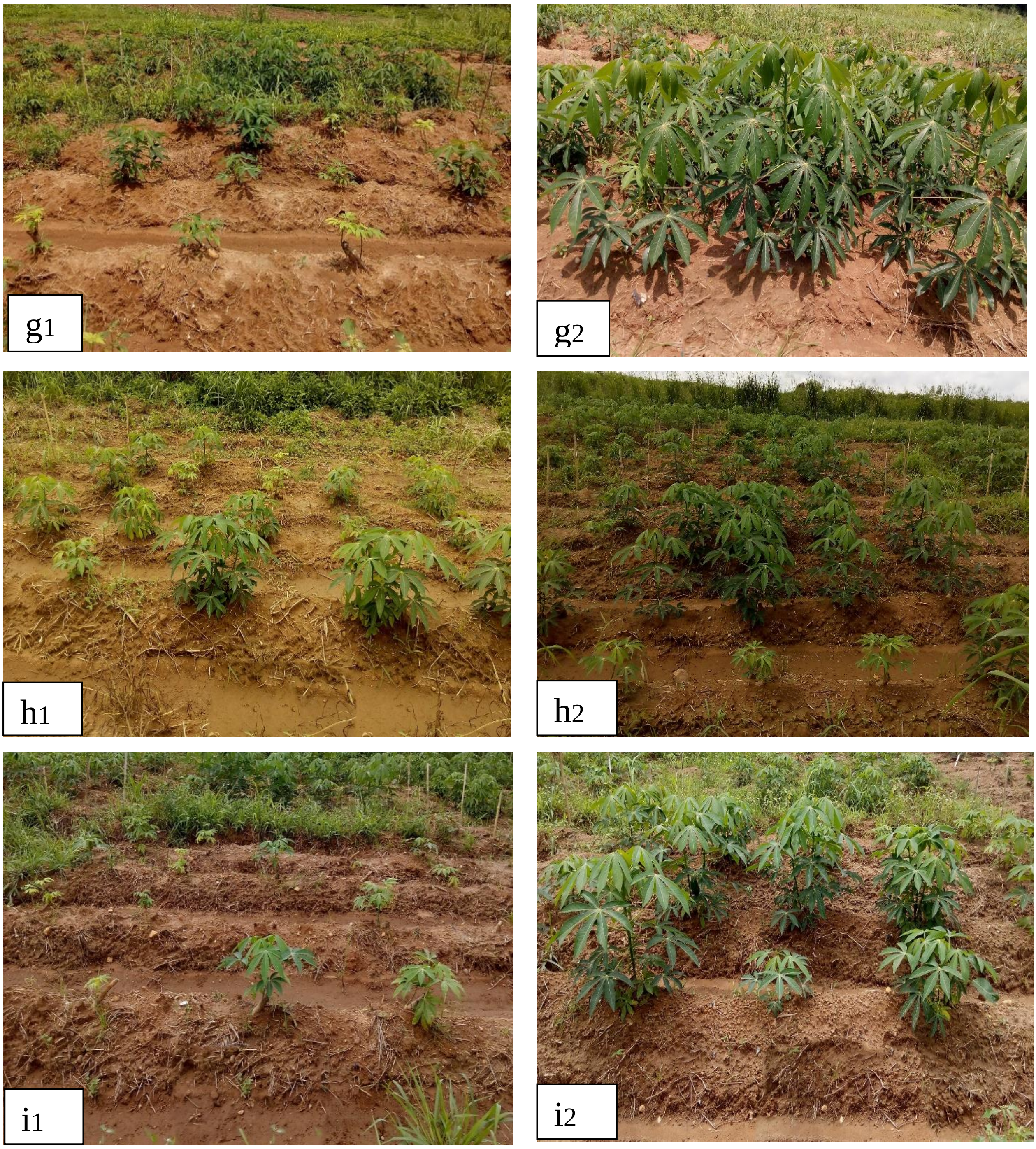


Plate 4.4: Influence of broadcast and banded application of: clethodim + lactofen (g1 and 2), trifloysulfuron-sodium (h1 and 2) and carfentrazone-ethyl (i1 and 2) at 2 WAP each followed by indaziflam + isoxaflutole at 4 WAP on cassava and weed

Weedy-check plots cassava had lowest height of 105.4 cm which was similar to treatment combinations of carfentrazone-ethyl followed by sulfentrazone (104.8 cm), carfentrazone-ethyl followed by flumioxazin + pyroxasulfone (106.3 cm), carfentrazone-ethyl followed by indaziflam + isoxaflutole (107.7 cm) and trifloysulfuron-sodium followed by sulfentrazone (108.5 cm) at 12 WAP (Table 4.19).

Interactions of spray methods, herbicides and year are presented in Tables 4.20 and 4.21. A significant spray methods-herbicide treatment interaction occurred for cassava vigour and height (Tables 4.20). Over the pre-emergence herbicides, band application of the post-emergence herbicides resulted in more vigorous and taller plants than those obtained with the broadcast application. For example, banded application of clethodim + lactofen combinations resulted in crop vigour and height at 12 WAP that ranged from 4.6 to 4.9 and 123 to 136 cm compared to their broadcast application with the ranges of 4.4 to 4.7 and 113 to 122 cm respectively. A similar trend was observed for trifloysulfuron-sodium and carfentrazone-ethyl (Tables 4.20). Cassava plants heights at 8 WAP in 2015 and 2017 under the banded spray method was significantly higher than heights of plants in 2016 and in the broadcast application. Taller plants at 12 WAP were recorded under banded spray in 2017 but were not significantly different from plant heights in 2015 and heights in broadcast spray in 2017. The number of stems was significantly higher in broadcast spray 2017 than in other years under both banded and broadcast methods of application (Table 4.21).

### 4.3.3 Yield and yield components of cassava at 12 MAP under post- and pre-emergence herbicides application

The influences of spray methods, herbicide, year and their interactions on yield and yield components are presented in Tables 4.22 to 4.24. The effect of spray methods was not significant. Averaged over the pre-emergence herbicide treatments, the numbers of cassava plants/ha and stems/ha were respectively 10,511 and 19,286 (clethodim + lactofen), 10,388 and 19,028 (trifloysulfuron-sodium), 9021 and 15673 (Carfentrazone-ethyl) and 11675 and 18910 (controls). Furthermore, the weights of top shoot for cafertrazone-ethyl and trifloysulfuron-sodium were 3.6 which was greater than that of 3.5 in control plots and clethodim + lactofen. Similarly, weights of the stem in carfentrazone-ethyl and clethodim + lactofen sprayed plots was 10.1 which was greater than 9.8 in trifloysulfuron-sodium, carfentrazone-ethyl and control plots. Storage root yield weights were in the order: plots sprayed with clethodim + lactofen 26.1 > 25.1

**Table 4.20: Interaction of spray methods and herbicide treatments on cassava crop vigour and plant height**

| **Spray-Methods** | **POST herbicdcides + PRE herbicides** | | Crop vigour | | Plant height | |
|---|---|---|---|---|---|---|
| | | | Weeks after planting | | | |
| | | | 8 | 12 | 8 | 12 |
| Broadcast | Trifloysulfuron-sodium | Sulfentrazone | 3.67c | 3.11c | 42.7c | 106.7c |
| | | Flumioxazin + Pyroxasulfone | 4.22b | 4.56ab | 47.2bc | 123b |
| | | Indaziflam + Isoxaflutole | 4.11bc | 4.11b | 47.4bc | 114.3bc |
| | Clethodim + Lactofen | Sulfentrazone | 4.33b | 4.44ab | 42.4c | 113.1bc |
| | | Flumioxazin + Pyroxasulfone | 4.44b | 4.78a | 47.9b | 122b |
| | | Indaziflam + Isoxaflutole | 4.22b | 4.56ab | 43.4bc | 115.1b |
| | Carfentrazone-ethyl | Sulfentrazone | 3.11d | 3.11c | 38.4c | 104.4c |
| | | Flumioxazin + Pyroxasulfone | 3.56cd | 3.22c | 38.1c | 108.4c |
| | | Indaziflam + Isoxaflutole | 3.22cd | 4b | 39.6c | 105.5c |
| Banded | Trifloysulfuron-sodium | Sulfentrazone | 4.22b | 4.11b | 44.6bc | 110.3c |
| | | Flumioxazin + Pyroxasulfone | 4.78ab | 4.89a | 49.4a/b | 123.4b |
| | | Indaziflam + Isoxaflutole | 4.56ab | 4.89a | 47.5bc | 126.2a |
| | Clethodim + Lactofen | Sulfentrazone | 4.33b | 4.56ab | 50.1ab | 122.8b |
| | | Flumioxazin + Pyroxasulfone | 5a | 4.89a | 49.3ab | 134.3a |
| | | Indaziflam + Isoxaflutole | 4.78ab | 4.78a | 53.9a | 136.1a |
| | Carfentrazone-ethyl | Sulfentrazone | 4.33b | 3.89b | 45.4bc | 105.2c |
| | | Flumioxazin + Pyroxasulfone | 4.78ab | 4.56ab | 50.3ab | 104.2c |
| | | Indaziflam + Isoxaflutole | 4.22b | 4.56ab | 47.1bc | 109.9c |

Means within a column followed by a similar letter(s) are not significantly different ($p \leq 0.05$). WAP, week after planting

**Table 4.21: Interaction of year by spray methods on cassava plant height and number of stems**

| Spray methods | Year | Height (cm) | | Number of stems |
|---|---|---|---|---|
| | | Weeks after planting | | Months after planting |
| | | 8 | 12 | 12 |
| Broadcast | 2015 | 41.2bc | 109.7b | 16508bc |
| | 2016 | 40.1c | 102.8 b | 15867c |
| | 2017 | 45.9b | 118.6ab | 21498a |
| Banded | 2015 | 52.4a | 122.1ab | 17362bc |
| | 2016 | 42bc | 114.3b | 18703b |
| | 2017 | 53.3a | 127.4a | 17640bc |

Means within a column followed by a similar letter(s) are not significantly different ($p \leq 0.05$). WAP, week after planting

**Table 4.22: Yield and yield components of cassava at 12 MAP in response to methods of spray and herbicide treatments**

| **Spray method (S)** | | Number (count/ha) | | Weight (tonnes/ha) | | |
|---|---|---|---|---|---|---|
| | | Plants | Stem | Top shoot | Stems | Storage root |
| Broadcast | | 10258 | 17791 | 3.47 | 9.06 | 24.25 |
| Banded | | 10354 | 17890 | 3.59 | 10.48 | 24.81 |
| **POST herbicides + PRE herbicides (T)** | | | | | | |
| Trifloysulfuron-sodium | Sulfentrazone | 9343b | 18578a | 2.93b | 6.22c | 18.98c |
| | Flumioxazin + Pyroxasulfone | 11107ab | 18664a | 3.84a | 11.77a | 27.34ab |
| | Indaziflam + Isoxaflutole | 10713ab | 19843a | 3.89a | 11.46ab | 28.69ab |
| Clethodim + Lactofen | Sulfentrazone | 9854b | 19440a | 3.64ab | 9.53b | 23.99bc |
| | Flumioxazin + Pyroxasulfone | 10907ab | 19391a | 3.26ab | 12.02a | 30.3a |
| | Indaziflam + Isoxaflutole | 10772ab | 19028a | 3.6ab | 11.22ab | 28.68ab |
| Carfentrazone-ethyl | Sulfentrazone | 7115c | 12668c | 3.07b | 6.84c | 16.57c |
| | Flumioxazin + Pyroxasulfone | 9618b | 15751b | 3.82a | 9.38b | 21.52bc |
| | Indaziflam + Isoxaflutole | 10330b | 18599a | 3.72ab | 9.48b | 24.73b |
| Control | | | | | | |
| Atraz + s-met fb 2HW | | 11350ab | 18540a | 3.86a | 11.92a | 27.96a |
| Hoe-weeded (3ce) | | 12000a | 19280a | 3.90ab | 12.10a | 29.44a |
| Weedy-check | | 11474ab | 15078b | 2.93b | 7.67bc | 13.86c |
| **Year** | | | | | | |
| 2015 | | 9524b | 17322 | 2.59b | 9.93 | 21.45b |
| 2016 | | 10678ab | 17943 | 2.89b | 11.15 | 23.66b |
| 2017 | | 11625a | 17947 | 5.07a | 9.51 | 29.61a |
| SxT | | Ns | * | Ns | ns | ns |
| SxY | | Ns | * | Ns | ns | ns |
| YxT | | Ns | * | Ns | ns | ns |

Means within a column followed by a similar letter(s) are not significantly different (p≤0.05). MAP, month after planting; no, number; wt, weight; ns, not significant; *significant at p≤0.05; Atraz + s-met fb 2HW, Atrazine + s-metolachlor followed by two hoe-weeding (control) > 25.0 (trifloysulfuron-sodium) > 24.7 (carfentrazone-ethyl) respectively (Table 4.22).

The effect of post- and pre-emergence herbicide treatment combinations on yield parameters varied. Cassava plants in plots treated with clethodim + lactofen followed by flumioxazin + pyroxasulfone produced the highest root fresh weight of 30.3 t/ha which was not significantly different from those in the plot of the standard check of three-times hoe-weeding (29.44 t/ha), trifloysulfuron-sodium followed by indaziflam + isoxaflutole (28.69 t/ha), clethodim + lactofen followed by indaziflam + isoxaflutole (28.68 t/ha), atrazine + s-metolachlor followed by two times hoe-weeding (27.96 t/ha) and trifloysulfuron-sodium followed by flumioxazin + pyroxasulfone (27.34 t/ha) (Table 4.22). Weedy plots produced the lowest yield (13.86 t/ha) that was not significantly different to carfentrazone-ethyl followed by sulfentrazone (16.57 t/ha), trifloysulfuron-sodium followed by sulfentrazone (18.98 t/ha), carfentrazone-ethyl followed by flumioxazin + pyroxasulfone 21.52 t/ha and clethodim + lactofen followed by sulfentrazone. Similarly, the highest yields of cassava stem by weight were obtained from plots that were hoe- weeded three times and those that received the treatment combinations involving clethodim + lactofen followed by flumioxazin + pyroxasulfone, atrazine + s-metolachlor followed by two times hoe-weeding and trifloysulfuron-sodium followed by flumioxazin + pyroxasulfone with yields of 12.1, 12.02, 11.92 and 11.77 t/ha respectively. These were not significantly greater from stem yields of 11.46 and 11.22 t/ha, obtained from plots treated with combinations of trifloysulfuron-sodium followed by indaziflam + isoxaflutole and clethodim + lactofen followed by indaziflam + isoxaflutole. The stem yields of 9.53, 9.48 and 9.38 t/ha from plots treated with herbicide combinations of clethodim + lactofen followed by sulfentrazone, carfentrazone-ethyl followed by indaziflam + isoxaflutole and carfentrazone-ethyl followed by flumioxazin + pyroxasulfone were comparable to those from the plots that produced stem yields of 11.46 and 11.22 t/ha but significantly lower than those that had highest stem yield. These stem yields were not significantly different from 7.67 t/ha (weedy check) but they were significantly higher than the lowest stem weight of 6.22 t/ha obtained from plots treated with trifloysulfuron-sodium followed by sulfentrazone. Top shoot weight was not significantly different for the treatment combinations including, trifloysulfuron-sodium followed by flumioxazin + pyroxasulfone (3.84 t/ha), trifloysulfuron-sodium followed by indaziflam + isoxaflutole (3.89 t/ha), clethodim +

lactofen followed by sulfentrazone (3.6 t/ha), clethodim + lactofen followed by flumioxazin + pyroxasulfone (3.26 t/ha), clethodim + lactofen followed by indaziflam + isoxaflutole (3.6 t/ha), carfentrazone-ethyl followed by flumioxazin + pyroxasulfone (3.82 t/ha, carfentrazone-ethyl followed by indaziflam + isoxaflutole (3.72 t/ha), atrazine + s-metolachlor followed by two-times hoe-weeding (3.86 t/ha). However, all these treatment combinations were comparable to the maximum stem weight obtained from three-times hoe-weeding (3.90 t/ha) (Table 4.22).

The year effect was significant for the number of plants, the weight of top shoot and storage roots but was not significant for the number and weight of stems. The number of plants and weight of top shoot and storage roots was significantly higher in 2017 than in the other years. Interactions of spray methods by herbicide treatments, year by spray method and year by treatment were significant for the number of stems (Table 4.22). Carfentrazone-ethyl supplemented with indaziflam + isoxaflutole was influenced by the spray method (Table 4.23). The number of stems was significantly higher in the broadcast application (21857 t/ha) of carfentrazone-ethyl supplemented with indaziflam + isoxaflutole than when it was band-sprayed (15823 t/ha). The interaction of year by treatment presented in Table 4.24 revealed number of stems in carfentrazone-ethyl combinations treated plots in 2017 was significantly higher than in the previous years.

### 4.3.4 Correlation among yield and yield components of cassava under three post-emergence herbicides

The number of stems and stem weight were not significantly correlated for clethodim + lactofen and carfertrazone-ethyl except trifloysulfuron-sodium (Table 4.25). The number of stems and top shoot weight were least correlated in trifloysulfuron-sodium treated cassava plots (r = 0.120), while the number of stems and top shoot weight were significantly correlated in carfentrazone-ethyl sprayed plots (r = 0.493). All the post-emergence herbicide treated plots showed significant positive between cassava number of stem and its root weight (r = 0.31, 0.27, 0.45). Root fresh weight was significantly correlated with stem and top shoot weight for all the herbicides.

**Table 4.23: Interaction of spray methods and herbicide treatments on the number of stems of cassava (count/ha) at 12 MAP**

| Spray methods | POST herbicides + PRE herbicides | | Number of stems |
|---|---|---|---|
| Broadcast | Trifloysulfuron-sodium | Sulfentrazone | 17575ab |
| | | Flumioxazin + Pyroxasulfone | 18854ab |
| | | Indaziflam + Isoxaflutole | 20026ab |
| | Clethodim + Lactofen | Sulfentrazone | 19400ab |
| | | Flumioxazin + Pyroxasulfone | 19634ab |
| | | Indaziflam + Isoxaflutole | 17894ab |
| | Carfentrazone-ethyl | Sulfentrazone | 11094c |
| | | Flumioxazin + Pyroxasulfone | 16278b |
| | | Indaziflam + Isoxaflutole | 21857a |
| Banded | Trifloysulfuron-sodium | Sulfentrazone | 19638ab |
| | | Flumioxazin + Pyroxasulfone | 18471ab |
| | | Indaziflam + Isoxaflutole | 19661ab |
| | Clethodim + Lactofen | Sulfentrazone | 19480ab |
| | | Flumioxazin + Pyroxasulfone | 19151ab |
| | | Indaziflam + Isoxaflutole | 20235ab |
| | Carfentrazone-ethyl | Sulfentrazone | 14464bc |
| | | Flumioxazin + Pyroxasulfone | 15241bc |
| | | Indaziflam + Isoxaflutole | 15823bc |

Means within a column followed by a similar letter(s) are not significantly different ($p \leq 0.05$). MAP, month after planting

**Table 4.24: Year x herbicide treatments interaction on the number of stems of cassava at 12 MAP as influenced by herbicide treatments**

| Year | POST herbicides + PRE herbicides | | No of stems (plants/ha) |
|---|---|---|---|
| 2015 | Trifloysulfuron-sodium | Sulfentrazone | 19939ab |
| | | Flumioxazin+ Pyroxasulfone | 20526ab |
| | | Indaziflam + Isoxaflutole | 22856ab |
| | Clethodim + Lactofen | Sulfentrazone | 19679ab |
| | | Flumioxazin+ Pyroxasulfone | 18189ab |
| | | Indaziflam + Isoxaflutole | 20235ab |
| | Carfentrazone-ethyl | Sulfentrazone | 9313d |
| | | Flumioxazin+ Pyroxasulfone | 12462c |
| | | Indaziflam + Isoxaflutole | 14514bc |
| 2016 | Trifloysulfuron-sodium | Sulfentrazone | 16448b |
| | | Flumioxazin+ Pyroxasulfone | 20040ab |
| | | Indaziflam + Isoxaflutole | 18789ab |
| | Clethodim + Lactofen | Sulfentrazone | 17775b |
| | | Flumioxazin+ Pyroxasulfone | 19999ab |
| | | Indaziflam + Isoxaflutole | 16815b |
| | Carfentrazone-ethyl | Sulfentrazone | 11577cd |
| | | Flumioxazin+ Pyroxasulfone | 16338bc |
| | | Indaziflam + Isoxaflutole | 19081ab |
| 2017 | Trifloysulfuron-sodium | Sulfentrazone | 19557ab |
| | | Flumioxazin+ Pyroxasulfone | 15805bc |
| | | Indaziflam + Isoxaflutole | 18193ab |
| | Clethodim + Lactofen | Sulfentrazone | 21004ab |
| | | Flumioxazin+ Pyroxasulfone | 20045ab |
| | | Indaziflam + Isoxaflutole | 20249ab |
| | Carfentrazone-ethyl | Sulfentrazone | 18854ab |
| | | Flumioxazin+ Pyroxasulfone | 19187ab |
| | | Indaziflam + Isoxaflutole | 23222a |

Means within a column followed by a similar letter(s) are not significantly different ($p \leq 0.05$). No, number, MAP, month after planting

**Table 4.25: Pearson correlation coefficient values of yield components of cassava under different three post-emergence herbicides**

| Parameters | Clethodim + lactofen | Trifloysulfuron-sodium | Carfentrazone-ethyl |
|---|---|---|---|
| Number and weight of stems | 0.10 | 0.345* | 0.085 |
| Number and weight of top shoot | 0.25 | 0.120 | 0.493* |
| Number of stems and weight of root | 0.31* | 0.266* | 0.448* |
| Weight of stem and top shoot | 0.14 | 0.181 | 0.251 |
| Weight of stem and storage root | 0.39* | 0.439* | 0.297* |
| Weight of top shoot and storage root | 0.58* | 0.375* | 0.586* |

*Significant at 5%; n = 54

### 4.3.5 Broadleaf, grass and sedge weeds control by post-emergence herbicides at 4 WAP or at two weeks after treatment (WAT)

Broadleaf, grass and sedge weeds as affected by post-emergence herbicides over three years are presented in Table 4.26. The weed control efficacy of broadleaf, grass and sedges by clethodim+lactofen was significantly higher than trifloysulfuron-sodium and carfentrazone-ethyl. Clethodim + lactofen control of broadleaf weeds at 2 WAT (4 WAP) was not significantly different from trifloysulfuron-sodium treated plots, which was significantly higher than carfentrazone-ethyl control of broadleaf weeds. The trend was similar for grass and sedge control. Weed control efficacy in 2016 and 2017 was significantly higher than in 2015 and year by treatment interaction was significant for the three weed groups. The interaction of year by post-emergence herbicides is presented in Table 4.27. The weed control efficacy of broadleaf, grass and sedge weeds was best with the use of trifloysulfuron-sodium in 2016 and clethodim + lactofen in 2016 and 2017. The treatments gave significantly higher control of the weedy groups, than the use of the three post-herbicides in 2015. Weed control by clethodim + lactofen was significantly higher in 2016 and 2017 than in 2015. Carfentrazone-ethyl control of grass, sedge and broadleaf was the same as clethodim + lactofen in the three years.

### 4.3.6 Broadleaf, sedge and grass weed control at 12 WAP and weed dry weight at 14 WAP

The weed control efficacy of the post-emergence herbicides supplemented with pre-emergence herbicides and the controls of three times hoe-weeding and Atrazine + s-metolachlor followed by two hoe-weeding is presented in Table 4.28. Broadleaf, grass and sedge control of each of the post-emergence herbicides, averaged over the three pre-emergence herbicides and control were 97, 98, 97% (control) > 94, 91, 94% (clethodim + lactofen) > 81, 75, 93% (tryfloysulfuron-sodium) > 77, 68, 89% (carfentrazone-ethyl). Similarly, weed dry weight reductions, relative to weedy check, were 86%, 79%, 70% and 64%, obtained from control plots, clethodim + lactofen, tryfloysulfuron-sodium and carfentrazone-ethyl treated plots, respectively.

Plots treated with atrazine + s-metolachlor followed by two times hoe-weeding (97%) and weed-free (97%) had the highest weed control efficacy and it was significantly similar to the control by trifloysulfuron-sodium with indaziflam + isoxaflutole (93%) and clethodim

**Table 4.26: Effect of post-emergence herbicides weed control treatments on weed groups at 2 WAT**

| **Year** | Broadleaf | Grass | Sedge | TWC |
|---|---|---|---|---|
| | | % | | |
| **Spray method (S)** | | | | |
| Broadcast | 94 | 88 | 95 | 88 |
| Banded | 93 | 88 | 95 | 88 |
| **Treatment** | | | | |
| Trifloysulfuron-sodium | 95b | 88b | 95b | 88b |
| Clethodim + Lactofen | 97a | 97a | 97a | 97a |
| Carfentrazone-ethyl | 89c | 79c | 93c | 79c |
| **Year** | | | | |
| 2015 | 87b | 85b | 89b | 90a |
| 2016 | 92a | 90a | 93a | 90a |
| 2017 | 93a | 89a | 93a | 89a |
| YxS | ns | ns | ns | ns |
| SxT | ns | ns | ns | ns |
| YxT | * | * | * | ns |

Means within a column by a similar letter(s) are not significantly different ($p \leq 0.05$). WAT week after treatment, *significant at $p \leq 0.05$; Atraz + s-met fb 2HW, Atrazine + s-metolachlor followed by two hoe-weeding; TWC, total weed control

**Table 4.27: Year x post-emergence herbicides interactions of WCE at 2 WAT on weed groups**

| **Year** | **POST herbicides** | Broadleaf | Grass | Sedge |
|---|---|---|---|---|
| | | | % | |
| 2015 | Trifloysulfuron-sodium | 91c | 86c | 90c |
| | Clethodim + Lactofen | 95b | 94b | 95b |
| | Carfentrazone-ethyl | 77d | 70e | 85d |
| 2016 | Trifloysulfuron-sodium | 98a | 98a | 98a |
| | Clethodim + Lactofen | 98a | 98a | 98a |
| | Carfentrazone-ethyl | 98a | 86c | 95b |
| 2017 | Trifloysulfuron-sodium | 96ab | 85c | 97ab |
| | Clethodim + Lactofen | 98a | 98a | 98a |
| | Carfentrazone-ethyl | 93bc | 82d | 97ab |

Means within a column followed by a similar letter(s) are not significantly different at probability level of 5%. WAT, week after treatment

**Table 4.28: Effect of herbicide treatments at 12 WAP on weed control efficacy (%) on broadleaf, grasses, sedge and weed dry weight**

| **Year** | Treatments | Broadleaf | Grass | Sedge | Weed dry weight |
|---|---|---|---|---|---|
| | | | % | | (g/ $m^2$) |
| **Spray method (S)** | | | | | |
| Broadcast | | 84 | 87 | 96 | 54.0 |
| Banded | | 84 | 87 | 97 | 51.0 |
| **POST herbicides + PRE herbicides** | | | | | |
| Trifloysulfuron-sodium | Sulfentrazone | 74c | 63d | 95a | 65.56d |
| | Flumioxazin + Pyroxasulfone | 77c | 71c | 95a | 66.44d |
| | Indaziflam + Isoxaflutole | 93ab | 91b | 90a | 30.93f |
| Clethodim + Lactofen | Sulfentrazone | 92b | 87b | 97a | 47.66e |
| | Flumioxazin + Pyroxasulfone | 95ab | 90b | 95a | 44.8e |
| | Indaziflam + Isoxaflutole | 96ab | 95ab | 91a | 21.75g |
| Carfentrazone-ethyl | Sulfentrazone | 66c | 55e | 92a | 82.72b |
| | Flumioxazin + Pyroxasulfone | 74c | 61d | 91a | 75.45c |
| | Indaziflam + Isoxaflutole | 91b | 88b | 85a | 35.24f |
| Control | | | | | |
| Atraz + s-met fb 2HW | | 97a | 98a | 97a | 31.35f |
| Hoe-weeded (3ce) | | 97a | 98a | 97a | 19.17g |
| Weedy-check | | 46d | 44f | 65b | 179.6a |
| **Year** | | | | | |
| 2015 | | 81a | 80a | 87b | 66.77a |
| 2016 | | 80a | 75b | 83c | 68.27a |
| 2017 | | 84a | 82a | 94a | 58.45b |
| YxS | | ns | ns | ns | ns |
| SxT | | ns | ns | ns | ns |
| YxT | | * | * | * | * |

Means within a column followed by a similar letter(s) are not significantly different ($p \leq 0.05$); *significant at $p \leq 0.05$; MAP, month after planting; no, number; Atraz + s-met fb 2HW, Atrazine + s-metolachlor followed by two hoe-weeding

+ lactofen with indaziflam + isoxaflutole (91%) for broadleaf weeds (Table 4.28). The differences between clethodim + lactofen followed by indaziflam + isoxaflutole (95%) and control (98%) were not significant for grass weed control. Weedy-check plots had the highest significant weed dry weight (179.6 g/m$^2$) compared to other treated plots. Weed dry weight reductions relative to weedy-check in plots are as listed: hoe-weeded (89%); clethodim + lactofen followed by indaziflam + isoxaflutole (88%); trifloysulfuron-sodium followed by indaziflam + isoxaflutole and atrazine + s-metolachlor followed by two-times hoe-weeding (83%); carfentrazone-ethyl followed by indaziflam + isoxaflutole, (80%); clethodim + lactofen followed by flumioxazin + pyroxasulfone (75%); clethodim + lactofen followed by sulfentrazone (73%); trifloysulfuron-sodium followed by sulfentrazone and trifloysulfuron-sodium followed by flumioxazin + pyroxasulfone (63%); carfentrazone-ethyl followed by flumioxazin + pyroxasulfone (58%) and carfentrazone-ethyl followed by sulfentrazone (54%). Year effect revealed significantly lower weed dry weight and higher sedge control in 2017 than in the previous years while grass weed control was significantly lower in 2016 than in 2015 and 2017. Broadleaf weed control was not affected by year however, year by herbicide treatments was significant. Interaction between year and treatment on broadleaf, grass, sedge and weed dry weight is presented in Table 4.29. The least weed dry weight was recorded in plot of clethodim + lactofen / indaziflam + isoxaflutole in 2017. Weed control efficacy of broadleaf, grass and sedge in 2015, 2016 and 2017 by the herbicide treatments were trifloysulfuron-sodium (75, 80, 92%), (86,73, 90%) and (83, 72, 94%); clethodim + lactofen (97%), (89, 79, 94%) and (98, 96, 98%); carfentrazone-ethyl (76, 69, 93%), (82, 66, 93%) and (74, 69, 96%). Weed dry weight by: trifloysulfuron-sodium treated plot of 60g/ m$^2$ was higher in 2015 than 54 in 2016 and 49 in 2017; clethodim + lactofen was 46 (2015), 38 (2016) and 29 (2017): carfentrazone-ethyl was 65, 68 and 61 in 2015, 2016 and 2017 respectively.

### 4.3.7 Economic analysis of cassava production under post-pre application sequence

The MRR of the treatment combinations involving the selected pre- and post-emergence herbicides other than those involving sulfentrazone ranged from 726 to 1,332%. Those involving sulfentrazone ranged from 96 to 370% while those of the controls of three times hoe-weeding and atrazine + s-metolachlor followed by two hoe-weeding were 321 and 479% respectively (Table 4.30).

**Table 4.29: Year x herbicide treatments interaction on weed group (12 WAP) and weed dry weight at 14 WAP**

| Year | POST herbicides | PRE herbicides | Broadleaf | Grass | Sedge | Weed dry weight |
|---|---|---|---|---|---|---|
| | | | | % | | (g/ $m^2$) |
| 2015 | Trifloysulfuron-sodium | Sulfentrazone | 66e | 75d | 97a | 72.85bc |
| | | Flumioxazin + Pyroxasulfone | 67e | 73de | 90b | 68.97bc |
| | | Indaziflam + Isoxaflutole | 93b | 93ab | 88bc | 37.65de |
| | Clethodim+ Lactofen | Sulfentrazone | 96a | 97a | 98a | 56.4cd |
| | | Flumioxazin + Pyroxasulfone | 96a | 96ab | 97a | 55.78cd |
| | | Indaziflam + Isoxaflutole | 98a | 98a | 95ab | 26.75ef |
| | Carfentrazone-ethyl | Sulfentrazone | 67e | 58ef | 95ab | 79.4ab |
| | | Flumioxazin + Pyroxasulfone | 69de | 59ef | 94ab | 75.42b |
| | | Indaziflam + Isoxaflutole | 92bc | 91b | 90b | 39.95de |
| 2016 | Trifloysulfuron-sodium | Sulfentrazone | 78cd | 52f | 95ab | 66.87bc |
| | | Flumioxazin + Pyroxasulfone | 89bc | 79cd | 90b | 66.12bc |
| | | Indaziflam + Isoxaflutole | 91bc | 87bc | 85c | 27.98ef |
| | Clethodim+ Lactofen | Sulfentrazone | 82c | 68de | 98a | 47.25d |
| | | Flumioxazin + Pyroxasulfone | 93b | 79cd | 93b | 45.47d |
| | | Indaziflam + Isoxaflutole | 91bc | 89bc | 90b | 22.72ef |
| | Carfentrazone-ethyl | Sulfentrazone | 70de | 48f | 95ab | 88.87a |
| | | Flumioxazin + Pyroxasulfone | 86c | 66e | 92b | 80.37ab |
| | | Indaziflam + Isoxaflutole | 89bc | 83c | 90b | 33.97e |
| 2017 | Trifloysulfuron-sodium | Sulfentrazone | 78cd | 63e | 98a | 56.95cd |
| | | Flumioxazin + Pyroxasulfone | 75d | 61e | 95ab | 64.25c |
| | | Indaziflam + Isoxaflutole | 95ab | 92ab | 90b | 27.15ef |
| | Clethodim+ Lactofen | Sulfentrazone | 98a | 97a | 98a | 39.33de |
| | | Flumioxazin + Pyroxasulfone | 98a | 96ab | 98a | 33.15e |
| | | Indaziflam + Isoxaflutole | 98a | 96ab | 97a | 15.78f |
| | Carfentrazone-ethyl | Sulfentrazone | 62e | 58ef | 98a | 79.88ab |
| | | Flumioxazin + Pyroxasulfone | 67e | 59ef | 96a | 70.57bc |
| | | Indaziflam + Isoxaflutole | 92bc | 90bc | 95ab | 31.8e |

Means within a column followed by a similar letter(s) are not significantly different ($p \leq 0.05$).

**Table 4.30: Budget analysis for cassava production with the application of herbicides in sequence (post-pre) for weed control on 1-hectare land during 2015-2018 cropping year**

| Treatment combinations | Yield (t/ha) (Y) | Stem (t/ha) (ST) | Stem (bundles/ha) (STB) | Cost of weed control (₦) (CWC) | Total Variable Cost (₦) (TVC) | Total Gross Return (₦) (TGR) | Net Benefit (₦) (NB) | Marginal Rateof Return (%) (MRR) |
|---|---|---|---|---|---|---|---|---|
| Trifloysulfuron-sodium + Sulfentrazone | 18.98 | 6.22 | 247 | 22701 | 187701 | 548600 | 360899 | 219.8 |
| Clethodin-Lactofen + Sulfentrazone | 23.99 | 9.53 | 379 | 44842 | 209842 | 713450 | 503608 | 370.4 |
| Cafertrazone-ethyl + Sulfentrazone | 16.57 | 6.84 | 272 | 21263 | 186263 | 495850 | 309587 | 95.9 |
| Trifloysulfuron-sodium + Flumioxazin-Pyroxasulfone | 27.34 | 11.77 | 935 | 35861 | 200861 | 964000 | 763139 | 918.1 |
| Clethodin-Lactofen + Flumioxazin-Pyroxasulfone | 30.30 | 12.02 | 955 | 58002 | 223002 | 1044000 | 820998 | 725.8 |
| Cafertrazone-ethyl + Flumioxazin-Pyroxasulfone | 21.52 | 9.38 | 745 | 34423 | 199423 | 761500 | 562077 | 557.0 |
| Trifloysulfuron-sodium + Indaziflam-Isoxaflutole | 28.69 | 11.46 | 910 | 22245 | 187245 | 990250 | 803005 | 1331.9 |
| Clethodin-Lactofen + Indaziflam-Isoxaflutole | 28.69 | 11.22 | 891 | 44386 | 209386 | 984550 | 775164 | 811.3 |
| Cafertrazone-ethyl + Indaziflam-Isoxaflutole | 24.73 | 9.48 | 753 | 20807 | 185807 | 844150 | 658343 | 1005.1 |
| Atrazine-S-metolachlor + 2-Hoe-weeding | 27.96 | 11.92 | 947 | 117500 | 258500 | 983100 | 724600 | 479.5 |
| 3-Hoe-weeding | 29.44 | 12.1 | 961 | 150000 | 291000 | 1024300 | 733300 | 321.0 |
| Weedy | 13.86 | 7.67 | 244 | nil | 141000 | 419700 | 278700 | nil |

TVC= CWC + operational cost; TGR= Y × Farm Gate Price (FGP) of storage root + STB × FGP of bundle of stem; NB = TGR – TVC; where FGP cassava storage root = ₦25.000 and stem bundle = ₦300

## 4.4 Alternative sequence of application of pre- and post-emergence herbicides

### 4.4.1 Percentage estimate difference between pre-post and post-pre sequence of herbicide application

The estimated percentage of contrast between the two sequences of herbicide application is presented in Table 4.31 – 4.34. All the herbicides in a post-pre sequence had a significant greater number of sprouted cassava plants than in the pre-post sequence. Across the herbicides, the number of sprouted plants in the post-pre sequence was 5% significantly higher than pre-post. However, variations between the two sequences occurred with the herbicides. Estimate percentage of vigour score and plant height was significantly higher in pre-post sequence compared to post-pre across the herbicides and for each of the pre- and post-emergence herbicides except for plant height measured in sulfentrazone sprayed plots where post-pre sequence produced taller plants than in pre-post (Table 4.31). There was no significant difference between the two sequences of application for the number of plants however, the number of stems was 18% higher under pre-post sequence across the herbicides. Among the herbicides, sulfentrazone and carfentrazone-ethyl in a pre-post sequence had a significantly greater number of plants than in post-pre. Pre-post application sequence resulted in a significantly greater number of stems than in post-pre for some of the herbicides with a 61% estimate difference for sulfentrazone, 13% for trifloysulfuron-sodium, 11% for clethodim + lactofen and 23% for carfentrazone-ethyl (Table 4.32). In addition, for the weight of stem and storage root, there was no significant difference between the two sequences across the herbicides, however, the weight of top shoot in post-pre was 15% significantly higher than pre-post sequence. The post-pre application of sulfentrazone resulted in higher percentage of the top shoot, stem and storage root weight than in pre-post. However, pre-post application of carfentrazone-ethyl, indaziflam + isoxaflutole and flumioxazin + pyroxasulfone had significantly higher percentage of top shoot, stem weight and storage root weight than in post-pre sequence. However, application of clethodim + lactofen was not influenced by the two sequences (Table 4.33).

Effect of pre-post application sequence on broadleaf, sedge and grass weed control across the herbicides was significantly greater than in post-pre sequence. The estimate percentage difference of 13% for broadleaf, 23% for grass weed and 18% for sedge under pre-post was better than in

**Table 4.31: Contrast test of estimate of differences in cassava vigour, plant count and height at 12 WAP as influenced by the two sequences of application of the pre- and post-emergence herbicides**

| Sequence of herbicide application | | Plant count | | Vigour | | Height | |
|---|---|---|---|---|---|---|---|
| | | Estimate (%) | P-value | Estimate (%) | P-value | Estimate (%) | P-value |
| Pre-Post vs Post-Pre across the herbicides | | -5 | *<.0001* | 10 | *<.0001* | 9 | *<.0001* |
| Sulfentrazone1st/Sulfentrazone 2nd | Pre-Post vs Post-Pre | -5 | *0.0016* | 7 | *0.0085* | -10 | *0.0002* |
| Flumioxazin+Pyroxasulfone1st /Flumioxazin+Pyroxasulfone2nd | Pre-Post vs Post-Pre | -1 | *0.446* | 10 | *<.0001* | 20 | *<.0001* |
| Indaziflam+Isoxaflutole1st/Indaziflam+ Isoxaflutole 2nd | Pre-Post vs Post-Pre | -8 | *<.0001* | 12 | *<.0001* | 15 | *<.0001* |
| Trifloysulfuron-sodium1st/Trifloysulfuron-sodium 2nd | Post-pre vs pre-post | 6 | *0.0004* | -9 | *<.0001* | -6 | *0.0046* |
| Clethodim+Lactofen1st/Clethodim+Lactofen 2nd | Post-pre vs pre-post | 5 | *0.0025* | 0.4 | *0.8501* | -1 | *0.5567* |
| Carfentrazone-ethyl1st/Carfentrazone-ethyl 2nd | Post-pre vs pre-post | 4 | *0.0228* | -17 | *<.0001* | -16 | *<.0001* |

WAP, week after planting; pre-post, pre-herbicides application follow-up with post- herbicides; post-pre, post-herbicides application follow-up with pre-herbicides; vs, versus

**Table 4.32: Percentage estimate of differences between the two sequences of application of the pre- and post-emergence herbicides on number of plants and stems at 12 MAP**

| Sequence of herbicide application | | No of plants Estimate (%) | P-value | No of stems Estimate (%) | P-value |
|---|---|---|---|---|---|
| Pre-Post vs Post-Pre across the herbicides | | 2 | *0.2952* | 18 | *<.0001* |
| Sulfentrazone1st/Sulfentrazone 2nd | Pre-Post vs Post-Pre | 8 | *0.0433* | 61 | *<.0001* |
| Flumioxazin+Pyroxasulfone1st /Flumioxazin+Pyroxasulfone2nd | Pre-Post vs Post-Pre | 0.3 | *0.915* | 5 | *0.1811* |
| Indaziflam+Isoxaflutole1st/Indaziflam+Isoxaflutole 2nd | Pre-Post vs Post-Pre | -1 | *0.7488* | -6 | *0.1046* |
| Trifloysulfuron-sodium1st/Trifloysulfuron-sodium 2nd | Post-pre vs pre-post | 1 | *0.7488* | -13 | *<.0001* |
| Clethodim+Lactofen1st/Clethodim+Lactofen 2nd | Post-pre vs pre-post | 1 | *0.6694* | -11 | *0.001* |
| Carfentrazone-ethyl1st/Carfentrazone-ethyl 2nd | Post-pre vs pre-post | -9 | *0.008* | -23 | *<.0001* |

WAP, week after planting; pre-post, pre-herbicides application follow-up with post- herbicides; post-pre, post-herbicides application follow-up with pre-herbicides; vs, versus

**Table 4.33: Contrast test of estimate of the differences between the two sequences of application of the pre- and post-emergence herbicides on weight of top shoot, stem and storage root weight at 12 MAP**

| Sequence of herbicide application | | Weight of top shoot Estimate (%) | P-value | Weight of stem Estimate (%) | P-value | Weight storage root Estimate (%) | P-value |
|---|---|---|---|---|---|---|---|
| Pre-Post vs Post-Pre across the herbicides | | -15 | *<.0001* | 5 | *0.2021* | 1 | *0.7718* |
| Sulfentrazone1st/Sulfentrazone 2nd | Pre-Post vs Post-Pre | -40 | *<.0001* | -29 | *0.0006* | -36 | *<.0001* |
| Flumioxazin+Pyroxasulfone1st /Flumioxazin+Pyroxasulfone2nd | Pre-Post vs Post-Pre | -7 | *0.2422* | 10 | *0.0868* | 12 | *0.0335* |
| Indaziflam+Isoxaflutole1st/Indaziflam+Isoxaflutole 2nd | Pre-Post vs Post-Pre | -2 | *0.7001* | 24 | *<.0001* | 17 | *0.0029* |
| Trifloysulfuron-sodium1st /Trifloysulfuron-sodium 2nd | Post-pre vs pre-post | 19 | *0.01* | 6 | *0.306* | 11 | *0.0669* |
| Clethodim+Lactofen1st/Clethodim+ Lactofen 2nd | Post-pre vs pre-post | 9 | *0.1699* | -10 | *0.1246* | -1 | *0.919* |
| Carfentrazone-ethyl1st/Carfentrazone-ethyl 2nd | Post-pre vs pre-post | 29 | *0.0003* | -17 | *0.0074* | -17 | *0.0069* |

WAP, week after planting; pre-post, pre-herbicides application follow-up with post- herbicides; post-pre, post-herbicides application follow-up with pre-herbicides; vs, versus

post-pre (Table 4.34). All the pre- and post-emergence herbicides gave significantly higher control of all the weed groups under pre-post sequence of application except indaziflam + isoxaflutole and clethodim + lactofen. The percentage difference ranged from 15 to 38%. For indaziflam + isoxaflutole and clethodim + lactofen, the difference ranged from 3 to 7% (Table 4.34).

#### 4.4.2 Plant count, vigour score and plant height as influenced by application sequences

Plant count, vigour score, and height as influenced by the herbicide application sequences are presented in Table 4.35.

Pre- and post-emergence herbicide combinations involving sulfentrazone and trifloysulfuron-sodium resulted in 5.5% more plants in post-pre sequence than in pre-post arrangement, however, the difference was not significant. The same trend was observed for combining sulfentrazone and clethodim + lactofen or indaziflam + isoxaflutole and carfentrazone-ethyl combinations with 6.1% and 4.9% respectively more plants in post-pre sequence than in the pre-post sequence of application. However, the 16.6% difference for post-pre arrangement in the combination involving indaziflam + isoxaflutole and trifloysulfuron-sodium was significant over the pre-post arrangement. A similar number of plants/ha was recorded for herbicide combinations in pre-post and post-pre orders for combination involving flumioxazin + pyroxasulfone and trifloysulfuron-sodium, flumioxazin + pyroxasulfone and clethodim + lactofen or sulfentrazone and carfentrazone-ethyl as well as indaziflam + isoxaflutole and carfentrazone-ethyl. Cassava plants treated with flumioxazin + pyroxasulfone / trifloysulfuron-sodium and flumioxazin + pyroxasulfone / carfenrazone-ethyl recorded the highest number of plants in the pre-post. Both treatments were significantly higher than indaziflam + isoxaflutole / trifloysulfuron-sodium and indaziflam + isoxaflutole / clethodim + lactofen. In the post-pre treatments, highest plant count was obtained in clethodim + lactofen / sulfentrazone, however, this differed not significantly from other treatments. (Table 4.35).

Cassava vigour score was significantly higher in flumioxazin + pyroxasulfone treated plots irrespective of the post treatments and in plots with indaziflam + isoxaflutole / carfentrazone-ethyl than sulfentrazone irrespective of the post treatments. Vigour score was significantly influenced by pre-post and post- pre sequence of applications for

**Table 4.34: Contrast test of estimate of the differences between the two sequences of application of the pre- and post-emergence herbicides on broadleaf, grass, sedge and TWC at 12 WAP**

| | | Broadleaf | | Grass | | Sedge | | TWC | |
|---|---|---|---|---|---|---|---|---|---|
| Sequence of application | | Estimate (%) | P-value | Estimate (%) | P-value | Estimate (%) | P-value | Estimate (%) | P-value |
| Pre-Post vs Post-Pre across the herbicides | | 13 | <.0001 | 23 | *<.0001* | 18 | *<.0001* | 23 | *<.0001* |
| Sulfentrazone1st/Sulfentrazone 2nd | Pre-Post vs Post-Pre | 19 | <.0001 | 38 | *<.0001* | 26 | *<.0001* | 38 | *<.0001* |
| Flumioxazin+Pyroxasulfone1st /Flumioxazin+Pyroxasulfone 2nd | Pre-Post vs Post-Pre | 15 | <.0001 | 29 | *<.0001* | 21 | *<.0001* | 29 | *<.0001* |
| Indaziflam+Isoxaflutole1st/Indaziflam +Isoxaflutole 2nd | Pre-Post vs Post-Pre | 5 | 0.2985 | 7 | 0.3421 | 6 | 0.3321 | 7 | 0.3421 |
| Trifloysulfuron-sodium1st/Trifloysulfuron-sodium 2nd | Post-pre vs pre-post | -16 | <.0001 | -22 | *<.0001* | -22 | *<.0001* | -22 | *<.0001* |
| Clethodim+Lactofen1st/Clethodim+Lactofen 2nd | Post-pre vs pre-post | -3 | 0.4646 | -6 | 0.4377 | -6 | 0.3493 | -6 | 0.4377 |
| Carfentrazone-ethyl1st/Carfentrazone-ethyl 2nd | Post-pre vs pre-post | -19 | <.0001 | -28 | *<.0001* | -26 | *<.0001* | -28 | *<.0001* |

WAP, week after planting; pre-post, pre-herbicides application follow-up with post- herbicides; post-pre, post-herbicides application follow-up with pre-herbicides; vs, versus

**Table 4.35: Comparison of the two sequences of pre- and post-emergence herbicide applications on cassava plants count (plants/ha), vigour and height at 12 WAP**

| **Herbicides** | Plant count | Vigour | Height (cm) |
|---|---|---|---|
| Pre-post | | | |
| Sulfentrazone / Trifloysulfuron-sodium | 11521ab | 4.44bc | 101.4c |
| Sulfentrazone / Clethodim + Lactofen | 11604ab | 4.11c | 108.9c |
| Sulfentrazone /Carfentrazone-ethyl | 11521ab | 4.22bc | 106.4c |
| Flumioxazin+Pyroxasulfone/Trifloysulfuron-sodium | 12196a | 4.78ab | 133.8ab |
| Flumioxazin+ Pyroxasulfone / Clethodim + Lactofen | 11604ab | 5. 0a | 133.6ab |
| Flumioxazin+ Pyroxasulfone /Carfentrazone-ethyl | 12196a | 5. 0a | 139.8a |
| Indaziflam + Isoxaflutole/ Trifloysulfuron-sodium | 10179b | 5. 0a | 135.6ab |
| Indaziflam + Isoxaflutole/ Clethodim + Lactofen | 10980b | 4.78ab | 143.1a |
| Indaziflam + Isoxaflutole/Carfentrazone-ethyl | 11604ab | 5. 0a | 130.2ab |
| Post-pre | | | |
| Trifloysulfuron-sodium / Sulfentrazone | 12196a | 4.11c | 106.7c |
| Trifloysulfuron-sodium/Flumioxazin+ Pyroxasulfone | 12196a | 4.89ab | 123.4b |
| Trifloysulfuron-sodium / Indaziflam + Isoxaflutole | 12196a | 4.89ab | 124.3b |
| Clethodim + Lactofen / Sulfentrazone | 12357a | 4.56b | 122.8b |
| Clethodim + Lactofen / Flumioxazin+ Pyroxasulfone | 11896ab | 4.89ab | 134.3ab |
| Clethodim + Lactofen / Indaziflam + Isoxaflutole | 11896ab | 5. 0a | 136.1ab |
| Carfentrazone-ethyl / Sulfentrazone | 11757ab | 3.89c | 105.2c |
| Carfentrazone-ethyl / Flumioxazin+ Pyroxasulfone | 12196a | 4.56b | 131.2ab |
| Carfentrazone-ethyl / Indaziflam + Isoxaflutole | 12196a | 4.56b | 124.9b |
| **Year** | | | |
| 2016 | 12308 | 4.46 | 122.9 |
| 2017 | 12408 | 4.56 | 120.9 |
| Y x T | * | * | ns |

Means within a column followed by a similar letter(s) are not significantly different ($p \leq 0.05$); *significant at $p \leq 0.05$; ns, not significant; WAP, week after planting sulfentrazone supplemented with clethodim + lactofen, flumioxazin + pyroxasulfone supplemented with carfentrazone-ethyl and indaziflam + isoxaflutole supplemented with carfentrazone-ethyl. There was no significant difference in vigour score between the two sequences for the rest of the herbicide combinations. Vigour score in indaziflam + isoxaflutole supplemented with trifloysulfuron-sodium treated plots among the herbicide treatment combinations was significantly higher than carfentrazone-ethyl supplemented with flumioxazine + pyroxasulfone and carfentrazone-ethyl supplemented with indaziflam + isoxaflutole which in turn was significantly greater than the plant vigour of sulfentrazone supplemented with clethodim + lactofen, carfentrazone-ethyl. Pre-post application sequence on plant height was not significantly higher than post-pre sequence Table 4.35. Plant height of cassava treated with indaziflam + isoxaflutole supplemented with clethodim + lactofen and flumioxazin + pyroxasulfone supplemented with carfentrazone-ethyl was significantly higher than the cassava plant height in carfentrazone-ethyl supplemented indaziflam + isoxaflutole, clethodim +lactofen supplemented with sulfentrazone, trifloysulfuron-sodium supplemented with indaziflam + isoxaflutole and trifloysulfuron-sodium supplemented with flumioxazin + pyroxasulfone which in turn was significantly higher than plant height in sulfentrazone supplemented with trifloysulfuron-sodium, trifloysulfuron-sodium supplemented with sulfentrazone, sulfentrazone supplemented with clethodim + lactofen, sulfentrazone supplemented with carfentrazone-ethyl, carfentrazone-ethyl supplemented with sulfentrazone. The year by herbicide treatment combinations was significant for plant count and vigour score except plant height (Table 4.35).

Interaction between year and treatment is presented in Table 4.36. In 2017, plants count in sulfentrazone supplemented with trifloysulfuron-sodium, indaziflam + isoxaflutole, and trifloysulfuron-sodium, indaziflam + isoxaflutole with carfentrazone-ethyl, sulfentrazone with carfentrazone-ethyl, and sulfentrazone followed by clethodim + lactofen treated plots was significantly higher than in 2016. There was a significantly higher number of plants in 2016 than in 2017 when indaziflam + isoxaflutole was supplemented with clethodim + lactofen. Vigour score in 2017 was significantly higher than in 2016 when sulfentrazone was followed with carfentrazone-ethyl.

**Table 4.36: Comparison of the two sequences of pre- and post-emergence herbicide application on cassava plants, vigour at 12 WAP in two years**

| | 2016 | 2017 | 2016 | 2017 |
|---|---|---|---|---|
| **Herbicides** | Plant count | | Vigour | |
| Pre-post | | | | |
| Sulfentrazone / Trifloysulfuron-sodium | 11604b | 12500a | 4.33ab | 4.33ab |
| Sulfentrazone / Clethodim + Lactofen | 11604b | 12500a | 3.97b | 4.67ab |
| Sulfentrazone /Carfentrazone-ethyl | 11604b | 12500a | 4.00b | 5.00a |
| Flumioxazin+Pyroxasulfone/Trifloysulfuron-sodium | 12500a | 12500a | 4.67ab | 5.00a |
| Flumioxazin+ Pyroxasulfone / Clethodim + Lactofen | 12500a | 12500a | 5.00a | 5.00a |
| Flumioxazin+ Pyroxasulfone /Carfentrazone-ethyl | 12500a | 12500a | 5.00a | 5.00a |
| Indaziflam + Isoxaflutole/ Trifloysulfuron-sodium | 10000c | 11604b | 5.00a | 5.00a |
| Indaziflam + Isoxaflutole/ Clethodim + Lactofen | 12500a | 11652b | 5.00a | 5.00a |
| Indaziflam + Isoxaflutole/Carfentrazone-ethyl | 11604b | 12500a | 5.00a | 5.00a |
| Post-pre | | | | |
| Trifloysulfuron-sodium / Sulfentrazone | 12500a | 12500a | 4.00b | 4.00b |
| Trifloysulfuron-sodium/Flumioxazin+ Pyroxasulfone | 12500a | 12500a | 5.00a | 4.67ab |
| Trifloysulfuron-sodium / Indaziflam + Isoxaflutole | 12500a | 12500a | 5.00a | 4.67ab |
| Clethodim + Lactofen / Sulfentrazone | 12500a | 12070ab | 4.33ab | 5.00a |
| Clethodim + Lactofen / Flumioxazin+ Pyroxasulfone | 12500a | 12500a | 5.00a | 4.67ab |
| Clethodim + Lactofen / Indaziflam + Isoxaflutole | 12500a | 12500a | 5.00a | 4.67ab |
| Carfentrazone-ethyl / Sulfentrazone | 12500a | 12070ab | 4.00b | 3.67b |
| Carfentrazone-ethyl / Flumioxazin+ Pyroxasulfone | 12500a | 12500a | 4.67ab | 4.33ab |
| Carfentrazone-ethyl / Indaziflam + Isoxaflutole | 12500a | 12500a | 4.67ab | 4.33ab |

Means within a column followed by a similar letter(s) are not significantly different ($p \leq 0.05$); WAP, week after planting; pre, pre-emergence; post, post-emergence

### 4.4.3 The influence of the two sequences of application of the pre- and post-emergence herbicides on yield and yield components of cassava

The highest number of plant was recorded in combination of flumioxazin + pyroxasulfone / carfentrazone-ethyl and clethodim + lactofen / indaziflam + isoxaflutole, however, there was no significant difference with some of the treatments. A significantly higher number of stems was produced in pre-post sequence than in post-pre for combination involving trifloysulfuron-sodium and sulfentrazone, clethodim + lactofen sulfentrazone, sulfentrazone and carfentrazone-ethyl (Table 4.37). Conversely, there was a significant higher weight of top shoot in post-pre than in pre- post sequence with the highest in clethodim + lactofen / sulfentrazone. Stem weight was 60% higher in the post-pre application of clethodim + lactofen and sulfentrazone than in the pre-post sequence. However, stem weight in pre-post sequence of application of indaziflam + isoxaflutole and carfentrazone-ethyl was 31% higher than in the post-pre sequence. The other herbicide combinations did not show significant differences between the two sequences although results were higher in the pre-post application sequence. Although cassava storage root weight was highest in indaziflam + isoxaflutole / clethodim + lactofen most of the herbicide combinations in the pre-post sequence gave higher weight of storage root. Storage root and top shoot weight were significantly greater in 2017 than in 2016. Year by treatment interaction was not significant.

### 4.4.4 Effect of the two sequences of application of the pre- and post-emergence herbicides on broadleaf weeds, grass and sedge

Except for the combinations of clethodim + lactofen and indaziflam + isoxaflutole, and flumioxazin + pyroxasulfone and clethodim +lactofen, whose application sequences had no significant influence on broadleaf and grass weed control efficacies, pre-post herbicide application sequences gave significantly higher grass and broadleaf weed suppression than post-pre application (Table 4.38). There was no difference in the sequence of application on sedge control. Broadleaf and grass weed control were significantly higher in 2016 than in 2017. Year by treatment interaction was significant for broadleaf and grass weeds. The effect of interaction between year and herbicide treatments on broadleaf and grass weeds is presented in Table 4.39. Trifloysulfuron-sodium and flumioxazin + pyroxasulfone, carfentrazone-ethyl and flumioxazin combinations in post-pre application sequence significantly suppressed weeds in 2016

**Table 4.37: Yield and yield components of cassava at 12 MAP as influenced by the two sequences of pre- and post-emergence herbicides application**

| | (count /ha) | | (tonnes /ha) | | |
|---|---|---|---|---|---|
| **Treatments (T)** | Plant | Stem | Top shoot | Stem | Storage root |
| Pre-post | | | | | |
| Sulfentrazone / Trifloysulfuron-sodium | 9215b | 27990a | 2.1b | 4.51cd | 12.57c |
| Sulfentrazone / Clethodim + Lactofen | 9710ab | 25171a | 1.62b | 4.32d | 14.75c |
| Sulfentrazone /Carfentrazone-ethyl | 11194ab | 29201a | 2.15b | 4.6cd | 14.6c |
| Flumioxazin+Pyroxasulfone/Trifloysulfuron-sodium | 10411ab | 19165bc | 3.75a | 12.79ab | 29.06ab |
| Flumioxazin+ Pyroxasulfone / Clethodim + Lactofen | 10278ab | 19387b | 2.94ab | 10.91b | 28.58ab |
| Flumioxazin+ Pyroxasulfone /Carfentrazone-ethyl | 11476a | 19085bc | 3.8a | 12.37ab | 28.56ab |
| Indaziflam + Isoxaflutole/ Trifloysulfuron-sodium | 10750ab | 18557bc | 3.74a | 12.12ab | 29.46ab |
| Indaziflam + Isoxaflutole/ Clethodim + Lactofen | 10703ab | 19324bc | 3.7a | 13.59ab | 34.92a |
| Indaziflam + Isoxaflutole/Carfentrazone-ethyl | 10534ab | 17382bc | 3.73a | 14.64a | 30.13ab |
| Post-pre | | | | | |
| Trifloysulfuron-sodium / Sulfentrazone | 10202ab | 19638b | 3.41a | 7.54c | 19.68c |
| Trifloysulfuron-sodium/Flumioxazin+ Pyroxasulfone | 11020ab | 18471bc | 3.48a | 10.79b | 22.73bc |
| Trifloysulfuron-sodium / Indaziflam + Isoxaflutole | 10202ab | 19661b | 3.87a | 11.78ab | 29.23ab |
| Clethodim + Lactofen / Sulfentrazone | 10534ab | 19480b | 3.89a | 10.74b | 19.94c |
| Clethodim + Lactofen / Flumioxazin+ Pyroxasulfone | 11424a | 19151bc | 3.28a | 12.33ab | 29.72ab |
| Clethodim + Lactofen / Indaziflam + Isoxaflutole | 10578ab | 20235b | 3.36a | 12.2ab | 30.34ab |
| Carfentrazone-ethyl / Sulfentrazone | 9515ab | 14464c | 3.62a | 8.69bc | 17.96c |
| Carfentrazone-ethyl / Flumioxazin+ Pyroxasulfone | 9641ab | 15241c | 3.8a | 10.36bc | 23.01bc |
| Carfentrazone-ethyl / Indaziflam + Isoxaflutole | 10202ab | 15823c | 3.29a | 9.85bc | 27.04b |
| **Year (Y)** | | | | | |
| 2016 | 10678a | 18876a | 2.87b | 11.12a | 23.96b |
| 2017 | 11625a | 18218a | 4.87a | 9.61a | 29.27a |
| Y x T | Ns | ns | ns | ns | ns |

Means with in a column followed by a similar letter(s) are not significantly different ($p \leq 0.05$); *significant at $p \leq 0.05$; ns, not significant; MAP, month after planting; pre, pre-emergence; post, post-emergence

**Table 4.38: Effect of the two sequences of pre- and post-emergence herbicide application on broadleaf, grass and sedge at 12 WAP**

| **Treatments** | Broad leaf | Grass | Sedges |
|---|---|---|---|
| | | % | |
| Pre-post | | | |
| Sulfentrazone / Trifloysulfuron-sodium | 97a | 95ab | 97ab |
| Sulfentrazone / Clethodim + Lactofen | 98a | 97a | 98a |
| Sulfentrazone /Carfentrazone-ethyl | 95ab | 90b | 97ab |
| Flumioxazin+Pyroxasulfone/Trifloysulfuron-sodium | 97a | 96ab | 98a |
| Flumioxazin+ Pyroxasulfone / Clethodim + Lactofen | 97a | 97a | 97ab |
| Flumioxazin+ Pyroxasulfone /Carfentrazone-ethyl | 96ab | 93ab | 96ab |
| Indaziflam + Isoxaflutole/ Trifloysulfuron-sodium | 98a | 97a | 98a |
| Indaziflam + Isoxaflutole/ Clethodim + Lactofen | 98a | 98a | 98a |
| Indaziflam + Isoxaflutole/Carfentrazone-ethyl | 98a | 97a | 98a |
| Post-pre | | | |
| Trifloysulfuron-sodium / Sulfentrazone | 74c | 63d | 94ab |
| Trifloysulfuron-sodium/Flumioxazin+ Pyroxasulfone | 77c | 71c | 94ab |
| Trifloysulfuron-sodium / Indaziflam + Isoxaflutole | 93b | 91b | 96ab |
| Clethodim + Lactofen / Sulfentrazone | 92b | 88b | 94ab |
| Clethodim + Lactofen / Flumioxazin+ Pyroxasulfone | 95ab | 94ab | 97ab |
| Clethodim + Lactofen / Indaziflam + Isoxaflutole | 96ab | 95ab | 96ab |
| Carfentrazone-ethyl / Sulfentrazone | 66d | 57d | 93b |
| Carfentrazone-ethyl / Flumioxazin+ Pyroxasulfone | 74c | 59d | 91b |
| Carfentrazone-ethyl / Indaziflam + Isoxaflutole | 91b | 88b | 97ab |
| **Year** | | | |
| 2016 | 83b | 70b | 85b |
| 2017 | 88a | 86a | 94a |
| Y x T | * | * | ns |

Means within a column followed by a similar letter(s) are not significantly different ($p \leq 0.05$); *significant at $p \leq 0.05$; ns, not significant; WAP, week after planting; pre, pre-emergence; post, post-emergence

**Table 4.39: Weed control efficacy on broadleaf and grass at 12 WAP as influenced by the two sequences of pre- and post-emergence herbicide application**

| **Treatments** | 2016 | 2017 | 2016 | 2017 |
|---|---|---|---|---|
| | Broadleaf % | | Grasses % | |
| Pre-post | | | | |
| Sulfentrazone / Trifloysulfuron-sodium | 95ab | 98a | 88b | 98a |
| Sulfentrazone / Clethodim + Lactofen | 97a | 98a | 95ab | 98a |
| Sulfentrazone /Carfentrazone-ethyl | 92ab | 98a | 77c | 98a |
| Flumioxazin+Pyroxasulfone/Trifloysulfuron-sodium | 96ab | 98a | 93ab | 98a |
| Flumioxazin+ Pyroxasulfone / Clethodim + Lactofen | 95ab | 98a | 95ab | 98a |
| Flumioxazin+ Pyroxasulfone /Carfentrazone-ethyl | 93ab | 98a | 85bc | 98a |
| Indaziflam + Isoxaflutole/ Trifloysulfuron-sodium | 97a | 98a | 96ab | 98a |
| Indaziflam + Isoxaflutole/ Clethodim + Lactofen | 97a | 98a | 97a | 98a |
| Indaziflam + Isoxaflutole/Carfentrazone-ethyl | 97a | 98a | 96ab | 98a |
| Post-pre | | | | |
| Trifloysulfuron-sodium / Sulfentrazone | 78cd | 78cd | 50e | 63d |
| Trifloysulfuron-sodium/Flumioxazin+ Pyroxasulfone | 89b | 75d | 78c | 62d |
| Trifloysulfuron-sodium / Indaziflam + Isoxaflutole | 91b | 95ab | 88b | 92ab |
| Clethodim + Lactofen / Sulfentrazone | 82c | 98a | 70cd | 98a |
| Clethodim + Lactofen / Flumioxazin+ Pyroxasulfone | 93ab | 98a | 82bc | 95ab |
| Clethodim + Lactofen / Indaziflam + Isoxaflutole | 91b | 98a | 92ab | 95ab |
| Carfentrazone-ethyl / Sulfentrazone | 70de | 62e | 50e | 63d |
| Carfentrazone-ethyl / Flumioxazin+ Pyroxasulfone | 86bc | 67e | 62d | 60de |
| Carfentrazone-ethyl / Indaziflam + Isoxaflutole | 89b | 92ab | 83bc | 90ab |

Means within a column followed by a similar letter(s) are not significantly different ($p \leq 0.05$); WAP, week after planting; pre-post; pre- followed by post-emergence; post-pre; post followed by pre-emergence herbicide than in 2017 while application of clethodim + lactofen irrespective of the pre-treatments gave significantly higher control of broadleaf weeds in 2017 than in 2016.

### 4.4.5 Weed control efficiency of selected herbicides under pre-post and post-pre sequence of application

Weed control efficiency of herbicides as influenced by application sequences is presented in Table 4.40. Pre-post sequence had higher weed control efficiency in all the herbicide combinations. Weed control efficiency ranged from 66 to 82% in pre-post and 44 to 78% in post-pre. The difference in weed control efficiency between the two sequences was greater in sulfentrazone and trifloysulfuron-sodium (20%) and least in combination of indaziflam + isoxaflutole and clethodim + lactofen (4%).

**Table 4.40: Weed control efficiency (at 14 WAP) of the two sequences of application of the pre- and post-emergence herbicides**

| **Pre post** | WCE (%) | **Post pre** | WCE (%) |
|---|---|---|---|
| Sulfentrazone / Trifloysulfuron-sodium | 78 | Trifloysulfuron-sodium / Sulfentrazone | 53 |
| Flumioxazin+Pyroxasulfone / Trifloysulfuron-sodium | 77 | Trifloysulfuron-sodium / Flumioxazin+Pyroxasulfone | 53 |
| Indaziflam+Isoxaflutole/ Trifloysulfuron-sodium | 81 | Trifloysulfuron-sodium / Indaziflam+Isoxaflutole | 73 |
| Sulfentrazone / Clethodim + Lactofen | 80 | Clethodim + Lactofen / Sulfentrazone | 65 |
| Flumioxazin+Pyroxasulfone / Clethodim + Lactofen | 79 | Clethodim + Lactofen / Flumioxazin+Pyroxasulfone | 65 |
| Indaziflam+Isoxaflutole/ Clethodim + Lactofen | 82 | Clethodim + Lactofen / Indaziflam+Isoxaflutole | 78 |
| Sulfentrazone /Carfentrazone-ethyl | 66 | Carfentrazone-ethyl / Sulfentrazone | 44 |
| Flumioxazin+Pyroxasulfone /Carfentrazone-ethyl | 70 | Carfentrazone-ethyl / Flumioxazin+Pyroxasulfone | 48 |
| Indaziflam+Isoxaflutole/Carfentrazone-ethyl | 80 | Carfentrazone-ethyl / Indaziflam+Isoxaflutole | 70 |

WAP, week after planting; pre, pre-emergence; post, post-emergence; fb, followed by; WCE, weed control efficiency

# CHAPTER 5
# DISCUSSION

The effect of pre-emergence herbicides on cassava plants was not the same. There was an early crop establishment with atrazine + s-metolachlor, and flumioxazin + pyroxasulfone while indaziflam + isoxaflutole persistently delayed sprouting of cassava all the years of investigation. Moyo *et al.* (2012) reported that s-metolachlor and triazine among other active ingredients evaluated on cassava did not affect crop establishment. Since the common practice among farmers to manage weeds in cassava cultivation is either to weed cassava farms three times or to apply a one-time pre-emergence herbicide in subsequent with a two-time hoe-weeding before the crop reached maturity period, atrazine + s-metolachlor followed by two-time hoe-weeding and three-time hoe-weeding were used as a standard check in this experiment (Agahiu *et al.*, 2012; Quee *et al.*, 2016). Cassava tolerated flumioxazin + pyroxasulfone better as vigour score reported was not different from what was obtained in standard plots (atrazine + S-metolachlor followed by 2-times hoe-weeding and three-times hoe-weeding). Pyroxasulfone as one of the active ingredients could not be easily taken in by cassava roots because, as Shaner (2014) observed, it could not leach into the soil due to its relatively low water solubility. Sulfentrazone applied at 0.6 kg/ha injured cassava plants with significant reduction in vigour and height. This result corroborates earlier submission that sulfentrazone could easily be absorbed by cassava plant roots as reported by Rodrigues and Almeida (2011) and Costa *et al.* (2015) due to its high solubility and mobility.

Early application of post-emergence herbicides on two weeks old cassava plants resulted in significant injury under the broadcast spray method. Although these herbicides did not kill sprouted cassava plants, they affected their vigour. Injury caused to cassava plants of two weeks old under broadcast spray method ranged from 19 to 92% with the record of 92% by carfentrazone-ethyl, 55% by trifloysulfuron-sodium and 19% by clethodim + lactofen respectively. In addition, findings in this study established the fact that the post-emergence herbicides did not significantly affect sprouted cassava plants but caused a varying amount of injury. Carfentrazone-ethyl was introduced for control of broadleaf weeds. However, it was not selective to cassava in a broadcast application.

Although it did not kill the stem, it burned cassava leaves completely. Banded application of trifloysulfuron-sodium was selective to cassava with only 7.7% injury but in broadcast spray injury was as high as 57.4%. Other authors reported that trifloysulfuron-sodium applied at 2 to 4 true leaf stage caused injury from 6 to 67%, while applications made after the fourth true leaf stage resulted in injury ranging from 0 to 24% and no visual symptom at 3 to 4 weeks after treatment (Richardson, 2006, 2007). According to Boyd and Dittmar (2018), applying trifloysulfuron-sodium to the bottom of a tomato crop did not result in crop harm. Trifloysulfuron-sodium caused the shrinking of cassava apical stem nodes in broadcast applications. O´Berry *et al.* (2008) reported that although trifloysulfuron-sodium did not influence cotton height but it affected its apical main stem nodes.

Ekeleme *et al.* (2016) noticed that trifloysulfuron-sodium at 0.052 kg/ha injured the cassava plant. Interaction between spray methods and treatments signifies that cassava performed better with banded spray method of application. This was confirmed with 92% injury scored for carfentrazone-ethyl in broadcast spray in contrast to 8% injury score recorded in the banded application. Effect of supplemental application of pre-emergence herbicides at 4-5 WAP observed at four and eight weeks later revealed that the combination of post- and pre-emergence herbicides in a post-pre arrangement did not negatively influence the number of sprouted cassava plants. However, plant vigour and height were affected. It was ascertained that sulfentrazone reduced the vigorous growth of cassava; hence, combination of sulfentrazone with non-selective post-emergence herbicides increased the injury on cassava plants. Such herbicide combinations included carfentrazone-ethyl followed by sulfentrazone and trifloysulfuron-sodium followed by sulfentrazone. Treatment arrangements such as clethodim + lactofen followed by flumioxazin + pyroxasulfone, trifloysulfuron-sodium followed by flumioxazin + pyroxasulfone, clethodim + lactofen followed by indaziflam + isoxaflutole, trifloysulfuron-sodium followed by indaziflam + isoxaflutole and clethodim + lactofen followed by sulfentrazone produced results that were similar to three-time hoe-weeding and atrazine + s-metolachlor followed by two times hoe-weeding. Plants under sulfentrazone combinations could not express their maximum performance as a result of injury they received earlier. Consequently, the yield and yield components were affected. Fresh storage root yield was higher in combinations that included indaziflam + isoxaflutole and flumioxazin + pyroxasulfone as pre-emergence herbicides and each supplemented with any of the post-emergence herbicides. The former probably was as a result of its excellent weed control as it gave longer residual control even though it delayed sprouting. At the same time, the latter seemed to be well tolerated by cassava plants. Root fresh weight measured 32.86 t/ha in plots treated with indaziflam + isoxaflutole followed by clethodim + lactofen at 12 MAP, which was higher than the yield from the hoe-weeded plot (30.54 t/ha) however, this was not statically significant. This level of storage root yield harvested was already reported by Dixon (2015), who opined that among other factors, appropriate weed management could increase national cassava yield from 12-13 t/ha to 20-39 t /ha. It was also reported by other authors that yield of more than 25 t /ha was achieved in Nigeria on research plots while yield that ranged from 20 to greater than 35% are being recorded in Asian and Caribbean countries (Ekeleme *et al*., 2016). Despite the fact that indaziflam + isoxaflutole delayed sprouting, all of its pairings with any of the selected post-emergence herbicides at harvest yielded results that were not significantly different from those in standard plots. This finding revealed that indaziflam + isoxaflutole would not cause the death of young cassava stems. Hence, the active ingredients in flumioxazin + pyroxasulfone and indaziflam + isoxaflutole could be safely used in cassava (Biffe *et al.* 2010; Santiago 2018).

Although, the broadcast application of post-emergence herbicides injured cassava plants and reduced their vigour at the early period after treatment application, the spray method did not significantly affect yield at 12 MAP. Uremis *et al.* (2004) in their studies on different herbicide application methods in the second-crop maize field reported that banding was as effective as a broadcast application on crop yield. More studies revealed that band application gave similar maize and soya-bean yield and gross return to the broadcast spray method (Swanton *et al.*, 2002). These are especially true with selective herbicides. However, with herbicides that are perceived as non-selective in some crops, as observed in this study, the cassava plants were able to revived after being injured by some of the post-emergence herbicides, hence the high yields of cassava treated with the post-emergence broadcast spray of trifloysulfuron-sodium and clethodim + lactofen. The only issue is that farmers will not be able to withstand the sight of their plants being injured by the broadcast spray. Costa (2013) affirmed that there could be crop recovery after herbicide application due to weather conditions. However, the combination involving broadcast a spray of carfentrazone-ethyl following pre-emergence spray of sulfentrazone caused high storage root yield reduction and should not be considered. This was because both herbicides respectively reduced cassava growth when applied post- and pre-emergence respectively. Carfentrazone-ethyl in the broadcast spray was found non-selective to cassava. The shoot part of plants was severely injured, especially the leaves, and this could consequently influence storage root. Viana *et al.* (2001) and Filho *et al.* (2018) stated that reduced shoot growth leads to a reduction in photosynthetic tissue, which has an impact on glucose buildup in the roots and, as a result, crop yield. Filho *et al.* (2018) affirmed that carfentrazone-ethyl had been reported to cause a higher reduction in root dry matter of cassava.

It was observed that storage root yield from the post-pre application of clethodim + lactofen followed by flumioxazin + pyroxasulfone, trifloysulfuron-sodium followed by indaziflam + isoxaflutole, clethodim + lactofen followed by indaziflam + isoxaflutole and trifloysulfuron-sodium followed by flumioxazin + pyroxasulfone treated plots was comparable to three-time hoe-weeding except in broadcast application of carfentrazone-ethyl as well as sulfentrazone combinations. This suggested that both carfentrazone-ethyl and sulfentrazone may not be suitable for use in cassava however the former is tolerated when sprayed banded.

Although sulfentrazone increased the number of tiny stems, there was no corresponding rise in the weight of fresh root, as the number of stems had a poor correlation with storage root weight. However, an increase in stem weight could significantly influence top shoot weight, and root weight positively, as it was observed among the pre-emergence herbicides.

The higher weeds suppression by the herbicide treatments in 20I7 than in the previous years could be as a result of weed species present (Scariot *et al.,* 2013). The most common weeds present on experimental plots included *Euphorbia heterophylla*, *Euphorbia hirta*, *Calopogonium mucunoides*, *Tridax procumbens*, *Spermacoce vertillata*, *Mitracarpus villosus*, *Panicum maximum*, *Cynodon dactylon, Paspalum orbiculare*, *Bracheria deflexa and Rottboellia cochinchinensis*. Quee *et al.* (2016) also found *Tridax procumbens*, *Mimosa pudica*, *Euphorbia heterophylla*, *Spigellia anthelmia*, *Digitaria ciliaris*, *Centrosema pubescens, Bracheria deflexa* and *Panicum maximum* while Ekeleme *et al.* (2019) identified *Imperata cylindrica*, *Panicum maximum, Digitaria horizontalis, Rottboellia cochinchinensis*, *Chromolaena odorata*, *Aspilia africana*, *Commelina benghalensis*, *Euphorbia heterophylla* as problematic weeds in cassava. It was observed that all the treatments including atrazine + s-metolachlor gave excellent control of weeds up to 95 - 97% at 4 WAP. This was buttressed by Moyo *et al.* (2012) who reported that s-metolachlor, triazine with other active ingredients reduced early weed growth by 53.7 to 97.9%. However, Sulfentrazone, indaziflam + isoxaflutole, and flumioxazin + pyroxasulfone adequately suppressed weed seedlings emergence until eight weeks after application. Yamaji *et al.* (2016) reported pyroxasulfone applied at a rate of 200 g a.i./ha showed an efficiency of 98% weed control up to 63 days after treatment (DAT). Indaziflam + isoxaflutole was the only pre-emergence herbicide that maintained 95% control of grass weeds till 12 WAP. In another study Santiago *et al.* (2018) found isoxaflutole in combination with flumioxazin and ametryn gave 90 and 95 % control of grass at 55 DAT. Ekeleme *et al.* (2016) also confirmed indaziflam + isoxaflutole to provide >90% control of broadleaf and grass weeds for up to eight weeks. Ciobanu *et al.* (2008) commented on the higher efficacy of isoxaflutole in combination with other herbicides. In another study, Mehmeti *et al.* (2019) investigated the effectiveness of isoxaflutole (0.4 L/ha), foramsulfuron (2.5 L/ha), foramsulfuron + iodosulfuron-methyl-sodium (1.5 L/ha) and found isoxaflutole most efficient with weed control coverage of 92.5% - 98.1% in a two-year field trial. Yamaji (2014) affirmed indaziflam to exhibit an excellent herbicidal activity. Hence, an exceptional potency of the product was visible on the field. Flumioxazin + pyroxasulfone gave excellent residual control of broadleaf weeds and sedge for more than six weeks. Pyroxasulfone was evaluated for selectivity and efficacy in the sequential application. It was discovered that this active ingredient provided greater weed control than s-metolachlor in a pre-emergence application (Goodrich *et al.*, 2018). It was observed that two weeks later, after post-emergence herbicides were applied, clethodim + lactofen combinations gave superior control of all emerged weed seedlings among all others. Carfentrazone-ethyl, which was used at 5.84 g/ha on weeds did not give a satisfactory result and consequently, all its combinations, especially with pre-emergence herbicides that lack post-activity, gave significantly lower weed control. The uncontrolled emerged weeds/weed residue could have resulted in interception or barrier to the applied pre-emergence herbicides, especially those that lack post-activities which consequently reduced the efficacy of the combinations. However, Chopra and Chopra, (2005) reported that carfentrazone-ethyl (20 g/ha) in a tank mixture with clodinafop (60 g/ha) was able to give 88-90% control of all grass and broadleaf weeds.

The application of post-emergence herbicides at 8 to 10 WAP to control later emerged weeds suggested that a single application of soil-applied herbicide is insufficient to manage weeds in cassava cultivation. In 2014, Korieocha carried out an experiment where weeds were removed with the use of atrazine (2-3 kgai/ha), atrazine + s-metolachlor at 2.5-3.0 kgai/ha, diuron (1.5-3 kgai/ha) and later had to supplement with foliar herbicides of paraquat at 0.5-1 kg ai/ha and glyphosate at 1.8-3.6 kg a.i/ha. Cafertrazone-ethyl, trifloysulfuron-sodium and clethodim + lactofen that were used as supplementary control did not negatively affect the parameters under observation. This implies that the application of these post-emergence herbicides to two months old cassava would not likely cause injury to the plants. Carfentrazone-ethyl applied at 5.8 g/ha failed to give satisfactory control of emerged grass weed seedlings. The poor performance of carfentrazone-ethyl on grass weeds may not be obvious when combined with pre-emergence herbicide like indaziflam + isoxaflutole. Its potency could persist for more than two months. It, however had a fair control of broadleaf weeds. Carfentrazone sprayed at 20-25 g/ha successfully reduced the biomass of several broadleaf weeds in barley cultivars, according to Bhullar *et al*. (2013). These weeds included *Chenopodium album L., Anagallis arvensis L., Rumex dentatus L*., and *Medicago polymorpha L*. According to Chopra and Chopra (2005), tank mixing of clodinafop 60 g/ha with cafertrazone (20 g/ha) controlled grass and broadleaf weeds resulting in 88 - 90% weed control efficiency. In the sequential application of post-emergence herbicides followed-up by pre-emergence herbicides, results at eight weeks revealed that all plots that received active ingredient indaziflam + isoxaflutole as second treatment application gave better control of all broadleaf and grass weeds. It was observed that indaziflam + isoxaflutole showed post-emergence activities of bleaching and killing of young broadleaf and grass weeds, but it was not effective on sedge. Silva *et al.*, (2016) tested sulfentrazone + diuron and isoxaflutole on *Cyprerus rotundus* and *Urochloa decumbens* and reported isoxaflutole not to be effective on *Cyprerus rotundus*. In another study, it was observed that isoxaflutole induced initial symptom of foliar chlorosis and yellowed leaves with white spots on bahia grass at 14 Days After Application (DAA) and caused its death at 42 DAA while it became symptomatic on Bermuda grass at 7 DAA and at 14 DAA resulted in 85% death of the grass, imperial and Japanese lawn grass (Silva *et al.*, 2016). Marble *et al.* (2016); stated that indaziflam though a pre-emergence herbicide, could manifest post-emergence activities on weed. The authors reported that indaziflam (SC) at 12.6, 25.1, 50.2 and 100.4 g/ha gave control of > 90% of *Oxalis stricta* similar to glyphosate. Also, indaziflam + isoxaflutole combinations reduced weed dry weight significantly, and this could be compared with results in plots that received hoe-weeding three times. Pre-emergence herbicides with post-herbicide activities could greatly improve the effectiveness of post-pre sequence of herbicide application. This benefit could not be over-emphasized since several post-emergence herbicides lack residual activities giving room to early weed emergence. Ciobanu *et al.* (2008) had earlier reported higher efficacy of isoxaflutole as pre-emergence in combination with other herbicides while Mehmeti *et al.* (2019) was convinced that isoxaflutole could be used as a post-emergence herbicide. Flumioxazin + pyroxasulfone application in post-pre sequence, revealed no post-emergence activities. This was more evidence when the active ingredient of initial post-emergence herbicide applied was ineffective on weed seedlings. Bhutto *et al.* (2016) confirmed in their investigation of pyroxasulfone, clodinafop propargyl and pendimenthalin alone and in various combinations as a post-emergence application for weed control that pyroxasulfone alone or in combination showed poor response comparable to the weedy check. In an evaluation of flumioxazin efficacy for annual bluegrass control, post-emergence application of flumioxazin was found not to control annual bluegrass except when tank-mixed with other herbicides (Reed, 2014). Weed suppression was high at three months after planting with 91 -98% control in some plots. This, however, depended on the pre- and post-emergence herbicides that were combined. Percentage weed density reflected the population of individual weed species per unit area of occurrence. Weed species recorded varied from year to year as different fields were used for repeated trials. Most weed species recorded in untreated plots were missing after the application of indaziflam + isoxaflutole. However, there was a higher percentage of sedge. Pre-emergence herbicides effect on sedge varied: sulfentrazone had 2.4%, 1.5% and null; flumioxazin + pyroxasulfone recorded 14.3%, 13.1% and 10.3 while indaziflam + isoxaflutole recorded 40%, 40.3% and 16.5% in 2015, 2016 and 2017 respectively. This suggests that indaziflam + isoxaflutole may not have high efficacy control of sedge seedlings like other weed groups. It was observed across the three years that indaziflam + isoxaflutole, sulfentrazone, and flumioxazin + pyroxasulfone completely suppressed *Oldenlandia corymbosa*, *Commelina diffusa*, *Phyllanthus amarus* and *Acmella grandiflora.* Other weeds species completely suppressed by sulfentrazone, indaziflam + isoxaflutole and flumioxazin + pyroxasulfone were *Spigelia anthelmia*, *Ageratum conyzoides, Celosia laxa*, *Gomphrena celosiodes*, *Passiflora foetida*, *Calopogonium* *mucunoides*, *Chromolaena odorata*, *Talinum fruticosm*, *Amaranthus spinosus*, *Mitracarpus villosus*, *Sida acuta*, *Rottboellia cochinchinensis*, *Vernonia cinerea*, *Euphorbia heterophylla*, *Euphorbia hirta*, *Paspalum orbiculare*, *Bracharia deflexa*, *Tridax procumbens*, *Ipomoea involucrata*, *Ipomoea mauritiana*, *Portulaca oleracea*, *Portulaca quadrifida*, *Spermacoce verticullata* and *Panicum maximum*.

The use of herbicides could help manage weeds on cassava farm. However, growth stage and time of application could be critical to its effectiveness and phytotoxicity (Motley, 2001). Weed management strategies carefully developed may be able to tackle these issues. Findings in this study indicated that the type of active ingredients combined could influence the effectiveness of the sequence chosen. Results obtained at 12 MAP indicated that number of plant stands in the two sequences were not significantly different. It was noteworthy that sulfentrazone in pre-post arrangement gave a significantly higher number of stems with poor shoot weight. In the post-pre sequence, results were vice-versa. This suggested that the negative effect of sulfentrazone when sprayed immediately after planting will be very harsh on tender cassava plants compared to the post-pre arrangement where the plants were already two weeks old. Plant age impacts herbicide absorption, translocation, and activity in plants and it is expected that young plants will succumb to herbicides effect (Oliveira and Inoue 2011; Filho 2018). Remarkably, indaziflam + isoxaflutole and flumioxazin + pyroxasulfone combined with other post-emergence herbicides in either pre-post or post-pre order did not show significant effects on root fresh weight although pre-post arrangement had higher root weight. Carfentrazone-ethyl in combination with indaziflam + isoxaflutole and flumioxazin + pyroxasulfone showed a significant difference between the sequences with vigour and plant height most affected in the post-pre arrangement.

In comparing the effect of sequences of herbicides application on weed, it was observed that weeds were more significantly suppressed in the pre-post arrangement. However, there could be an exception where the active ingredients of the herbicides combined are highly potent. The findings showed that a combination of clethodim + lactofen and indaziflam + isoxaflutole in a post-pre were as effective as in pre-post sequence. This probably may be as a result of post-emergence activities of indaziflam + isoxaflutole, especially on grass weed seedlings. According to the contrast table, in post-pre order, the sprouting of the stem was 5% higher across the herbicides. Specifically, it was higher by 1% for flumioxazin + pyroxasulfone, 8% for indaziflam + isoxaflutole, 5% for sulfentrazone, 6% for trifloysulfuron-sodium, 5% for clethodim + lactofen and 4% for carfentrazone-ethyl, respectively. By implication, the active ingredients causing suppression of cassava sprouting could be applied in post-pre sequence to minimize this effect. Top shoot weight measured in the two sequences was compared, the result was better in post-pre. This result could still be a result of active herbicide ingredients. Indaziflam + isoxaflutole sprayed plots had their top shoot weight to be just 2% higher while sulfentrazone was as high as 40%. The difference in estimate percentage between pre-post and post-pre on stem weight also varied with the herbicides with higher weight recorded in pre-post order for indaziflam + isoxaflutole by 24%, flumioxazin + pyroxasulfone by 10%, clethodim + lactofen by 6%. At the same time, sulfentrazone, trifloysulfuron-sodium and carfentrazone-ethyl gave better stem weight in a post-pre sequence with the difference of 29, 10 and 17% respectively. Storage root yield which is the target of most farmers was influenced by pre-post and post-pre sequence of herbicide application and the results varied with herbicides. Active ingredient indaziflam + isoxaflutole, flumioxazin + pyroxasulfone, trifloysulfuron-sodium, carfentrazone-ethyl in the pre-post arrangement had greater storage root production with estimated difference of 17%, 12%, 1% and 17% respectively. Sulfentrazone and clethodim + lactofen treated cassava had greater stem and storage root weight under post-pre order of herbicide application with the estimate difference of 36% and 11%. These findings show the importance of understanding of how herbicide active ingredients work in order to correctly combine them and know the suitable application sequence to adopt. Weed infestation was managed under the two sequences of herbicide application. However, pre-post order gave excellent control of all weed types, regardless of the active ingredients combined. In addition, several authors affirmed improved weed control in a pre-post arrangement in crops such as sugar-beet, corn, cotton and soya-bean (Rabaey and Harvey, 1997; Schweizer, 1980; Taylor-Lovell *et al.*, 2002; Richardson *et al.*, 2007b). The estimated percentage difference between the sequences was not much for indaziflam + isoxaflutole and clethodim + lactofen. The implication of this is that out of all the active ingredients evaluated, a combination of indaziflam + isoxaflutole and clethodim + lactofen was best in a post-pre arrangement for weed control. The variations in results of the planting years could probably be as a result of weather conditions and existing vegetation of cropping sites.

Hoe-weeding as a method of weed control when carried out timely in crop cultivation provided other factors are checked could yield optimally. However, the cost of production with hoe-weeding is relatively high and it is tedious (Orr *et al*., 2002; Iyagba, 2013). The total variable cost calculated during the trial for production of cassava on one hectare was ₦291000 ($831) on the assumption that $1 ≡ ₦350. This cost was higher than the cost of applying atrazine + s-metolachlor followed by two hoe-weeding, ₦249750 ($714) and the sequential applications of pre- and post-emergence herbicides, which ranged from ₦185807 to 223002 ($531 to 637) depending on the herbicides combined. Marginal rate of return (MRR) varied with the methods of weed control and types of herbicides combined. The MRR on hoe-weeding (324, 321) was lower than atrazine + s-metolachlor followed by two hoe-weeding (488, 451) in the first and second experiments respectively. All combinations of sulfentrazone had negative MRR in the pre-post sequence; however, the reverse was the case in post-pre sequence with trifloysulfuron-sodium + sulfentrazone, cafertrazone-ethyl + sulfentrazone and clethodim + lactofen and sulfentrazone having MRR of 220, 96 and 370 respectively. Also, MRR from other herbicide combinations ranged from 557 to 1669, with the highest MRR from indaziflam + isoxaflutole and cafertrazone-ethyl and the lowest MRR cafertrazone-ethyl followed by flumioxazin + pyroxasulfone. The sequence of application influenced the returns since the yields of the two sequences were not the same.

# CHAPTER 6

# SUMMARY, CONCLUSION AND RECOMMENDATIONS

## 6.1 Summary

Weed infestation is a menace especially during the early stage of cassava growth. Farmers therefore continually seek improved knowledge to escape from drudgery and hardship that accompany its management. Herbicides could be a solution; however, the inadequacy of their applications could sabotage their beneficial use. Hence selected pre- and post-emergence herbicides were evaluated and their combinations were explored through sequential applications under broadcast and banded spraying.

Out of the pre-emergence herbicides tested on cassava, flumioxazin + pyroxasulfone was well tolerated. However, all the pre-emergence herbicides evaluated (flumioxazin + pyroxasulfone, sulfentrazone and indaziflam + isoxaflutole) suppressed weeds longer than atrazine + s-metolachlor. Indaziflam + isoxaflutole controlled grass weeds more efficiently than other pre-emergence herbicides.

Clethodim being one of the post-emergence herbicides evaluated was the only active ingredient that was selective to cassava plants. It controlled grass weeds but showed no activity on broadleaf and sedge weed. This necessitated its combination with lactofen that is a contact herbicide. Consequently, the post-emergence herbicides were not selective. Broadcast application of post-emergence herbicides led to 55% injury of two weeks old cassava; however, the number of sprouted stems were not affected. Carfentrazone-ethyl caused 92%, trifloysulfuron-sodium was 55% and 19% in clethodim + lactofen. Trifloysulfuron-sodium caused a shrinking of apical stem nodes while necrotic symptoms were visible on carfentrazone-ethyl treated plants. The injury effect wears off by the twelfth week, however, traces were still seen in some treatment combinations. The banded spray method reduced injury by 94 - 98%.

Combinations involving banded spray of trifloysulfuron-sodium and clethodim + lactofen with indaziflam + isoxaflutole and flumiosaxin + pyroxasulfone enhanced growth and yields and weed control in cassava. Indaziflam + isoxaflutole in a post-pre application sequence enhanced cassava sprouting compared to its application in a pre-post arrangement.

All sulfentrazone combinations significantly affected the performance of cassava plants and the storage root yield negatively. However, storage root yield was high in flumioxazin + pyroxasulfone and indaziflam + isoxaflutole treatment combinations.

Trifloysulfuron-sodium and clethodim + lactofen (7 g/ha and 0.21 + 0.41 kg/ha) gave 96-98% control of two weeks old grass weed seedlings. Carfentrazone-ethyl at 5.8 g/ha gave average control of broadleaf weeds but did not affect the grass. Weed residues resulting from ineffective post-emergence herbicide limited the penetration of later applied pre-emergence herbicides, which negatively influenced the efficacy of some treatment combinations. Indaziflam + isoxaflutole in post-pre revealed its post-activity on young grass and broadleaf weeds but it showed a null effect on sedge. It bleached the leaves and eventually resulted in plant death.

Weeds were significantly suppressed at 12 WAP with the treatment combinations of all pre- followed by the three post-emergence herbicides ranging from 80-98 %. Trifloysulfuron-sodium followed by indaziflam + isoxaflutole, clethodim + lactofen followed by indaziflam + isoxaflutole, clethodim + lactofen followed by flumioxazin + pyroxasulfone, clethodim + lactofen followed by sulfentrazone and carfentrazone-ethyl followed by indaziflam + isoxaflutole controlled weed by 85-97%.

Generally, there was a contrast between pre-post and post-pre sequence application strategies on cassava and weed. The estimate difference for sprout count was 5%, vigour score 10%, height 9%, number of plants at harvest 2%, number of stems 18%, the weight of top shoot 15%, the weight of stem 5%, the weight of fresh root 1%, broadleaf control 13%, grass weed 23% and sedge 18%. However, results varied in different treatment combinations. It was observed that storage root yield was higher in pre-post than in post-pre sequence. Pre-post herbicide application controlled weeds more than post-pre sequence. Sulfentrazone and cafertrazone-ethyl were not suitable for weed control in cassava.

All the treatments were profitable except combinations of sulfentrazone in the pre-post application sequence resulting in a negative marginal rate of return. Debt was incurred with sulfentrazone combinations in a pre-post sequence of application.

## 6.2 Conclusion

Given the information obtained from the research work, not all the herbicides evaluated are suitable for cassava cultivation. Flumioxazin + pyroxasulfone and indaziflam + isoxaflutole were tolerated by cassava better than sulfentrazone however, all of these herbicides suppressed weeds better than atrazine + s-metolachlor. All the post-emergence herbicides evaluated are better applied banded as they were found non-selective to cassava plants. Clethodim + lactofen is the best post-emergence herbicide option to consider in post-pre application sequence.

## 6.3 Recommendations

Flumioxazin + pyroxasulfone and indaziflam + isoxaflutole could be an alternative choice to atrazine + s-metolachlor which is the commonly used pre-emergence herbicide among cassava farmers. The combination of clethodim + lactofen (post-) and indaziflam + isoxaflutole (pre-), and clethodim + lactofen and flumioxazin + pyroxasulfone (pre-) could be used in an alternative post-pre application sequence.

In consideration of the environment, it will be a great benefit if more environment friendly herbicides are screened. In addition, research works that could increase herbicides options of different site of action should be encouraged in order to achieve good herbicide combinations which could be applied in sequence especially in crops with long life cycle thereby preventing antagonistic reactions or delaying the problem of herbicide resistance.

## 6.4 Contributions to knowledge

1. Flumioxazin+pyroxasulfone and indaziflam+isoxaflutole were found effective for pre-emergence weed control in cassava.
2. Band application of clethodim+lactofen and trifloysulfuron-sodium enhanced weed control in cassava.
3. A post-pre sequence of clethodim+lactofen as post-emergence herbicide followed by any pre-emergence herbicides other than sulfentrazone is established to be as effective as any pre-post sequence of application.
4. The alternative herbicide application sequence (post-pre) could afford farmers the luxury of control of already emerged weeds with post-emergence herbicides thereby enhancing the effectiveness of follow-up of pre-emergence herbicides.

5. It is possible to manage weeds in cassava during the first three to four months, critical for weed control in cassava, without encountering drudgery associated with hoe-weeding. This could be accomplished by sequentially applying different types of herbicides.

# REFERENCES

ACAI, 2020. Tailored fertilizer application recommendation for cassava. African Cassava Agronomy Initiative. http://acai-project.org

Adigun, J. A. and Lagoke, S. T. O. 2003. Weed control in transplanted rainfed and irrigated tomatoes in the Nigerian savanna. *Nigerian Journal of Weed Science* 16: 23-29.

Adetunji, A. S., Akeredolu, O. A., Arowolo, O. V. and Ogundoyin, A. A. 2020. Effect of adoption of improved cassava varieties on household income in Oyo State, Nigeria. *Nigerian Agricultural Journal* 51:362 -369.

Agahiu, A. E., Udensi, U. E., Tarawali, G., Okoye, B. C., Ogbuji, R. O. and Baiyeri, K. P. 2011. Assessment of weed management strategies and intercrop combinations on cassava yield in the middle belt of Nigeria. *African Journal of Agricultural Research* 6: 5729–5735.

Agahiu, A. E., Baiyeri, K. P., Ogbuji, R. O. and Udensi, U. E. 2012. Assessment of status, perception of weed infestation and methods of weed control adopted by cassava farmers in Kogi state, Nigeria. *Journal of Animal and Plant Sciences* 13: 1823 – 1830.

Akinyosoye, V. O. 1999. Senior Tropical Agriculture for West Africa, BAS pp 199.

Akobundu, I. O. 1980. Weed control in cassava cultivation in the sub-humid tropics. *Tropical Pest Management* 26: 420-426.

Akobundu, I. O. 1981. Weed control in direct-seeded lowland rice under poor water control conditions. *Weed Research* 21.6: 273–278.

Akobundu, I. O. 1987. Weed Science in the tropics; Principles and Practices. A Wiley-Inter Science Publications. 71: 364-367.

Alebrahim, M. T., Majd, R., Rasheed-Mohassei, M. H., Wilcockson, S., Baghestani, M. A., Ghorbani, R. and Kudsk, P. 2012. Evaluating the efficacy of pre- and post-emergence herbicides for controlling *Amaranthus retroflexus* L and *Chenopodium album* L. in potato. *Crop Protection* 42, 345 – 350.

Alister, C. A., Gomez, P. A., Rojas, S., Kogan, M. 2009. Pendimethalin and oxyfluorfendegradation under two irrigation conditions over four years' application. *Journal of Environmental Science and Health* 44: 337–343.

Alves, M. C., Moreira, M. A. B., Chagas, M. C. M., Holanda, J. S., Silva, J and Lima, J. D. S. 2009. Recomendaçõ estécnicas para o cultivo da mandioca. In: Lira M. A., Chagas M. C. M., Lima J. M. P, Holanda J. S., editores. Culturasalimentaresna agricultura familiar. Natal: Emparn pp 23.

Anderson, J. M. and Ingram, J. S. I. 1993. Tropical soil biology and fertility: A handbook of methods. In the Cambrian News United Kingdom, pp 221.

Anonymous, 2011. Production of Barley in India 1990-2011. http://www.indiastat.com/agriculture/2/foodgrains/17180/barley/17201/stats.aspx

Anwar, M. P., Juraimi, A. S., Mohamed, M. T. M., Uddin, M. K., Samedani, B., Puteh, A. and Man, A. 2013. Integration of agronomic practices with herbicides for sustainable weed management in aerobic rice. *The Scientific World Journal* 2:9-16.

Arregui, M. C., Scotta, R. and Sanchez, D. 2000. Improved weed control with broadleaf herbicides in glyphosate-tolerant soybean (*Glycine max) Crop Protection* 25:653 – 656.

Ayeni, A. O. 1991. Hand/Mechanical Weed Management as an option in Nigerian agriculture. *Nigerian Journal of Weed Science* 4:71-78.

Banerjee, H., Das, T. K., Ray, K., Laha, A., Sarkar, S. and Pal, S. 2006. Herbicide ready-mixes effects on weed control efficacy, non-target and residual toxicities, productivity and profitability in sugarcane and green-gram cropping system. *International Journal of Pest Management* 64: 221-229.

Beck, L., Marsalis, M., Lauriault, L. and Serena, M. 2020. Efficacy of various herbicides for the control of perennial *Plantago spp*. and effects on Alfafa damage and yield. *Agronomy Journal* 10:1 – 14.

Bergkvist, P. and Ledin, S. 1997. Effects of herbicides propaquizafop and primisulfuronmethyl on salix plants and weeds in energy plantations. *Biomass and Energy* 12:25 – 33.

O'Berry, N. B., Faircloth, J. C., Edmisten, K. L., Collins, J. D., Herbert, D. A. and Abaye, A. O. 2008. Trifloxysulfuron-sodium Application Does Not Provide Season-long Plant Height Control or Hasten Maturity of Cotton (*Gossypium hirsutum* L.). The *Journal of Cotton Science 12:378–385*

Bhullar, M. S., Kaur, S., Kaur, T., Singh, T., Singh, M. and Jhala, A. J. 2013. Control of broadleaf weeds with post-emergence herbicides in four barley (*Hordeum spp*.) cultivars. *Crop Protection* 43: 216-222.

Bhutto, W. F., Javed, M. A., Pervez, A.M. and Shahid, A. Z. 2016. Efficacy of herbicide (pyroxasulfone 85WG) in combination with previously existing herbicides used for weed management. *African Journal of Agronomy* 4:280-287.

Biffe, D. F. 2010. Avaliação de herbicidas para doiscultivares de mandioca. *Planta Daninha*, Viçosa 28: 807-816.

Boifrey-Arku, G., Owusu-Akyaw, J. V. K., Afun, J., Adu-mensah, F. O., Anno-Nyako, E., Osei-Yeboah, K., Mochiah, M. B., Adama, I., Dankyi A. A., Brandenburg, R. I., Bailey, J. E. and Jordan, D. L. 2006. Survey of weed management in peanut fields in Southern Ghana, West Africa. *Peanut Science* 33: 90-96.

Bond, J and Griffin, J. 2005. Weed control in corn (*Zea mays*) with an imazethapyrplus imazapyr prepackaged mixture 1. *America Journal of Plant Sciences* 2:5-9.

Boutsalis, P., Gill, G. and Preston, C. 2010. New mode of action herbicides to combat herbicide resistant rigid ryegrass (*Lolium rigidum*) in Australian cereal production. *Proceedings of the Australasian Weeds Conference*, 17:278–280.

Boyd, N. S., Dittmar, P. 2018. Evaluation of Postemergence-Directed Herbicides for Purple Nutsedge (*Cyperus rotundus*) Control in Fresh-Market Tomato. *Weed Technology* 32:260–266.

Brabham, C., Lei, L., Gu, Y., Stork, J., Barrett, M. and DeBolt, S. 2014. Indaziflam herbicidal action: a potent cellulose biosynthesis inhibitor. *Plant Physiology* 166:1177–1185

Bray, R. H. and Kurtz, L. T. 1945. Determination of total, organic, and available forms of phosphorus in soils. *Soil Science* 59: 39 -45.

Brosnan, J. T., McCullough, P. E. and Breeden, G. K. 2011. Smooth crabgrass control with indaziflam at various spring timings. *Weed Technology* 25:363 366.

Buondonno, A., Rashad, A. A. and Coppola, E. 1995. Comparing tests for soil fertility. The hydrogen peroxide/sulfuric acid treatment as an alternative to the copper/selenium catalyzed digestion process for routine determination of soil nitrogen-Kjeldahl. *Communications in Soil Science and Plant Analysis* 26: 1607-1619.

Burton, J. D.; Gronwald, J. W.; Somers, D. A.; Gegenbach, B. G.; Wyse, D. L. 1989. Inhibition of corn acetyl-coA carboxylase by cyclohexanedione and aryloxyphenoxypropionate herbicides. *Pesticide Biochemistry and Physiology* 34: 76–85.

Burton, J. D., Gronwald, J. W., Keith, R. A., Somers, D. A., Gengenbach, B. G. and Wyse, D. L. 1991. Kinetics of inhibition of acetyl-coenzyme A carboxylase by sethoxydim and haloxyfop. *Pesticide Biochemistry and Physiology* 39: 100-109.

Cardoso, A. D., Viana, A. E. S., Barbosa, R. P., Teixeira, P. R. G., Cardoso, J. N. S. and Fogaça J. J. N. L. 2013. Levantamento fitos sociológico de plantas daninhasna cultura da mandioca em Vitória da Conquista, Bahia. *BioScience Journal* 29:1130-1140.

Carvalho, L. B., Bianco, S. and Pitelli, R. A. 2007. Estudo comparative do acumulo de massa seca e macronutrients por plantas de milho var. BR-106 e Brachiaria. *Planta Daninha* 25:293-301.

Chikoye, D. 2000. Weed management in small-scale production systems in Nigeria. In: Akoroda, M.O. (Ed.) Agronomy in Nigeria 153-156.

Chikoye, D., Ekeleme, F. and Udensi, U. E. 2001. Cogon grass suppression by intercropping cover crops in corn/cassava systems. *Weed Science Society of America* 49: 658-667.

Chopra, N. and Chopra, N. K. 2005. Bio-efficacy of clodinafop, fenoxaprop, metribuzin alone and in combination against weeds in wheat and their residual effect on succeeding crops. *Indian Journal of Weed Science*, 37: 163-166.

CIAT. 1976. Agronomy. *In: Cassava Production Systems, Annual Report for 1975*. Cassava Cali, Columbia pp 31.

Ciobanu, C., Ciobanu, G. and Vuscan, A. 2008. The influence of some herbicides on weed degree decreasing and influence on maize yield in the north-western part of Romania. *Research Journal of Agricultural Science* 1: 371-374.

Costa, N. V. 2013. Seletividade de herbicidasaplicados com óleo mineral nacultura da mandioca “Cascuda”. RevistaBrasileira de Herbicidas 12:251-259.

Costa, N. V. 2015. Sulfentrazone selectivity and efficiency in cassava crops in sandy and clayey soils. Planta Daninha, Viçosa 33:787-793.

Damalas, A. C. 2004. Herbicide Tank Mixtures: Common Interactions. *International Journal of Agriculture and Biology 6: 1-5.*

Dayan, F. E., Green, H. M., Weete, J. D. and Hancock, H. G. 1996. Postemergence activity of sulfentrazone: effects of surfactants and leaf surfaces. *Weed Science Society of America* 44:797-803.

Devine, M. D. and Shimabukuro, A. 1994. Resistance to acetyl coenzyme A carboxylase inhibiting herbicides. *In 'Herbicide resistance in plants: biology and biochemistry'*, eds S. Powles and J. Holtum, pp. 141-169. (Lewis Publishers).

Dixon, A. 2015. Farmers can double cassava yield with improved weed control. [Online]. Available: http://www.vanguardngr.com/2015/07/11

Doll, J. D. and Piedrahita W. C. 1973. Effects of time of weeding and plant population on the growth and yield of cassava. *In: Proceeding of the Third International Symposium on Tropical Root Crops, Ibadan, Nigeria,* 2-9 December 1973.

Doll, J. D. and Piedrahita W. 1976. Methods of weed control in cassava" C. I. A. T. Series EE-21 California Columbia pp 1-12.

Duke, S. O. 1990. Overview of herbicide mechanisms of action. *Environmental Health Perspectives* 87:263–271.

Eadie, A. G., Swanton, C. J., Shaw J. E. and Anderson G. W. 1992. Banded herbicide applications and cultivation in a modified no-till corn system. *Weed technology* 6: 535-542.

Eberlein, C. V., Whitmore, J. C., Stanger, C. E. and Guttieri, M. J. 1994. Post emergence weed control in potatoes (*Solanum storage rootosum*) with rimsulfuron mixtures. *Weed Technology* 11, 755 - 761.

Ekeleme, F., Akobundu, I. O., Fadayomi, R. O., Chikoye, D. and Abayomi, Y. A. 2003. Characterization of Legume cover crops for weed suppression in the moist savanna of Nigeria. *Weed Technology* 17:1 – 13.

Ekeleme, F. 2013. A Report on weeds of cassava and management choices for small holders in Africa.

Ekeleme, F., Hauser, S., Atser, G., Dixon, A., Weller, S., Olorunmaiye, P., Usman, H., Olojede, A., and Chikoye, D. 2016. Weed management in cassava in Africa: Challenges and opportunities. *Outlook Pest Management* 27: 208-212.

Ekeleme, F., Atser, G., Dixon, A, Hauser, S., Chikoye, D., Olorunmaiye, P. M., Sokoya, G., Alfred, J., Okwusi, M. C., Korieocha, D. S., Olojede, A. O., Toye Ayankanmi and Lagoke, S. T. O. 2019. «Assessment of Weeds of Cassava and Farmers' Management Practices in Nigeria», *Tropicultura* [Enligne], 3.

Ekeleme, F., Dixon, A., Atser, G., Hauser, S., Chikoye, D., Olorunmaiye, P. M., Olojede, A., Korie, S., and Weller, S. 2020. Screening pre-emergence herbicides for weed control in cassava. *Weed Technology* 34: 1 – 39.

Enyong, J. K., Ndaeyo, N. U., Ndon, B. A, Ugbe, L. A. and Akpan, E. A. 2013. Preliminary evaluation of effects of herbicide types and rates on growth and yield of cassava (*Manihot esculenta* Crantz). *International Journal of Basic and Applied Sciences* 2: 65 – 70.

Eze, S. C. and Ugwuoke, K. I. 2010. Evaluation of different stem portions of cassava (*Manihot esculentus* Crantz) in the management of its establishment and yield. *Research Journal of Agricultural and Biological Sciences* 6: 181-185.

Ezulike, T. O., Nwosu, K. I., Udealor, A. Eke-Okoro, O. N. 2006. Guide to Cassava Production in Nigeria. Extension Guide No. 16. National Root Crops Research Institute, Umudike, Nigeria, 10 pp.

FAO, 2013. Food and Agriculture Organization of the United Nation

FAO, 2018. Food outlook – Biannual Report on Global Food Markets – November 2018. Rome p. 104.

FAOSTAT. 2019. FAOSTAT Food and Agriculture Data 2019. http://www.fao.org/faostat/en/#data/ Goggle Scholar.

Fermont, A. M., Van Asten, P. J. A., Tittonell, P., Van Wijk, M. T. and Giller, K. E. 2009. Closing the cassava yield gap: An analysis from smallholder farms in East Africa. *Field Crops Research* 112: 24-36.

Filho, G. C. M., Mota, M. A., Montelo, A. B., deFarias, A. D. I. O., doNascimento, I. R. and dosSantos, M. M. 2018. Herbicide selectivity to cassava crop in post-emergence application. *Communication in Plant Sciences* 8: 112-115.

Fonne-Pfister, R., Chemla, P. and Ward, E. 1996. The mode of action and the structure of a herbicide in complex with its target: binding of activated hydantocidin to the feedback regulation site of adenylosuccinate synthetase. *Proceedings of the National Academy of Sciences USA*. 1996: 9431–9436.

Franz, J. E., Sikorski, J. A. and Mao, M. K. 1997. Glyphosate: A Unique Global Herbicide. Washington, DC: American Chemical Society Monograph 189, 6–16.

Galon, L. 2009. Seletividade de herbicidas a genótipos de cana-de-açúcar. Planta Daninha 27:83-93.

Gomez, K. A. and Gomez, A. A. 1984. *Statistical for Agricultural Research*, 2nd edition. John Wiley and Sons, New York.

Goodrich, L. V., Butts-Wilmsmeyer, C. J., Bollero, G. A. and Riechers, D. E. 2018. Sequential Pyroxasulfone Applications with Fluxofenim Reduce Sorghum Injury and Increase Weed Control. *Agronomy Journal* 110:1–10.

Green, J. M. and Owen, M. D. K. 2011. Herbicide-resistant crops: utilities and limitations for herbicide-resistant weed management. *Journal of Agricultural and Food Chemistry* 5819–5829.

Gupta, S. K., Mishra, G. C. and Purushottam, L. 2018. Efficacy of pre- and post-emergence herbicide on weed control in kharif maize (*Zea mays* L.). *International Journal of Chemical Studies*. 6:1126-1129.

Harker, K. N. 2013. Slowing weed evolution with integrated weed management. *Canadian Journal of Plant Science* 93:759-764.

Harper, R. S. 1974. Chemical Weed Control in Cassava using Paraquat. Pest Articles and News Summaries, 20:185-189.

Hartzler, R. G., Battles, B. and Nordby, D. 2004. Effect of common water-hemp (*Amaranthus rudis*) emergence date on growth and fecundity in soybean. *Weed Science* 52:242–245.

Haskins, B. 2012. Using pre-emergent herbicides in conservation farming systems – weed management. NSW DPI, District Agronomist, Hillston, Broadacre Cropping Unit, pages 20.

Hauser, S. 2014. Cassava system cropping guide. Africa Soil Health Consortium, Nairobi.

Hauser, S., Ekeleme, F. and Dixon, A. 2015. Weed biomass Production and Cassava Yields in varying Cassava Cropping Systems: Management of Land Use Systems for Enhanced Food Security Conflicts, Controversies and Resolutions. *Tropentag*, Berlin, Germany.

Heap, I. 2011. The International Survey of Herbicide Resistant Weeds; available at www.weedscience.com.

Heap, I. 2014. The International Survey of Herbicide Resistant Weeds, http://www.weedscience.com.

Howeler, R. H. 2002. Cassava mineral nutrition and fertilization. In: Cassava: Biology, Production and Utilization, Hillocks, R.J., CABI, Wallingford, UK, pp 115-148.

Hudetz, M., Foery, W., Wells, J. and Soares, J. E. 2000. CGA- 362622, a new low rate Novartis post-emergent herbicide for cotton and sugarcane. *Proceedings of Southern Weed Science Society* 52, 163–166.

IBGE, Instituto Brasileiro de Geografia e Estatística. Banco de dados. 2010. Disponível em: <http://www.ibge.gov.br>. Acessoem: 19-9-6.

ICAC. 2005. *Cotton Production Practices*. Washington, D. C.

IFAD. 1998. Agricultural implements used by women in Africa, Rome.

IITA. 2010. Post-Harvest Technology". IITA Annual Report. 62-80.

IITA, 2020. IITA News letter. iita.org/news-item/science.

Ikuemonisan, E. S. and Adenegan, K. 2020. Cassava production in Nigeria: trends, instability and decomposition analysis (1970 - 2018). *Heliyon ScienceDirect* 6:10

Illango, R. V. J., 2003. Evaluation of carfentrazone-ethyl for control of weeds in tea (*Camellia spp*.). *Indian Journal Weed Science* 35: 296-297.

Iyagba, A. G. and Ayeni, A. O. 2000. Efficacy of post-emergence herbicides on Guinea grass and Siam weed in Cassava 1: Influence of rate and mode of application. *Nigerian Journal of Crop, Soil and Forestry* 6: 24-37.

Iyagba, A. G. 2003. Weed control in a cassava-fluted pumpkin intercrop with selected herbicides. *Nigerian Journal of Horticultural Science* 8: 35-40.

Iyagba, A. G. and Ayeni, A. O. 2007. Post-emergence herbicides for weed control in cassava (*Manihot esculenta* Cratz) in the rain forest zone of Nigeria. *Acta Agronomica Nigeriana* 7: 126-134.

Iyagba, A. G. 2013. Assessing the safety use of herbicides by horticultural farmers in Rivers state, Nigeria. *European Scientific Journal* 9: 97 – 108.

Jablonkai, I. 2015. Herbicide metabolism in weeds —selectivity and herbicide resistance,
herbicides, physiology of action, and Safety, Andrew Price, Jessica Kelton and Lina Sarunaite, IntechOpen, DOI: 10.5772/61674. Available from: https://www.intechopen.com/books/herbicides-physiology-of-action-and-safety/herbicide-metabolism-in-weeds-selectivity-and-herbicide-resistance

Jacobs, J. M. and Jacobs, N. J. 1987. Oxidation of protoporphrinogen protoporphyrin, a step in chlorophyll and heme biosynthesis. *New Journal Chemistry* 244:219.

Janaki, P., Meena, S. and Chinnusamy, C. 2015. Dynamic of metolachlor in sandy clay loam soil and its residues in maize and soyabean. *Trends in Biosciences* 8:131-137.

Jeanmart, S., Edmunds, J. F. A., Lamberth, C., Pouliot, M. 2016. Synthetic approaches to the 2010-2014 new agrochemicals. *Bioorganic and Medicinal Chemistry* 24:317-341

Johnson, D. E. 1995. Weed management strategies for smallholder rice production. In ‘‘Brighton Crop protection Conference: Weeds. *Proceedings of an International Conference*’’, British Crop Protection Council, Farnham, UK pp. 1171–1180.

Jordan, D. L., Frans, R. E. and McClelland, M. R. 1993. Interactions of DPXPE350 with fluazifop-P, sethoxydim, clethodim, and quizalofop-P. *Weed Technology* 7:605–610.

Kabwe, S. 2014. Opportunities and Challenges of the Cassava Sector in Zambia. Indaba Agricultural Policy Research Institute, Luapula. 26pp.

Kandasamy, O. S. 1997. Influence of repeated application of herbicides on weed succession and yield of rice-based cropping system in India. *Journal of Agronomy and Crop Science* 179: 187 – 190.

Khanthavong, P., Oudthachit, S. and Souvannalat, A. 2016. Effect of weed biomass on cassava yield related to weeding times. *Advanced Plant Agriculture Research* 5: 630 – 632.

Knezevic, S. Z., Evans, S. P. and Mainz, M. 2003. Row spacing influences thecritical timing for weed removal in soybean (*Glycine max*). *Weed Technology* 17, 666–673.

Knezevic, S. Z., Datta, A., Scott, J. and Porpiglia, P. J. 2009. Dose response curves of KIH-485 for PRE-emergence weed control in corn. *Weed Technology* 23:34–39.

Kolo, M. J. 2004. Herbicide utilization by farmers in Niger State, Nigeria. *Nigerian Journal of Weed Science* 17: 21-28.

Korieocha, D. S. 2014. Weed control in national root crops research institute umudike and its recommendation. *Research Journal of Agriculture and Environmental Management*. 4: 001-004.

Kukorelli, K., Reisinger, P. and Pinke, G. 2013. Accase inhibitor herbicides, selectivity, weed resistance and fitness cost: a review. *International Journal of Pest Management* 59: 165-173.

Kumar, A., Vivek, Naresh, R. K., Ghasal, P. C., Kumar, R., Singh, V., Kumar, S., and Chandhary, K. 2017. Weed management effects on weed control efficiency, yield and economics of transplanted rice in Typic Ustochrept soil of Uttar Pradesh. *International journal of chemical studies* 5:1346-1351.

Lambreda, M. D., Russo, D. and Polticelli, F. 2014. Structure/function/dynamics of photosystem II plastoquinone binding sites. *Current Protein and Peptide Science* 15:285–295.

Landor, J. R. 1991. *Brooker Tropical Soil Manual.* A handbook for soil survey in the tropics and subtropics. Longman Group. England. pp. 106 – 144.

Leyva-Soto, L. A., Balderrama-Carmona, A. P., Moran-Palacio, E. F., Diaz-Tenorio, L. M. and Gortares-Moroyoqui, P. 2018. Glyphosate and aminomethylphosphonic acid in population of agricultural fields: Health risk assessment overview. *Applied Ecology and Environmental Research* 16: 5127–5140.

Little, R. C., Milligen, G. A., Stroup, W. W., Wolfinger, R. D. 1996. SAS System for Mixed Models, Cary, NC. *SAS Institute Inc.*, 633p.

Little, R. C., Pendergast, J. and Natarajan, R. 2000. Tutorial in biostatistics: Modelling covariance structure in the analysis of repeated measures data. *Statistics in Medicine,* 19: 1793–1819.

Lockhart, S. J. and Howatt, K. A. 2004. Split applications of herbicides at reduced rates can effectively control wild oat (*Avena fatua*) in wheat. *Weed Technology* 18:369–374.

Loux, M. M., Dobbels, A. F., Johnson, W. G. and Young, B. G. 2011. Effect of residual herbicide and postemergence application timing on weed control and yield in glyphosate-resistant corn. *Weed Technology* 25:19-24.

Liu, L. C, Acevedo-Borrero, E. and Ortiz, F. F. 1982. Herbicide evaluation for sweet potatoes. *The Journal of Agriculture of the University of Puerto Rico* 66: 254-260.

Marble, S. C., Chandler, A. and Archer, M. 2016. Impact of application rate, timing, and indaziflam formulation on early POST control of *Oxalis stricta*. *Weed Technology* 30:701-707.

Markovic, M., Protic, R., and Protic, N. 2008. Efficiency and selectivity of herbicides in maize (*Zea mays* L.) *Romanian Agricultural Research* 25,77 -82.

Mathiassen, S. K., and Kudsk, P. 2016. Effect of sequential treatments. Julius-Kuhn-Archive 455:176–177.

Matocha, M. A. and Senseman, S. A. 2007. Trifloxysulfuronsodium dissipation at selected pH levels and efficacy on palmer amaranth (*Amaranthus palmeri*). *Weed Technology* 21: 674–677.

Mavudzi, Z., Mashingaidze, A. B., Chivinge, O. A., Ellis-Jones, J. and Riches, C. 2001. Improving Weed Management in a Cotton-Maize System in the Zambezi Valley Zimbabwe. *Brighton Crop Protection Conference, Weeds,* 169-174.

Mclean, E. O. 1982. Soil pH and lime requirements In: Page, A.L. Miller, R.H and Keeney, D.R. Editors. Methods of Soil Analysis, Part 2, *Chemical and Microbiological Properties* 2nd Edition. American Society of Agronomy Maidison, Wisconsin, USA p 34.

McWhorter, C. G. 1982. The physiological effects of surfactants on plants. *Weed physiology* 2: 141-158.

Mehmeti, A., Fetahaj, A., Demaj, A., Nishori, F. and Rracaj, F. 2019. Evaluation of pre- and post-emergence herbicides for weed control in maize (*Zea mays* L.) *Journal of Central European Agriculture* 20:208-221.

Meister, R. T. 1992. Farm Chemicals Handbook '92. Meister Publishing Company, Willoughby, Ohio.

Mekki, M. and Leroux, G. D., 1994. Activity of nicosulfuron, rimsulfuron and their mixture on field corn (Zea mays), soybean (Glycine max) and seven weed species. *Weed technology* 8:436-440.

Melifonwu, A. A. 1994. Weeds and their control in Cassava. *African Crop Science Journal* 2:519-530.

Melifonwu, A., James B., Aihou K., Weise S., Awah E. and Gbaguidi B. 2000. Weed control in cassava farms. IITA Plant Health Management Division, Biological control center for Africa. Cotonou, Republic of Benin, 13p.

Merritt, L. H., Ferguson, J. C., Brown-Johnson, A. E., Reynolds, D. B., Tseng, T. and Lowe, J. W. 2020. Reduced herbicide antagonism of grass weed control through spray application technique. *Agronomy* 10:1131-1145.

Mohammed, Z. and Addisu, S. 2016. Evaluation of sequential application of herbicides for broad and grass weed management in Durum Wheat, Ethiopia. *American Journal of Environmental and Resource Economics* 1:32-36.

Motley, K., Dellow, J., Storrie, A. and Spenceley, J. 2001. Using Herbicides in Lippia Management Program. Agnote DPI-384, NSW Agriculture.

Moyo, C. C., Jumbo, S., Mahungu, N. M., Benesi, I. R. M., Ntawuruhungu, P. and Sandifolo V. S. 2012. Evaluation of commercially available herbicides for weed control in cassava. In: *Proceedings of 11th triennial Symposium of the International Association of Hydrological* Sciences held at Memling Hotel: Tropical roots and storage root crops and challenges of globalization and climate changes, 269-275. Kinshasa.

Murphy, J. and Riley, J. P. 1962. A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta* 27: 31-36.

Muthamia, J. G. N., Musembi, F., Maina, J. M. Okuro, J. O., Amboga, S. Muriithi, F. Micheni, A. N., Terry, J., Overfield, J., Kibata, G. and Muthura, J. 2001. Participatory on-farm trials on weed control in smallholder farms in maize-based cropping systems. *Proceedings of Seventh Eastern and South Africa Regional Maize Conference*. 468 - 473.

Nedunchezhiyan, M., Ravi, V. George, J. and Ss, V. 2017. Effect of weed control methods in yield and starch content of storage root of cassava (*Manihot esculenta* Crantz) and soil health. *Indian Journal of Agricultural Sciences* 87:342-349.

Niazmand, A. R., Shaker, M. and Zakeria, A. R. 2008. Evaluation of different herbicide application methods and cultivation effect on yield and weed control of corn (*Zea mays* L.) *Journal of Agronomy* 7:314-320.

Nweke, F. I. 2004. New challenges in the cassava transformation in Nigeria and Ghana. Conference paper No. 8. Paper presented at the INVENT, IFPRI, NEPAD, CTA Conference. Success in African Agriculture, Pretoria, 1, and 3 December, 2003.

Nyam, T. 2005. Opening address: In Chikoye, D., J. Ellis-Jones, A. F. Lum, G. Tarawali and T. Avav (editors): Reducing Poverty through improved *Imperata* control. *Proceedings of the second Imperatamanagement stakeholders" conference,* held in Makurdi, Benue State, Nigeria, 14-15 September 2004, IITA, Ibadan, Nigeria, p. 119.

Obermeier, M. R. and Kapusta, G. 1996. Postemergence broadleaf weed control in corn (*Zea mays*) with CGA-152005. *Weed Technology* 10:689–698.

Ojo, J. 2016. Pesticides use and health in Nigeria. Ife Journal of Science 18:981 -991.

Ojo, E. O. and Adebayo, P. F. 2012. Food security in Nigeria: An overview. *European Journal of Sustainable Development* 1:199 – 222.

Olasantan, F. O. 2001. Optimum plant populations for okra (*Abelmoschus esculentus*) in a mixture with cassava (*Manihot esculenta*) and its relevance to rainy season-based cropping systems in South-Western. *Nigerian Journal of Agricultural Science* 136: 207-214.

Olasantan, F. O. 2007. Effect of population density and sowing date of pumpkin on soil hydrothermal regime, weed control and crop growth in a yam and pumpkin intercrop. *Experimental Journal Agriculture* 43: 365-380.

Oliveira, J. R. S. 1994. Seletividadeeficiencia de trifluraline e diuron aplicadosem diferentesformasnacultura da mandioca (*Manihot esculuenta* Crantz). R. Unimar 16: 317-325.

Oliveira, J. R. S and Inoue, M. H. 2011. Seletividade de herbicidas para culturas e plantas daninhas. Biologia e Manejo de PlantasDaninhas. Curitiba: Omnipax. pp.243-262.

Olorunmaiye, P. M., and Olorunmaiye, K. S. 2009. Effect of integrated weed management on weed control and yield components of maize cassava intercrop in a southern Guinea savanna ecology of Nigeria. *Australian Journal of Crop Science, 3*:129-136.

Onwueme, I. C. 1978. The tropical storage root crop: yam cassava, sweet potato and cocoyam. John Wiley and sons chichester New York Pp 19-75.

Orr, A., Mwale, B. and Saiti, D. 2002. Modelling Agricultural ‘Performance’: Smallholder Weed Management in Southern Malawi. *International Journal of Pest Management* 48: 265-278.

Osundare, B., 2007. Effects of Different Interplanted legumes with cassava on major soil nutrients, weed biomass, and performance of cassava (*Manihot esculenta* Crantz) in the South Western Nigeria. ASSET *International Journal of Services Science* A 7.1: 216-227.

Overfield, D., Murithi, F. M., Muthamia, J. N., Ouma, J. O., Birungi, K. F., Maina, J. M., Kibata, J. N., Musembi, F. J., Nyanyu, G., Kamidi, M., Mose, L.O., Odendo, M., Ndungu, J., Kamau, G., Kikafunda, J. and Terry, P. J. 2001. Analysis of the constraints to adoption of herbicides by smallholder maize growers in Kenya and Uganda. *The BCPC Conference on Weeds* 907-912.

Owen, D. K. K., Zelaya, A. I. 2005. Herbicide resistant crops and weed resistance to herbicides. *Pest Management Science* 301-311.

Pappiernik, S., Yates, B. Koskinen, W. and Barber, B. 2007. Processes affecting the dissipation of the herbicide Isoxaflutole and its diketonitrile metabolite in agricultural soils under field conditions. *Journal of Agriculture and Food Chemistry* 55:8630–8639.

Phillips-McDougall, D. C. 2013. The Cost of New Agrochemical Product Discovery, Development and Registration in 1995, 2000, 2005–8 and 2010 to 2014—R and D Expenditure in 2014 and Expectations for 2019; R and D Report; Phillips McDougall: Path-head, UK, 2016; 41p. [Online]. Available: http://phillipsmcdougall.co

Pingali, P. L. and Gerpacio, R.V. 1997. Towards reduced pesticide use for cereal crops in Asia. CIMMYT Working Paper, 97-04.

Polubesova, T., Nir, S., Rabinovitz, O., Borisover, M. and Rubin, B. 2003. Sulfentrazone adsorbed on micelle-montmorillonite complexes for slow release in soil. *Journal of Agriculture and Food Chemistry,* 51:3410–3414.

Qasem, J. R. 2007. Chemical control of wild oat (*Avene strelilis* L.) and other weeds in wheat (*Triticum durum* Defs.) in Jordan. *Crop Protection* 26:1315–1324.

Qin, G., Gu, H., Ma, L., Peng, Y., Deng, X. W., Chen, Z., Qu, L-J. 2007. Disruption of phytoene desaturase gene results in albino and dwarf phenotypes in Arabidopsis by impairing chlorophyll, carotenoid, and gibberellin biosynthesis. *Cell Research* 17:471–482.

Quee, D. D., Sarkodie-Addo, J., Duku, S., Samura, A. E., Conteh, A. R., Bebeley, J. F. and Sesay1, J. F. 2016. Economic Evaluation of Weed Control and Herbicide Residues on Cassava (*Manihot esculenta* Crantz) in Ghana. *Journal of Agricultural Science* 8:47-53.

Quinones, V. and Moreno, N. 1995. Weed control in cassava in Barinas, Venezuela. *Agronomica Tropical* Maracay 45:85-93.

Rabaey, T. L. and Harvey, R. G. 1997. Sequential applications control woolly cup grass (*Eriochloa villosa*) and wild proso millet (*Panicum miliaceum*) in corn (*Zea mays*). *Weed Technology* 11: 537-542.

Rana, S. S. and Rana, M. C. 2015. Advances in weed management. Department of Agronomy, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, 55p.

Rao, V. S. 2000. Principles of Weed Science. Oxford and IBH publication New Delhi, India

Ravindran, C. S. and Ravi, V. 2009. Weed Management in Cassava. Annual Report. Central Storage root Crops Research Institute, Thiruvananthapuram, India, pp. 53-54.

Reed, T. V., McCullough, P. E. and Grey, T. 2014. Evaluation of adjuvants on flumioxazin efficacy for post-emergence annual bluegrass and residual smooth crabgrass control. *Applied Turfgrass Science* 11:1-6.

Rendina, A. R., Craig-kennard A. C., Beaudoin, J. D. and Breen M. K. 1990. Inhibition of acetylcoenzyme A carboxylase by two classes of grass-selective herbicides. *Journal of Agriculture Food Chemistry* 38:1282-1287.

Richardson, R. J., Wilson, H. P., Armel, G. R. and Hines. T. E. 2006. Trifloxysulfuron plus pyrithiobac mixtures for broadleaf weed control in cotton (*Gossypium hirsutum*). *Weed Technology* 20:130-136.

Richardson, R. J., Wilson, H. P., Armel, G. R. and Hines, T. E. 2007. Growth stage affects cotton (*Gossypium hirsutum*) response to trifloxysulfuron. *Weed Technology* 21:37-40.

Richardson, R. J., Wilson, H. P. and Hines, T. E. 2007b. Preemergence herbicides followed by trifloxysulfuron post-emergence in cotton. *Weed Technology* 21: 1-6.

Robert, E. B., O'Donovan, J. T., Harker, K. N., Clayton, G. W. and Stougaard, R. N. 2006. Reduced erbicide doses in field crops: A review. *Weed Biology and Management* 6:10-17.

Robinson, D. K., Monks, D. W. and Monaco, J. J. 1996. Potato (*Solanum storage rootosum*) tolerance and susceptibility of eight weeds to rimsulfuron with and without metribuzin. *Weed Tecnology* 10, 29 - 34.

Roch, T. and Krieger-Liszkay, A. K. 2014. Regulation of photosynthetic electron transport and photoinhibition. *Current Protein and Peptide Science* 15:351–362.

Rodrigues, B. N. and Almeida, F. S. 2011. Guia de Herbicidas. 7$^{th}$ edition. Londvina: Edicao dos Autoren. 679p.

Santabarbara, S. 2006. Limited sensitivity of pigment photo-oxidation in isolated thylakoids to singlet excited state quenching in photosystem II antenna. Archives of Biochemistry and Biophysics, 455:77–88.

Dias Santiago, A., Cavalcante, M. H. B., Braz, G. B. P. and Procópio, S. O. 2018. Efficacy and selectivity of herbicides applied in cassava pre-emergence. Rev. Caatinga, Mossoró, 31:640 – 650.

Dias Santiago, A., Procopio, S. O. and Braz, G. B. P. 2020. The use of pre-emergence herbicides in cassava decreases the need of manual weeding. *Plant health* 67: 22-27.

Sarmah, A. K. and Sabadie, J. 2002. Hydrolysis of sulfonyurea herbicides in soils and aqueous solutions: A review. *Journal of Agriculture, Food and Chemistry* 50:6253-6265.

SAS Institute (2016) SAS/STAT 9.4 user's guide. SAS Institute, Cary, NC.

Satterthwaite, F. E. 1946. "An Approximate Distribution of Estimates of Variance Components.", *Biometrics Bulletin*, 2: 110–114.

Scariot, C. A. 2013. Seletividade e eficiência de herbicidas aplicadosempré-emergênciana culturada mandioca. *Pesquisa Agropecuária Tropical*. 43:300-307.

Schweizer, E. E. 1980. Herbicides applied sequentially for economical control of annual weeds in sugar-beets. *Weed science* 28:152-159.

Searle, S. R., Casella, G., McCulloch, C. E. 1992. Variance components. John Wiley and Sons, NY.

Secor, J. and Cséke, C. 1988. Inhibition of acetyl-COA carboxylase activity by haloxyfop and tralkoxydim. *Plant Physiology* 86:10-12.

Shaner, D. L. 2014. Herbicide Handbook. 10th ed. Weed Science Society of America, Lawrence, KS.

Shaw, D. R. and Arnold, J. C. 2002. Weed control from herbicide combinationswith glyphosate. *Weed Technology* 16, 1–6.

Sherwani, S. I., Arif, I. A. and Khan, H. A. 2015. Modes of action of different classes of herbicides. Herbicides, physiology of action and safety. Andrew Price, Jessica Kelton and Lina Sarunaite, IntechOpen, Available from: https://www.intechopen.com/books/herbicides-physiology of action-and safety/modes-of-action-of-different-classes-of-herbicides

Sieczka, J. B. and J. F. Creigton. 1984. Weed control of potatoes on Long Island. *Proceedings Northeast Weed Science Society* 39:176-180.

Silva, F. M. L. 2009. Moléculas de herbicidasseletivos à cultura da mandioca. *Revista Trópica: CiênciasAgrárias eBiológicas*, Chapadinha, 3: 61-72.

Silva, D. V. 2011. Tolerância de cultivares de mandioca aosherbicidasfomesafen e fluazifop-p-butil. R. Bras. Herbic. 10:219-231.

Silva, M. G. O., Freitas, F. C. L., Negreiros, M. Z., Mesquita, H. C., Santana, F. A. O. and Lima, M. F. P. 2013. Manejo de plantasdaninhasnacultura da melancianossistemas de plantiodireto e convencional. HorticulturaBrasileira, 31:494-499.

Silva, D. C. M., Cesarin, A. E., Martins, F. R. B., Ferrarezi, D. P., Alves, C. A. and Pivetta, K. F. L. 2016. Selectivity and efficiency of herbicides in warm season turfgrass varieties. *African Journal of Agricultural Research* 11:3299-3306.

Sims, G., Taylor-Lovel, S., Tarr, G. and Maskel, S. 2009. Role of sorption and degradation in the herbicidal function of isoxaflutole. *Pest Management Science* 65:805–810.

Singh, H. and Angiras, N. N. 1996. Weed management study in Garden pea (Pisum sativum sub sp. Hortens L). *Indian Journal Weed Science* 36:1 135 – 137.

Singh, A., Virk, A. S., Singh, J. and Singh, J. 2001. Comparison of pre- and post-emergence application of herbicides for the control of weeds in sugarcane. *Sugar Technology* 3:3, 19 – 112.

So, Y. S. and Edwards, J. 2009. A comparison of mixed model analyses of the lowa crop performance test for corn. *Crop Science* 49: 1593–1601.

Swanton, C. J., Clements, D. R. and Derksen, D. A. 1993. Weed succession under conservation tillage. A Hierchical Framework for Research and Management. *Weed Technology* 7:2 286 – 297.

Swanton, C. J., Shrestha, A., Clements, D. R., Booth, B. D. and Chandler, K. 2002. Evaluation of alternative weed management systems in a modified no-tillage maize-soybean-winter wheat rotation: Weed densities. Crop Yield, Economics. *Weed Science* 50: 504-511.

Tabib, F. A. I., Akhteruzzaman, M. T., Islam, K. and Khalekuzzaman, M. 2014. Efficacy of different herbicides over manual weeding in controlling cotton weed. *Bangladesh Journal of Weed Science* 4:39-44.

Tahir, M., Javed, M. R., Tanveer, A., Nadeem, M. A., Wasaya, A., S., Bukhari, S. A. H. and Rehman, J. U. 2009. Effect of different herbicides in weeds, growth and yield of spring planted maize (*Zea mays* L.). *Pakistan Journal Life Society Science* 7.2: 168-174

Tateno, M., Brabham, C. and Debolt, S. 2006. Cellulose biosynthesis inhibitors-a multifunctional toolbox. *Journal of Experimental Botany*, 67;533-542.

Taylor-Lovell, S., Sims, G. K. and Wax, L. M. 2002. Effects of moisture, temperature, and biological activity on the degradation of isoxaflutole in soil. *Journal of Agriculture, Food and Chemistry* 50: 5626-5633.

Theodoridis, G., Baum, J. S., Hotzman, F. W., Manfredi, M. C., Maravetz, M. L., Lyga, J. W., Tymonko J. M., Wilson, K. R., Poss, K. M. and Wyle, M. J. 1992. Synthesis and herbicidal properties of aryltriazolinones. A new class of pre- and postemergence herbicides. p 135-1446 in Baker, D.R., J.G. Fenyes, J.J. Steffens, eds.; Synthesis and Chemistry of Agrochemicals lll. ACS symposium series 504.

Thompson, C. R., Peterson, D. E., Fick, W. H., Stahlman, P. W. and Wolf, R. E. 2009. Chemical weed control for field crops, pastures, rangeland, and noncropland. Report of Progress 1007. Kansas State University, Manhattan, KS.

Tomlin, C. D. S. (Ed.). 2006. The pesticide manual: a world compendium, BCPC Publications, Hampshire (UK).

Torrens, F. and Castellano, G. 2014. Molecular classification of pesticides including persistent organic pollutants, phenylurea and sulphonylurea herbicides. *The Molecules* 19:7388–7414.

Travlos, I. S. and Chachalis, D. 2012. Relative competitiveness of glyphosate-resistant and glyphosate-susceptible populations of hairy fleabane (*Conyz abonariensis* L.). *Journal of Pest Science 86*: 345–351.

Travos, I. S., Lysandrou, M. and Apostolidis, V. 2014. Efficacy of the herbicide GF-2581 (penosulam + florasulam against broadleaf weeds in olives. *Plant Soil Environment* 6:12 574 – 579.

Trenkamp, S., Martin, W. and Tietjen, K. 2004. Specific and differential inhibition of very-long- chain fatty acid elongases from Arabidopsis thaliana by different herbicides. *Proceedings of the National Academy of Sciences* USA. 101:11903–11908.

Tresch, S., Niggeweg, R. and Grossmann, K. 2008. The herbicide flamprop-M-methyl has a new antimicrotubule mechanism of action. *Pest Management Science* 64:1195–1203.

Ukekje, E. 2004. Modernizing Small Holder Agriculture to Ensure Food Security and Gender Empowerment: Issues and Policy. International Group of Twenty-Four. Research Papers available at *http://www.g24.org/research.htm#U*.

Uremis, I., Bayat, A., Uludag, A., Bozdogan, N., Aksoy, E., Soysal, A. and Gonen, O. 2004. Studies on different herbicide application methods in second-crop maize fields. *Crop Protection* 23:1137–1144.

U.S. Environmental Protection Agency. 2010. Pesticide fact sheet. Conditional registration. pp. 1–108.

Van Heemst, H. D. J. 1985. The influence of weed competition on crop yield. *Agricultural Systems, Elsevier* 18:81-93.

Varshney, S., Hayat, S., Alyemeni, M. N. and Ahmad, A. 2012. Effects of herbicide applications in wheat fields: is phytohormones application a remedy? Plant Signaling and Behavior. 7:570–575.

Velmurugan, M., Pugalendhi, L. and Manickam, S. 2017. Effect of weed management practices on the growth and yield of cassava (*Manihot esculenta* Crantz). *Journal of Root Crops* 43: 34-38.

Vencill, W. K. 2012. Herbicide resistance: towards an understanding of resistance development and the impact of herbicide-resistant crops. *Weed Science* Champaign, 60:2-30.

Viana, A. E. S., Sediyama, T. and Cecon, P. R. 2001. Efeito do comprimento e de incisões no córtex da manivasobre o cultivo da mandioca (*Manihot esculenta* Crantz). *Acta Science,* 23:1263-1269.

Vidah, R. A., Trezzi, M. M., De Prado, R., Ruiz-Santaella, J. P. and Vila-Aiub, M. M. 2007. Glyphosate resistant biotypes of wild poinsettia (*Euphorbia heterophylla* L.) and its risk analysis on glyphosate tolerant soybeans. *International Journal of Food, Agriculture and Environment* 2:265-269.

Vissoh, P. V., Gbehounou, G., Ahanchede, A., Kuyper, T. W. and Roling, N. G. 2004. Weeds as Agricultural Constraint to Farmers in Benin: Results of a Diagnostic Study. *Journal of Life Sciences* 52:305-329.

Walkey, A. and Black, C. 1947. A critical examination of a rapid method for determination of organic carbon in soils - effect of variations in digestion conditions and of inorganic soil constituents. *Soil Science* 63: 251-257.

Weed Science Society of America. 2007. *Herbicide handbook*, 9th Edition. Lawrence, K. S. ISBN 1-891276-56-5.

Wesley, R. A., Smith, L. A. and Spurlock, S. R. 1993. Economic analysis of irrigation and deep tillage in soya beans production systems on clay soil. *Soil and Tillage Research* 28: 63-78.

Westra, E. P. 2012. Adsorption, leaching, and dissipation of pyroxasulfone and two chloroacetamide herbicides. Colorado State University.

Whitcomb, C. E.1999. An introduction to ALS-inhibiting herbicides. *Toxicology and Industrial Health*.15:231–239.

Williams, H. J. 1979. Estimation of HCN released from cassava by organic solvents. *Experimental Agriculture 15:* 393–9.

Witkowski, D. A., and Halling, B. P. 1989. Inhibition of plant protoporphyrinogenn oxidase by the herbicide acifluorfen-methyl. *Plant Physiology* 90:1239-1242.

Yamaji, Y., Honda, H., Kobayashi, M., Hanai, R. and Inoue, J. 2014. Weed Control Efficacy of a Novel Herbicide, Pyroxasulfone. *Pesticide Science* 39:165-169.

Yamaji, Y., Honda, H., Hanai, R. and Inoue, J. 2016. Soil and Environmental Factors Affecting the efficacy of pyroxasulfone for weed control. *Pesticide Science* 41:1-5.

Yang, X., Guschina, I. A., Hurst, S., Wood, S., Langford, M., Hawkes, T. and Harwood, J. L. 2010. The action of herbicides on fatty acid biosynthesis and elongation in barley and cucumber. *Pest Management Science* 66:794–800.

Yu, Q., and Powles, S. 2014. Metabolism-based herbicide resistance and cross-resistance in crop weeds: a threat to herbicide sustainability and global crop production. *Plant physiology* 166:1106-1118.

Yoshida, R., Sakaki, M., Sato, R., Haga, T., Nagano, E., Oshio, H. and Kamoshita, K. 1991. S-53482: a new *N*-phenyl phthalimide herbicide. Proceedling Brighton Crop Protection Conference Weeds 1:69–75.

Zand, E., Baghestani M. A., Soufizadeh, S., PourAzar R. J., Veysi, M., Bagherani, N., Barjasteh, A., Khayami, M. M. and Nezamabadi, N. 2007. Broadleaved weed control in winter wheat (*Triticum aestivum* L.) with post-emergence herbicides in Iran. *Crop Protection* 26:746 – 752.

Zand, E., Baghestani, M. A., Alikhani, M. A., Soufizadeh, S., Khayami, M. M., PourAzar, R., Sabeti, P., Jamali, M., Bagherani, N. and Forouzesh, S. 2010. Chemical control of weeds in wheat (*Triticum aestivum* L.) in Iran. *Crop Protection* 29:1223–1231.

Ziska, L., Runion, G. B., Tomecek, M., Prior, S. A., Torbet, H. A. and Sicher, R. 2009. An evaluation of cassava, sweet potato and field corn as potential carbohydrate sources for bioethanol production in Alabama and Maryland. *Biomass and Bioenergy* 33:1503-1508.

## APPENDICES

**Table 1:** Total cost for cassava production under different treatments in naira per hectare during 2015-2018 cropping year

| Items | S+T | S+CL | S+C | FP+T | FP+CL | FP+C | II+T | II+CL | II+C | Atrazine + s-metolachlor | Hoe-weeding | Weedy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plough | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 |
| Harrow | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 |
| Ridge | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 |
| Planting material | 21000 | 21000 | 21000 | 21000 | 21000 | 21000 | 21000 | 21000 | 21000 | 21000 | 21000 | 21000 |
| Planting | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 |
| Herbicides spraying | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 12000 | nil | nil |
| Fertilizer | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 |
| Harvesting | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 | 20000 |
| Herbicides cost/weeding | 22701 | 44842 | 21263 | 35861 | 58002 | 34423 | 22245 | 44386 | 20807 | 117500 | 150000 | nil |
| TOTAL | 187701 | 209842 | 186263 | 200861 | 223002 | 199423 | 187245 | 209386 | 185807 | 258500 | 291000 | 141000 |

S, sulfentrazone (₦14840/ha); T, trifloysulfuron-sodium (₦7862/ha) CL, clethodim + lactofen (₦9282 + 20720/ha) C, cafertrazone-ethyl (₦6423/ha) FP, flumioxazin + pyroxasulfone (₦28000/ha) II, indaziflam + isoxaflutole (₦14386/ha)

**Table 2: Partial budget analysis for cassava production with application of herbicides in sequence: pre-post and post-pre for weed control on 1-hectare land during 2015-2018 cropping year**

| Treatment | Pre-post Net Benefit (₦) | Pre-post Marginal Rate of Return (%) | Post-pre Net Benefit (₦) | Post-pre Marginal Rate of Return (%) | Average net benefit |
|---|---|---|---|---|---|
| Sulfentrazone + Trifloysulfuron-sodium | 177469 | -296.4 | 360899 | 219.8 | 269184 |
| Sulfentrazone + Clethodin-Lactofen | 165907 | -209.8 | 503608 | 370.4 | 334757.5 |
| Sulfentrazone + Cafertrazone-ethyl | 184867 | -288.3 | 309587 | 95.9 | 247227 |
| Flumioxazin-Pyroxasulfone +Trifloysulfuron-sodium | 852922 | 1040.0 | 763139 | 918.1 | 808030.5 |
| Flumioxazin-Pyroxasulfone + Clethodin-Lactofen | 767793 | 622.8 | 820998 | 725.8 | 794395.5 |
| Flumioxazin-Pyroxasulfone + Cafertrazone-ethyl | 846937 | 1057.3 | 562077 | 557.0 | 704507 |
| Indaziflam-Isoxaflutole + Trifloysulfuron-sodium | 871685 | 1442.5 | 803005 | 1331.9 | 837345 |
| Indaziflam-Isoxaflutole + Clethodin-Lactofen | 949575 | 1052.9 | 775164 | 811.3 | 862369.5 |
| Indaziflam-Isoxaflutole + Cafertrazone-ethyl | 937885 | 1668.9 | 658343 | 1005.1 | 798114 |
| Atrazine-S-metolachlor + 2-Hoe-weeding | 796781 | 488.4 | 733350 | 450.5 | 765065.5 |
| 3-Hoe-weeding | 761820 | 323.7 | 733300 | 321.0 | 747560 |
| Weedy | 303320 | nil | 278700 | nil | |

F= E + operational cost; G= B × price of storage root + D × price of stem; H = F – G; 1 bundle= ₦300

$$I = \frac{\text{Marginal benefit from weed control}}{\text{Marginal investment on weed control}}$$

**Table 3**: Major weeds identified on experimental field and their common names

| Botanical names | Common names |
|---|---|
| *Passiflora foetida* Linn. | Passion flower |
| *Panicum maximum* Jacq. | Guinea grass |
| *Spigelia anthelmia* Linn. | Wormwood/pinkroot |
| *Gomphrena celosiodes* Mart. | Cockscomb |
| *Digitaria horizontalis* Willd. | Crabgrass |
| *Spemacoce verticillata* Linn. | Shrubby false buttonweed |
| *Portulaca quadrifida* Linn. | Chicken weed |
| *Talinum fruticosm*. | Water leaf |
| *Portulaca oleracea* Linn. | Duck weed |
| *Acmella grandiflora Turcz.* | Swamp daisy |
| *Boerhavia ereta* Linn. | Erect spiderling |
| *Paspalum orbiculare* Forst. | Scrobic |
| *Rottboellia cochinchinensis* (Lour.) | Itch grass |
| *Euphorbia heterophylla* Linn. | Dovemilk/milkweed |
| *Oldenlandia corymbosa* Linn. | Diamond flower |
| Sedges | Sedges |
| *Cleome rutidosperma* D.C. | Spiderflower |
| *Tridax procumbens* Linn. | Coat buttons |
| *Calopogonium mucunoides* Desv. | Wild groundnut |

**Pearson Correlation Coefficients, N = 54**
**Prob > |r| under H0: Rho=0**

| | stemno_A | stemwt_A | shtwt_A | rootwt_A |
|---|---|---|---|---|
| **stemno_A** | 1 | | | |
| **stemwt_A** | 0.05152<br>0.7114 | | | |
| **shtwt_A** | 0.44924<br>0.0007 | 0.09571<br>0.4912 | | |
| **rootwt_A** | 0.08897<br>0.5223 | 0.37376<br>0.0054 | 0.33425<br>0.0135 | |

| | stemno_F | stemwt_F | shtwt_F | rootwt_F |
|---|---|---|---|---|
| **stemno_F** | 1 | | | |
| **stemwt_F** | 0.23227<br>0.091 | | | |
| **shtwt_F** | 0.22526<br>0.1015 | 0.03307<br>0.8123 | | |
| **rootwt_F** | 0.01375<br>0.9214 | 0.56133<br><.0001 | 0.44335<br>0.0008 | |

| | **stemno_M** | **stemwt_M** | **shtwt_M** | **rootwt_M** |
|---|---|---|---|---|
| **stemno_M** | 1 | | | |
| **stemwt_M** | 0.06729 | | | |
| | 0.6288 | | | |
| **shtwt_M** | 0.27871 | 0.05204 | | |
| | 0.0413 | 0.7086 | | |
| **rootwt_M** | 0.15566 | 0.65248 | 0.53833 | |
| | 0.261 | <.0001 | <.0001 | |

| | **stemno_S** | **stemwt_S** | **shtwt_S** | **rootwt_S** |
|---|---|---|---|---|
| **stemno_S** | 1 | | | |
| **stemwt_S** | 0.08462 | | | |
| | 0.5429 | | | |
| **shtwt_S** | 0.49297 | 0.25121 | | |
| | 0.0002 | 0.0669 | | |
| **rootwt_S** | 0.44754 | 0.2968 | 0.5864 | |
| | 0.0007 | 0.0293 | <.0001 | |

| | stemno_SM | stemwt_SM | shtwt_SM | rootwt_SM |
|---|---|---|---|---|
| **stemno_SM** | 1 | | | |
| **stemwt_SM** | 0.09631<br>0.4884 | | | |
| **shtwt_SM** | 0.24988<br>0.0684 | 0.13606<br>0.3266 | | |
| **rootwt_SM** | 0.30802<br>0.0235 | 0.3933<br>0.0033 | 0.59732<br><.0001 | |

| | stemno_E | stemwt_E | shtwt_E | rootwt_E |
|---|---|---|---|---|
| **stemno_E** | 1 | | | |
| **stemwt_E** | 0.34451<br>0.0107 | | | |
| **shtwt_E** | 0.12023<br>0.3865 | 0.18127<br>0.1896 | | |
| **rootwt_E** | 0.26588<br>0.052 | 0.03948<br>0.7768 | 0.37538<br>0.0052 | |

# Anova tables

**plant count-12wap**

**Estimates**

| Label | Estimate | Standard Error | DF | t Value | Pr > \|t\| |
|---|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | -0.02299 | 0.004289 | 277 | -5.36 | <.0001 |
| Authority 1st Vs Authority 2nd | -0.02404 | 0.007429 | 277 | -3.24 | 0.0016 |
| Fierce 1st Vs Fierce 2nd | -0.00538 | 0.007429 | 277 | -0.72 | 0.4693 |
| MerlinTot 1st Vs merlinTot 2nd | -0.03956 | 0.007429 | 277 | -5.33 | <.0001 |
| Envoke 1st Vs Envoke 2nd | 0.02596 | 0.007429 | 277 | 3.49 | 0.0006 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 0.02247 | 0.007429 | 277 | 3.03 | 0.0027 |
| Shark 1st Vs Shark 2nd | 0.01719 | 0.007429 | 277 | 2.31 | 0.0214 |

**Contrasts**

| Label | Num DF | Den DF | F Value | Pr > F |
|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 1 | 277 | 28.74 | <.0001 |
| Authority 1st Vs Authority 2nd | 1 | 277 | 10.47 | 0.0014 |
| Fierce 1st Vs Fierce 2nd | 1 | 277 | 0.53 | 0.4693 |
| MerlinTot 1st Vs merlinTot 2nd | 1 | 277 | 28.36 | <.0001 |
| Envoke 1st Vs Envoke 2nd | 1 | 277 | 12.21 | 0.0006 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 1 | 277 | 9.15 | 0.0027 |
| Shark 1st Vs Shark 2nd | 1 | 277 | 5.35 | 0.0214 |

**plant count-12wap (untransformed data)**

**Estimates**

| Label | Estimate | Standard Error | DF | t Value | Pr > \|t\| |
|---|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | -563.27 | 105.06 | 277 | -5.36 | <.0001 |
| Authority 1st Vs Authority 2nd | -578.7 | 181.97 | 277 | -3.18 | 0.0016 |
| Fierce 1st Vs Fierce 2nd | -138.89 | 181.97 | 277 | -0.76 | 0.446 |
| MerlinTot 1st Vs merlinTot 2nd | -972.22 | 181.97 | 277 | -5.34 | <.0001 |
| Envoke 1st Vs Envoke 2nd | 648.15 | 181.97 | 277 | 3.56 | 0.0004 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 555.56 | 181.97 | 277 | 3.05 | 0.0025 |
| Shark 1st Vs Shark 2nd | 416.67 | 181.97 | 277 | 2.29 | 0.0228 |

**Contrasts**

| Label | Num DF | Den DF | F Value | Pr > F |
|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 1 | 277 | 28.75 | <.0001 |
| Authority 1st Vs Authority 2nd | 1 | 277 | 10.11 | 0.0016 |
| Fierce 1st Vs Fierce 2nd | 1 | 277 | 0.58 | 0.446 |
| MerlinTot 1st Vs merlinTot 2nd | 1 | 277 | 28.55 | <.0001 |
| Envoke 1st Vs Envoke 2nd | 1 | 277 | 12.69 | 0.0004 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 1 | 277 | 9.32 | 0.0025 |
| Shark 1st Vs Shark 2nd | 1 | 277 | 5.24 | 0.0228 |

**vigour-12wap**

**Estimates**

| Label | Estimate | Standard Error | DF | t Value | Pr > \|t\| |
|---|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 0.4136 | 0.05651 | 277 | 7.32 | <.0001 |
| Authority 1st Vs Authority 2nd | 0.2593 | 0.09788 | 277 | 2.65 | 0.0085 |
| Fierce 1st Vs Fierce 2nd | 0.463 | 0.09788 | 277 | 4.73 | <.0001 |
| MerlinTot 1st Vs merlinTot 2nd | 0.5185 | 0.09788 | 277 | 5.3 | <.0001 |
| Envoke 1st Vs Envoke 2nd | -0.4444 | 0.09788 | 277 | -4.54 | <.0001 |
| SeltmxCob 1st Vs SeltmxCob 2nd | -0.01852 | 0.09788 | 277 | -0.19 | 0.8501 |
| Shark 1st Vs Shark 2nd | -0.7778 | 0.09788 | 277 | -7.95 | <.0001 |

**Contrasts**

| Label | Num DF | Den DF | F Value | Pr > F |
|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 1 | 277 | 53.57 | <.0001 |
| Authority 1st Vs Authority 2nd | 1 | 277 | 7.02 | 0.0085 |
| Fierce 1st Vs Fierce 2nd | 1 | 277 | 22.37 | <.0001 |
| MerlinTot 1st Vs merlinTot 2nd | 1 | 277 | 28.07 | <.0001 |
| Envoke 1st Vs Envoke 2nd | 1 | 277 | 20.62 | <.0001 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 1 | 277 | 0.04 | 0.8501 |
| Shark 1st Vs Shark 2nd | 1 | 277 | 63.15 | <.0001 |

**plant height-12wap**

**Estimates**

| Label | Estimate | Standard Error | DF | t Value | Pr > \|t\| |
|---|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 10.438 | 1.6425 | 277 | 6.35 | <.0001 |
| Authority 1st Vs Authority 2nd | -10.6823 | 2.8449 | 277 | -3.75 | 0.0002 |
| Fierce 1st Vs Fierce 2nd | 24.1063 | 2.8449 | 277 | 8.47 | <.0001 |
| MerlinTot 1st Vs merlinTot 2nd | 17.8898 | 2.8449 | 277 | 6.29 | <.0001 |
| Envoke 1st Vs Envoke 2nd | -8.1369 | 2.8449 | 277 | -2.86 | 0.0046 |
| SeltmxCob 1st Vs SeltmxCob 2nd | -1.674 | 2.8449 | 277 | -0.59 | 0.5567 |
| Shark 1st Vs Shark 2nd | -19.8275 | 2.8449 | 277 | -6.97 | <.0001 |

**Contrasts**

| Label | Num DF | Den DF | F Value | Pr > F |
|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 1 | 277 | 40.38 | <.0001 |
| Authority 1st Vs Authority 2nd | 1 | 277 | 14.1 | 0.0002 |
| Fierce 1st Vs Fierce 2nd | 1 | 277 | 71.8 | <.0001 |
| MerlinTot 1st Vs merlinTot 2nd | 1 | 277 | 39.54 | <.0001 |
| Envoke 1st Vs Envoke 2nd | 1 | 277 | 8.18 | 0.0046 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 1 | 277 | 0.35 | 0.5567 |
| Shark 1st Vs Shark 2nd | 1 | 277 | 48.57 | <.0001 |

**plant count-12map**

**Estimates**

| **Label** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** |
|---|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 0.01732 | 0.01137 | 277 | 1.52 | 0.1289 |
| Authority 1st Vs Authority 2nd | 0.04691 | 0.01969 | 277 | 2.38 | 0.0179 |
| Fierce 1st Vs Fierce 2nd | 0.01001 | 0.01969 | 277 | 0.51 | 0.6117 |
| MerlinTot 1st Vs merlinTot 2nd | -0.00496 | 0.01969 | 277 | -0.25 | 0.8012 |
| Envoke 1st Vs Envoke 2nd | 0.004627 | 0.01969 | 277 | 0.23 | 0.8144 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 0.006812 | 0.01969 | 277 | 0.35 | 0.7297 |
| Shark 1st Vs Shark 2nd | -0.06717 | 0.01969 | 277 | -3.41 | 0.0007 |

**Contrasts**

| **Label** | **Num DF** | **Den DF** | **F Value** | **Pr > F** |
|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 1 | 277 | 2.32 | 0.1289 |
| Authority 1st Vs Authority 2nd | 1 | 277 | 5.67 | 0.0179 |
| Fierce 1st Vs Fierce 2nd | 1 | 277 | 0.26 | 0.6117 |
| MerlinTot 1st Vs merlinTot 2nd | 1 | 277 | 0.06 | 0.8012 |
| Envoke 1st Vs Envoke 2nd | 1 | 277 | 0.06 | 0.8144 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 1 | 277 | 0.12 | 0.7297 |
| Shark 1st Vs Shark 2nd | 1 | 277 | 11.63 | 0.0007 |

**plant count-12map (untransformed data)**

**Estimates**

| Label | Estimate | Standard Error | DF | t Value | Pr > \|t\| |
|---|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 218.62 | 208.48 | 277 | 1.05 | 0.2952 |
| Authority 1st Vs Authority 2nd | 733.02 | 361.09 | 277 | 2.03 | 0.0433 |
| Fierce 1st Vs Fierce 2nd | 38.5802 | 361.09 | 277 | 0.11 | 0.915 |
| MerlinTot 1st Vs merlinTot 2nd | -115.74 | 361.09 | 277 | -0.32 | 0.7488 |
| Envoke 1st Vs Envoke 2nd | 115.74 | 361.09 | 277 | 0.32 | 0.7488 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 154.32 | 361.09 | 277 | 0.43 | 0.6694 |
| Shark 1st Vs Shark 2nd | -964.51 | 361.09 | 277 | -2.67 | 0.008 |

**Contrasts**

| Label | Num DF | Den DF | F Value | Pr > F |
|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 1 | 277 | 1.1 | 0.2952 |
| Authority 1st Vs Authority 2nd | 1 | 277 | 4.12 | 0.0433 |
| Fierce 1st Vs Fierce 2nd | 1 | 277 | 0.01 | 0.915 |
| MerlinTot 1st Vs merlinTot 2nd | 1 | 277 | 0.1 | 0.7488 |
| Envoke 1st Vs Envoke 2nd | 1 | 277 | 0.1 | 0.7488 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 1 | 277 | 0.18 | 0.6694 |
| Shark 1st Vs Shark 2nd | 1 | 277 | 7.13 | 0.008 |

**stemno-12map**

**Estimates**

| Label | Estimate | Standard Error | DF | t Value | Pr > \|t\| |
|---|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 0.07627 | 0.01103 | 277 | 6.92 | <.0001 |
| Authority 1st Vs Authority 2nd | 0.2254 | 0.0191 | 277 | 11.8 | <.0001 |
| Fierce 1st Vs Fierce 2nd | 0.02404 | 0.0191 | 277 | 1.26 | 0.2092 |
| MerlinTot 1st Vs merlinTot 2nd | -0.02066 | 0.0191 | 277 | -1.08 | 0.2804 |
| Envoke 1st Vs Envoke 2nd | -0.04989 | 0.0191 | 277 | -2.61 | 0.0095 |
| SeltmxCob 1st Vs SeltmxCob 2nd | -0.04449 | 0.0191 | 277 | -2.33 | 0.0205 |
| Shark 1st Vs Shark 2nd | -0.1329 | 0.0191 | 277 | -6.96 | <.0001 |

**Contrasts**

| Label | Num DF | Den DF | F Value | Pr > F |
|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 1 | 277 | 47.84 | <.0001 |
| Authority 1st Vs Authority 2nd | 1 | 277 | 139.31 | <.0001 |
| Fierce 1st Vs Fierce 2nd | 1 | 277 | 1.58 | 0.2092 |
| MerlinTot 1st Vs merlinTot 2nd | 1 | 277 | 1.17 | 0.2804 |
| Envoke 1st Vs Envoke 2nd | 1 | 277 | 6.82 | 0.0095 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 1 | 277 | 5.43 | 0.0205 |
| Shark 1st Vs Shark 2nd | 1 | 277 | 48.4 | <.0001 |

**stemno-12map (untransformed data)**

**Estimates**

| Label | Estimate | Standard Error | DF | t Value | Pr > \|t\| |
|---|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 3509.85 | 423.69 | 277 | 8.28 | <.0001 |
| Authority 1st Vs Authority 2nd | 10740 | 733.85 | 277 | 14.64 | <.0001 |
| Fierce 1st Vs Fierce 2nd | 983.92 | 733.85 | 277 | 1.34 | 0.1811 |
| MerlinTot 1st Vs merlinTot 2nd | -1194.81 | 733.85 | 277 | -1.63 | 0.1046 |
| Envoke 1st Vs Envoke 2nd | -2906.43 | 733.85 | 277 | -3.96 | <.0001 |
| SeltmxCob 1st Vs SeltmxCob 2nd | -2434.17 | 733.85 | 277 | -3.32 | 0.001 |
| Shark 1st Vs Shark 2nd | -5110.73 | 733.85 | 277 | -6.96 | <.0001 |

**Contrasts**

| Label | Num DF | Den DF | F Value | Pr > F |
|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 1 | 277 | 68.63 | <.0001 |
| Authority 1st Vs Authority 2nd | 1 | 277 | 214.2 | <.0001 |
| Fierce 1st Vs Fierce 2nd | 1 | 277 | 1.8 | 0.1811 |
| MerlinTot 1st Vs merlinTot 2nd | 1 | 277 | 2.65 | 0.1046 |
| Envoke 1st Vs Envoke 2nd | 1 | 277 | 15.69 | <.0001 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 1 | 277 | 11 | 0.001 |
| Shark 1st Vs Shark 2nd | 1 | 277 | 48.5 | <.0001 |

**stemwt-12map**

**Estimates**

| Label | Estimate | Standard Error | DF | t Value | Pr > \|t\| |
|---|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 0.4684 | 0.3663 | 277 | 1.28 | 0.2021 |
| Authority 1st Vs Authority 2nd | -2.2084 | 0.6345 | 277 | -3.48 | 0.0006 |
| Fierce 1st Vs Fierce 2nd | 1.0905 | 0.6345 | 277 | 1.72 | 0.0868 |
| MerlinTot 1st Vs merlinTot 2nd | 2.5232 | 0.6345 | 277 | 3.98 | <.0001 |
| Envoke 1st Vs Envoke 2nd | -0.9773 | 0.6345 | 277 | -1.54 | 0.1246 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 0.6506 | 0.6345 | 277 | 1.03 | 0.306 |
| Shark 1st Vs Shark 2nd | -1.7121 | 0.6345 | 277 | -2.7 | 0.0074 |

**Contrasts**

| Label | Num DF | Den DF | F Value | Pr > F |
|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 1 | 277 | 1.64 | 0.2021 |
| Authority 1st Vs Authority 2nd | 1 | 277 | 12.12 | 0.0006 |
| Fierce 1st Vs Fierce 2nd | 1 | 277 | 2.95 | 0.0868 |
| MerlinTot 1st Vs merlinTot 2nd | 1 | 277 | 15.82 | <.0001 |
| Envoke 1st Vs Envoke 2nd | 1 | 277 | 2.37 | 0.1246 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 1 | 277 | 1.05 | 0.306 |
| Shark 1st Vs Shark 2nd | 1 | 277 | 7.28 | 0.0074 |

**topshootwt-12map**

**Estimates**

| Label | Estimate | Standard Error | DF | t Value | Pr > \|t\| |
|---|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | -0.5404 | 0.1232 | 277 | -4.39 | <.0001 |
| Authority 1st Vs Authority 2nd | -1.289 | 0.2134 | 277 | -6.04 | <.0001 |
| Fierce 1st Vs Fierce 2nd | -0.2501 | 0.2134 | 277 | -1.17 | 0.2422 |
| MerlinTot 1st Vs merlinTot 2nd | -0.08227 | 0.2134 | 277 | -0.39 | 0.7001 |
| Envoke 1st Vs Envoke 2nd | 0.2936 | 0.2134 | 277 | 1.38 | 0.1699 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 0.5534 | 0.2134 | 277 | 2.59 | 0.01 |
| Shark 1st Vs Shark 2nd | 0.7905 | 0.2134 | 277 | 3.7 | 0.0003 |

**Contrasts**

| Label | Num DF | Den DF | F Value | Pr > F |
|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 1 | 277 | 19.24 | <.0001 |
| Authority 1st Vs Authority 2nd | 1 | 277 | 36.49 | <.0001 |
| Fierce 1st Vs Fierce 2nd | 1 | 277 | 1.37 | 0.2422 |
| MerlinTot 1st Vs merlinTot 2nd | 1 | 277 | 0.15 | 0.7001 |
| Envoke 1st Vs Envoke 2nd | 1 | 277 | 1.89 | 0.1699 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 1 | 277 | 6.73 | 0.01 |
| Shark 1st Vs Shark 2nd | 1 | 277 | 13.72 | 0.0003 |

**rootwt-12map**

**Estimates**

| Label | Estimate | Standard Error | DF | t Value | Pr > \|t\| |
|---|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 0.2549 | 0.8779 | 277 | 0.29 | 0.7718 |
| Authority 1st Vs Authority 2nd | -7.0466 | 1.5206 | 277 | -4.63 | <.0001 |
| Fierce 1st Vs Fierce 2nd | 3.2486 | 1.5206 | 277 | 2.14 | 0.0335 |
| MerlinTot 1st Vs merlinTot 2nd | 4.5627 | 1.5206 | 277 | 3 | 0.0029 |
| Envoke 1st Vs Envoke 2nd | -0.1547 | 1.5206 | 277 | -0.1 | 0.919 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 2.7971 | 1.5206 | 277 | 1.84 | 0.0669 |
| Shark 1st Vs Shark 2nd | -4.1381 | 1.5206 | 277 | -2.72 | 0.0069 |

**Contrasts**

| Label | Num DF | Den DF | F Value | Pr > F |
|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 1 | 277 | 0.08 | 0.7718 |
| Authority 1st Vs Authority 2nd | 1 | 277 | 21.48 | <.0001 |
| Fierce 1st Vs Fierce 2nd | 1 | 277 | 4.56 | 0.0335 |
| MerlinTot 1st Vs merlinTot 2nd | 1 | 277 | 9 | 0.0029 |
| Envoke 1st Vs Envoke 2nd | 1 | 277 | 0.01 | 0.919 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 1 | 277 | 3.38 | 0.0669 |
| Shark 1st Vs Shark 2nd | 1 | 277 | 7.41 | 0.0069 |

**biomass-14wap**

**Estimates**

| Label | Estimate | Standard Error | DF | t Value | Pr > \|t\| |
|---|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | -0.2947 | 0.01199 | 277 | -24.58 | <.0001 |
| Authority 1st Vs Authority 2nd | -0.3824 | 0.02077 | 277 | -18.41 | <.0001 |
| Fierce 1st Vs Fierce 2nd | -0.3678 | 0.02077 | 277 | -17.71 | <.0001 |
| MerlinTot 1st Vs merlinTot 2nd | -0.1339 | 0.02077 | 277 | -6.45 | <.0001 |
| Envoke 1st Vs Envoke 2nd | 0.3544 | 0.02077 | 277 | 17.07 | <.0001 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 0.2109 | 0.02077 | 277 | 10.15 | <.0001 |
| Shark 1st Vs Shark 2nd | 0.3272 | 0.02077 | 277 | 15.76 | <.0001 |

**Contrasts**

| Label | Num DF | Den DF | F Value | Pr > F |
|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 1 | 277 | 604.01 | <.0001 |
| Authority 1st Vs Authority 2nd | 1 | 277 | 339.09 | <.0001 |
| Fierce 1st Vs Fierce 2nd | 1 | 277 | 313.58 | <.0001 |
| MerlinTot 1st Vs merlinTot 2nd | 1 | 277 | 41.54 | <.0001 |
| Envoke 1st Vs Envoke 2nd | 1 | 277 | 291.23 | <.0001 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 1 | 277 | 103.12 | <.0001 |
| Shark 1st Vs Shark 2nd | 1 | 277 | 248.24 | <.0001 |

**grass-12wap**

**Estimates**

| Label | Estimate | Standard Error | DF | t Value | Pr > \|t\| |
|---|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 22.8519 | 0.6898 | 277 | 25.88 | <.0001 |
| Authority 1st Vs Authority 2nd | 38.037 | 1.1947 | 277 | 21.79 | <.0001 |
| Fierce 1st Vs Fierce 2nd | 29.1481 | 1.1947 | 277 | 17.7 | <.0001 |
| MerlinTot 1st Vs merlinTot 2nd | 7.3704 | 1.1947 | 277 | 5.33 | 0.3421 |
| Envoke 1st Vs Envoke 2nd | -21.6296 | 1.1947 | 277 | -18.1 | <.0001 |
| SeltmxCob 1st Vs SeltmxCob 2nd | -6.0556 | 1.1947 | 277 | -5.07 | 0.4377 |
| Shark 1st Vs Shark 2nd | -27.9074 | 1.1947 | 277 | -21.69 | <.0001 |

**Contrasts**

| Label | Num DF | Den DF | F Value | Pr > F |
|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 1 | 277 | 669.84 | <.0001 |
| Authority 1st Vs Authority 2nd | 1 | 277 | 474.97 | <.0001 |
| Fierce 1st Vs Fierce 2nd | 1 | 277 | 313.35 | <.0001 |
| MerlinTot 1st Vs merlinTot 2nd | 1 | 277 | 28.43 | <.0001 |
| Envoke 1st Vs Envoke 2nd | 1 | 277 | 327.78 | <.0001 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 1 | 277 | 25.69 | <.0001 |
| Shark 1st Vs Shark 2nd | 1 | 277 | 470.25 | <.0001 |

**sedge-12wap**

**Estimates**

| Label | Estimate | Standard Error | DF | t Value | Pr > \|t\| |
|---|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 17.7222 | 0.5598 | 277 | 4.86 | <.0001 |
| Authority 1st Vs Authority 2nd | 26.037 | 0.9696 | 277 | 4.16 | <.0001 |
| Fierce 1st Vs Fierce 2nd | 21.3519 | 0.9696 | 277 | 2.43 | <.0001 |
| MerlinTot 1st Vs merlinTot 2nd | 5.7778 | 0.9696 | 277 | 1.83 | 0.3321 |
| Envoke 1st Vs Envoke 2nd | -22.7963 | 0.9696 | 277 | -2.88 | <.0001 |
| SeltmxCob 1st Vs SeltmxCob 2nd | -5.963 | 0.9696 | 277 | -2.02 | 0.3493 |
| Shark 1st Vs Shark 2nd | -25.2778 | 0.9696 | 277 | -3.38 | <.0001 |

**Contrasts**

| Label | Num DF | Den DF | F Value | Pr > F |
|---|---|---|---|---|
| Pre-Post-Trt Vs Post-Pre-Trt | 1 | 277 | 23.65 | <.0001 |
| Authority 1st Vs Authority 2nd | 1 | 277 | 17.34 | <.0001 |
| Fierce 1st Vs Fierce 2nd | 1 | 277 | 5.88 | 0.0159 |
| MerlinTot 1st Vs merlinTot 2nd | 1 | 277 | 3.36 | 0.0678 |
| Envoke 1st Vs Envoke 2nd | 1 | 277 | 8.32 | 0.0042 |
| SeltmxCob 1st Vs SeltmxCob 2nd | 1 | 277 | 4.1 | 0.0439 |
| Shark 1st Vs Shark 2nd | 1 | 277 | 11.43 | 0.0008 |