FIELD PERSISTENCE OF S-METOLACHLOR AND PENDIMETHALIN IN MAIZE-BASED CROPPING SYSTEM AND IMPACT ON EARTHWORM ACTIVITIES IN OGBOMOSO, NIGERIA

BY

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ABSTRACT

Application of chemicals on weed has been an effective method of weed control. However, this is with problems of persistence and hazardous effects on non-target organisms like arthropods. Common herbicides used in maize fields in Ogbomoso include atrazine, primextra, Lasso/atrazine, diuron pendimethalin, and S-metolachlor. Information on S-metolachlor and Pendimethalin persistence under field situations is inadequate. Therefore, persistence of S-metolachlor and Pendimethalin in maize field and their effects on earthworms were investigated.

Information on the use of herbicide was collected from 120 randomly selected respondents from three out of five local government areas in Ogbomoso. S-metolachlor (0.8, 1.2, 1.6 L/ha), Pendimethalin (1.0, 1.5, 2.0 L/ha), hoe weeded, Weedy Check (WC) and mancozeb (2 kg ai/ha) (as toxic standard) were applied to maize (Oba super variety) plots. Soil and worm cast were randomly sampled for physico-chemical analyses Before Planting (BP) and worm cast alone at 90 Days After Planting (DAP). Maize seedling survivals at 14 DAP, weed biomass at 56 DAP and Maize Grain Yields were assessed. Earthworm density and species were determined using formalin extraction method at planting and 30 DAP. Soil samples were taken for herbicide residue analyses using spectrophotometry to determine Disappearance Time for 50% (DT_{50}) of the herbicides. Lethal Concentrations for 50% (LC_{50}) mortality on two earthworm species were determined by Contact Filter Paper (CFP) and Soil Test (ST). Data were analysed using descriptive statistics and ANOVA at $\alpha_{0.05}$.

Thirteen herbicides including S-metolachlor and pendimethalin were being used. Approximately 37.4% and 21.4% of farmers used S-metolachlor (0.066 L/ha) and Pendimethalin (0.6 L/ha) which are below Recommended Rates (RR) of 1.6 L/ha and 2.0 L/ha respectively. Organic carbon (16.4 and 6.7 g/kg), nitrogen (1.3 and 0.5 g/kg), Phosphorus (15.6 and 5.9 mg/kg), Silt (210 and 80 g/kg), Clay (150 and 130 g/kg), and sand (640 and 790 g/kg) were obtained from worm casts and soil respectively BP. Phosphorus was significantly higher in worm casts 90 DAP (20.6 mg/kg) than BP (15.6 mg/kg). Seedling survivals at 14 DAP ranged from 90-94.2%. Weed biomass under S-metolachlor at 1.2 L/ha (26.6±7.9 g), Pendimethalin at 2.0 L/ha (27.2±7.2 g) and hoe weeded (33.0±8.3 g) were lower than WC (56.4±13.5 g). Maize grain yield under S-metolachlor at 1.2 L/ha (2111.1 kg/ha) and Pendimethalin at 2.0 L/ha (2244.7 kg/ha) were significantly higher than WC (602.2 kg/ha). Densities of *Lumbricus terrestris* (0.6±0.3), *Eisenia fetida* (0.9±0.3), and *Libyodrilus violaceus* (0.9±0.2) BP were lower at 30 DAP (0.8±0.2, 2.3±0.5

and 0.9±0.1 respectively). The DT_{50} were 53.4, 53.8 and 55.4 days for 0.8, 1.2, and 1.6 L/ha respectively under S-metolachlor and 48.3, 57.3 and 37.9 days for 1.0, 1.5 and 2.0 L/ha respectively under Pendimethalin. The LC_{50} under S-metolachlor in CFP and ST respectively were *E. fetida* (1.6, 1.5 L/ha) and *L. violaceus* (0.5, 1.4 L/ha) while under Pendimethalin were *E. fetida* (1.9, 1.8 L/ha) and *L. violaceus* (2.6, 1.8 L/ha), which were lower than RR.

S-metolachlor and Pendimethalin were moderately persistent. Their recommended rates gave highest maize grain yield, but were toxic to the two test earthworms.

Keywords: Herbicide Persistence, maize yield, worm casts

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. CERTIFICATION

I certify that this work was carried out by Mr. Kasali Amofe ADELASOYE of the Department of Crop Protection and Environmental Biology, University of Ibadan at Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria

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DEDICATION

This piece is dedicated to:

- my beloved queen **Adebisi**.**Iyabo,**
- my kids. Ibukun, Mayowa, Funbi, Femi and Tomilola.; and
- my sweet mother, **Deborah Atilola**.

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CHAPTER ONE

1.0 INTRODUCTION

Food security cannot be sustained and in fact cannot be guaranteed as agriculture is practised now in Nigeria in which, despite the natural endowment for agricultural production, heavy importation of rice, wheat, etc. is the order of the day. Research reports are being swept under carpets instead of implementation for possible improvement. Maize (*Zea mays* L.) is an important staple food crop and provides bulk of raw materials for the livestock and many agro-allied industries in the world (Bello *et al.*, 2010*;* Randjelovic *et al.*, 2011). Maize production fell from 11.49% in 2006 to -16.67% in 2007 thus the Nigerian Government had to lift ban on corn importation in 2008 and allowed imports at 5% tariff because domestic corn production was short of demand particularly for poultry producers (USDA, 2011). Maize production in Nigeria has been dwindling since independence with series of increasing and decreasing rates. USDA (2012) reported -16.67, 22.62, 12.30, 4.36 and -6.85% growth rate which correspond respectively to 6.50, 7.97, 8.95, 9.34 and 8.70 million tones for 2007, 2008, 2009,2010 and 2011, respectively.

Crop production is confronted with problem of pests which include insects and other invertebrates, vertebrates, weeds including parasitic higher plants, etc. Weeds must be controlled in order to grow crops economically. It is estimated that some 1,800 weed species cause serious economic losses in crop production and about 300 of these weed species are responsible for the serious economic losses in cultivated crops throughout the world (Chandler, 1984). Weeds and other pests reduce yields of agricultural crops by 15 to 20% in developed countries; reductions soar to 50% in undeveloped regions (Nata and Mitar, 2002). Weeds are one of the most important factors in maize production. Maize has been shown to be sensitive to weed infestation in the first four (4) weeks after planting (Onochie, 1975). Yield loses due to weed infestation can range from 40% (Akobundu, 1987) to 97% (Olabode *et al*., 1999a) in maize and 91% in sweet potato (Akobundu, 1987). In Nigeria, yield losses due to weed vary between 40 and 100% depending among other things on type of crops, type of weeds, and weed density (Fadayomi and Olofintoye, 1991). Udensi *et al.* (1991) reported that uncontrolled Cogon grass (*Imperata cylindrica* Linn.) reduced maize yield to zero. Farmers in Nigeria spend more time in controlling weeds than any other aspects of crop production (Akobundu, 1987).

Weed control methods include biological (live mulch, microbial control, allelopathy and plant canopy management); preventive (animal quarantine, fallow management, aborting seed formation, sanitation measures and rouging isolated weeds); cultural (hand weeding, mechanical, tillage, burning, flooding, mulching and crop rotation); chemical (herbicide mixtures); and integrated weed management which involves a combination of two or more of the other methods (Akobundu, 1987).

Herbicide use has been reported to be more profitable than hoe weeding in the production of various crops in Nigeria (Usoroh, 1983; Sinha and Lagoke, 1984; Adigun *et al.*, 1993; Ishaya *et al.*, 2008). Without herbicides, corn producers would have paid $2.3billion more for hand labour and other weed control costs, cotton growers would have paid $1.2 billion more, soybean growers $ 2.2 billion, and wheat growers $409 million more.

Pesticide availability is more required but it is not properly articulated, and different ecozones adopt whatever pesticide is available in the agrochemical market. Invariably, this market is also unstable and all sorts of agrochemicals are available at different times. It is not possible to predict which of the pesticides; especially herbicides would be available from season to season. Yet, farmers need to adopt herbicide use to enhance productivity, reduce the drudgery of weed control and reduce cost of production. The traditional and commonly used control method, hoe-weeding, employed by most farmers in Nigeria has become expensive and unreliable due to constant wage increase and unavailability of labour particularly at peak period of the growing season. The use of herbicides for weed control is considered to be a better alternative to hoe-weeding because it facilitates efficient weed control, reduces labour requirements and its attendant costs, with consequent higher profitability to the farmers. In the USA, the expenditure for herbicides in 2001and 2005 was respectively $2.265 billion and $2.634 billion for corn (Sinha *et al.*, 1982).

Okuneye *et al*. (2002) examined the trend in the importation of agrochemicals into Nigeria between 1977 and 1997. The trend showed increasing rate of importation of fungicides, insecticides, and predominantly, fertilizers. Herbicides were not recorded at all, indicating the very low level of their use; hence weed control was still mainly traditional hand weeding, but the trend must have changed by now. In Nigeria, Ayeni (1991) observed that many a time the scarcity of the herbicides makes it difficult for farmers to get them although; they are also both technically deficient to apply them correctly and economically poor to afford the high prices of the herbicides. Given that productivity remains low and food deficit remain high, the use of agrochemicals is, understandably inevitable, if low productivity must be redressed and food deficit corrected. The impacts of the adoption of modern technologies would need to be assessed, particularly with regard to the adoption by resource poor farmers before research into the efficacies of these agrochemicals are embarked upon (Adedipe *et al*., 2004).

Various types of herbicides are available but they are grouped broadly into foliar-applied and soil-applied. The former include glyphosate, 2, 4-dichlorophenoxyacetic acid, paraquat, diquat etc. while the latter include diuron, atrazine, butachlor, S-metolachlor, primextra, pendimethalin etc. Akinola and Egunjobi (1991) suggested that weed seed levels could be minimized in cropping systems by pre-emergence herbicides application or hand weeding.

The impacts of agrochemicals, particularly herbicides on the environments and especially on non-target beneficial organisms need to be investigated and ascertained. Soil-acting herbicides may have adverse effects on such beneficial non-target soil inhabiting, ecologically important soil organisms - vertebrates and invertebrates. Among these, earthworms, (Oligochaeta, Lumbricidae) may be regarded as a representative group, which significantly contributes to organic matter decomposition and maintenance of soil structure and fertility. The following lists of pesticide occupational and environmental risk indicators were developed (Fangio and Walter, 2002):

-Risk to pesticide operators; risk to workers, risk to bystanders, persistence in the soil; risk to groundwater contamination, acute risk to aquatic organisms, acute risk to birds, and acute risk to beneficial arthropods.

Haque and Ebing (1983) found that even though the herbicide atrazine was slightly toxic to *Lumbricus terrestris* L. and *Eisenia fetida* (Sav.), the decrease in biomass of the earthworms was large. If the results of laboratory toxicity tests are to be useful for predicting field situation, natural test media and relevant modes of pesticide application should be used in the test (Pizl, 1988). Some features of earthworms' morphology make these animals very suited for toxicity test (Haque and Ebing, 1983).

An area of concern in chemical weed control is that of herbicide persistence. The choice of which crop will immediately follow maize in a rotation within one year where pre-emergent herbicides have been applied for weed control depends largely on a knowledge of their persistence in the environment (Akinyemiju *et al*., 1986). Herbicide persistence is a measure of the extent to which herbicide used at a recommended rate remains active in the treated soil and causes injury to susceptible crops that follow the treated crop(s) on rotation (Akobundu, 1987). Persistence on one hand is used as an expression of the much desired duration of efficacy of a compound (positive image). On the other hand, it is an expression of the undesirably long life in the environment, and in particular, in soil (negative image) (Helmut and John, 1982).

Despite the environmental challenges of herbicides, it is pertinent to understand that the use of herbicides remains an effective, efficient and economically viable means of managing weeds which in most cases has no practical alternatives (Philip *et al*,. 1996). In order to ensure the efficacy, efficiency, economy and non-target safety, users of herbicides must have an understanding of herbicide application principles, plant responses to herbicides and precise rate of application which will result in the best crop performance, weed control, minimal impact on soil organisms and the environment. Hence, the study intended to find out which herbicides are commonly used in the ecozone under study, the effect of such herbicides on soil with earthworms as indicator species and the period for which their residues remain active in weed control. This study was designed to ascertain the efficacy of these herbicides in maize cultivation which predominates in the ecozone.

The main objective of this study was to evaluate the effect of S-metolachlor and Pendimethalin on maize yield; weed control; determine their residues in soil and their effects on earthworms as index of soil pollution. Specific objectives were to:

1. ascertain which herbicides were commonly used in Ogbomoso ecological zone.
2. ascertain the rate of herbicide application that gives the best crop performance and weed control in the zone.
3. study the persistence of each herbicide at the dose applied.
4. evaluate the impact of the herbicides on earthworms as index of soil pollution.
5. determine the LC_{50} and sub-lethal concentrations of the herbicides for earthworms.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Trends in Maize Production in Nigeria

Maize (*Zea mays* L.) is an important staple food crop and provides bulk of raw materials for the livestock and many agro-allied industries in the world (Bello *et al*., 2010; Randjelovic *et al*., 2011). Until recent years, the bulk of maize grains produced in Nigeria were from the southwest zone. Ogunbodede *et al.* (2001) reported that western Nigeria generally produced about 50% of Nigeria green maize, the remaining 50% being split between the North and East. This ratio may have changed by now. Although, a large proportion of the green maize is still being produced in the Southwestern part, there has been a dramatic shift of the dry grain production to savanna especially the Northern Guinea savanna. The savanna agro-ecology zone of Nigeria has a great potential for food production because of its high solar radiation that favours plant/crop performance. Thus, the zone can now be regarded as the maize belt of Nigeria (Ogunbodede *et al*., 2001). In this zone, farmers tend to prefer maize cultivation to sorghum.

This trend must have been brought about for several reasons, including availability of streak resistant varieties for all ecological zones in Nigeria, availability of high-yielding hybrid varieties, increase in maize demand coupled with the Federal government imposed ban on importation of rice, maize and wheat (Iken and Amusa, 2004). Local production had to be geared up to meet the demand for direct human consumption, breweries, pharmaceutical companies, baby cereals, livestock feeds and other industries. Seed production and certification have taken a new turn in Nigeria with the establishment of private seed companies. The National Seed Service that used to be the primary source of improved seed also expanded its facilities, widened its scope and hired better trained staff. Thus, improved seeds are readily available to farmers (Iken and Amusa, 2004). Maize is most productive in the middle and northern belts of Nigeria, where sunshine is adequate and rainfall is moderate (Obi, 1991). Under these conditions, storage of grains can be accomplished without much damage by insect pests and diseases. The recent achievement by breeders in the development and release of superior maize varieties with higher yield potentials and better resistance to insect pests and diseases has played a central role in increasing maize production in the country (Obi, 1991). The growth rate in maize production has been unstable since 1960. For example, from 2005-2011 the corresponding quantity (in million metric tonnes) and percentage growth rate (in bracket) were stated by USDA as follows: 7.0 (7.69%); 7.8 (11.43%); 6.5 (-16.67%); 7.97 (22.62%); 8.95 (12.3%); 9.34 (4.36%); and 8.7 (-6.85%) for 2005, 2006, 2007, 2008, 2009, 2010 and 2011, respectively (USDA, 2012). USDA (2011) forecast Nigeria's corn production in 2011/2012 at 9.2 million tonnes, up from the revised 8.8 million tonnes in 2010/2011. Local sources indicated that corn area would increase, as the prevailing high prices encourage farmers to bring new land into production.

2.2 Maize consumption and demand in Nigeria

Maize is an important cereal being cultivated in the rainforest and the derived savanna zones of Nigeria. It is a very important staple food consumed by millions of Nigerians. Studies in maize production and marketing in different parts of the country have shown an increasing importance of this crop, amidst growing utilization by food processing industries and livestock feed mill. The crop has thus become a local "cash crop" most especially in the south western part of Nigeria, where at least 30% of the cropland has been put to maize production under various cropping systems (Ayeni, 1991). Maize and other cereals constitute important sources of carbohydrates, proteins, vitamin B and minerals (Iken *et al*., 2002). Maize is a staple food crop for most sub-Saharan Africans of which Nigeria is inclusive with per capital kg/yr^{-1} of 40 (FAO, 2003). In Nigeria maize is the third most important cereal crop after sorghum and millet (Ojo, 2000). The demand for maize as a result of various domestic uses shows that a domestic demand of 3.5 million metric tonnes outstrips supply production of 2 million metric tonnes (Akande, 1994).

According to report, the bulk of Nigeria's corn is used for direct consumption being a staple food of the Nigerian diet (USDA, 2011). Breweries demand for corn grits is growing in step with growth in the sector. Feed utilization of corn is also increasing due to the steady growth in the poultry sector witnessed in recent years. Approximately, 95% of all feed produced in Nigeria is poultry feed. Total corn usage for feed production in Nigeria is forecast at 1.5 million tonnes in 2011/2012, up from 1.2 million tonnes in 2010/2011. Despite the good corn crop in 2010/11, prices remain high because of rising demand. At present, the price of corn in northern growing regions is 55,000 Naira per tonne ($366). The cost of corn delivered to the main poultry-keeping areas in Southern Nigeria is substantially higher. Poultry farmers are unable to get sufficient corn supplies from local sources and are looking for import. Also, if the price of feed wheat falls below $200 per ton as was in 2009, poultry producers will likely switch from corn to wheat to satisfy their needs.

Poultry producers are having difficulty in sourcing for sufficient quantities of domestic corn and are looking for import. Poultry production in Nigeria is concentrated in Southwestern parts near major urban centers (Lagos and Ibadan), and as such imported corn into Lagos has a transportation cost advantage to major poultry operations when compared with domestic supplies grown in the middle and northern regions. It was forecast that Nigeria's corn imports in 2011/2012 at 100,000 tonnes, same as 2009/2010. Imports are largely informal cross-border trade. The Nigerian government's import ban on corn was lifted in 2008 and imports were allowed at 5% tariff USDA (2011).

2.3 Effects of Weeds on the Performance of Crop

A weed may be defined as any plant growing where it is not wanted (Alam, 2003). Weeds are the undesirable plants, which hamper the healthy growth of cultivated crops. A crop plant is any plant grown for its value to man at a given time (Alam, 2003). Both weeds and crops extract moisture and mineral nutrients from the same soil, take carbon (IV) oxide and light for photosynthesis from the same atmosphere and accommodate their biomass within the same space. As both live in the same biosphere, competition takes place for a particular factor when it falls short of the demand for both. As such the competition for that factor alters several environmental factors and consequently the plant growth processes are affected.

Weeds are great menace in orchards, vegetable gardens, lawns and fields of economic and industrial crops. Presently, more than 250 weed species have been found associated with different crops (Alam, 2003). Weeds are major constraints to cassava cultivation in Nigeria and are the most common pests of crops in the world, especially in the tropics (Akinyosoye, 1999). Over 70% of Nigerians live in the rural areas where farming is the main occupation. Statistics suggest that an average Nigerian farmer who uses traditional tools for crop production contends with weed problems annually. Indeed, a major factor limiting the acreage of land under cultivation in traditional farming systems in developing countries is the problem of land clearing and weed control (Ogunwolu, 2004). In Nigeria, labour is often scarce and costly, leaving weeds as an intractable problem in the country's agriculture (Adetunji, 2002)

Crop losses due to weeds could be a direct or indirect consequence of weed activities on the farmland including competition, acting as alternate and/or alternative hosts to pests of crops and/or animals, provision of conducive environment for rapid multiplication of pests and pathogens, inflation of cost of production through cost of weeding, adulteration of farm produce, allelopathy, plugging of irrigation and drainage canals (Akobundu, 1987; Fournet and Hormmerton, 1991; Lavabre, 1991; Akobundu, 1993). Weeds serve as hosts for insects and plant pathogens that subsequently move to crop plants in the area, causing adverse effects on the main crop (Alam, 2003).

Competition for sunlight has been shown to favour broad-leaved plants and plants with spreading canopy over those with narrow leaves and little or no branches as seen in the competition between maize and *Tithonia diversifolia* (Olabode *et al*., 1999b). The superior competitive ability of weeds is generally accounted for by the rapidly spreading canopy and deeply penetrating root system at the early growth (Awodoyin and Ogunyemi, 2005b) coupled with the rapid rate of sprouting which usually gives the weed competitive advantage (Akobundu, 1987). Olabode *et al*. (1999a) working on *Tithonia diversifolia* found that there is a critical period for weed removal in crops depending on the crop and the weed(s) encountered. Ogunyemi and Ojo (2000) reported that competition from *Commelina benghalensis* led to a reduced number of leaves and leaf area in *Solanum macrocarpon* and *S. aethiopicum* in Nigeria. The length of the competition also influenced the effect on the crops. The longer the period of interference, the smaller the leaf area and the fewer the number of leaves on the two vegetable species. Moreover, Ogunyemi *et al* (2001) reported that *Acalypha segetalis* caused a yield reduction of 42% in *Amaranthus cruentus.* Crop losses can be as high as 80% in maize from spear grass interference (Koch *et al*., 1990; Chikoye *et al*., 2001). Chikoye *et al*. (2002) reported that it was cheaper to use glyphosate than hand weeding for spear grass control in maize and cassava. Yield losses due to weed infestation can range from 40% (Akobundu, 1987) to 97% (Olabode *et al.,* 1999a) in maize, and 91% in sweet potato (Akobundu, 1987). Alam (2003) reported the losses in grain yield ranging from 18-25, 20-65, 20-45, 13-43, 10-35, and 25-55% in wheat, rice, maize, cotton, sugarcane and pulses respectively. He reported further that in spite of modern weed control technology, weeds continue to cause annual losses of about 15% in agricultural production in the world.

2.3 Weed Control Methods

The methods by which weeds are controlled in cropland are determined largely by the growth and reproductive characteristics of the weeds and by the growth and cultural practices used in the crop production. There are five major ways of controlling weeds. These are: biological (live mulch, microbial control, allelopathy and plant canopy management); preventive (animal quarantine, fallow management, aborting seed formation, sanitation measures and rouging isolated weeds); cultural (hand weeding, mechanical, tillage, burning, flooding, mulching and crop rotation); chemical (herbicide mixtures); and integrated weed management which involves a combination of two or more of the methods. The effectiveness or otherwise of each of the methods depends on weed type, cropping pattern, time of application and environmental factors (Akobundu, 1987).

The weed populations in croplands are usually not adequately controlled by only one weed-control practice, so the use of several such methods during a single crop season is common. The use of two or more weed-control methods is referred to as integrated weed management.

Preventive weed control is practised by planting weed-free crop seed, by the use of manure and hay free of weed propagules, by cleaning of harvesting equipment before moving it from a weedy to a weed-free area, by screening of irrigation water to remove weed propagules before the water moves into cropland.

Cultural weed-control practices common to good land, crop and water management are involved in the use of smother crops, crop rotation, row spacing, seedling rate, planting date, fertilization, tillage operation, irrigation management, weed-free crop seed, field sanitation and use of adapted crop varieties/cultivars (Alam, 2003). Noxious weeds such as *Andropogon sp.*, *Cynodon dactylon*, and *Imperata cylindrica* and *Pennisetum sp.* are more effectively controlled through bush fallowing (Ruthernberg, 1976). Mat layer under bush fallowing as in forest prevents weed germination and smother seedlings just as thick canopy discourages weed seedling establishment and shade weed from sunlight thereby drastically reducing their photosynthetic activities (Olabode and Agboola, 2000). Awodoyin and Ogunyemi (2005b) observed that higher sickle pod (*Senna obtusifolia*) population was able to smother weeds more successfully than lower population densities. Any plant that is highly competitive with weeds may be used as smother crop and cover crop. Crops such as alfalfa, barley, clovers, corn, cowpeas, millet, rye, canary grass, soybeans, sunflower, sorghum, etc. are superior competitive crop. Crop rotation is the growing of different crops in recurring succession on the same land. Weed control is one of the principal reasons for crop rotation.

Mechanical weed control is a traditional and well established practice for controlling weeds. Mechanical weed control includes practices such as hand-pulling, hoeing, machine tillage and burning (Alam, 2003). Akobundu (1987) reported that mechanical weeding has met with little successes in the rain belt because of high moisture condition and high tree plant vegetation but great successes have been achieved in the savanna region.

Biological weed control techniques use natural predators and parasites as the agents of weed control. The most effective biotic agents for weed have been the phytophagous (plant-eating) organisms such as insects, fish, and snails. Biological weed control reduces the competitive ability of the weed and dissipates its energy reserves, while preventing or curtailing weed reproduction (Alam, 2003).

The system of weed control which employs the use of chemicals for killing or adversely affecting the growth of plants not desired is known as 'chemical weed control. Seasonal labour demands often delay timely weeding, resulting in severe crop losses. Labour-based weed control options are ineffective against spear grass (*Imperata cylindrica)* and other perennial weeds (Chikoye *et al*., 1999).

Awodoyin and Ogunyemi (2001) observed that the menace of weed infestation on the field occasioned by increased disturbance of the ecosystem had been effectively put at bay through the use of herbicides. This is because the method offers the most efficient approach to management because of low labour, low frequency of weed control thereby reducing cost, timeliness in weed control and reduced drudgery. Chemical weed control in croplands is achieved by the use of chemicals that effectively control weeds without harm to the crop plants. These phytotoxic chemicals are called herbicides (Akobundu, 1987). An herbicide is any chemical that kills herbaceous and other plants or greatly inhibits their growth. Herbicides available today can control weeds in either grass or broad-leaved crops. Herbicides may be applied to the soil before the emergence of weeds (pre-emergent) or directly to the foliage (post-emergent and foliar) of the emerged weeds. Properly used, herbicides increase crop yields, improve quality and lower crop production costs (Alam, 2003).

2.4 Herbicides

2.4.1 Herbicide classification based on mode of action

A Herbicides that inhibit photosynthesis

The triazines (Atrex, Princep, Sencor and others), ureas (Cotoran, Linex/Lorox and others)**,** nitriles (Buctril) and Basagran inhibit the process of photosynthesis in plants.. In general, soil applications of the triazines and ureas move with transpiration water upward in plants (systemic), but foliar applications of these same herbicides show little to very limited movement in plants. However, foliar applications of Buctril, Basagran or Storm act mainly on contact.

I Photosystem II Inhibitors

Phenylcarbamates, pyridazinones, triazines, triazinones, uracils, amides,ureas, benzothiadiazinones, nitriles, and phenylpyridazinones are examples of herbicides that inhibit photosynthesis by biding to QB-binding niche on the D1 protein of the photosystem II complex in chloroplast thylakoid membranes. Herbicides biding at these protein location blocks electron transport from QA to QB and stops CO_2 fixation and production of ATP and $NADPH_2$ which are all needed for plant growth. However, plant death occurs by other processes in most cases.

Inability to re-oxidize QA promotes the formation of triplet state chlorophyll which interacts with ground state oxygen to form single oxygen. Both triplet chlorophyll and singlet oxygen can extract hydrogen from unsaturated lipids, producing a lipid radical and initiating a chain reaction of lipid peroxidation. Lipids and proteins are attacked and oxidized, resulting in loss of chlorophyll and carotenoids and in leaky membranes which allow cells and cell organelles to dry and disintegrate rapidly. Some compounds in this group may also inhibit carotenoids biosynthesis (fluometuron) or synthesis of anthocyanins, RNA and proteins (propanil), as well as affecting the plasmalema (propanil) (WSSA, 2010).

II Photosystem I Inhibitor

Bipyridyliums are examples of herbicides that accept electrons from photosystem I and are reduced to form an herbicide radical. This radical then reduces molecular oxygen to form superoxide radicals. Superoxide radicals then react with themselves in the presence of superoxide dismutase to form hydrogen peroxides. Hydrogen peroxides and superoxides react to generate hydroxyl radicals.

Superoxides and, to a lesser extent, hydrogen peroxides may oxidize SH (sulfhydryl) groups on various organic compounds within the cell. Hydroxyl radical, however, is extremely reactive and readily destroys unsaturated lipids, including membrane fatty acids and chlorophyll. Hydroxyl radicals produce lipid radicals which react with oxygen to form lipid hydroperoxides plus another lipid radical to initiate a self-perpetuating chain reaction of lipid oxidation. Such lipid hydroperoxides destroy the integrity of cell membranes allowing cytoplasm to leak into intercellular spaces which leads to rapid leaf wilting and destruction. These compounds can be reduced/ oxidized repeatedly (Dodge, 1982).

B. **Herbicides that act at or before cell division**:

Herbicides that affect meristematic growth (i) Dichlobenil and Chlorthiamid, (ii) α chloroacetamides and others e.g Metolachlor and Butachlor, and (iii) Dinitroaniline herbicides e.g Pendimethalin, Trifluralin and Oryzalin (Kenneth, 1990). The Dinitroaniline or "yellow" herbicides (Treflan, Prowl and others) inhibit lateral root development in plants by interfering with the process of cell division. They exhibit practically no movement in plants. Therefore, they are contact. Two chemical families of soil-applied herbicides, the substituted amides (Dual II Magnum, Lasso, Surpass and others) and the carbamothioates (Eptam, Sutan + and others) are thought to work by inhibiting the synthesis of very-long-chain-fatty-acids, and in turn, growth of shoots in weeds immediately following germination. Herbicides in both chemical families tend to move readily from the roots, upward in the plant (systemic).

Mitosis Inhibitors

Benzamide, benzoic acid (DCPA), dinitroaniline**,** phosphoramidate, and ptridine herbicides are examples of herbicides that bind to tubulin, the major microtubule protein. The herbicide-tubulin complex inhibits polymerization of microtubule at the assembly end of the protein-based microtubule but has no effect on depolymerization of the tubule on the other end (WSSA, 2010), leading to a loss of microtubule structure and function. As a result, the spindle apparatus is absent, thus preventing the alignment and separation of chromosomes during mitosis. In addition, the cell plate cannot be formed. Microtubules also function in cell wall formation. Herbicide-induced microtubule loss may cause the observed swelling of root tips as cells in this region either divide or elongate (WSSA, 2010), The carbamate herbicides, carbentamide, chlorpropham, and propham, are examples of herbicides that inhibit cell division and microtubule organization and polymerization. Acetamide, chloroacetamides, oxyacetamide and tetrazolinone herbicides are examples of herbicides that are currently thought to inhibit very long chain fatty acid (VLCFA) synthesis. These compounds typically affect susceptible weeds before emergence, but do not inhibit seed germination (WSSA, 2010).

C. Herbicides that disrupt membranes:

(i) Diphenyl ether with light dependent action e.g. Oxythorfen and Fluorodifen. These herbicides, composed of the diphenylethers (Ultra Blazer, Cobra, Reflex, others) and the bipyridiliums (Gramoxone, Max and Reward)**,** work quickly as contact herbicides to disrupt plant cell membranes. Light is required for their herbicide activities. The cell membrane disrupters exhibit very little movement within plants, that is, they are contact herbicides.

Diphenylethers, N-phenylphthalimides, oxadiazoles, oxazolidinediones, phenylpyrazoles, pyrimidindiones, thiadiazoles and triazolinones are herbicides that appear to inhibit protoporphyrinogen oxidase (PPG oxidase or Protox), an enzyme of chlorophyll and heme biosynthesis catalyzing the oxidation of protoporphrinogen IX (PPGIX) to protporphrin IX (PPIX). Protox inhibition leads to accumulation of PPIX, the first light-absorbing chlorophyll precursor. PPGIX accumulation apparently is transitory as it overflows its normal environment in the thylakoid membrane and oxidizes to PPIX. PPIX formed outside its native environment probably is separated from Mg chelatase and other pathway enzymes that normally prevent accumulation of PPIX. Light absorption by PPIX apparently produces triplet state PPIX which interacts with ground state oxygen to form singlet oxygen. Both triplex PPIX and singlet oxygen can abstract hydrogen from unsaturated lipids, producing a lipid radical and initiating a chain reaction of lipid peroxidation. Lipids and proteins are attacked and oxidized, resulting in loss of chlorophyll and carotenoids and in leaky membranes which allows cells and cell organelles to dry and disintegrate rapidly (WSSA, 2010).

D. Herbicides that disrupt lipid biosynthesis

Thiolcarbarmates e.g. molinate and ethyldipropylthiolcarbamate (EPTC). Two families of chemistry, cychlohexanediones (the "DIMS" – sethoxydim, tralkoxydim, cycloxydim, clethodim, alloxydim e.g. Achieve, Poast/Poast Plus and Select) and the aryloxyphenoxypropionates ("FOPS"-chlodinafop-propargyl, dichlofop-methyl, fenoxaprop-p-ehtyl, fluazifop-butyl e.g. Fusilade, Fusion Assure II and Hoelon) comprise the post emergence grass herbicides. These herbicides all have the same mode of action. They inhibit an enzyme Acetyl Coenzyme A carboxylase (ACC'ase) which is crucial for the formation of lipids in plants. These herbicides are quickly absorbed and they move through the plants.

Benzofuranes, Phosphorodithioates, and thiocarbamate are examples of herbicides that are known inhibitors of several plant processes including: 1) biosynthesis of fatty acids and lipids which may account for reported reductions in cuticular wax deposition, 2) biosynthesis of proteins, isoprenoids (including gibberellins) and flavonoids (including anthocyanins), and 3) gibberellin synthesis inhibition which may result from the inhibition of kaurene synthesis (WSSA, 2010),. Photosynthesis also may be inhibited. A currently viable hypothesis may link all these effects that involve the conjugation of acetyl coenzyme A and other sulfhydryl-containing biomolecules by thiocarbamate sulfoxides (WSSA, 2010). The sulfoxide forms may be the active herbicides (Ashton and Craft, 1981).

There is the need to adapt herbicides to local or regional conditions. This is necessitated as most herbicides are developed and tested under foreign environmental conditions, with foreign weed species and temperate crop cultivars before herbicide dose rates are recommended. Flexible timing and use rates are beneficial in adapting herbicide use to local crops and weed-management strategies. Depending on cropping system and region, S-metolachlor may be applied either as early pre-plant (EPP), pre-plant, pre-emergence or early post emergence treatment (Peter *et al*., 1998). Kucey *et al*. (1988) reported that effects of herbicides are site-dependent; results ought to be drawn out from experiment carried out under field conditions, in the same region in which these results will be applied. S-metolachlor application is flexible, allowing adaptation according to local environmental, climatic and agronomic needs. The recent development in precision farming and field mapping can improve decision making, and ensure that application is appropriate to site specific needs (Peter *et al*., 1998).

Greenhouse and growth chamber studies designed to determine the effect of environmental conditions on the response of corn to metolachlor indicated that injury and growth reduction were greater at high soil moisture content than lower moisture content and greater at 15^{o}C than at 25^{o}C (Boldt and Barrette, 1989; Rowe *et al.*, 1990).

Predicting herbicide efficacy is challenging. Environmental conditions at application time (Doran and Anderson, 1976), herbicide rate (King and Oliver, 1992), weed size (Kells *et al*.,1984) and weed species, interaction with other herbicides (Hatzios and Penner, 1985) and the addition of an adjuvant (Roggenbuck *et al*., 1990), each influences herbicidal activity (Sharma and Singh, 2001). Consequent upon the varying efficacy of different herbicides, if certain biological and chemical compatibilities exist, the application of appropriate mixtures containing two or more either active ingredients used singly. This will benefit in saving time and effort in weed control and diminishing the overall cost of ingredient that must be applied at a time and in a manner that allows its herbicidal potential to be realized. The mode of action of the active ingredients should be complementary rather than antagonistic (Kenneth, 1990).

2.4.2 Characteristics of test herbicides

2.4.2.1 Dual Gold (S-metolachlor 960EC)

Metolachlor comprises two R-isomers and two S-isomers (Fig. 1) that are present in equal proportions, but with the S-isomers providing most herbicidal activity (Moser *et al*., 1983). Efforts to reduce the rates of herbicide application are often associated with reduced efficacy (Berti and Zanin, 1979; Muyonga *et al*., 1996) and therefore, added economic risk to the farmers. In contrast, the development of S-metolachlor provides a valuable opportunity, by virtue of its reduced application rate, to substantially reduce chemical load in the environment whilst maintaining biological performance. A 35-38% lower application rate of S-metolachlor gave equivalent weed control to normal rate of metolachlor use rate of 1,500 – 3,000g/ha (Peter *et al*., 1998).

Dual Gold 960EC, a residual herbicide of the group Acetanilide, contains 960g/l S-metolachlor. As with most residual herbicides, it is influenced by soil type, soil moisture and temperature. Very adsorptive soil requires high rates of application (Peter *et al.*, 1998). S-metolachlor works with the efficacy on major grass weeds and tolerance to different maize cultivars at 65% the use rate of metolachlor. The mean half-life of S-metolachlor was 23 days in distillation studies at different European field sites. At use rates and with highly concentrated formulations containing up to 90% (W/V) a.i. the use of S-metolachlor will result in a substantial reduction of risk to applicators, consumers and the environment (Peter *et al*., 1998).

S-metolachlor provides flexibility in crop production because of its short soil dissipation half-life. Its excellent selectivity in major crops enhances flexibility in use within alternate cropping systems such as strip (or inter-) cropping (Peter *et al*., 1998). Weeds that are susceptible to S-metolachlor include *Brachiaria* spp., *Chloric* spp., *Digitaria* spp., *Echinocloa* spp., *Elusine* spp., *Galisoga* spp. *Nicandra* spp., *Panicum* spp., *Setaria* spp. and *Urochloa* spp (Syngenta Group of Company).

. Moderately susceptible weeds include *Amaranthus* spp., *Cypsella* spp., *Cyperus esculentus*, *Portulaca* spp. and *Sorghum halepense* (Syngenta Group of Company).

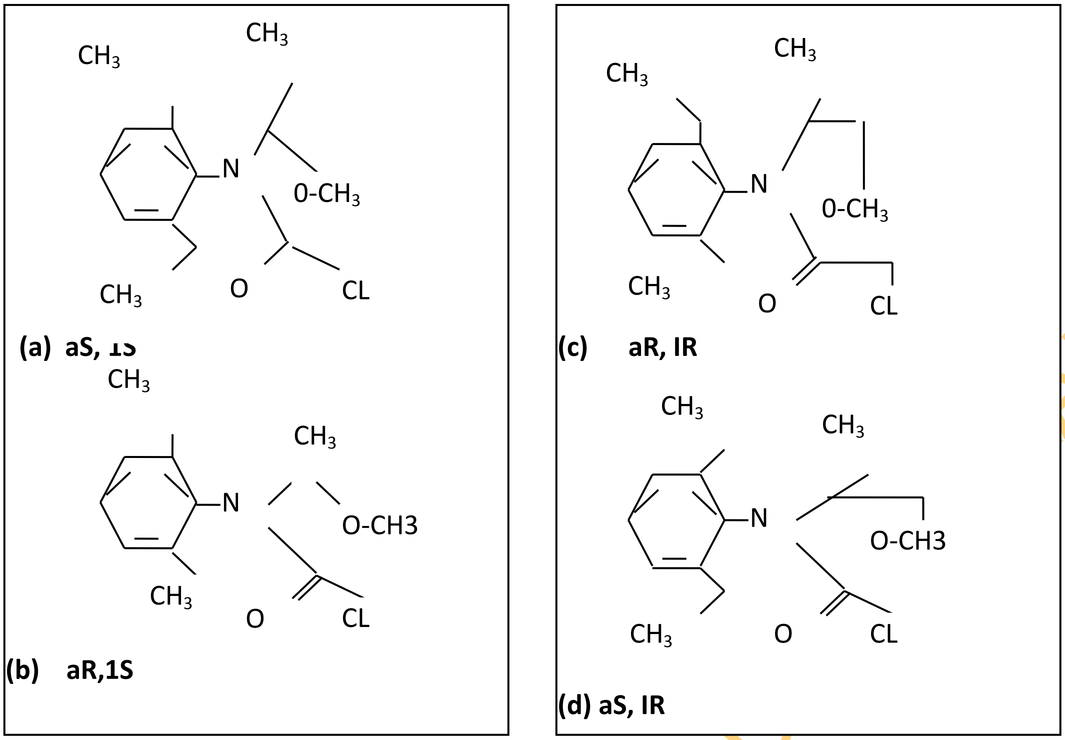
S-metolachlor is taken up mainly through the shoot of germinating seeds and seedlings. Root uptake is less pronounced and much slower. It affects meristematic growth and inhibits very long chain fatty acid (VLCFA) synthesis (WSSA, 2010). This inhibition typically affects susceptible weeds before emergence, but does not impair seed germination (WSSA, 2010).

Weeds are killed before emergence or at emergence or shortly after emergence. Translocation is not an essential characteristic as root activity is less pronounced (Syngenta Group of Company).

It could be applied as pre-emergence, during or after planting but before weeds and crop emerge. As pre-plant incorporated, it is applied to the soil and incorporated into the top 5cm of soil within 14 days before planting using disk harrow or rolling cultivator mostly used when a period of dry weather is expected after planting. Pre-plant surface application is only for minimum/no tillage systems (Syngenta Group of Company). It can be applied up to 45 days before planting certain crops. Spray equipment could be Knapsack (flood jet nozzle) or tractor-mounted (110^o flat fan nozzle) with spray volume of 120-600 litres total spray solution per hectare. Application rate ranges from 0.6-1.6 litres/hectare depending on level of weed infestation and can be up to 1.9 litres/ha in high organic soil due to increased adsorption (Syngenta Group of Company).

2.4.2.2 STOMP 500E (Pendimethalin)

Stomp 500E, an herbicide of dinitroaniline group, contains pendimethalin 500 g/litre. The chemical structure of pendimethalin is shown in Fig. 2. The chemical name is N-(1-ethylpropyl)-3, 4-dimethy1-2, 6-dinitrobenzea-amine. Dinitroanilines are sometimes used to suppress growth from buds on subterranean parts of perennial grasses, although this may require the use of higher concentration in the soil, with a risk of subsequent crop damage. Their major effect is on the growth of roots (Kenneth, 1990). The shoots that emerge often appear quite normal, but soon die because of failure of secondary root development when the hypocotyls come in contact with the herbicide in the soil (Kenneth, 1990). Pendimethalin disrupts cell division and elongation in shoot and root meristems following germination or shortly after emergence from the soil. Planting or replanting of any crop other than cotton, soybean, groundnuts, beans or sunflowers for a period of one year after application of stomp should be avoided (Manufacturer: BASF). It is used in the control of emerging annual broad-leaved weeds and grasses (including *Rottboellia spp*) in maize, rice, soybean, cotton, tobacco, tomato and



S-isomers R-isomers

Fig. 1: Isomeric forms of metolachlor

IUPAC names of the isomers:

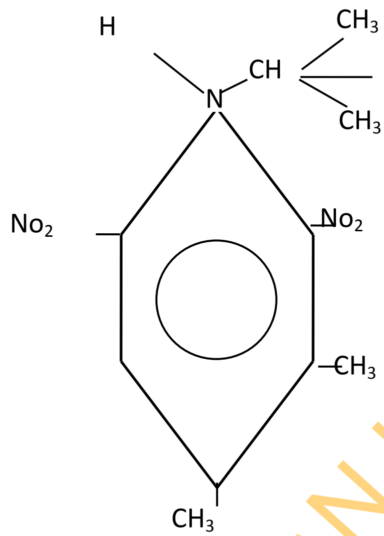
(a) = mixture of 80–100% (*aS*,1*S*)-2-chloro-6′-ethyl-*N*-(2-methoxy-1-methylethyl)acet-*o*-toluidide

(b) = mixture of 80–100% 2-chloro-*N*-(6-ethyl-*o*-tolyl)-*N*-[(1*S*)-2-methoxy-1-methylethyl]acetamide

(c) = 20–0% 2-chloro-*N*-(6-ethyl-*o*-tolyl)-*N*-[(1*R*)-2-methoxy-1-methylethyl]acetamide

(d) = 20–0% (*aRS*,1*R*)-2-chloro-6′-ethyl-*N*-(2-methoxy-1-methylethyl)acet-*o*-toluidide

Chemical Formula of S-metolachlor: $C_{15}H_{22}ClNO_2$



Chemical name of Pendimethalin: N-(1-ethylpropyl)-3, 4-dimethy1-2, 6-dinitrobenzea-amine

Figure 2: Chemical structure of Pendimethalin

onion (Manufacturer: BASF). Stomp can be mechanically incorporated as pre-weed emergence preferably within 24 hours of application for best results (but at most within 5 days) and before seeding or transplanting (Manufacturer: BASF).

As pre-emergence to crop, it is applied immediately after or within 5 days of sowing (all seeds should be sown at a minimum depth of 5 cm and covered before application. The spray equipment is Knapsack (flood jet nozzle) or tractor-mounted (110^{O} flat fan) with a total spray solution (water + stomp 500E) of 150-250 l/ha (Manufacturer: BASF). It should be sprayed onto smooth, well-leveled soil, free of clods or weed residue. The application rate in l/ha varies from 2l (light sandy loam soil), 3l (sandy clay loam) to 4l (sandy clay). (Manufacturer: BASF).

2.5.1 Effects of herbicides application on the environment

The good soil-applied herbicide would control weeds for the necessary time, then instantly degrade, and never move off-site into surface water or groundwater (OECD, 1997),. It would never be present to affect the growth of subsequent crops. However, this is not so as they constitute high risk to the environment. The Organization for Economic Cooperation and Development (OECD)

workshop on ‘’Pesticides Occupational and Environmental Risk (POCER) Indicator’’ held in Copenhagen on 21-23 April, 1997, developed and agreed to a set of principles for the development of pesticide risk indicator (OECD, 1997), which are:

1. risk indicators should be both scientifically based and effective as a public policy tool;
2. the basic purpose of pesticide risk indicators is to combine information on pesticide risk (hazard or exposure) with information on the quantity and conditions of pesticides use;

3. it would be better to have a set of indicators dealing separately with risk to human health and to the compartments of the environment; and
4. indicators need to be based on reliable data, including registration data and data on qualities and conditions of pesticide use.

Based on these principles, the following lists of Pesticide Occupational and Environmental Risk Indicators were developed:

- risk to pesticide operators;
- risk to workers;
- risk to bystanders;
- persistence in the soil;
- risk to groundwater contamination;
- acute risk to aquatic organisms;
- acute risk to birds; and
- acute risk to beneficial arthropods (Fangio and Walter, 2002).

2.5.2 Herbicide Persistence

Herbicide persistence is an important property of soil applied herbicides, and some post-emergence herbicides, that allows for extended weed control. When the herbicide remains unaltered in the soil during the cropping season of application, it is advantageous. If an herbicide remains in the soil and is present in a rotation system when a susceptible crop is planted, the persistence leads to herbicide carry over. In a broad sense, the resistance to degradation and the downward movement within the soil profile are both important for obtaining satisfactory weed control (William, 1998).Degradation of many herbicides follows first-order kinetic, meaning that, "the rate of degradation is roughly proportional to the herbicide concentration". The "half-life; (DT_{50})" or time when 50 percent of the parent compound disappeared is quite variable under field conditions and depends on environmental conditions (William, 1998).

As a consequence of widespread use, resistance to herbicides in weed populations has arisen and this now poses a threat to the long-term future of many herbicides (Peter *et al*., 1998). Heap (1997) reported 185 cases of unique herbicide-resistant weed biotypes worldwide, belonging to more than eight different modes of action groups. To meet this challenge, within the agrochemical industry, the Herbicide Research Action Committee (HRAC) worked together with public and private sector research organizations on a regional basis to promote the responsible use of herbicides.

2.6 Importance of earthworm

Earthworms must be seen not as a "miracle pill", a panacea for better soil and crop yields, but as an integral part of intelligent organic soil management practices. As earthworms depend upon plant for a supply of organic matter for food and mulches for protection from heat, cold and drought, so do growing plants depend upon well-maintained and improved soil structure and fertility that is accomplished by the earthworms, in combination with bacteria and other micro-organisms. The main aim of studying soil fauna is to improve soils and grow higher yield of healthy crops, to achieve this, earthworm has found a treasured place in the organic scheme of gardening and farming (Minnich, 1997).

Environmental Protection Agency (EPA), reported that the passage of organics through the earthworms' gut significantly alters the physical structure of the material (Camp, 1980)l.

Large particles are broken down into numerous smaller particles, with a resultant enormous increase in surface area. As a result of the increase in surface area, any remaining odour-producing sulfides are completely oxidized, microbial respiration is accelerated by a factor of 3, and *Salmonella* bacteria are destroyed at a higher rate (Camp, 1980).

Jim Jensen, YELM Earthworm and Casting Farm is presently commercializing worm castings (Vermicompost) at the following rates:

5 Ibs of 99% pure worm castings only $7.95 + shipping;

10 Ibs of worm castings only $13.95 + shipping;

40 Ibs of worm castings only $39.95 + shipping (Jensen, 1997).

The vermicompost analysis was produced by Jim Jensen of Yelm Earthworm and Casting Farm, Yelm WA at the soil ecology laboratory, Ohio State University (Test 1), and Washington State Cooperative Extension – Whatcom County in 1988 (Table 1). Obviously, earthworms cannot do transmutation from one element to another; the tested values reflect the feedstock input into the earthworm colony. The comparison of the nutrient status of vermicompost (prepared by two species of earthworms: *Eisenia* spp. and *Perionyx excarvatus*) and farm yard manure is shown in Table 2.

According to Jensen (1997), worm castings will not cause burning when applied directly to even the most delicate plants. They are highly water soluble, making their nutrients immediately available as plant food. Worm castings can be used indoors and outdoors on any and all plants, trees and shrubs. Earthworms will burrow as far as 180cm into the ground aerating the soil, making holes for rain to percolate and breaking up hardpans. Each year, their castings furnish a

Table 1: The nutrient values of worm cast (Vermicompost) at the soil ecology laboratory, Ohio State University

Parameter	Test 1	Test 2
pH	6.3	-
EC (mmho/cm)	5.92	-
C:N ratio	14.1	14.1
Moisture (%)	67	-
Total N (TKN) (%)	2.92	3.21
C:N ratio	45.70	45.90
Nitrate N (ppm)	630	420
Ammonium N (ppm)	<37	35
Organic carbon (%)	40.2	49
Total P (%)	1.1	1.1
P_20_5 (%)	0.187	-
Total K (%)	1.5	-
K_20 (%)	0.434	-
Calcium (%)	3.1	-
Magnesium (%)	0.7	-
Sodium (%)	0.3	-
Iron (%)	0.3	-
Manganese (ppm)	295	-
Copper (ppm)	123	-
Zinc (ppm)	357	-
Boron (ppm)	75	-

Source: Jensen (1997).
C:N = Carbon: Nitrogen

OC = Organic carbon,
EC = Exchangeable cations.

Table 2: Nutrient content of vermicompost from *Eisenia* sp. and *Perionyx excarvatus* compared to Farm Yard Manure (FYM)

Parameter	*Eisenia fetida*	*Perionyx excarvatus*	FYM
pH	7.40	7.00	7.20
Organic carbon (%)	27.43	30.31	12.20
Total nitrogen (%)	0.60	0.66	0.55
Total phosphate (%)	1.34	1.93	0.75
Total potassium (%)	0.42	0.42	2.30
C : N ratio	45.70	45.90	24.40

Source: Jensen (1997)

C: N = Carbon: Nitrogen

FYM = Farm Yard Manure

Table 3: Typical nutrient composition of worm casts from Jim Jensen of Yelm Earthworm and Easting Farm

Nutrient	Percentage (%)
Nitrogen	2
Phosphorus	1.2
Potassium	1
Sulphur	0.4
Calcium	1.5
Magnesium	0.4
Iron	0.7

Source: Jensen (1997)

considerable amount of valuable fertilizer which may amount to more than 50 tonnes per acre in a rich, organic soil (Table 3). Every morsel of soil and decayed vegetable matter taken in by the earthworm passes through a digestive system equipped with a gizzard-like organ. Food value in the swallowed matter is absorbed for use by the worm and the balance is excreted as worm castings. Vermicompost is also rich in growth hormones, vitamins and acts as a powerful biocide against diseases and nematodes (Jensen, 1997). Earthworms also produce enzymes which break down complex bio-molecules present in the garbage into simple compounds which are utilized by the microorganisms. The microorganisms in the worms gut also produce useful compounds like antibiotics, vitamins, and plant growth hormones etc., all of which are present in the wormcast (Jensen, 1997). The earthworms provide ideal temperature, pH and oxygen concentration for the speedy growth of useful bacterial and actinomycetes and thus have a microbial density of about 100 times greater than in the surrounding soil (Jensen, 1997).

The ability of some earthworms to consume a wide range of organic residues such as sewage, animal wastes, crop residues, and industrial refuse has been fully established (Jensen, 1997). Increasing organic waste due to human activities in the rural and urban areas and industries is globally a serious constraint in the maintenance of a clean and healthy environment. Earthworms are effective converters of these wastes (Munnoli *et al.*, 2010). Heavy metals were observed to decrease by between 35 and 55% of the bio-available metals in two months (Dominguez, 1997).

2.6.1 Earthworms Ecological Classification.

Earthworms are only part of the complex of organisms termed "decomposers" in agro- ecology. Other decomposers include springtails (collembola), nematodes, bacteria, protozoa and fungi. Earthworms themselves fall into several subgroups based on their behavioural ecologies (burrowing abilities, food preferences, body colour, shape and size) as Epigeic, Endogeic, Anecic, Coprophagic and Arboricolous species (Bouche, 1977; Lee, 1985; Curry, 1994).

2.6.1.1 **Epigeic-** These are surface-active earthworms that live in the superficial soil layers, pigmented, and are in general non-burrowing. They dwell in litter, feeding on undecomposed plant litter. These worms are usually small and produce new generations rapidly.

2,6,1,2 **Endogeic** – These earthworms forage below the soil surface in horizontal, branching burrows. These species ingest large amounts of soil, showing a preference for soil rich in organic matter. Endogeics may have a major impact on the decomposition of dead plant roots, but are not important in the incorporation of surface litter.

2,6,1,3 **Anecics –** They are large, deep – burrowing forms that come to the soil surface when it is more humid, usually during the night, and draw the litter down into the lower strata. They feed on manure, leaf litter and other organic matter. Anecics species such as the nightcrawlers, *Lumbricus terrrestris* and *Aporrectodea longa,* have profound effect on decomposition of organic matter and the formation of soil.

2,6,1,4 **Coprophagics-** They live in manure, e. g. *Eisenia foetida* and *Dendrobaena veneta.*

2,6,1,5 **Arboricolous: S**pecies live in suspended soils in humid tropical forests

2.7.1 *Eisenia fetida*

Phylum- Annelida, Class- Clitellata, Order-Haplotaxida, Family- Lumbricidae, Genus-*Eisenia*, Species- *fetida* (Fauna Europaea, 2004).

Eisenia fetida (older spelling: *fetida*), known under various common names such as red worm, brandling worm, panfish worm, trout worm, tiger worm and red wiggler worm, red Californian earthworm, is a species of earthworm adapted to decaying organic material. These worms thrive in rotting vegetation, compost, and manure, they are epigean. They are rarely found in soil, instead, preferring conditions that are inimical to some other worms. They live in leaf litters and decomposing plant materials. *E. fetida* are used for vermicomposting. They are native to Europe, but have been introduced (either intentionally or otherwise) to every other continent except Antarctica, occasionally threatening native species(Fauna Europaea, 2004). When roughly handled, *E. fetida* exudes a pungent liquid, thus the specific name *fetida* meaning foul-smelling. This is presumably an antipredator adaptation (Fauna Europaea, 2004). *E. fetida* is closely related to *Eisenia andrei*, also referred to as *E. fetida Andrei.* The only simple way of distinguishing the two species is that *E. fetida* is lighter in color. Molecular analyses have confirmed their identity as separate species and breeding experiments have shown that they do not produce hybrids (Fauna Europaea, 2004).

E. fetida is more commonly known as manure worm, tiger worm, and the red wiggler. Its colour was a key identification feature. Its colour can range from purple to red to a dark or brownish red (Fauna Europaea, 2004). However, it has an unusual pigmentation. The pigment is not evenly distributed, but appeared as dark segmental bands separated by lighter inter segmental bands. *E. fetida* had a lumbricine closely paired arrangement which is characteristic of the

Lumbricidae family. The lumbricine arrangement consists of eight setae per segment in ventral and latero-ventral pairs (Edwards and Bohlen, 1996). Body length was another diagnostic feature, ideally, *E. fetida* ranges from 35-130mm..

As with other earthworm species, *E. fetida* is hermaphroditic. However, two worms are still required for reproduction. The two worms join clitellums, the large orange-coloured bands which contain the worms' reproductive organs and which are only visible during the reproduction process. The two worms exchange sperm. Both worms then secrete cocoons which contain several eggs. These cocoons are lemon-shaped and are pale yellow at first, becoming more brownish as the worms inside become mature. These cocoons are clearly visible to the naked eye.

2.7.2 *Lumbricus terrestris*

Lumbricus terrestris is brownish to purplish red above, yellow-orange below and pigmented. It may also be dark brown to black in colour. It has flattened body with segment number between 140-160, and about 90-350mm in length. The distance between the nose and the start of the clitellum is greater than 2cm. clitellum starts after segment 30 (Sims and Gerard, 1985).

2.7.3 *Libyodrilus violaceus*

It is reddish but the clitellum is greenish. Body length is between 9.2-11.5cm, and width- 0.2-0.4cm. The shape is round with clear segmentation with segment number ranging from 122 to 198. The prostomium is epilobus. Spermathecal and male pores are unpaired and are respectively located on segments 13 and 17. The clitellum is annular in shape and covers segments 13-17. Dorsal pore is absent and the anus is posteriorly located (Bamgbose *et al.*, 2000)

2.8 Effects of agricultural activities on earthworms

Agricultural activities affect populations of earthworm and other invertebrates. A long history of rural landscape transformation has resulted in many changes in the distribution of earthworm species. Most large earthworms usually disappear from intensively tilled rural soil layer landscapes (Paoletti, 1999). Rich soil with high organic matter content generally supports higher earthworm diversity and biomass while sandy and acidic soils usually support smaller populations of earthworms (Ghilarov, 1979).

Tillage equipment, especially the machines developed to prepare a smooth seed bed after plowing, creates problems for the deep-burrowing species such as *Lumbricus terrestris* and other large earthworms (Stinner and House, 1990). Large species usually disappear soon after transformation of a natural soil into a cultivated field, mostly because of tillage operations. Minimum tillage, no-tillage and ridge-tillage tend to reduce the loss of earthworm biomass living on the soil surface, in part because these less invasive soil mixing practices incorporate dead mulch and/or crop residues 10-15cm below the surface of the top soil or allow it to stay on the soil surface (Stinner and House, 1990).

Adding manure positively affect earthworm biomass and abundance both in grasslands and fields. Earthworms generally respond better to organic manure than to chemical fertilizers (Curry, 1994). However, liquid manure such as pig slurry can stress earthworm population in grasslands and cultivated fields if applied in high quantities (e.g. 400 tons/ha) (Anderson, 1980). In apple orchards, Kuhle (1983) demonstrated that different mulching methods (grass cuttings, chopped wood residues and grass incorporation) can improve diversity, abundance and biomass of earthworms compared with bare soil.

Pesticides can exhibit both direct toxicity against earthworms and produce latent effects on their growth and fertility. In addition, pesticide-contaminated earthworms can represent a source of contamination of higher members of the food webs, e.g. seagulls and other birds. Pesticides usually reach the soil as mixtures of several products, especially in orchards. Upon entry into the soil, such mixtures are expected to have the greatest effects on earthworms feeding at the soil surface, i.e. epigeic, surface dwelling earthworms such as *L. terrrestris* and *L. castaneus* (Paoletti, 1999).

Fungicides are generally highly toxic to earthworms, especially copper and zinc residues from copper sulphate and carbamates, respectively (Paoletti, 1999). Soil fumigants, nematicides and fungicides such as D-D mixture (dichloropropane: dichloropropene), metham- sodium and methyl bromide are highly toxic to earthworms (Paoletti, 1999).. Carbamate fungicides such as Benomyl and carbendazim are also highly toxic to earthworms (Paoletti, 1999). It has been reported that about 1.8 kg/ha per year of Benomyl may destroy all the *L. terrrestris* and most of the *Allolobophora spp.* present in an apple orchard in England (Brown, 1978; Stringer and Wright, 1979).

Earthworms are strongly affected by many types of insecticides, which may be applied directly to the soil or enter the soil from treated crops (Edwards and Bohlen, 1992). Insecticides such as phorate and carbofuran are very deleterious to earthworms when applied to the soil (Edwards and Bohlen, 1992)

Although most herbicides are considered to exert little direct impact on earthworms (Edwards and Bohlen, 1996), the reduced weed cover resulting from their application obviously can render habitats less hospitable to earthworms. Laboratory tests have shown that the herbicide bentazon, bromophenoxin, bromoxynil, bromoxynil octanoate/ioxynil and atrazine are moderately toxic to earthworms (Pizl, 1988). Some broad spectrum herbicides, e.g. glyphosate, are quite harmful to earthworms such as *Aporrectodea calignosa* even at very low doses (Springett and Gray, 1992). Epigeic earthworms such as *Allolobophora chloritica* and endogeic *A. rosea* seem to be negatively affected in grasslands sprayed with atrazine and pentachlorophenol (PCP) (Conrady, 1986).

Heavy metals can enter the soil from different sources such as fertilizers, pesticides, organic and inorganic amendments. Wastes and sludge residues can contain variable amount of these metals. Treatment of orchards and vineyards with copper sulphate strongly affects soil invertebrates, especially earthworms (Rhee,1977a; 1977b; Paoletti, 1985; Paoletti *et al*., 1988) in terms of both biomass and species population response (Paoletti *et al*., 1988).

Agriculture was the first area to support the development and practical application of genetic engineering to improve crop yields and quality. Attributes of plants currently manipulated by genetic engineering include herbicide tolerance (47% of the transgenic plants generated to date), insect resistance (25%), altered product quality (20%), resistance to viruses (17%), and bacterial and fungal resistance (5%) (Paoletti, 1999). Engineered cotton and corn containing the *Bacillus thuringiences* (BT) toxin, effective against some key lepidopteran pest, have been on the market since 1995. If it is expected that plants engineered with BT toxin would be incorporated into soils, then it would be useful to evaluate the impact of toxin against non-target organisms, earthworms included (Jepson *et. al*., 1995; Paoletti and Pimentel, 1995; 1996).

2.8.1 Herbicides effects on earthworm

Earthworms react to herbicides due to an even distribution of sensitive receptors all over the body. In soil, they may escape into deeper layers and the toxic effect of herbicide on them may be partly reduced. Vaclav (1988) reported that Zeatin 50 was moderately toxic to earthworms and the degree of toxicity varied with species in the laboratory tests. The LC_{50} test (Lethal concentration that is expected to produce death in 50% of the tested organisms) is the most common way of estimating the toxicity of herbicides but it is difficult to conclude from such mortality test what kind of ecological effects a pesticide might have when it is used under field conditions. According to him, sub-lethal effects such as retarded growth or development, low fertility, etc. might cause population changes in the field although the animals do not suffer from high acute toxicity (Vaclav, 1988).

The LC_{50} values obtained by Vaclav (1988) for the herbicides used in the laboratory in contact Filter Paper tests (CFP-tests) with two earthworm species is shown in Table 4. There are differences in susceptibility of different earthworm species to Zeatin 50, which means that the toxicity of Zeatin 50 cannot be simply extrapolated from one earthworm species to the other. Various kinds of behaviour may strongly influence the degree of contact with herbicide. So also, different classes of pesticide have different effect on earthworm as they may have different mechanism of action. Thus, for practical reasons, it is necessary to select a monitoring species for the indication of potential hazard from chemicals to earthworms *Eisenia fetida* has been suggested by many authors since it is easy to rear in large number (Goats, 1981; Stenersen, 1981; Heimbach, 1985).

2.8.2 Effects of herbicides on soil microorganisms

When herbicides are applied, the possibility exists that these chemicals may exert certain effects on non-target organisms, including soil microorganisms (Simon-Sylvestre and Fournier, 1979). The microbial biomass plays an important role in the soil ecosystem where they fulfill a crucial role in nutrient cycling and decomposition (De-Lorenzo *et al.,* 2001). During the past four decades, a large number of herbicides have been introduced as pre- and post- emergent weed killers in many countries of the world. In Nigeria, herbicides have effectively been used to control weeds in agricultural systems (Adenikinju and Folarin, 1976). As farmers continue to realize the usefulness of herbicides, larger quantities are applied to the soil. But the fate of these compounds in the soil is becoming increasingly important since they could be leached, in which case groundwater is contaminated or immobile and persist on the top soil (Ayansina *et al*., 2003). These herbicides could then accumulate to toxic levels in the soil and become harmful to microorganisms, plant, wild life and man (Amakiri, 1982). There is an increasing concern that herbicides not only affect the target organisms (weeds) but also the microbial communities present in soils, and these non-target effects may reduce performance of important soil functions. These critical soil functions include organic matter degradation, the nitrogen cycle and methane oxidation (Hutsch, 2001). All the transformation of nutrients occurring in soil is simulated by the enzymes that condition their conversion into forms available to plants and microorganisms. Enzymes are frequently referred to as markers of soil environment purity (Aon and Colaneri, 2001). Microbial activity measurements appear as good indicators of the degree of pollution of contaminated soils (Nordgren *et a*l., 1988; Aoyama and Nagumo, 1995; Insam *et al.,* 1996; Kuperman and Margaret, 1997*).*

Table 4: Toxicity of Zeatin 50 to earthworms as obtained by two different methods

Earthworm species	LC_{50} in kg/ha (95% CI)	
	CFP-test	S-test
Aporrectodea calignosa	20.9 (14.7-29.7)	58.0 (37.8-89.1)
Eisenia fetida	5.7 (3.7-12.2)	83.1 (57.9-191.5)
Lumbricus rubellus	10.5 (9.0-12.2)	31.4 (14.5-67.9)
Octolasion tacteum	4.0 (3.3-4.9)	94.0 (66.2-113.6)

CI = Confidential Interval in bracket

S-test = Soil test

CFP = Contact filter paper

Source: Vaclav (1988)

Dehydrogenase is thought to be an indicator of overall microbial activity, because it occurs intercellularlly in all living microbial cells and is linked with microbial oxido-reduction processes (Quilchano and Maranon, 2002; Stepniewska and Wolinska, 2005). It is a specific kind of enzyme which plays significant role in the biological oxidation of soil organic matter by transferring protons and electrons from substrates to acceptors. Soil dehydrogenase activity is considered to be a valuable parameter for assessing the side effects of herbicides treatments on the soil microbial biomass (Quilchano and Maranon, 2002; Stepniewska and Wolinska, 2005).

Ayansina and Oso (2006) discovered that higher concentrations of herbicides treatments resulted in much lower microbial counts when compared to soils treated with recommended doses. Experiments have shown that microbes may use herbicides as a source of carbon (Radosevich *et al*., 1995). Some studies reported increased populations of actinomycetes and fungi after treatment with glyphosate (Araujo *et al*., 2003), increased soil microbial biomass (Hanley *et al*., 2002) or no long-term change in microbial populations (Busse *et al*., 2001). Ayansina and Oso (2006) reported that soil treatment with atrazine resulted in significant changes in percentage organic matter measurements. Ali (1990) had shown that the fate of pesticides in soils is greatly affected by the presence of organic matter in the soil by aiding disappearance. Glyphosate was found to inhibit dehydrogenase activities in sandy loam soil (Dzantor and Felsot, 1991). No effects on soil dehydrogenase activity were detected by Lethbridge *et al*., (1981) and Nakamura *et al.,* (1990). Reduced enzymatic activities were also found by Dzantor and Felsot (1991) in studies on the interference of atrazine with phosphatase, dehydrogenase and esterase activity of soil. Under laboratory conditions, a normal dose of glyphosate inhibited dehydrogenase activity by 5-10% (3 weeks after application) (Nata and

Mitar, 2002). A tenfold dose of glyphosate affected negatively, the activity of this oxide-reducing enzyme by 5% at 11 weeks after herbicide application (Schuster and Schroder, 1990). Microbial activity increased as an adaptation to the stress caused by increase in concentration of the herbicides over weeks of treatment. The results obtained demonstrated a potential capacity for adaptation of the microorganisms in soils when large amounts of herbicides are added.

2.9 Herbicide persistence in the soil

Residual herbicides are those for which season-long weed control is expected due to their persistence in soil. The economic advantage of residual soil activity can be partially off-set by two problems: carryover of herbicide residue that may injure susceptible rotational crops, and increased risk of transport of herbicide to surface water or groundwater. Herbicide persistence is determined by complex interactions between the pesticide and the soil environment (Akobundu, 1987). Among the most important parameters and processes are: (a) herbicide chemistry; (b) intrinsic soil properties (e.g. texture, organic matter content, pH); (c) extrinsic soil and meteorological factors (e.g., temperature, rainfall); and (d) other parameters (e.g. mode and rate of herbicide application, prior history of pesticide use, plant cover, topography.

An area of concern in chemical weed control is that of herbicide persistence. Persistence refers to how long a pesticide [or its metabolite(s)] remains detectable in the environmental compartment of interest. One biologically-based definition of a persistent herbicide is one "...that, when applied at the recommended rate, will harm susceptible crops planted in normal rotation, after harvesting the treated crop, or that interferes with re-growth of native vegetation in non-crop sites for an extended period of time" (Vencil, 2002). This practical description of persistence varies depending on plant sensitivity, and is influenced by chemical, soil, weather, and management factors (Vencil, 2002).

Herbicide persistence is a measure of the extent to which an herbicide used at a recommended rate remains active in the treated soil and causes injury to susceptible crops that follow the treated crop(s) on rotation (Akobundu, 1987). Persistence on one hand is used as an expression of the much desired duration of efficacy of a compound (positive image); on the other hand, it is used as an expression of the undesirably long life in the environment, and in particular, in soil (negative image) (Helmut and John, 1982). Persistence is the residence time of a chemical species in a specifically defined compartment of the environment (Helmut and John, 1982). In the context of this definition , 'chemical species' denotes a specific chemical which may be the parent compound or a derivative, but not both; 'resident time' is the period in which the chemical remains in one compartment; 'compartment' is one phase of the environment (i.e. soil, water, air, animal or plant tissues) which must be described (Helmut and John, 1982).

Herbicide persistence is affected by mechanisms such as hydrolytic, chemical, oxidative and microbial breakdown which are in turn conditioned by soil temperature, moisture, texture, organic matter and pH. Soil moisture is often, the key to efficacy of soil applied herbicides in the field. If the soil is water saturated, some soluble herbicides may be washed from the weed-seed germination zone. Too little water may hamper herbicide effectiveness and allow weeds to germinate and emerge without satisfactory control (William, 1998).

The primary reason for estimating the biologically active fraction of an herbicide in soil is to evaluate the potential injury to rotational crops. The potential for follow-crop injury is greatest when an herbicide with soil activity on broad-leaved weed is used on a monocot and the follow crop is a dicot. Examples would be atrazine carry over to soybean, cucurbits and other dicots; and chlorimuron, prosulfuron, and sulfonylurea carry over to dicots. Herbicides with grass and broad-leaved activities that exhibit safety to soybean may be carried over to injure corn, sorghum or wheat the following year (William, 1998). Aladesewa *et al.* (2001) reported that *Celosia argentea* should not be allowed to succeed maize in which atrazine (3.0kgai/ha) has been used for selective weed control in order to avoid crop injury and yield reduction particularly because most maize varieties cultivated in Nigeria mature within 12 weeks of planting, the period observed in the screen house as not sufficient for atrazine degradation.

There is no universally accepted classification of pesticide environmental persistence. However, Roberts (1996) used a classification based on the mean half-life of the pesticide in the soil: I) impersistent [or "nonpersistent"], DT_{50} <5 days; 2), slightly persistent, DT_{50} = 5-21 days; 3) moderately persistent, DT_{50} = 22-60 days; and 4), very persistent, DT_{50} >60 days. For the purpose of identifying a set of "residual herbicides", however, this author has set DT_{50}> 40 d as indicating moderate to long persistence. Any estimate of field dissipation half-life or comparable index of persistence is dependent on a variety of factors. For example, DT_{50} values tend to be shorter in warm, moist climates compared to cooler, drier soils. Alkaline soils tend to prolong persistence for certain herbicide classes, notably sulfonylureas and triazines. Although, a single value may be reported for DT_{50}, for an herbicide, it usually represents a range, often very wide.

2.9.1. Processes affecting herbicide dissipation

Many reviews (Helling *et al*., 1971; Helling, 1976; Khan, 1980; Helling and Gish, 1985; Cheng, 1990; Mangels, 1991; Koskinen and Clay, 1997; Cessna *et al*., 2002) have described the environmental fate of herbicides or other types of pesticides. The fundamental principles affecting their fate and behaviour in the soil are the same.

2.9.1.1 Herbicide dissipation as affected by adsorption

Adsorption is defined as the accumulation of herbicide at the soil solution-soil colloid interface, or at the soil-air interface. "Sorption" is sometimes used instead of adsorption to describe the physical loss of chemical from the soil solution phase through contact with soil solids. The adsorption of an herbicide to the soil affects the transformation and transport of the herbicide, as well as its bioavailability. The bioavailability of an herbicide affects its performance by regulating the amount of residual chemical in the soil solution that is readily available for uptake. This in turn is directly related to persistence. As with much that is associated with the soils, even the correlation between herbicide adsorption and bioavailability is not always clear (Hance, 1988), especially with respect to availability of the herbicide to microorganisms. However, increased adsorption probably protects herbicides from biological degradation (Ogram *et al*., 1985). All other things being equal, herbicide persistence is expected to be longest for the most strongly adsorbed chemicals and in the most strongly sorbing soils. The former tend to be compounds with low water solubility (e.g. Trifluralin) or those that are cations (e.g. diquat and paraquat). Finer-textured mineral soils high in organic matter tend to have highest capacity for adsorbing herbicides. That is, high organic matter soils adsorbed more than low organic matter soils (Ogram *et al*., 1985).

Herbicide chemical structure greatly influences soil adsorption strength and type. Cations such as diquat and paraquat are strongly sorbed, especially to soil clay. Glyphosate is also bound and largely inactivated in soil. The specific formulation of acidic herbicides can affect adsorption (Vencil, 2002). Hydrolysis will quickly convert both to the free acid, but initially the low adsorption of the salt implies a much higher potential for some leaching into the soil; that in turn, would protect the triclopyr from decomposition.

2.9.1.2 Herbicide dissipation as affected by degradation

Degradation of herbicides in soils occurs by abiotic and biotic processes. The transformation products usually are less phytotoxic than the parent. Complete mineralization of the herbicide to carbon dioxide rarely occurs, and often a significant fraction of the herbicide forms part of a bound residue (BR) pool. BRs are not easily characterized, but are likely to be high molecular weight polymers or metabolic fragments that become covalently bonded to soil organic matter. Khan (1991), in a review of BRs identified Dinitroaniline, atrazine and prometryn as residual herbicides that may produce large amounts of BRs. Although, BRs may have some biological availability, they probably represent no inherent threat despite long persistence.

Abiotic loss is often inferred when half-lives are similar for non-sterile and sterilized soil in laboratory tests. However, microbial metabolism of the parent herbicide is the dominant mechanism of loss from the surface horizon. Atrazine is degraded by both chemical and biological mechanisms, although the latter seems to be the dominant pathway (Mandelbaum *et al.*, 1993). At low pH, atrazine is chemically transformed to hydroxyatrazine in the soil. However, biological dehalogenation of atrazine to hydroxyatrazine has also been demonstrated

(Mandelbaum *et al.,* 1993). Although, atrazine has been commercially available since 1958, only comparatively recently was a soil bacterium isolated that could mineralize the s-triazine ring (Radosevich *et al*., 1995).

Herbicide degradation, as for metribuzin is generally slower in subsoil, where the microbial population is much less than in top soil (Moorman and Harper, 1990). Unless photo degradation is a significant process, degradation is slower in the surface organic debris than in soil. Atrazine loss, for example, was faster in the underlying mineral soil than in the organic layer of a coniferous forest soil (Entry and Emmingham, 1996). Microbial degradation is sensitive to many factors including soil temperature, aeration, moisture content, pH, soil organic matter, existence of an active rhizosphere (plant growth) and perhaps nutritional status. Today, most-probable-number enumeration methods are increasingly being used for herbicide such as 2, 4-D and atrazine (Jayachandran *et al*., 1998) to better understand persistence.

2.9.1.3 Herbicide adsorption as affected by transportation

I Leaching effect on herbicide transportation

Herbicide movement into soils following rainfall or irrigation is often beneficial when root uptake is necessary for weed control. Depending on the product's chemical characteristics, leaching from the soil surface reduces losses by volatilization and photo degradation (Radosevich *et al*., 1996). Thus, limited leaching may extend soil persistence. Deeper migration reduces the residual herbicide in the upper vadose zone (region below water table), and so could lessen persistence in the zone most relevant to crop production. Such leached chemical no longer contribute to weed control and may contaminate ground water or surface water via lateral discharge. Since microbial activity is much lower in the subsurface horizons and in ground water compared to the vadose zone, herbicide persistence generally is much longer once it moves below the vadose zone. However, when abiotic degradation is important- as with atrazine, increased persistence in subsoil may be slight (Radosevich *et al*., 1996). The persistence of atrazine in ground water is quite long (Klint *et al*., 1993; Widmer *et al*., 1993), no doubt contributing to the observation that it has been the most commonly detected pesticide in the U.S. (Public Health Service, 2003) and Canadian water samples.

Leaching potential has long been predicted based on herbicide and soil characteristics, and on various laboratory methods such as adsorption, soil leaching column, and soil thin-layer chromatography tests. Rapid degradation greatly reduces the potential loss by leaching. For example, the relatively new herbicide florasulam has very high potential mobility- 68-92% leached through a soil column. It may not contaminate ground water because it had DT_{50} values of 2-10 days and DT_{90} values of 16-34 days (Vencil, 2002; Health Canada, 2004). The principal metabolite, 5-hydroxyflorasulam, was equally mobile, but more persistent, and presents a higher potential for carryover, so leaching may occur under conditions of excessive rainfall or irrigation (Health Canada, 2004).

Most herbicide leaching occurs during mass flow of water through the soil matrix, ensuring ample exposure of chemical to soil and soil biota surfaces. Preferential (or macro pore) transport represents a condition whereby water and dissolved constituents rapidly percolate deeper into the soil profile by following larger pores formed from root channels, arthropod activity, or natural soil structure voids; by unstable wetting front flow; or by funnel flow in sloping layered soils (Kung, 1990).

II Runoff and herbicide transportation

Runoff refers to the off-site surface transport of herbicides in solution, suspension, or while adsorbed to particulates. Comprehensive reviews on runoff have been written (Waucope, 1978; Leonard, 1988; Leonard, 1990). There is a direct correlation between persistence and the potential for runoff loss, particularly when the chemical remains within the upper 1 cm of surface soil. Runoff is triggered by rainfall, and the highest pesticide loss occurs during the first major runoff-producing event. The losses are affected by many factors, including the timing of pesticide application relative to the timing, intensity and duration of rainfall, antecedent soil moisture, soil texture, surface crusting, compaction, topography, pesticide formulation, and management practices (e.g. no-till; buffer strips; controlled drainage). While herbicide transport by runoff represents an important mechanism for potential environmental contamination of surface waters, the process itself generally removes less than 5% of total applied chemical and for most pesticides, less than 0.3% (Waucope, 1978).

III Volatilization as it affects transport of herbicide

Volatilization of herbicides has been considered to be relatively small due to the inherently low vapour pressure of most such chemicals, or because loss is reduced through soil incorporation or formulations that minimize vapour phase loss. However, it is recognized today that many pesticides are transported far from their site of application via volatilization and losses are likely to greatly exceed those from leaching or runoff (Taylor and Spencer, 1990). Despite its relatively low vapour pressure, the consistent occurrence of atrazine in rainwater (Miller *et al*., 2000) is a strong indicator of some loss by volatilization, spray drift, and as material sorbed onto dust (wind erosion). Metolachlor is another herbicide for which vapour phase loss can be large during the first 48 hours after application, depending on the climatic conditions. Volatilization peaks during and immediately after application, but sensitive methods for monitoring air also show vapour phase fluxes early in precipitation events, or even diurnal fluctuations, as soil water moves towards the soil surface. Minimum loss is expected when application occurs in moist soil followed by a long period of drying. Once the herbicide has moved into the soil (probably only a few centimeters) and adsorption occurs, loss by volatilization should greatly diminish.

2.9.2 Factors affecting soil persistence of herbicides

2.9.2.1 Soil and related meteorological characteristics:

I Soil pH and persistence of herbicides

Herbicide adsorption to soil can be strongly affected by soil pH, and this can affect persistence. In general, ionizable chemicals may protonate at low pH (e.g. weakly basic amines), or conversely, become anions at neutral or alkaline conditions, such as the weak acids 2, 4-D or picloram. The solubility and hydrolytic stability of sulfonylureas, which are weak acids, increase in alkaline soil and result in a substantially increased potential for carryover. On the other hand, triazines and imidazolinones are more strongly adsorbed and more persistent, in acidic soils. Even if the pesticide itself does not become changed, soil pH may affect the soil surface characteristics, potentially strengthening or weakening binding of certain herbicides. Soil pH has also been proposed as the underlying reason for in-field spatial variability in the degradation of phenyl urea herbicide isoproturon. The bacterial strains found to degrade isoproturon had a very narrow to optimum pH for metabolism of 7-7.5 (Bending *et al*., 2003).

Thus, liming, for example could easily affect localized differences in residual herbicide, whether the transformation is biotic or abiotic.

II Soil organic matter content and persistence of herbicides

In general, microbial activity is higher in soils with high soil OM content, so herbicide degradation is expected to be faster, and persistence shorter as soil OM increases. Counterbalancing this is the greater capacity for higher soil OM to sorb the herbicide, keeping less in soil solution and reducing transport by leaching. This was given as a possible explanation of the increasing DT_{50} of 2, 4-D as soil OM increased (Bolan and Baskaran, 1996), although in another study (Benoit *et al*., 1999), increased sorption seemed to enhance the rate of mineralization of 2, 4-D and its polar phenolic metabolites to carbon dioxide.

III Soil texture and composition as they affect herbicide persistence

Nash (1988), after evaluating numerous reports, was unable to conclude that soil type *per se* affected herbicide persistence. Contributing- but sometimes contradictory-factors include the relationships of soil type to moisture holding capacity, organic matter content, aeration status, soil temperature, pH, and microbial activity. Adsorption can be affected markedly by the composition of the soil's mineral fraction; for example, imazapyr is strongly bound to a Hawaiian oxisol soil that is dominated by amorphous iron and aluminum oxides (Helling and Doherty, 1995; Helling, 1997). This had the practical effects of reducing the herbicide's phytotoxicity and preventing its leaching, although not its degradation.

IV Soil moisture content as it affects herbicide persistence

Prolong drought not only reduces herbicide performance by reducing uptake by weeds, but also slows the rate of degradation in the soil (Pesaro *et al*., 2004). Higher soil moisture in aerobic soils is normally associated with enhanced microbial activity and decreased persistence. However, unless anaerobic degradation is important, saturated soils prolonged herbicide persistence. Soil moisture fluctuations impact microbial cell number, biomass, enzyme activities, etc (Pesaro *et al*., 2004). Generic fingerprinting has been used to show which microbial communities are resistant or resilient to soil drying-rewetting in a study on the degradation of two pesticides (Pesaro *et al*., 2004). Drying the soil greatly lengthened the half-life (DT_{50}) values for the pesticides and their metabolites. Mojaeviá *et al.* (1996) found a consistent, parallel increase in DT_{50} for seven pesticides (including herbicides alachlor, atrazine, cyanazine, metolachlor and metribuzin) as soil moisture content decreased from 35 to 25 to 12%, except that carbofuran dissipation was disproportionately reduced at 12% moisture content. Field persistence of these pesticides was more variable compared to laboratory studies, but the rankings were similar.

V Soil temperature as it affects herbicide persistence

Within the normal environmental range, higher soil temperature has been associated with faster dissipation of herbicides. The approximate effect is a 2.2-fold increase in rate per 10^{o}C increase. While the longer term effect is likely to be accelerated degradation, volatilization also increases as temperature increases, especially during and soon after application. On a large scale, Nash (1988) used the data of Hamaker (1972) to demonstrate the greatly extended half-life of picloram going from latitude- 25^{o}N -55^{o}N. Similarly, the half-life of diphenamid ranged from 1-2 weeks in the southern United States to 5-6 weeks in the northern U.S. (Vencill, 2002). There are many reports of herbicides and other pesticides dissipating more rapidly in tropical than in temperate climates (Helling, 1997; Racke *et al.*, 1997; Laabs *et al*., 2002), most likely related to higher mean soil temperature in tropical and subtropical areas. Bailey, (2003) attributed reduced persistence of autumn-applied isoproturon to an apparent two-decade warming trend in Great Britain. If these observations are true, this would seem to have significant long-term implications for herbicide use and effectiveness as the global temperature increases.

2.9.3 Application/Management factors and soil persistence

Higher rates of herbicide application are associated with longer persistence of residues, even though the DT_{50} values are generally unaffected. At very high rates, simulating chemical spills, longer DT_{50} values have been shown (Gan *et al*., 1995), indicating that the first-order dissipation model for loss cannot be projected indiscriminately. The lower rates of many new herbicides do not preclude carryover, however, as exemplified by chlorsulfuron, which is applied at ca. 5-50 g/ha, but may affect sensitive species such as sugar beets 3-5 years after application in an alkaline soil (Vencil, 2002). It is likely that most cases of higher-than-label rates of herbicide will occur when unintentional application overlap occurs, and carryover damage to sensitive rotational crops may be limited to such isolated spots in the field.

Vegetated buffer strips are used to reduce soil and pesticide runoff. The higher soil organic carbon and microbial activity within the strip promote adsorption and degradation. For example, the DT_{50} for metolachlor is 23 days in a bare field soil versus 10 day within an adjacent buffer strip (Staddon *et al*., 2001).

Prior history of the use of certain herbicides and other pesticides may affect their soil persistence (Racke and Coats, 1990). For example, thiocarbamate herbicides such as EPTC and butylate show accelerated degradation in fields previously treated with these compounds

(Roeth, 1986; Harvey, 1987). More recently, there have been several reports of shorter persistence of atrazine in sites where this herbicide had been used for a number of years, and more atrazine-degrading microorganisms were isolated from the "history" soils, indicating that adaptation had occurred (Koskinen and Clay, 1997; Jayachandran *et al.*, 1998). The DT_{50} of isoproturon was related to the recency and frequency of prior use (Walker and Austin, 2004). Failure of carbetamide to adequately control grasses following repeated annual application was associated with its enhanced degradation by adaptive soil bacteria (Hole *et al.*, 2001); reapplication once, 14 months after the first dose, reduced its DT_{50} from 54 to 9 days. In these examples, enhanced microbial degradation with diminished soil persistence and weed control is distinguished from loss of efficacy that arises from herbicide-resistant weed biotypes (Heap, 2004).

Cross-enhancement is enhanced degradation that may occur for a chemical applied to soil treated previously with a different- though usually structurally similar- pesticide. One such case is the use of the fumigant (and herbicide) metham sodium. This degrades to the biocide methyl isothiocyanate (MITC). Degradation of three other isothiocyanates was enhanced when incubated with a MITC- history soil (Warton *et al*., 2003). With long-term use of individual products, or sometimes classes, some degree of enhanced herbicide degradation is likely.

2.9.4 Earthworms acute toxicity tests guidelines (OECD, 1984)

This test guideline can be used for substances that are either insoluble or soluble in water, although the methods of application differ. There are no relevant international standards for earthworms' toxicity testing. There are many methods of testing toxicity of chemicals to earthworms, including spot application, forced feeding and immersion tests.

A simple paper contact toxicity test is described as an optional initial screen to indicate those substances likely to be toxic to earthworms in soil and which will require further more testing in an artificial soil. The LC_{50} is the median lethal concentration i.e. that concentration of the test substance which kill 50 per cent of the test animals within the test period. The condition for the validity of the test is that the mortality in the controls should not exceed 10 per cent at the end of either test. Worms should be adult (at least two months old with clitellum) with an individual weight of 300-600mg. Test conditions, description and details of any variation of the test materials and recommended conditions must be clearly reported.

CHAPTER THREE

3.0 MATERIALS AND METHODS

sThis farm research was conducted in 2008 and 2009 planting seasons while earthworms' toxicity test was conducted in 2012 at Ladoke Akintola University of Technology (LAUTECH), Teaching and Research Farm (LTRF), Ogbomoso and Ogbomoso farm settlement (OFS), located on (Lat. 80^{o} $10^{'}$; Long $4^{o}10^{'}$E; Altitude 700 m), in the Southern Guinea Savanna (SGS) vegetation zone in the South Western Nigeria.

3.1. Survey of herbicides used in Ogbomoso

An evaluation of herbicides in use in Ogbomoso ecological Zone of South Western Nigeria was carried out using structured questionnaire (Appendix VII). Three local government councils were randomly selected by balloting out of the five in Ogbomoso land. The councils picked were: Ogbomoso south, Orire and Surulere (Figures 3, 4, 5 and 6).

Extension programme officers in each of the local government councils were approached for questionnaire administration. Some of their assistants were familiarized with the questionnaire and were briefed on how to administer the questionnaires. Copies of same were given to the Extension Agent Assistants who distributed them to the farmers to collect pertinent information and retrieved the questionnaires back to the programme officers. Forty (40) respondent maize farmers were randomly selected and interviewed in each local council. Demographic and agricultural technology adoption data were collected through the questionnaire. The survey was necessary because knowing the herbicides adopted by farmers in the zone is paramount in selecting the herbicides to be used in this research (Adedipe *et al.*, 2004). The selected herbicides for the study were those with dearth of information on work done

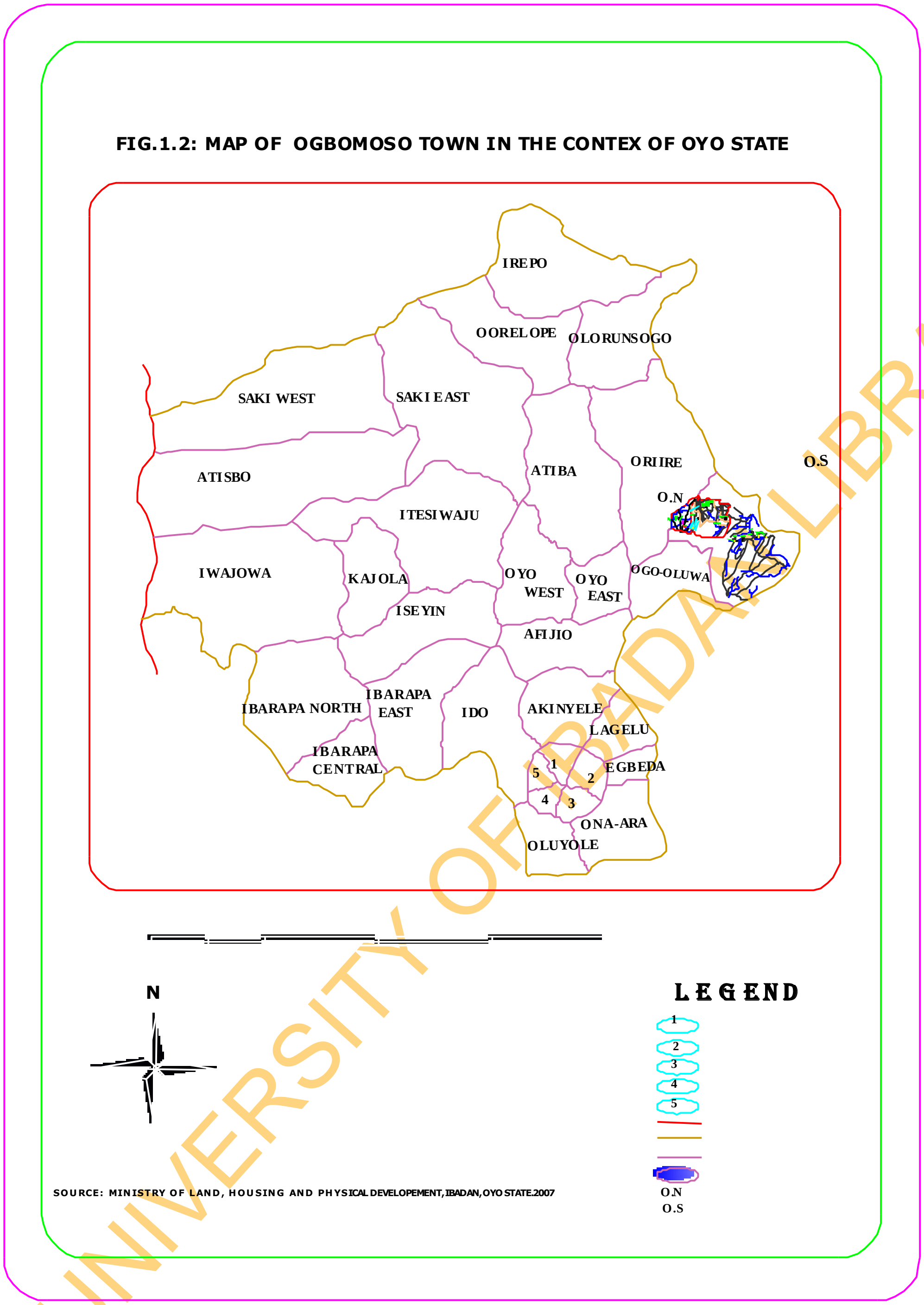


Figure 3: Map of Oyo state showing local governments.

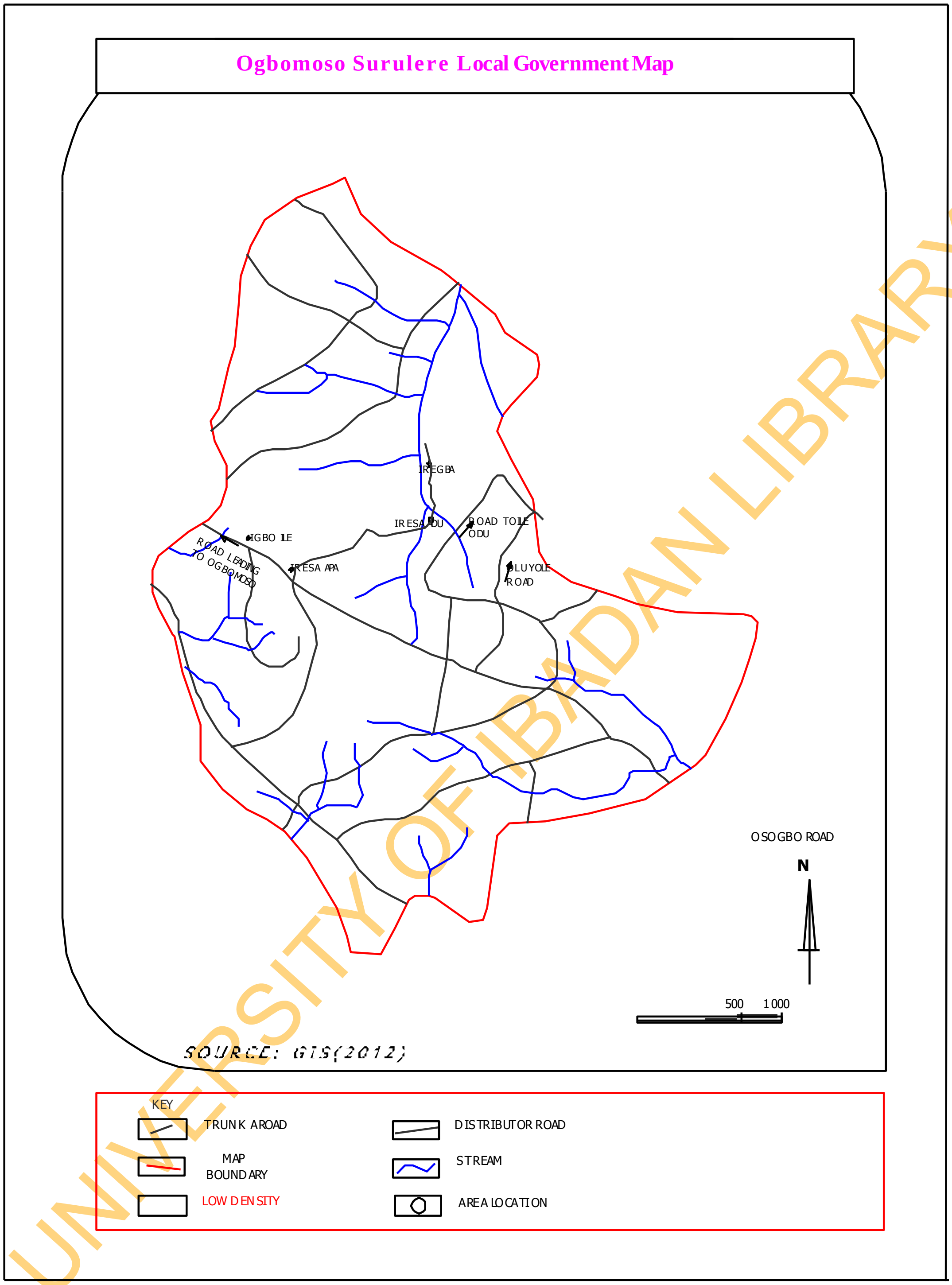


Figure 4: Surulere local government council

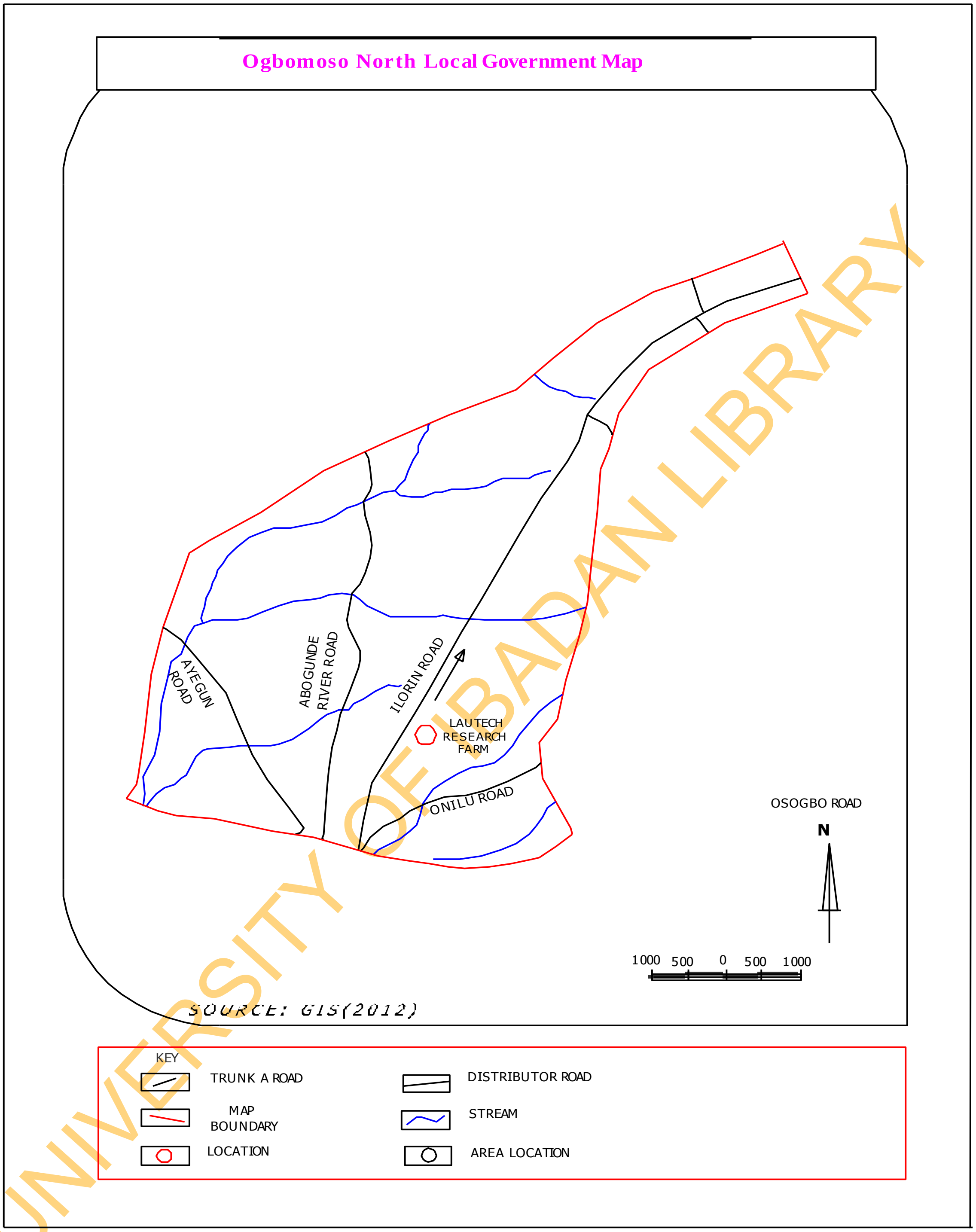


Figure 5: Ogbomoso North local government council

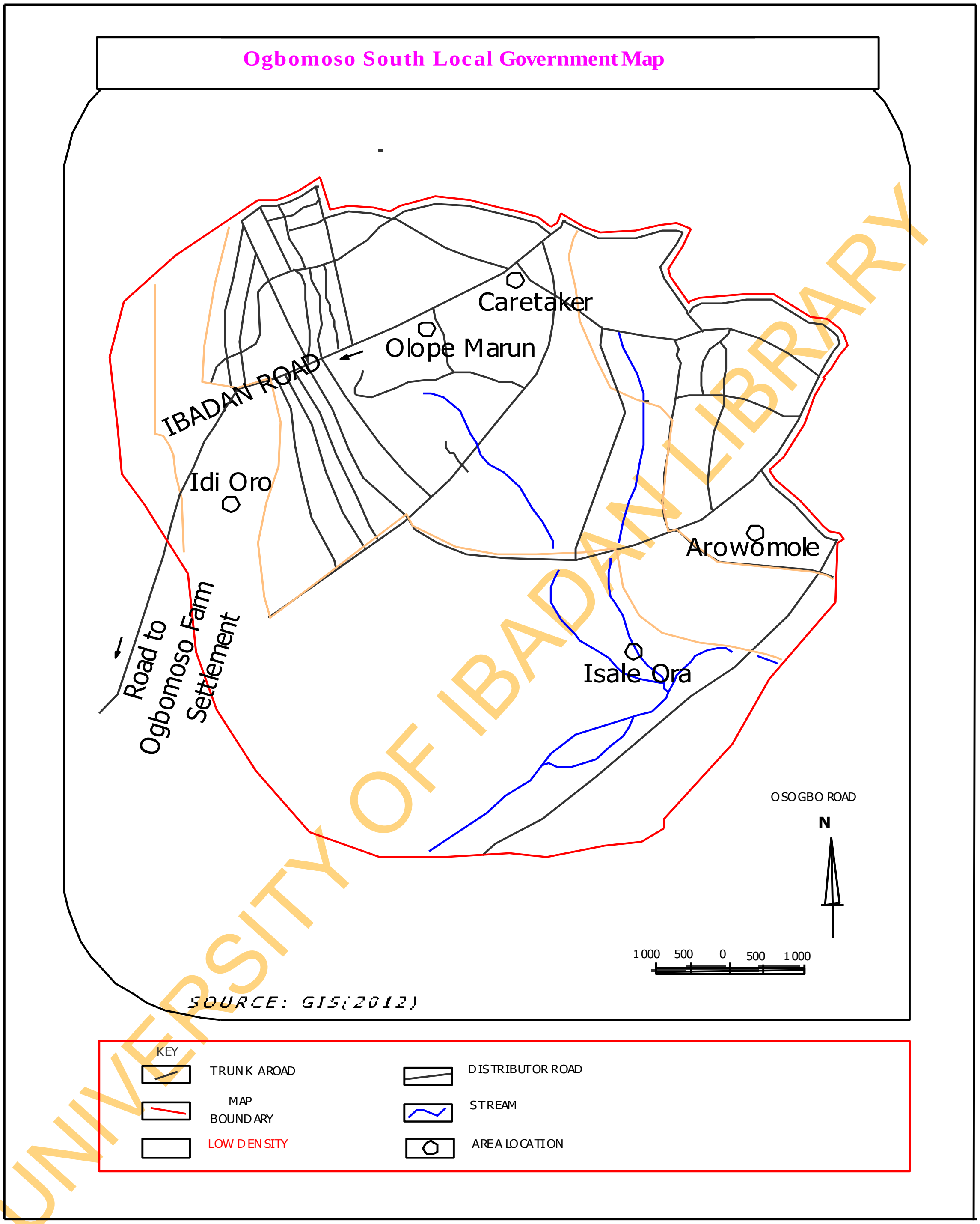


Figure 6: Ogbomoso south local government council

on them in the ecozone and which were not formulated mixtures. Atrazine had been worked upon in the South Western Nigeria (Akinyemiju *et al*., 1986). Two herbicides were randomly picked out of S-metolachlor, Diuron and Pendimethalin by balloting and the outcome favoured S-metolachlor and Pendimethalin.

3.2 Weed management in maize with S-metolachlor and Pendimethalin in a field experiment

3.2.1 Untreated soil and worm cast sampling for Physico-chemical analysis

Systematic soil sampling, 0-15cm deep (top soil) was carried out on the field using soil auger. This was done across each of the field (2,059 m^2) in diagonal systematic sampling on thirty spots before land preparation started. The soil samples were mixed, sub-sampled and analyzed for pH, cation exchange capacity, particle size and organic matter (OM). Also, 0.25m x 0.25m quadrat was used to sample worm cast following the same diagonal method. Worm casts within the quadrats were collected, weighed and analyzed for exchangeable cations such as Potassium, Calcium, Magnesium, Sodium, Zinc, Copper, Manganese, Iron, exchangeable acidity and exchangeable cation exchange capacity. Particle size and pH were also determined. All these samples were analyzed at International Institute of Tropical Agriculture (IITA) soil laboratory, Ibadan.

3.2.2 Methods used in soil analyses

3.2.2.1 Soil Digestion

3.2.2.1.1 Extraction procedure for Ca, Mg, K, P, Cu, Zn, Mn, and Fe: (Mehlich, 1984)

3.2.2.1.2 Stock solution's preparation

Mehlich-3 extraction solution: Into a 500 ml polythene bottle was added to 250 ml de-ionized water. 69.45 g NH_4F and 36.75 g EDTA were added and diluted to 500 ml. About 8 litres of water and 200 g NH_4NO_3 were added to a 10 litre jug then 40 ml of the EDTA/NH_4F solution, 115 ml acetic acid, and 8.2 ml of 70% nitric acid were added and diluted to 10 litres. The pH was then adjusted to 2.5±0.1.

2) With a 3.0 ml scoop, 3.0 ml of soil was weighed in a 50 ml centrifuge tube, and recorded to the nearest 0.01 g. The soil sample in the scoop was then leveled.

3) 30 ml of Mehlich-3 extractant was added to a batch of 24 samples capped securely and shaken for 5 minutes, allowed to stand for 10 minutes and then centrifuge for 5 minutes at 3000 rpm. The blank samples were centrifuged.

4) Step 3 was repeated until all samples have been centrifuged. The samples were staggered appropriately so that samples stand exactly 10 minutes between shaking and centrifugation.

5) After centrifugation, extracts and blanks were transferred to separate bottles to minimize soil contact after centrifugation.

3.2.2.1.3 Preparation of standard/working solution for Calcium, Magnessium, and Potassium analysis (Mehlich-3 extracts):

1) Strontium (Sr), 1000 ppm: 6.08 g of strontium chloride ($SrCl_2.6H_2O$) was dissolved in 2 litres of de-ionized water in a volumetric flask. The strontium chloride was certified to contain less than 0.0015 %K.

2) Ca-Mg-K mixed stock solution: Into a 100 ml volumetric flask, 8.00 ml of 1000 ppm Ca, 1.6 ml of 1000 ppm Mg, and 0.800 ml of 1000 ppm K were added and diluted to 100 ml with de-ionized water. This solution contains 80.0 ppm Ca, 16.0 ppm Mg, and 8.00 ppm K.

3) Standard preparation: 1.00 ml of Mehlich-3 extractant from each of the 5 blanks added into 5 centrifuge glass vials. 19.0 ml of 1000 ppm Sr was diluted and mixed well. From the 5 respective vials, 0, 0.200, 0.400, 0.600, and 0.800 ml of solution were removed and t the same amount of mixed stock solution were added back and, mixed well.

4) Sample preparation: 1.00 ml of the sample was added to the glass vials used in step 2. The pipette was rinsed with 1.00 ml of 1000 ppm Sr following each sample addition. Dilution was further made by the addition of 18.0 ml of 1000 ppm (or La) solution.

5) The samples and standards were then read on an Atomic Absorption Spectrophotometer (AAS Buck Scientific 210). Calcium was read normally while the burner head was rotated for Mg readings and a flame photometer was used for K determinations.

6) Calculations: Sample concentrations were determined from a standard curve. The following calculation was used:

$$\text{Soil concentration}\,(\text{cmol}(+)\text{kg}^{-1}) = \frac{\text{ppm} \times 30}{\text{Eq. wt.} \times \text{sample wt.}}$$

Ppm of each element from the curve

The units of sample weight were in g, and the equivalent weights (Eq. wts.) are as follows: Ca = 20.04, Mg = 12.12 and K = 39.1 (Mehlich, 1984)

3.2.2.1.4 Sample preparation

Phosphorus analysis of Mehlich-3 extracts

1) Murphy-Riley stock solution: To approximately 1.5 litres of de-ionized water, 140 ml of concentrated H_2SO_4 was slowly added and then, 12.0 g ammonium molybdate was added. 0.290 g of antimony potassium tartarate was dissolved in 50ml water and added to the ammonium molybdate – sulfuric acid mixture, then made up to 2 litres with distilled water and stored in an amber bottle.

2) Working solution: 1.056 g of ascorbic acid was added to 200 ml of Murphy-Riley stock solution and made up to 1000 ml with distilled water.

3) P stock solution, 90 ppm: 0.3954 g of oven-dried KH_2PO_4 was dissolved in 1 litre of distilled water.

4) P standard solutions: To 50 ml centrifuge tubes was added 30 ml of Mehlich extraction solution. Removed from the 5 respective tubes were 0, 0.250, 0.500, 0.750, and 1.00 ml of the Mehlich extraction solution, and then the same amounts of the 90 P stock solution in 13 above were added back, capped and shaken for 5 minutes.

5) 1.00 ml of the Mehlich-3 soil extracts was pipetted into glass vials, and each sample was followed by 1.00 ml de-ionized water to rinse the pipette. Added was 8.0 ml of Murphy-Riley working solution. After 30 minutes, the absorbance was read at 860 nm. Colour was stable for 24 hours.

6) Calculations: Sample concentrations were determined from a standard curve. The following calculation was applied:

$$\text{Soil concentration (ppm P)} = \frac{\text{ppm} \times 30}{\text{sample wt.}}$$

Ppm of each element from the curve

The units of sample weight are in g. The sample matrix is 100% Mehlich-3 extractant (Murphy and Riley, 1962)

Cu, Zn, Mn, and Fe analysis of Mehlich-3 extracts

1) Zn-Cu-Mn-Fe stock solution: To a 250 ml volumetric flask was added 100 ml of 1000 ppm Mn, 100 ml 1000 ppm Fe, 1.00 ml of 1000 ppm Cu, and 1.00 ml of 1000 ppm Zn. Dilution was made to the mark with de-ionized water. This solution contained 400 ppm Mn and Fe, and 8.0 ppm Cu and Zn.

2) Standards: To 5 50-ml centrifuge tubes was added 30 ml of Mehlich-3 extractant. 0, 0.375, 0.750, 1.50, and 3.00 ml were removed from the 5 respective tubes. The same amount of the mixed stock solution from 18) was added, capped and shake for 5 minutes. These samples contained 0, 5.00, 10.00, 20.0, and 40.0 ppm Fe and Mn, and 0, 0.100, 0.200, 0.400, and 0.800 ppm Cu and Zn.

3) The standards and undiluted sample extracts were read on the AAS. .

4) Calculations: Concentration of the samples was determined from a standard curve as follows:

$$\text{Soil concentration (ppm)} = \frac{\text{ppm} \times 30}{\text{sample wt.}}$$

Ppm of each element from the curve

The unit of sample weight is g. The sample matrix is 100% Mehlich-3 extractant.

3.2.2.2 Analyses of nutrients

Organic carbon determination

Preparation of solutions:

1) Potassium dichromate, 1N: 98.08 g of reagent-grade $K_2Cr_2O_7$ was dissolved in distilled water and diluted to 2 litres.

2) Standard sucrose solutions: Into 5, 250 ml volumetric flasks were weighed 0, 1.471, 2.942, 4.414, and 5.885 g of oven-dried sucrose and dilute to 250 ml.

PROCEDURE:

1) The soil samples were ground to pass through a 0.2 mm sieve before weighing. The soils were mixed thoroughly and weighed out 500 mg soil samples into a 50 ml digestion tubes.

1.00 ml of the 5 standard solutions was added into 5 digest tubes and after taking 1 ml each of the standards, the pipette was rinsed with 1.00 ml of de-ionised water into the digest tubes.

2) 5 ml of $K_2Cr_2O_7$ solution was added to samples and standards, and then 10 ml of concentrated H_2SO_4 was added, capped with a rubber stopper, and swirled on a vortex mixer until the soil sample was completely dispersed.

3) They were placed in a digestion block pre-heated to 150^o C for exactly 30 minutes.

4) The tubes were allowed to cool and then diluted to 50 ml and mixed.

5) The organic carbon of standards and samples were read on a Spectrophotometer (Buck Scientific 210) at a wavelength of 600 nm using a 1 cm cell. The standards contained 0, 2, 4, 6, 8, and 10 mg of C.

Calculations:

The amount of C was determined from a standard curve and % OC was calculated as:

% OC = mg C / mg of sample X 100

Total nitrogen in soil

Procedure:

1) Soil samples were ground to pass through a 0.5mm sieve

2) Approximately 0.5g soil was weighed into 50ml digestion tubes (5 digestion tubes were without soil samples for the preparation of standards). The soil was mixed uniformly before weighing and recorded to the nearest 0.001g.

3) 2.5ml of sulphuric acid-selenium mixture was added into each tube. (Sulphuric acid-selenium mixture: 6.25g of selenium only was added to 1 litre concentrated (98%) sulphuric acid.), and then mix d with the acid on a vortex mixer.

4) 4. 2 X 1ml of H_2O_2 (hydrogen peroxide) was added into each tube

5) The tubes were placed on a hotplate preheated to 300^oC.

6) After 30 minutes of boiling, condensing bottles were placed over each digest tube.

7) The temperature was increased to 320^oC, and then left on hotplate until the digest was clear.

8) The samples were allowed to cool, diluted to 50ml with distilled water.

N STOCK SOLUTION, 500ppm: 1.9107g of NH_4Cl was dissolved in 1 litre of distilled water.

N WORKING STANDARD SOLUTIONS: 0.5, 1.0, 1.5 and 2.5ml of stock standard were separately added to 5 digestion tubes which already contained digesting solution, which had been digested along with the samples and then made up to 50ml mark with distilled water. These solutions contained 0, 5.0, 10.0, 15.0 and 25.0ppmN. The standards and samples were run on auto analyzer (TIC, 1971; Bremner and Mulvaney, 1982).

EXCHANGEABLE ACIDITY (Al + H) (Titration method)

Reagents

1) Potassium chloride (1.0*N* AR grade KCl): dissolve 74.5g KCl per liter of distilled water.
2) Sodium hydroxide: 0.05*N* NaOH (made from ampoules with concentrated volumetric solution).
3) Sodium fluoride (3*N* AR grade NaF at 126g / liter).
4) Hydrochloric acid (0.05*N* AR grade HCl).
5) Phenolphthalein indicator: 0.1g in 100ml 95% ethanol

Procedures of extraction

1) 3g of air-dried soil (grind to pass a 2mm sieve) weighed into folded filter paper placed on the extraction cups.
2) Fifty (50) ml of 1.0*N* KCl solution was gently poured through the soil in the filter paper to collect the leachate
3) 5 drops of phenolphthalein indicator was added to the leachate
4) The leachate was titrated with 0.05*N* NaOH to pink end point.
5) The volume (ml) of NaOH used, V, was recorded.

Calculations

Exchangeable acidity (meq/100 g)

$$= \frac{V x 0.05 x 100}{W} = Vx1.67 = 1.67V$$

Where

V = Titre volume of NaOH used (ml)

0.05*N* is the normality of NaOH

W = weight of soil sample used 3 (g) (Maclean, 1965).

Procedure for dry ash digestion and analysis for sodium extraction

1) 0.48-0.52g sample was weighed into a clean ceramic crucible and one empty crucible was included for a blank.

2) It was placed in a cool muffle furnace and ramp temperature to 500°C over a period of 2 hours and allowed to remain at 500°C for an additional 2 hours. It was allowed to cool down in the oven.

3) a. The sample was removed from the oven when the environment was free from breeze.

b. The ashed sample was then poured, first into already labeled 50ml centrifuge tubes.

c. The crucible was rinsed with 5ml of distilled water into the centrifuge tube.

d. The crucible was rinsed again with 5ml of aqua regia.

e. The above (d) was repeated two more times to make a total volume of 20ml.

4) The sample was vortexed for proper mixing.

5) The sample was centrifuged for 10mins at 3000rpm.

6) The supernatant was decanted into clean vials for sodium determination using Atomic Absorption Spectrophotometer (AAS BUCK SCIENTIFIC 210).

Preparation of aqua regia solution

1.2 litre of distilled water was poured into a 2 litre volumetric flask. 400 ml conc. HCl and 133ml of 70% Nitric acid was carefully added and then diluted to 2 litres.

Soil pH determination

Soil pH was determined by equilibrating 10g of soil with 10ml distilled water (ratio 1:1) on mechanical shaker for 30mins and allowed to stand for 10mins after which the pH was measured by dipping a pH meter (OMEGA PH H200) equipped with a pair of electrodes initially calibrated in buffer solution 4,7 and 9.

3.3. Land preparation, experimental design and treatments application

3.3.1 **Land preparation and experimental design**

The site in each of the two locations was disc ploughed twice and manually leveled after pegging into plots. The total area cultivated in each site was 71m by 29m (2,059m^2). The experiment was laid out in a Randomized Complete Block Design (RCBD) with nine treatments in a block and replicated thrice. Each block contained nine (9) beds of 5 m by 5 m. There were 2m alley between blocks and beds. The treatments were shown below in Figure 7. There were three levels each of S-metolachlor and Pendimethalin; two Controls of hand weeding alone and zero weed Control (weedy check); and a toxic standard chemical (Mancozeb) to cater for earthworm toxicity testing (Hogger, and Ammon, 1994).

3.3.2: Treatments Application

D3 = (50%=0.8l/ha)	W_0 = (zero weed control) .
D2 = (75%=1.2l/ha)	Wh = (hand weeding alone)
D1 = (100%=1.6l/ha)	D = Dual gold (S- metolachlor).
P3 = (50%=1.0/ha)	P = Pendimethalin (Stomp).
P2 = (75%=1.5 l/ha)	T. = (100%= 2.0kgai/ha)
P1 = (100%=2.0l/ha)	T = Toxic standard (Fungicide: mancozeb) (2.0kg/ha)

The spray volume for S-metolachlor is 300l/ha while that of Pendimethalin was 200L/ha

Maize (*Zea mays L.*), Oba super variety bought from IITA (7^{o} 23' 47" N 3^{o} 55 0" E / 7.39639^{o}N), Ibadan, was planted in August as late maize at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (Southern Guinea Savanna).The prepared plots were sowed with the maize grains spaced at 100cm x 30 cm at 2 grains per stand which was thinned down to one at two weeks after planting (2WAP) given a population of 40,800 plants/ha. 18 – 25kg/ha of good seed were used. Seeds were treated with Apron plus. All herbicides and the toxic standard (Mancozeb) treatments were applied pre – emergent. The herbicides and their application rates used on the field were shown in Table 5. Fertilizers, 45 kg/ha N P K at 2WAP and 45 kg/ha as urea at six weeks after planting were applied (Chikoye *et al*., 2002).

3.3.3. Measured Parameters

3.3.3.1 Germination rates

Germination rates 2WAP were carried out by counting the number of seedlings per bed.

3.3.3.2 Number of leaves

Number of leaves was counted from the first leaf at the base to the last opened leaf per bed

3.3.3.3 Plant height

Plant height was measured with a meter rule from the plant base to the last node on the stem.

3.3.3.4 Stem diameter

Stem diameter was measured at the fourth node using manual Vernier calipers NNDC type) at 28 DAP.

3.3.3.5 Maize Grain harvesting

Matured grains were harvested, dried, shelled and weighed on Gibertini TM 1600 Max.1600, d=0.01 Top Loading balance at Agronomy laboratory, LAUTECH

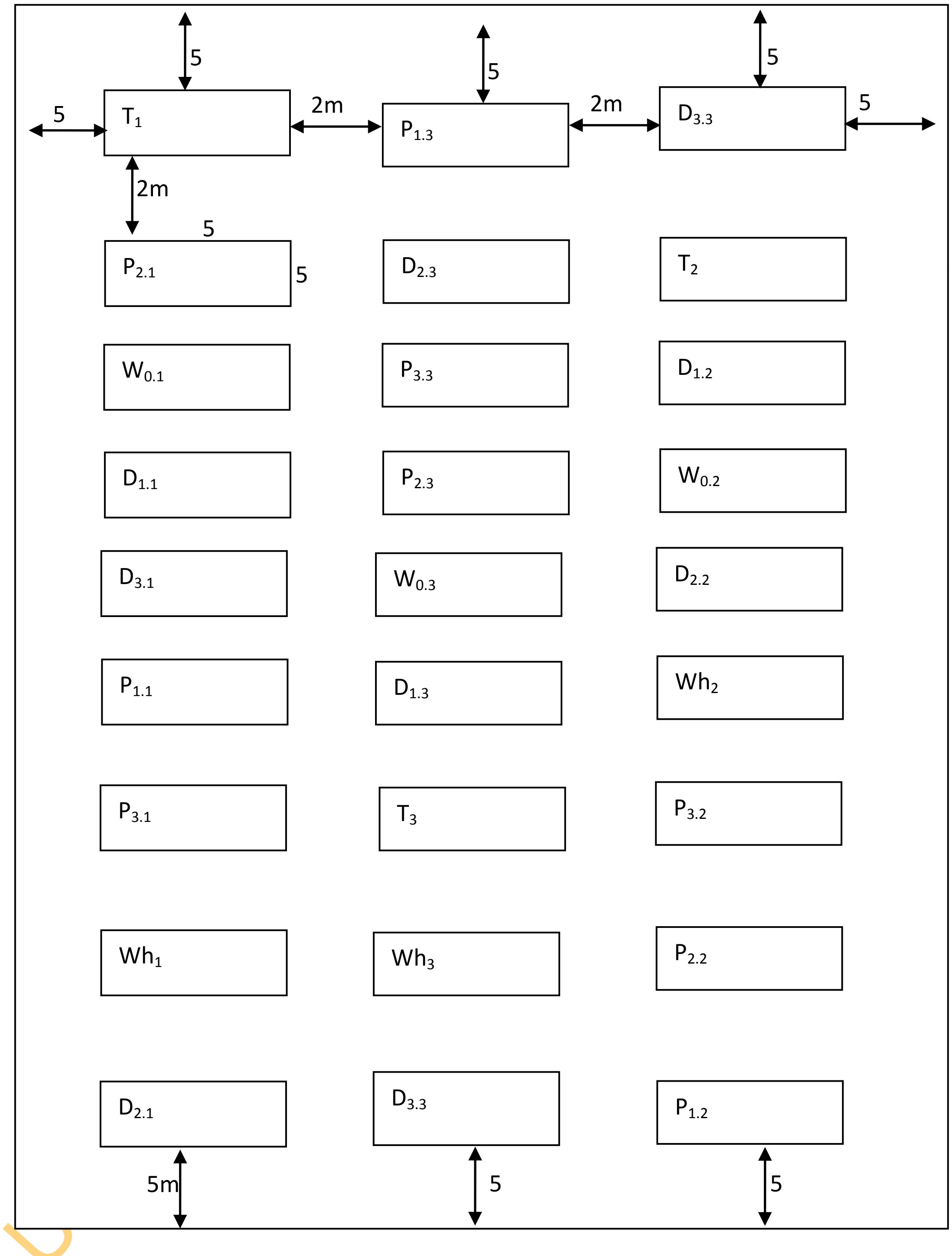


Figure 7: Plot layout in Randomized Complete Block Design (RCBD)

Table 5: Herbicides and their application rates on the field

Treatment		Concentration applied (%)		
		50	75	100
D	Dual gold (S-metolachlor)	0.8L ai/ha	1.2L ai/ha	1.6L ai/ha
P	Pendimethalin (Stomp)	1.0L ai/ha	1.5L ai/ha	2.0L ai/ha
T	Mancozeb (fungicide)	-	-	2.0kg ai/ha
W0	Zero weeds control			
Wh	Hand weeding alone			

3.3.4. Weed assessment

Weeds on the plots were assessed using 0.25 m x 0.25 m quadrats located randomly at two spots per plot to take weed numbers per unit area by counting weed seedlings within the quadrat 21 DAP and weed biomass, fresh weight of harvestable weeds (within the quadrat) eight weeks after spraying, The weeds were oven-dried in JP SELECTA, S. a. CE V230 Cod: 2000209 Serial number 0446955 at $80^{o}C$ to constant weight and weighed for dry matter evaluation using Gibertini TM 1600 Max.1600, d=0.01 Top Loading balance at Agronomy laboratory, LAUTECH.

3.3.5. Data analysis

Information collected from the questionnaires were analysed by frequency distribution and percentages. All the data collected including the results of soil analysis were subjected to analysis of variance (ANOVA) at $\alpha_{0.05}$. Means were separated with Duncan Multiple Range Test (DMRT) where F – value was significant.

3.4. Estimation of earthworm abundance in the field

Earthworm population was estimated three times in the course of the experiment. The first estimation took place before the herbicide application. The second and third estimation were respectively carried out at one, and three months after herbicide application (Kula, 1992; Hogger, 1994). Extraction of the earthworms was done with three applications of five litres each of 0.1% formaldehyde solution in a metal quadrat of 0.25 metre square (0.56 m diameter) and 0.15m height. The metal ring was always pressed into the soil to about 5 cm with strong wood (Hogger, 1993). Two samples per plot were taken and the expelled earthworms were collected in water, identified to species level, counted and weighed using a digital scale of capacity 0.1 – 120grammes.

3.4.1 Data analysis

All data collected were analyzed using analysis of variance (ANOVA) after square root ($\sqrt{(x+0.5)}$, where x is the number) and log transformations ($\log_e(x+1)$, where x is the weight) for earthworm number and weight respectively. The treatment means were separated using Duncan Multiple Range Test (DMRT) where F-values were significant.

3.5 Assessment of herbicide persistence in treated field plots

The herbicide residues were estimated by extraction from the soil. Eight soil samples were taken and put in polyethylene bags with the first immediately after herbicides application. Two other samples were taken at weekly intervals while the remaining five were taken at two weekly intervals (Akinyemiju *et. al.*, 1986). Three samples per plot, mixed together to form a composite sample were taken at a depth of 0-15 cm using soil auger. The samples were taken to the laboratory of Institute of Agricultural Research and Training (IAR&T), Ibadan within 48 hours of collection, for spectrophotometric analysis of the herbicides' residue using Spectronic 2ID.

3.5.1 Extraction of Herbicide Residues from the soil

5g of soil sample was weighed using a Top loading balance A & GULF Digital Scale of 600g maximum capacity and can weigh to an accuracy of 0.01g. To this, 25 ml of ethyl acetate was added along with anhydrous sodium sulphate (10g) and sodium chloride (10g). They were homogenized on shaker at a high speed 3000 revolutions per minute for 3 minutes. The homogenate was filtered through a Whatman No. 1 filter paper. The filtrate was left to pass through activated charcoal, (i.e. the activated charcoal was put on filter paper when the solution was then poured). The clear filtrate was then read on the spectronic 21D at 420nm wavelength (Miller, *et al.*, 1981).

3.5.2 Preparation of standard solution

The standard solutions were prepared using the appropriate herbicides: S-metolachlor and Pendimethalin at 0.5ppm, 1.0ppm, 1.5ppm, 2.0ppm.

The standard curve was plotted to the slope.

3.5.3 Determination of herbicide residue

Calculation

Absorbance x Slope x Dilution Factor

Slope for S – metolachlor = 0.148

Slope for Pendimethalin = 0.120 (AOAC 2005)

3.5.4 Data analysis

Data from persistence soil analysis were analyzed by regression analysis and regression plots obtained.

3.6 Toxicity experiment to determine LC_{50} and sub lethal toxicity of the two herbicides on *Eisenia fetida* (Sp. A) and *Libyodrilus violaceus* (Sp. B)

The two species of earthworms were collected at LAUTECH environment under Teak/Gmelina woodlot which is about 1.26ha.

3.6.1 Extraction of earthworms from the soil

Earthworm collection was done by digging the soil to about 0.3m, picking the worms with hand into small quantity of soil in polyethylene bags and kept according to species in labelled plastic containers containing soil and decaying plant materials. The worms were kept for only seven days before use.

3.6.2 Treatments applied for earthworms' toxicity testing

The following treatments were applied to *E. fetida* (Sp. A) and *L. violaceus* (Sp. B) to test the toxicity of the two herbicides:

S-metolachlor (D)		*E. fetida*	*L. violaceus*
50% (0.8 L/ha)	6ml/2.38L of distilled water	D5A	D5B
75% (1.2 L/ha)	9ml/2.38L of distilled water	D4A	D4B
100% (1.6 L/ha)	12ml/2.38L of distilled water	D3A	D3B
125% (2 L/ha)	15ml/ 2.38L of distilled water	D2A	D2B
150% (2.4 L/ha)	18ml/ 2.38L of distilled water	D1A	D1B
Pendimethalin (P)			
50% (1 L/ha)	7.5ml/1.485L of distilled water	P5A	P5B
75% (1.5 L/ha)	11.3ml/1.485L of distilled water	P4A	P4B
100% (2 L/ha)	15ml/1.485L of distilled water	P3A	P3B
125% (2.5L/ha)	18.5ml/1.485L of distilled water	P2A	P2B
150% (3 L/ha)	22.5ml/1.485L of distilled water	P1A	P1B
Control (C)	No herbicide (distilled water)	CA	CB.

3.6.3 Earthworms' lethal toxicity testing

Two test methods were used to evaluate the LC_{50} of the herbicides for earthworms: the contact filter paper and the soil tests.

3.6.3.1. Contact Filter Paper Test (CFP- test)

The herbicides were dispersed in water at the indicated concentrations and shaken properly for two minutes. 1 ml of the solution was then transferred to each filter paper lined Petri dish. The solution was allowed to evaporate to dryness and the paper rewetted with 2ml distilled water. One earthworm was added to each dish. The dishes were then covered with lid and stored in M30C incubator at 20^{o}C in the dark for 48hours (Pizl, 1988) at Pure and Applied Biology Department, LAUTECH. Another set was placed under shade of Teak/Gmelina woodlot for the same period and average minimum and maximum daily temperature range measured; four replicates were prepared for each herbicide concentration and earthworm species and a control of no herbicide. Earthworms were considered dead if they fail to respond to gentle mechanical stimulus to the epilobium.

3.6.3.2 Soil Test (S-Test)

Natural soil was collected under the Teak/Gmelina woodlot at LAUTECH where earthworms were collected and used as test substrate (Vaclav, 1988). The soil was air dried, sieved through a 4 mm sieve, and 750 g was transferred to each plastic container (OECD, 1984). The container is one liter capacity with respective top and bottom diameter of 13 and 11cm and a height of 8cm. Moisture content of the dried soil was determined, and then moist to 25% moisture content. The pH of the soil was measured at the beginning by equilibrating 10g of soil with 10ml distilled water (ratio 1:1) on mechanical shaker for 30mins and allowed to stand for 10mins after which the pH was measured by dipping a pH meter (OMEGA PH H200) equipped with a pair of electrodes initially calibrated in buffer solution 4,7 and 9.

moisture content of the soil at the end was determined. Ten earthworm specimens were added to each container, covered with perforated lid and arranged on the ground under canopy in the Teak/Gmelina woodlot in a Completely Randomized Design (CRD). The temperature was measured as in CFP-test. After acclimatization for seven days, 10 ml of each herbicide solution was added onto the soil in each container. Four replicates were maintained. Earthworm mortality was assessed after 7 days on the basis of response to mechanical stimuli.

3.6.3.3 Earthworms' sub-lethal toxicity testing

Change in growth rate of worms cultured in soil was selected as the criterion for sub-lethal toxicity evaluation. 100g of the dried soil was placed into each container and 25cm^3 water distilled was added to bring moisture level to 25%. Earthworms were washed with distilled water, gently blotted with tissue paper and weighed immediately using A & GULF Digital Scale of 600g maximum capacity and can weigh to an accuracy of 0.01g. A single worm was placed on the soil in each container. After 5 hours, to allow the earthworms to penetrate into the substrate, 5ml of each herbicide solution was measured onto the soil surface at the stated concentrations. A control of no herbicide was included. The treatment was in four replicates. The containers were covered with perforated lid and treated as for the soil test. After 7 days, the earthworms were sorted out of the soil and weighed. Dead worms were not considered (Vaclav, 1988). The growth rate (r*) of the earthworms in each treatment was calculated as:

$$r^* = \mathrm{Log}_e \frac{\sum \text{mass day 7}}{\sum \text{mass day 0}}$$

(Martin, 1982)

Where, ∑mass day 7 is the sum of mass at day 7, and ∑mass day 0 is the sum of mass at day zero (The first day of introduction of treatment).

Percentage weight loss was also calculated for the two of species earthworms by expressing the initial weight as a percentage of the final weight.

3.6.3.4 Data analysis

The mortality data from the lethal toxicity tests were evaluated using Probit analysis (Finney, 1971) with the help of a computer programme. The sub lethal toxicity was compared with Chi square (X^2) test.

4.0 CHAPTER FOUR RESULTS

4.1 Survey of herbicides

4.1.1 Age and literate parameter

The fact that about 46% of the farmers were between 41-49 years augurs well for the future of farming (Figure 8). The older farmers were being succeeded by appreciable number of young ones. Majority of the farmers (86.1%) interviewed were literate who can read and understand the instructions on the herbicide label (Figure 9).

4.1.2 Farm size, crop cultivated and Farmers awareness of herbicides use.

Over 80% of the farmers in the zone cultivated more than 2 ha while about 60% had more than 7 ha. Most of the farmers engaged in the cultivation of both arable and permanent crops. Almost all farmers in the zone were quite aware of the use of herbicides in farming (Table 6).

4.1.3 Herbicide use by farmers

Extension agents, radio, families and friends, and agro-chemical dealers and agents form the major source of information for the interviewed farmers in the zone (Figure 10).

Figure 8 shows that the interviewed farmers were familiar with 12 different herbicides in the zone. The most familiar ones were Atrazine, Gramoxone, Glyphosate, Primextra, Galex, Fusilade, Lasso/atrazine, Pendimethalin, and S-metolachlor.

4.1.4 Constraints and hazard to the use of herbicides

The responses of the interviewed farmers indicated that the major obstacles in the use of herbicides were lack of knowledge about some good herbicide, irregular supply, and fear of misuse, poverty, and requirement for technical know-how to use the herbicide (Table 7).

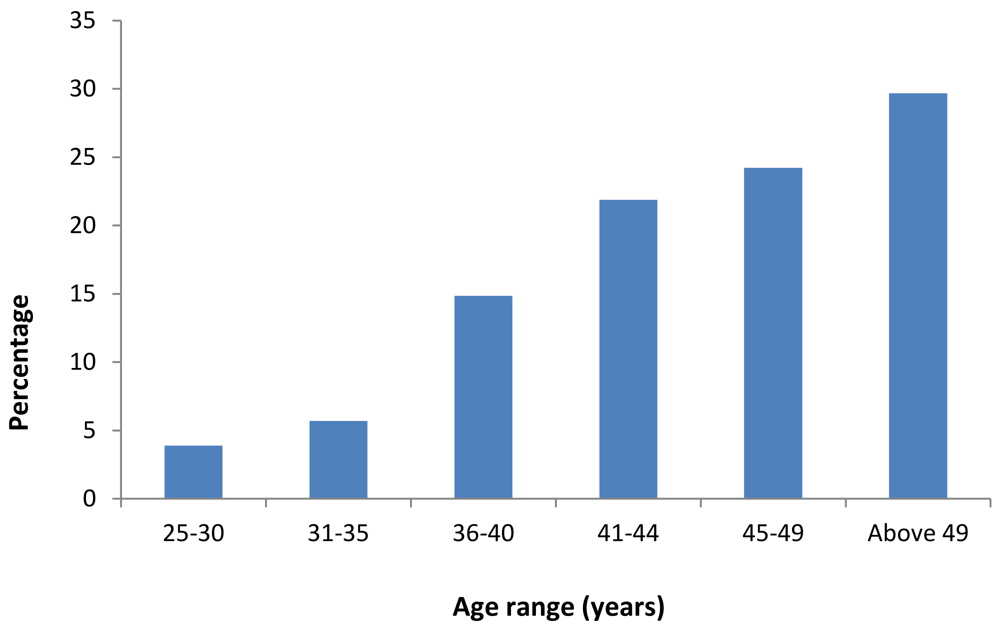


Figure 8: Age range of maize farmers in Ogbomoso

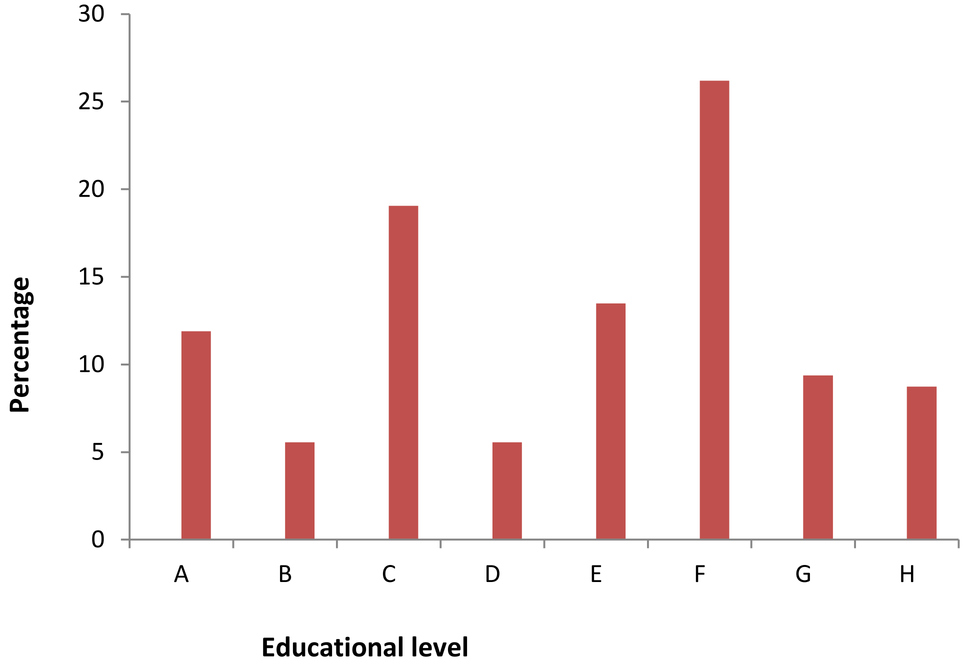


Figure 9: Maize farmers level of education in Ogbomoso area

Key:
A= Did not attend school
B= Attended adult education classes
C= Attend primary school but did not complete
D= Completed primary school
E= Completed modern III
F= Did not complete secondary school
G= Completed secondary school
H= Tertiary education

Table 6 Farm size, Crop cultivated and Farmers awareness of herbicides use in Ogbomoso area

	Farm size (ha)				
	1-4	5-8	7-9	13+	TR
NR	15	35	38	38	126
%	11.91	27.78	30.16	30.16	100%

Types of crops cultivated		
Arable	Perm.	Arable/Perm.
23	0	104
18.11	0	81.89

Farmers awareness of herbicides	
Yes	No
127	1
99.2	0.8

NR = No of respondents

TR = Total respondents

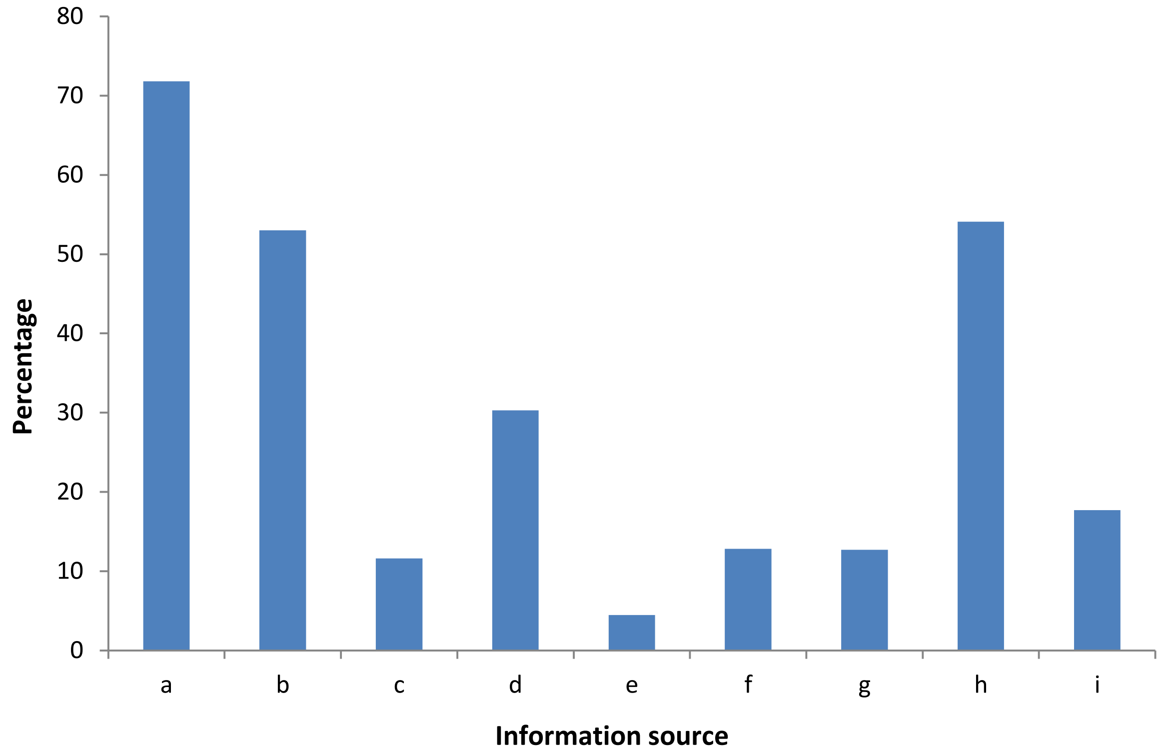


Figure 10: Sources of information on herbicide use by farmers in Ogbomoso

Key:
a= Extension agent
a= Friends and neighbours
c= Advisory bulletins
d= Herbicide dealers and agents
e= Announcement on radio and television
f= Farmers organization
g= Pages of news paper
h= Radio
i= Television

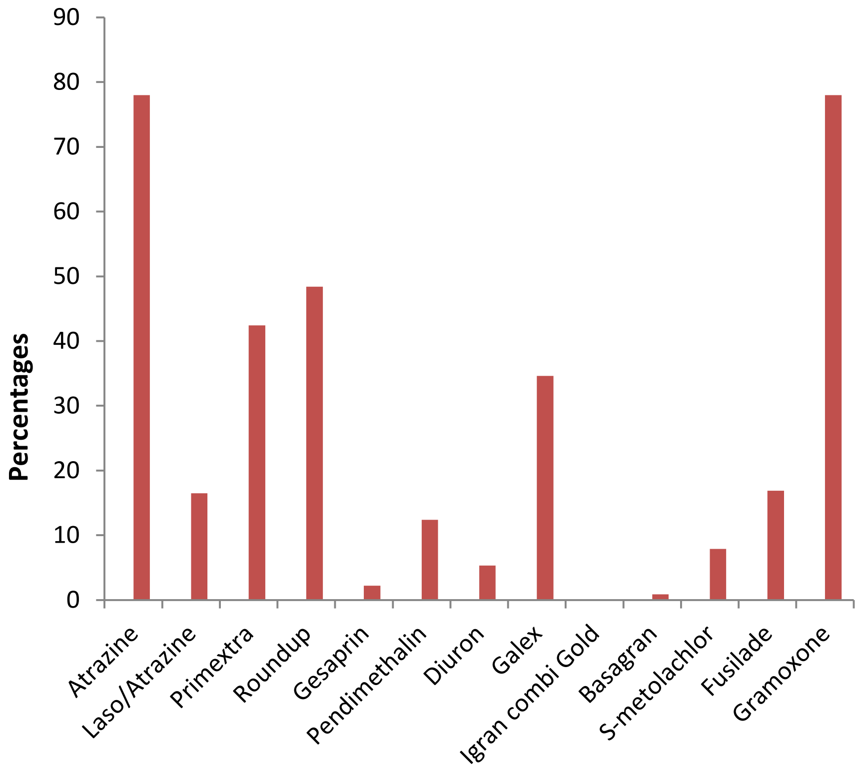


Figure 11: Common herbicides used by farmers in Ogbomoso and their percentages.

Table 7: Constraints to the use of herbicide in Ogbomoso

Constraint	*NR
Lack of knowledge about some good herbicides	81 (57.1)
Lack of suitable herbicide applicator	24 (17)
Irregular supply of herbicides	68 (49.1)
Herbicide packs usually too large to handle	14 (10)
The fear of herbicide misuse	62 (42.7)
Fear of handling herbicides	35 (24.6)
Availability of cheap labour relative to herbicide cost	30 (21.5)
No money to buy expensive but good herbicide	52 (36.9)
Herbicides require technical know how to use	41 (28.6)
Cost of herbicide is too high for me	45 (31.2)

Figures in brackets are percentages

* Multiple responses

NR = Number of respondent

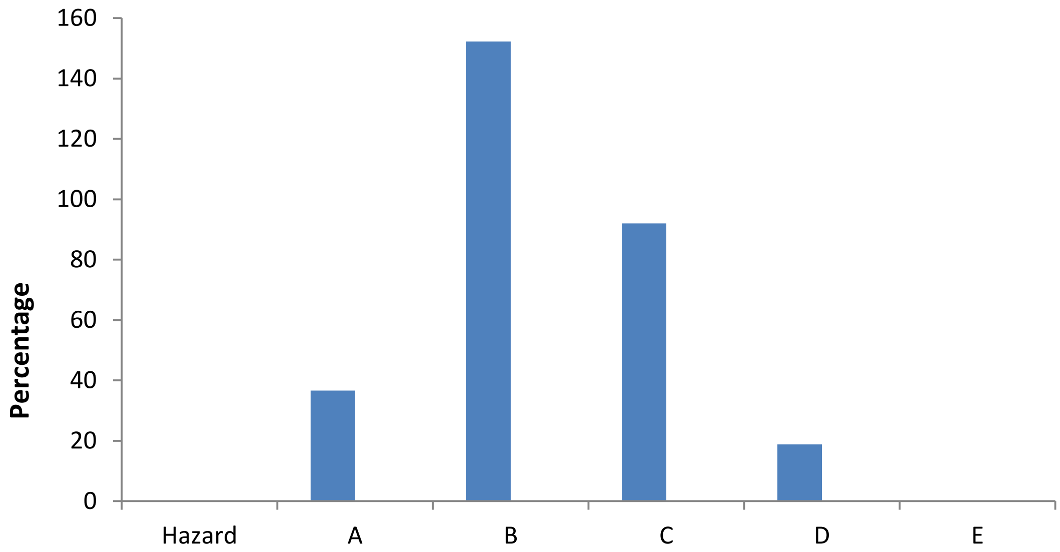


Figure 12: Hazard experienced by farmers since adoption of herbicide use in Ogbomoso area

Key:
A = accidental oral ingestion of herbicide
B = accidental pouring on the skin
C = killing of untargeted plants
D = killing of animal
E = other hazards (specify)

Table 8: Frequency of herbicide use by farmers in Ogbomoso

Time of application	* No of respondent	Percentage
Once in the growing season	13	11.5
Twice in the growing season	51	45.13
Depending on the weed problem	49	43.36

*Multiple responses

The majority of the hazards experienced by farmers were accidental pouring on the skin or eye, killing of untargeted plants and accidental oral ingestion of herbicides (Figure 9). More than 45% of farmers interviewed in the zone applied herbicides at least twice in a growing season while about 43% applied the herbicides based on weed problem (Table 8).

4.1.5 Herbicide use rates in the Ogbomoso

The rates of the herbicides used by farmers are summarized in Table 9. Higher rates of the herbicides were not common among the farmers as expressed by the percentage of respondents which was very low beyond 3L/ha of all the herbicides. Gramoxone, Round up, Primextra, and Atrazine, in decreasing order recorded 10, (1.7, 8.3), 3.3 and 0.8% respondents used between 3-5L/ha of the stated herbicides. Majority of the farmers applied lower rates (0.1-1L/ha) of the herbicides in the zone (Table 9).

The percentages of farmers decreased with increasing rate of Pendimethalin and about 21.6% respondents applied between 0.1-2 L/ha. Only 0.8% applied between 2.1-2.5L/ha which was the maximum range of the rates applied. Considering S-metolachlor, 5% of the respondents applied between 1.1-2 L/ha while only 2.5% applied 2.6-3 L/ha as the maximum rates. Higher percentages of respondents applied lower rates (0.1-1L/ha) of Pendimethalin (10.7) and S-metolachlor (33.2).

4.1.6 Attitude of farmers to herbicide use in Ogbomoso

A considerable majority of the respondents strongly agreed that government subsidy will encourage the use of herbicides. So also, the use of herbicides was believed to reduce the stress associated with weed control by almost all the farmers interviewed (95.93%).The respondents in general supported the fact that adequate information will facilitate the use of

Table 9: Percentage of respondents and rates of herbicides applied by farmers in Ogbomoso

Herbicide	Use rate (L/ha) (percentages)								
	0.1-1	1.1-1.5	1.6-2	2.1-2.5	2.6-3	3.1-3.5	3.6-4	4.1-4.5	4.6-5
Atrazine	0(0)	4(3.3)	7(5.8)	1(0.8)	0(0)	0(0)	1(0.8)	0(0)	0(0)
Gramoxone	0(0)	0(0)	13(10.8)	1(0.8)	5(4.2)	0(0)	0(0)	0(0)	12(10)
Pendimethalin	20(10.7)	11(7.3)	4(3.3)	1(0.8)	0(0)	1(0.8)	1(0.8)	0(0)	0(0)
Roundup	4(3.3)	2(1.7)	15(12.5)	0(0)	1(0.80	0(0)	2(1.7)	0(0)	10(8.3)
S-metolachlor	40(33.2)	5(4.2)	1(0.8)	0(0)	3(2.5)	0(0)	0(0)	0(0)	0(0)
Diuron	0(00	0(0)	3(2.5)	0(0)	1(0.8)	0(0)	0(0)	0(0)	0(0)
Fusilade	5(4.2)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
Primextra	5(4.2)	4(3.3)	13(10.8)	6(5)	2(1.75)	0(0)	0(0)	0(0)	4(3.3)

Note: Values in parentheses are percentage of the respondents.

herbicides by more farmers in the zone. More than half of the farmers interviewed disagreed with the concept that herbicides are too dangerous to be handled by most farmers. More farmers in the zone believed that herbicides were not too costly to give reasonable profit from farm produce. The side effects of herbicide use could not discourage farmers from the use of herbicides as indicated by the number of respondents that disagreed with the assertion (Table 10).

4.2 Soil characteristics.

4.2.1 Worm cast weight per unit area before land preparation

Table 11 shows the weight of worm cast per unit area estimated from the two sites before land preparation. Ogbomoso farm settlement had significantly higher worm cast weight (6.93 ton/ha) than LAUTECH farm (6.33 ton/ha) ($p \leq 0.05$) in 2008. In 2009, no significant difference was observed in worm cast weight at the two sites. Though not statistically verified, 2009 had higher worm cast than 2008.

4.2.2 Physico-chemical properties of worm cast and soil

Tables 12 shows the results of worm cast and soil analysis for the pre-land preparation, while Table 13 shows worm casts analysis three months after spraying of the herbicides and before land preparation, Though the textural classes of the soil and worm cast were sandy loam: worm cast contained significantly higher silts and clay and less sand when compared with the ordinary soil from the sites. This was observed during the two seasons of the experiment. The pH of the soil indicated slightly acidic nature (6.3-6.9) of the ordinary soil while worm cast varied from slightly acidic to slightly alkaline (6.7-7.4) Apart from pH, virtually all the measured parameters were higher in worm cast when compared with the soil sample taken before land clearing e. g.

OC, N, P, Ca, Mg, K, ECEC, Zn, Mn and Fe were significantly greater in cast than soil in 2008 and 2009 except K in 2009 that soil was greater than cast at $p \leq 0.05$. The pH, Na and Cu were statistically the same. Farm settlement recorded higher P, Ca, Mg and ECEC than Lautech farm in 2008. Nutrient contents in worm cast and soil were respectively 16.4 and 6.7 mg/kg, 1.33 and 0.5 mg/kg, 15.57 and 5.9 mg/kg P, 0.33 and 0.19 c mol+/kg K, 210 and 8 0mg/kg Silt, and 210 mg/kg and 130 mg/kg Clay. Only phosphorus was significantly higher in worm cast collected before (20.6mg/kg) land preparation than 3 months after spraying (15.6 mg/kg).

In 2008, the following parameters were not significantly different in cast before land preparation and after 3 months: pH, OC, %N, P, Mg, K, Na, Exchangeable acidity, ECEC, Cu, Fe, silt and clay. Calcium, Zn, Mn and sand were greater in cast than cast b in 2008 (Table 13). Also in 2008 in Lautech farm OC, %N, P, Na, Zn, Cu and Mn were greater in cast after spraying than before land clearing. In Lautech farm in 2008, the cast before and 3 months after treatment had all the parameters statistically the same except Ca, Zn, and Mn which were statistically greater in cast before land clearing than post herbicide treatment at $p \leq 0.05$.

Farm settlement, in 2009 had only %N, P, Exchangeable acidity, Cu, Fe and silt statistically different at $p \leq 0.05$ between the cast b and cast while others were statistically the same.

4.3 Weeds encountered at the study sites during 2008 and 2009 cropping seasons

Table 14 shows the weed species present at the sites of the experiment. These weeds were common weeds of cultivated fields and fallow lands. Most of them were troublesome perennial weeds found in the open cultivated fields and plantation crops. Some were weeds of lowland and flood plain e.g. *Kylinga squamulata* and *Ludwigia hyssopifolia* both of which were found at Ogbomoso farm settlement. The weed species were highest at LAUTECH farm in 2008 in terms of species composition with 24 weed species. This was followed by the Ogbomoso farm settlement in the same 2008 with 17 weed species while the least species (13 species each) was recorded at both sites in 2009. Thus weed problem encountered in 2008 was greater than in 2009. Out of the 35 weed species recorded at the four experimental plots, only three species, Imperata *cylindrica*, *Paspalum scrobiculatum* and *Tithonia diversifolia* appeared in all the plots. Eight species, *Crotalaria retusa, Eleusine indica, Euphorbia heterophylla, Euphorbia hirta, Mitracarpus vilosus, Pennisetum polystachion, Rottboelia cochinchinensis* and *Tridax procumbens* appeared in at least three of the four plots during the two cropping seasons. Another eight species appeared in at least two of the plots and these were: *Andropogon gayanus, Chromolaena odorata, Commelina benghalensis, Dactyloctenium aegyptium, Digitaria horizontalis, Kylinga squamulata, Panicum maximum* and *Triumfetta cordifolia*. The rest 16 weed species appeared only once at some of the four plots. There were 18 dicotyledonous and 17 monocotyledonous species in the 35 weed species.

Table 10: Attitude of farmers to herbicide use in Ogbomoso

Statement	SA	A	U	D	SD
Government subsidy will encourage the use of herbicides.	83 (68.03)	37 (30.33)	2 (1.64)	0 (0)	0 (0)
Use of herbicides reduces stresses associated with weed control	60 (48.78)	58 (47.15)	4 (3.25)	1 (0.81)	0 (0)
Crops cultivated with herbicides are both high yielding and gives more profit	26 (20.97)	50 (40.32)	19 (15.32)	25(20.16)	4(3.23))
Adequate information will facilitate the use of herbicide by most farmers	37 (27.82)	83 (62.41)	10 (7.52)	3 (2.26)	0 (0)
Herbicides are too dangerous to handle by most farmers	7 (5.47)	37 (28.91)	13 (10.16)	64 (50)	7(5.47)
Herbicides are too costly to give reasonable profit from farm produce	8 (6.61)	11 (9.09)	13 (10.74)	83 (68.6)	6(4.96)
Undesirable side effects of the use of herbicides discourage most Farmers from its use	9 (7.5)	24 (20)	29 (24.17)	47(39.17)	11 (9.17)

Figures in brackets are percentages

*Multiple responses.
Key:

SA = Strongly agree. D = Disagree, SD = Strongly disagree, A = Agree, U = Undecided

Table11: Mean worm cast weight (ton/ha) at the two sites during 2008 and 2009 growing seasons

	2008 Mean±SD	2009 Mean±SD
LAUTECH farm	6.33±0.93	10.13±1.35
Ogbomoso farm settlement	6.93±2.13	9.60 ±0.70
LSD	0.45	ns

SD = Standard Deviation

Table 12 Physico-chemical properties of worm casts and soil samples taken before land preparation at the two experimental sites during 2008 and 2009 cropping seasons.

		LTRF		OFS	
		2008	2009	2008	2009
pH(water)1:1	Cast	6.7[a]	7.00[a]	7.4[a]	6.7[a]
	Soil	6.3[a]	6.70[a]	6.9[a]	6.4[a]
% OC	Cast	1.81[a]	1.90[a]	0.73[a]	2.13[a]
	Soil	0.66[b]	0.80[b]	0.65[a]	0.57[b]
% N	Cast	0.12[a]	0.13[a]	0.13[a]	0.15[a]
	Soil	0.05[b]	0.06[b]	0.06[b]	0.04[b]
Mehlich P(µg/g)	Cast	12.25[a]	15.06[a]	18.69[a]	16.28[a]
	Soil	3.29[b]	11.11[b]	5.69[b]	3.36[b]
Ca (c mol+/kg)	Cast	8.39[a]	10.8[a]	10.74[a]	11.64[a]
	Soil	3.73[b]	5.89[b]	4.74[b]	3.38[b]
Mg (c mol+/kg)	Cast	1.09[a]	1.17[a]	1.21[a]	1.22[a]
	Soil	0.50[b]	0.52[b]	1.36[a]	0.40[b]
K (c mol+/kg)	Cast	0.25[a]	0.27[b]	0.50[a]	0.29[a]
	Soil	0.13[b]	0.41[a]	0.13[b]	0.07[b]
Na(c mol+/kg)	Cast	0.16[a]	0.17[a]	0.17[a]	0.16[a]
	Soil	0.18[a]	0.14[a]	0.15[a]	0.17[a]
Exch. Acidity	Cast	0.0[a]	0[a]	0.08[a]	0[a]
	Soil	0.0[a]	0[a]	0.00[b]	0[a]

ECEC	Cast	10.08^{a}	12.44^{a}	12.17^{a}	13.36^{a}
	Soil	17.83^{a}	6.96^{b}	6.38^{b}	4.10^{b}
Zn (ppm)	Cast	20.56^{a}	21.33^{a}	22.4^{a}	23.48^{a}
	Soil	11.40^{b}	11.49^{b}	10.41^{b}	9.18^{b}
Cu (ppm)	Cast	0.29^{a}	0.39^{a}	0.44^{a}	0.67^{a}
	Soil	0.18^{a}	0.10^{b}	0.06^{b}	0^{b}
Mn (ppm)	Cast	192.49^{a}	207.83^{a}	184.83^{a}	207.05^{a}
	Soil	146.48^{b}	168.45^{b}	149.88^{a}	127.25^{b}
Fe (ppm)	Cast	248.44^{a}	166.9^{a}	183.83^{a}	179.43^{a}
	Soil	148.54^{b}	126.67^{b}	121.59^{b}	101.86^{b}
Sand	Cast	6.40^{b}	79.0^{a}	62.0^{b}	60.0^{b}
	Soil	79.0^{a}	64.0^{b}	79.0^{a}	79.0^{a}
Silt	Cast	21.0^{a}	21.0^{a}	19.0^{a}	23.0^{a}
	Soil	8.0^{b}	8.0^{b}	8.0^{b}	8.00^{b}
Clay	Cast	15.0^{a}	15.0^{a}	19.0^{a}	17.00^{a}
	Soil	13.0^{a}	13.0^{b}	13.0^{b}	13.00^{a}

Table 13 Physico-chemical properties of worm casts taken before land preparation and 3 months after planting at the two experimental sites during 2008 and 2009 cropping seasons.

		LTRF		OFS	
		2008	2009	2008	2009
pH(water)1:1	Cast b	6.70 [a]	7.00 [a]	7.40 [a]	6.7 [a]
	Cast	6.40 [a]	7.87[a]	6.70 [a]	6.3 [a]
% OC	Cast b	1.81 [a]	1.90 [a]	0.73 [b]	2.13[a]
	Cast	1.90 [a]	1.95 [a]	1.87 [a]	2.52 [a]
% N	Cast b	0.12 [a]	0.13 [a]	0.13 [a]	0.15 [b]
	cast	0.14 [a]	0.13 [a]	0.13 [a]	0.17 [a]
Mehlich P(µg/g)	Cast b	12.25 [a]	15.06 [b]	18.69 [a]	16.28 [b]
	Cast	16.45 [a]	19.72 [a]	18.02 [a]	27.71 [a]
Ca (c mol+/kg)	Cast b	8.39 [a]	10.84 [a]	10.74 [a]	11.64 [a]
	Cast	7.54 [b]	10.75 [a]	10.41 [a]	11.64 [a]
Mg (c mol+/kg)	Cast b	1.09 [a]	1.17 [a]	1.21 [a]	1.22 [a]
	Cast	0.94 [a]	1.01 [b]	1.01 [a]	1.14 [a]
K (c mol+/kg)	Cast b	0.25 [a]	0.27 [b]	0.5 [a]	0.29 [a]
	Cast	0.20 [a]	0.53 [a]	0.31 [a]	0.46 [a]
Na(c mol+/kg)	Cast b	0.16 [a]	0.17 [a]	0.17 [a]	0.16 [a]
	Cast	0.18 [a]	0.17 [a]	0.17 [a]	0.15 [a]
Exch. Acidity	Cast b	0. 0 [a]	0 [a]	0.08 [a]	0 [b]
	Cast	0 .08 [a]	0 [a]	0.08 [a]	0.08 [a]
ECEC	Cast b	10.00 [a]	12.44 [a]	12.17 [a]	13.36 [a]
	Cast	8.94 [a]	12.46 [b]	11.98 [a]	12.81 [a]
Zn (ppm)	Cast b	20.56 [b]	21.33 [a]	22.44 [a]	23.48 [a]

	Cast	26.04 [a]	19.30 [a]	20.22 [a]	23.71 [a]
Cu (ppm)	Cast b	0.29 [a]	0.39 [a]	0.44 [b]	0.67 [a]
	Cast	0.31 a	0.25 [a]	0.47 [a]	0.5 [b]
Mn (ppm)	Cast b	192.5 [b]	207.82 [a]	184.83 [a]	207.05 [a]
	Cast	216.69 [a]	204.60 [a]	207.64 [a]	207.6 [a]
Fe (ppm)	Cast b	248.44 [a]	166.9 [a]	183.83 [a]	179.43 [b]
	Cast	242.05 [a]	163.34 [a]	163.76 [b]	213.52 [a]
Sand	Cast b	64.0 [a]	64.0 [a]	62.0 [b]	68.00 [a]
	Cast	64.0 [a]	64.0 [a]	64.0 [a]	64.0 [a]
Silt	Cast b	21.0 [a]	21.0 [a]	19.0 [a]	23.0 [a]
	Cast	19.0 [a]	19.0 [a]	19.0 [a]	19.0 [b]
Clay	Cast b	15.0 [a]	15.0 [a]	19.0 [a]	17.0 [a]
	Cast	17.0 [a]	17.0 [a]	17.0 [b]	17.0 [a]

Cast b = worm cast sampled before land preparation; Cast = worm cast 3 month after spraying

4.4.1 Effects of treatments on maize seed germination

Germination of maize seeds was observed at Lautech Teaching and Research Farm (LTRF) to be high irrespective of the herbicide rate, and hoe weeding or weedy checks 14 DAP. There were no significant differences among all the treatments during both growing seasons (Tables 15 and 16). Herbicide rates significantly influenced maize germination 14 DAP in 2008 growing season at OFS. Significant influence was also noticed with herbicide mean (2008) in which case hoe weeded and weedy check plots supported highest number of maize seedling establishment. In OFS, significant difference was recorded in the treatments and rates. No significant difference in LTRF,

The germination percentages ranged from 84.4% for S-metolachlor in 2008 at OFS to 99.6% for Pendimethalin in 2009 at LTRF (Table 17).The highest concentration of Pendimethalin used gave the highest germination percentage (99.6) in 2009 at LTRF. No significant difference in treatment and rates.

Table 14: Weeds encountered at the study sites

Weed Species.	LF2008	LF2009	FS2008	FS2009	REMARK
Aspilia africana (Pers.) C.D. Adams (Asteraceae).	-	+	-	-	D
Andropogon gayanus. Kunth. Var. gayanus. (Poaceae).	+	+	-	-	M
Centrosema pubescence (Fabaceae).	+	-	-	-	D
Chromolaena odorata (L.) R.M. King and Robinson (Asteraceae).	+	+	-	-	D
Commelina benghalensis L. (Commelinaceae).	+	+	-	-	M
Crotalaria retusa Lnn. (Fabaceae).	+	-	+	+	D
Cynodon dactylon (Linn.) Pers. (Poaceae)	-	-	+	-	M
Cyperus esculentus Linn. (Cyperaceae).	+	-	-	-	M
Cyperus haspan Linn. (Cyperaceae).	-	-	+	-	M
Dactyloctenium aegyptium (Linn.) P.Beauv (Poaceae).	+	-	+	-	M
Daniellia oliveri (Rolfe) Hutch & Dalz. (Fabaceae; Caesalpiniaceae).	-	+	-	-	D
Digitaria horizontalis Willd. (Poaceae).	+	-	+	-	M
Eleusine indica Gaertn. (Poaceae)	-	-	+	+	M
Emilia coccinea (Sims.) G. Don (Asteraceae)	+	-	-	-	D
Eragrostis tenella (Linn.) (Poaceae).	+	-	-	-	M
Euphobia heterophylla Lnn.(Euphorbiaceae).		-	+	+	D
Euphorbia hirta Linn. (Euphorbiaceae).	+	-	+	+	D
Gomphrena celosioides Mart.. (Amaranthaceae).	+	-	-	-	D
Imperata cylindrica (Linn) Raeusched (Poaceae).	+	+	+	+	M
Ipomoea involucrata P. Beauv. (Convolvucaceae)	+	-	-	-	D
Kylinga squamulata Thonn. Ex Vahl. (Cyperaceae).	-	-	+	+	S
Ludwigia hyssopifolia (G. Don) Exell.(Onagraceae)	-	-	+	-	D
Mariscus alternifolius Vahl (= *M. umbellatus* Vahl) (Poaceae).	+	-	-	-	M
Melochia corchorifolia Linn. (Sterculiaceae).	-	+	-	-	D
Mitracarpus villosus (Sw.) (Rubiaceae) Dc	+	+	+	-	D

(= *M. scaber* Zucc.).					
Panicum maximum Jacq. (Poaceae)	-	-	+	+	M
Paspalum scrobiculatum Lnn. (Poaceae)	+	+	+	+	M
Pennisetum polystachion (Linn.) (Poaceae).	+	-	+	+	M
Pennisetum spp. (Poaceae).	-	+	-	-	M
Rottboellia cochinchinensis (Lour.) Clayton (Poaceae)	+	-	+	+	M
Sida acuta Burm.F. (Malvaceae)	-	-	+	-	D
Sida garckeana Polak. (= *S. corymbosa* R.E. Fries) (Malvaceae).	+	-	-	-	D
Tephrosia bracteolata Guill.& Perr. (Fabaceae).	+	-	-	-	D
Tithonia diversifolia (Hemsl.) A. Gray (Asteraceae).	+	+	+	+	D
Tridax procumbens Lnn. (Asteraceae).	+	+	-	+	D
Triumfetta cordifolia A. Rich. (Tiliaceae).	-	+	-	+	D

Key: + = Present, - = Absent.
LF = LAUTECH Farm
FS = Farm Settlement
M = Monocotyledon.
D = Dicotyledonous.
S = Sedges

4.4.2 Treatments effects on number of leaves

There were no significant differences among all the treatments in terms of their effects on number of leaves at both LTRF and OFS during the two growing seasons (Table 18). The main feature of Tables 18 & 19 was that the two herbicides, S-metolachlor and Pendimethalin gave higher number of leaves than the hoe weeding and no weedy plots. In 2009 growing season, higher numbers of leaves were recorded at 28 DAP at OFS than 2008. The weedy check plot had more leaves than other treatments in both sites and years. No significant difference in the treatments and rates. No significant difference in the treatments and rates (Table 18). There is significant difference in treatments at LTRF (Table 19).

4.4.3 Response of maize plant height to herbicides

Although, some variations were observed in the plant height recorded in Tables 20 & 21, they were not significant at 5% level of probability but significant difference were observed in the treatments in 2009 in both sites. S-metolachlor sprayed plots gave highest maize plant height (15.63cm) at site A while Pendimethalin gave the least (17.56cm) at OFS in 2009. The same trend but varied higher plant height in 2008 than 2009 at LTRF was observed. OFS recorded higher plant height (19.06cm) in 2009 than 2008 (14.0cm) (Tables 20&21). No significant difference in treatment and rates (Table 20).Significant difference was observed In the treatment in LTRF and OFS at 5% level of probability (Table 21).

4.4.4 Treatments effect on maize stem diameter

Tables 22 and 23 shows the non-significant ($p \geq 0.05$) effects of all the treatments including the control on stem diameter at four weeks after planting. Similarly, higher stem diameter was

Table 15 Treatments influence on number of maize seedlings±SD 14 days after planting at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2008)

Treatments	Percentage Rate (%) 50	75	100	Treatment Mean±SD
	LTRF			
Dual Gold	191.0±5.6	196.0±2.0	192.7±10.1	199.6±5.9
Pendimenthalin	185.0±11.8	191.0±8.2	190.0±8.8	199.4±9.5
Hoe Weeding	192.0±5.7	192.0±5.7	192.0±5.7	192.0±5.7
Weedy Check	192.7±2.1	192.7±2.1	192.7±2.1	192.7±2.1
Rate Mean±SD	192.9±7.7	193.8±4,5	191.6±6.7	
LSD(Trt.)	ns			
LSD(Rate)	ns			
LSD(TxR)	ns			
	OFS			
Dual Gold	168.7±12.1	174.0±20.1	178.7±13.0	173.8±15.1
Pendimenthalin	165.7±4.2	172.0±16.8	175.3±19.2	171.0±13.4
Hoe Weeding	181.0±16.0	181.0±16.0	181.0±16,0	181.0±16.0
Weedy Check	179.3±14.6	179.3±14.6	179.3±14.6	179.3±14.6
Rate Mean±SD	177.9±11.2	176.3±16.9	174.0±15.7	
LSD(Trt.)	7.64			
LSD(Rate)	3.49			
LSD(TxR)	ns			

ns = not significant at 5% level of probability

Table 16: Treatments influence on number of maize seedlings±SD 14 days after planting at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2009)

Treatments	Percentage Rate (%) 50	75	100	Treatment Mean±SD
	LTRF			
Dual Gold	185.0±12.5	192.7±3.8	194.0±11,4	190.6±9.2
Pendimenthalin	191.0±2.1	194.0±4.4	183.3±11.4	189.4±6.0
Hoe Weeding	192.7±2.5	192.7±2.5	192.7±2.5	192.7±2.5
Weedy Check	190.3±6.8	190.3±6.8	190.3±6.8	190.3±6.8
Rate Mean±SD	190.1±6.0	192.0±4.4	189.3±8.0	
LSD(Trt.)	ns			
LSD(Rate)	ns			
LSD(TxR)	ns			
	OFS			
Dual Gold	176.0±25.9	172.7±9.9	188.0±14.2	178.9±16.7
Pendimenthalin	191.3±2.1	189.7±14.0	174.3±7.6	185.1±7.9
Hoe Weeding	178.7±22.5	178.7±22.5	178.7±22.5	178.7±22.5
Weedy Check	180.3±23.7	180.3±23.7	180.3±23.7	180.3±23.7
Rate Mean±SD	179.9±18.6	179.9±17.5	180.9±17	
LSD(Trt.)	ns			
LSD(Rate)	ns			
LSD(TxR)	ns			

.
ns = not significant at 5% level of probability

Table 17: Proportion of Maize(%) seedlings 14 DAP at the experimental sites

	LTRF Germination %		OFS Germination %	
Treatment l/ha	2008	2009	2008	2009
Dual gold				
1.6	95.5	92.5	84.4	88.0
1.2	98.8	96.4	87.0	86.4
0.8	96.4	97.0	89.4	94.0
Pendimethalin				
2.0	92.5	99.6	82.9	95.7
1.5	95.5	97.0	86.o	94.5
1.0	95.0	91.5	87.7	87.2
Hoe Weeding	96.0	96.4	90.5	89.4
Weedy Check	96.4	95.2	89.7	90.2

Table 18: Effect of treatments on number of maize leaf±SD 28 days after planting at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2008)

Treatments	Percentage	Rate (%)		Treatment Mean±SD
	50	75	100	
	LTRF			
Dual Gold	10.53±2.4	9.47±0.4	9.87±0.5	9.96±1.1
Pendimenthalin	10.10±0.2	9.57±0.5	9.77±0.7	9.81±0.5
Hoe Weeding	9.00±0.9	9.00±0.9	9.00±0.9	9.00±0.9
Weedy Check	10.53±2.4	10.53±2.4	10.53±2.4	10.53±2.4
Rate Mean±SD	9.94±1.5	9.62±1.1	9.74±1.1	
LSD(Trt.)	ns			
LSD(Rate)	ns			
LSD(TxR)	ns			
	OFS			
Dual Gold	8.90±0.2	8.53±0.4	8.53±0.7	8.66±0.4
Pendimenthalin	8.43±0.2	8.87±0.5	8.70±0.0	8.67±0.2
Hoe Weeding	8.37±0.3	8.37±0.3	8.37±0.3	8.37±0.3
Weedy Check	8.77±0.5	8.77±0.5	8.77±0.5	8.77±0.5
Rate Mean±SD	8.59±0.3	8.60±0.4	8.60±0.4	
LSD(Trt.)	ns			
LSD(Rate)	ns			
LSD(TxR)	ns			

ns =not significant at 5% level of probability

Table 19: Effect of treatments on number of maize leaf±SD 28 days after planting at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2009)

Treatments	Percentage Rate (%)			Treatment Mean±SD
	50	75	100	
	LTRF			
Dual Gold	8.67±0.6	9.00±0.3	8.90±0.2	8.86±0.4
Pendimenthalin	9.30±0.0	8.90±0.4	8.80±0.2	9.00±0.2
Hoe Weeding	8.43±0.2	8.43±0.2	9.00±0.2	8.43±0.2
Weedy Check	8.80±0.2	8.80±0.2	10.53±0.2	8.80±0.2
Rate Mean±SD	8.91±0.3	8.90±0.3	9.74±0.2	
LSD(Trt.)	0.43			
LSD(Rate)	ns			
LSD(TxR)	ns			
	OFS			
Dual Gold	9.23±0.4	9.20±0.2	9.76±0.5	9.40±0.4
Pendimenthalin	8.80±0.2	9.27±0.4	8.80±0.2	8.96±0.3
Hoe Weeding	8.33±1.2	8.33±1.2	8.37±1.2	8.33±1.2
Weedy Check	8.77±0.7	8.77±0.7	8.77±0.7	8.77±0.7
Rate Mean±	8.81±0.6	8.89±0.6	8.60±0.7	
LSD(Trt.)	ns			
LSD(Rate)	ns			
LSD(TxR)	ns			

ns =not significant at 5% level of probability

observed in 2008 over that of 2009 at LTRF and the reverse was observed at OFS for 4WAP, where significant differences were observed in the treatments ($p \geq 0.05$).

4.4.5 Treatments effects on weed density 21 days after spraying

Weed density per $0.0625m^2$ was significantly influenced ($p \leq 0.05$) by the treatments as the sprayed plots recorded significantly lower number of weed seedlings than the unsprayed plots (hoe weeding (139) and weedy check (179), (Tables 23 and 24). At LTRF and OFS, 50% rate gave significantly higher weed number (89.1, 86.4) per unit area than 100% rate (78.4, 79.4) in 2009. No significant difference was observed in 2008 among the three rates. In 2008, LTRF recorded higher weed density than 2009 in all the treatments. The reverse was the case for OFS.

At OFS in 2008, there was no significant difference between 75% rate (39.9) and 100% rate (39.2) but the two were significantly different from 50% rate (42.9) in terms of weed density.

4.4.6 Weed biomass (g) 56 days after spraying

Weed biomass per $0.0625m^2$ recorded for LTRF during the two cropping seasons indicated significant difference ($p \leq 0.05$) among weedy check, control plots, the herbicide treated and hoe weeded plot. Highest weed biomass was recorded for both seasons in weedy check (Tables 26 & 27) which were control plots. Fifty percent rate was next to weedy plot in biomass in 2008 for both LTRF and OFS. Significant differences were observed at the two sites for the three rates in 2009 for LTRF and OFS. Weed biomass was generally higher in 2008 than 2009 at both LTRF and OFS. The percentage weed control shown in Table 28 indicated that LTRF recorded higher weed control in 2009 than 2009. The percentage weed density and biomass reduced with reduction in concentration of the two herbicides. The herbicide treatments had greater percentage

Table 20: Maize plant height (cm) ±SD 28 days after planting at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2008)

Treatments	Percentage Rate (%)			Treatment Mean±SD
	50	75	100	
	LTRF			
Dual Gold	19.87±4.0	17.67±2.9	19.80±4.4	19.11±3.8
Pendimenthalin	19.30±3.7	18.80±4.7	18.97±5.3	19.02±4.1
Hoe Weeding	20.07±3.9	20.07±3.7	20.07±3.7	20.07±3.7
Weedy Check	18.13±2.0	18.13±2.0	18.13±2.0	18.13±2.0
Rate Mean±SD	19.09±3.4	18.35±3.3	19.01±3.9	
LSD(Trt.)	ns			
LSD(Rate)	ns			
LSD(TxR)	ns			
Dual Gold	14.43±2.9	14.20±1.8	13.37±1.5	14.00±2.1
Pendimenthalin	14.27±1.3	14.07±1.6	12.03±2.8	13.46±1.9
Hoe Weeding	12.70±1.0	12.70±1.0	12,.70±1.0	12.70±1.0
Weedy Check	14.73±2.5	14.73±2.5	14.73±2.5	14.73±2.5
Rate Mean±SD	13.96±1.9	13.87±1.7	13.30±2.0	
LSD(Trt.)	ns			
LSD(Rate)	ns			
LSD(TxR)	ns			

ns =not significant at 5% level of probability

Table 21: Maize plant height (cm)±SD 28 days after planting at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2009)

Treatments	Percentage Rate (%)			Treatment Mean±SD
	50	75	100	
	LTRF			
Dual Gold	16.67±2.2	14.17±1.3	16.07±0.2	15.63±1.2
Pendimenthalin	15.10±1.1	15.23±0.3	15.26±2.7	15.20±1.4
Hoe Weeding	14.60±1.8	14.60±1.8	14.60±1.8	14.60±1.8
Weedy Check	14.73±0.3	14.73±0.3	14.73±0.3	14.73±0.3
Rate Mean±SD	14.79±1.4	14.32±0.9	14.71±1.3	
LSD(Trt.)	2.61			
LSD(Rate)	ns			
LSD(TxR)	ns			
Dual Gold	18.77±1.8	18.43±2.5	19.97±2.4	19.06±2.2
Pendimenthalin	19.10±0.9	18.30±3.0	15.27±2.7	17.56±2.2
Hoe Weeding	19.13±0.3	19.13±0.3	19.13±0.3	19.13±0.3
Weedy Check	17.90±0.4	17.90±0.4	17.90±0.4	17.90±0.4
Rate Mean±SD	19.16±0.9	18.93±1.6	18.63±1.5	
LSD(Trt.)	2.66			
LSD(Rate)	ns			
LSD(TxR)	ns			

ns =not significant at 5% level of probability

Table 22: Maize stem diameter (cm) ±SD 28 days after planting at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2008)

Treatments	Percentage Rate (%)			Treatment Mean±SD
	50	75	100	
	LTRF			
Dual Gold	1.95±0.4	1.79±0.3	1.76±0.2	1.84±0.3
Pendimenthalin	1.68±0.3	1.74±0.3	1.74±0.2	1.72±0.3
Hoe Weeding	1.70±0.2	1.70±0.2	1.70±0.2	1.70±0.2
Weedy Check	1.67±0.1	1.67±0.1	1.67±0.1	1.67±0.1
Rate Mean±SD	1.77±0.3	1.75±0.2	1.74±0.2	
LSD(Trt.)	ns			
LSD(Rate)	ns			
LSD(TxR)	ns			
	OFS			
Dual Gold	1.22±0.1	1.08±0.1	1.12±0.2	1.14±0.1
Pendimenthalin	1.16±0.2	1.16±0.0	1.10±0.2	1.14±0.1
Hoe Weeding	1.21±0.1	1.21±0.1	1.21±0.1	1.21±0.1
Weedy Check	1.19±0.3	1.19±0.3	1.19±0.3	1.19±0.3
Rate Mean±SD	1.22±0.2	1.19±0.1	1.86±0.2	
LSD(Trt.)	ns			
LSD(Rate)	ns			
LSD(TxR)	ns			

ns =not significant at 5% level of probability

Table 23: Maize stem diameter (cm) ±SD 28 days after planting at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2009)

Treatments	Percentage Rate (%)			Treatment Mean±SD
	50	75	100	
	LTRF			
Dual Gold	1.49±0.1	1.49±0.1	1.18±0.4	1.38±0.2
Pendimenthalin	1.53±0.1	1.58±0.1	1.56±0.2	1.56±0.1
Hoe Weeding	1.53±0.1	1.53±0.1	1.53±0.1	1.53±0.1
Weedy Check	1.47±0.1	1.47±0.1	1.47±0.1	1.47±0.1
Rate Mean±SD	1.57±0.1	1.58±0.1	1.52±0.2	
LSD(Trt.)	ns			
LSD(Rate)	ns			
LSD(TxR)	ns			
Dual Gold	1.43±0.1	1.57±0.2	1.63±0.2	1.54±0.2
Pendimenthalin	1.51±0.2	1.56±0.3	1.56±0.2	1.54±0.2
Hoe Weeding	1.58±0.3	1.58±0.3	1.58±0.3	1.58±0.3
Weedy Check	1.44±0.1	1.44±0.1	1.44±0.1	1.44±0.1
Rate Mean±SD	1.55±0.2	1.59±0.3	1.60±0.2	
LSD(Trt.)	0.32			
LSD(Rate)	ns			
LSD(TxR)	ns			

ns =not significant at 5% level of probability

Table 24: Weed densities±SD (per $6.25x10^{-6}$ha) 21 days after planting at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2008)

Treatments	Percentage Rate (%)			Treatment Mean±SD
	50	75	100	
	LTRF			
Dual Gold	92.0±7.0	85.3±4.5	84.31±2.4	87.2±2.3
Pendimenthalin	92.0±12.9	72.7±32.7	69.3±33.1	78.2±26.2
Hoe Weeding	139.0±56.5	139.0±56.5	139.0±56.5	139.0±56.5
Weedy Check	179.0±30.0	179.0±30.0	179.0±30.0	179.3±30.0
Rate Mean±SD	126.6±40.7	121.3±31.0	120.4±30.5	
LSD(Trt.)	62.3			
LSD(Rate)	ns			
LSD(TxR)	ns			
Dual Gold	17.7±12.7	12.7±9.9	13.5±11.3	14.6±7.1
Pendimenthalin	20.5±12.1	10.2±1.9	5.8±3.0	12.2±5.7
Hoe Weeding	51.8±4.3	51.8±4.3	51.8±4.3	51.8±4.3
Weedy Check	56.8±28.2	56.8±28.2	56.8±28.2	56.8±28.2
Rate Mean±SD	42.9±14.3	39.9±11.1	39.2±11.7	
LSD(Trt.)	33.5			
LSD(Rate)	2.6			
LSD(TxR)	ns			

ns =not significant at 5% level of probability

Table 25: Weed densities±SD (per 6.25x10^{-6}ha) 21 days after planting at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2009)

Treatments	Percentage	Rate (%)		Treatment
	50	75	100	Mean±SD
	LTRF			
Dual Gold	55.7±16.1	25.0±27.7	21.8±12.5	34.2±18.8
Pendimenthalin	45.3±31.4	45.5±24.7	25.5±10.3	38.8±22.1
Hoe Weeding	114.3±21.8	114.3±21.8	114.3±21.8	114.3±21.8
Weedy Check	111.8±43.8	111.8±43.8	111.8±43.8	111.8±43.8
Rate Mean±SD	89.1±28.4	83.0±29.5	78.4±22.1	
LSD(Trt.)	47.7			
LSD(Rate)	9.3			
LSD(TxR)	ns			
Dual Gold	31.2±10.2	23.0±7.6	21.3±6.8	25.2±8.2
Pendimenthalin	50.8±0.8	41.8±15.7	25.5±10.3	39.4±8.9
Hoe Weeding	110.0±14.8	110.0±14.8	110.0±14.8	110.0±14.8
Weedy Check	117.0±14.0	117.0±14.0	117.0±14.0	117.2±14.0
Rate Mean±SD	86.4±10.0	83.0±13.0	79.4±11.5	
LSD(Trt.)	20.9			
LSD(Rate)	4.5			
LSD(TxR)	ns			

ns = not significant at 5% level of probability

Table 26: Effect of treatments on weed biomass±SD (g) (per $6.25x10^{-6}$ha) 56 days after planting at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2008)

Treatments	Percentage Rate (%)			Treatment Mean±SD
	50	75	100	
	LTRF			
Dual Gold	39.1±7.9	34.6±5.1	34.4±2.2	36.0±5.1
Pendimenthalin	46.7±5.7	39.1±9.2	37.7±3.5	41.0±6.1
Hoe Weeding	34.4±7.4	34.4±7.4	34.4±7.4	34.4±7.4
Weedy Check	55.0±8.8	55.0±8.8	55.0±8.8	55.0±8.8
Rate Mean±SD	42.9±7.5	39.5±7.5	39.07±5.5	
LSD(Trt.)	10.7			
LSD(Rate)	2.06			
LSD(TxR)	ns			
Dual Gold	33.2±4.8	31.7±3.2	29.0±2.0	31.3±3.3
Pendimenthalin	38.5±3.2	30.6±0.3	29.7±2.3	32.9±1.9
Hoe Weeding	30.3±1.7	30.3±1.7	30.3±1.7	30.3±1.7
Weedy Check	51.7±3.0	51.7±3.0	51.7±3.0	51.7±3.0
Rate Mean±SD	38.4±3.2	36.1±2.1	35.2±2.3	
LSD(Trt.)	ns			
LSD(Rate)	ns			
LSD(TxR)	ns			

ns = not significant at 5% level of probability

Table 27: Effect of treatments on weed biomass±SD (g) (per $6.25x10^{-6}$ha) 56 days after planting at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2009)

Treatments	Percentage Rate (%) 50	75	100	Treatment Mean±SD
	LTRF			
Dual Gold	19.7±3.9	20.9±3.5	19.6±3.9	20.1±3.8
Pendimenthalin	24.4±2.8	21.6±3.6	20.8±2.3	22.3±2.9
Hoe Weeding	26.6±12.9	26.6±12.9	26.6±12.9	26.6±12.9
Weedy Check	64.4±26.4	64.4±26.4	64.4±26.4	64.4±26.4
Rate Mean±SD	31.4±11.5	31.1±11.6	30.7±11.4	
LSD(Trt.)	25.8			
LSD(Rate)	ns			
LSD(TxR)	ns			
	OFS			
Dual Gold	26.7±13.2	24.5±6.0	23.4±11.4	24.9±10.2
Pendimenthalin	28.5±9.7	32.4±6.9	20.8±2.3	27.2±6.3
Hoe Weeding	25.9±1.9	25.9±1.9	25.9±1.9	25.0±1.9
Weedy Check	54.4±5.1	54.4±5.1	54.4±5.1	54.4±5.1
Rate Mean±SD	32.4±7.5	32.7±5.0	30.2±5.2	
LSD(Trt.)	10.7			
LSD(Rate)	ns			
LSD(TxR)	ns			

ns = not significant at 5% level of probability

Table 28: Effect of S-metolachlor and pendimethalin on weed density (per $6.25x10^{-6}$ha) 21 days after planting, and weed biomass (per $6.25x10^{-6}$ha) 56 days after planting at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS)

	HERBICIDES			
	S-METOLACHLOR		PENDIMETHALIN	
Application rate(%)	Weed density (% of control)	Weed biomass (% of control)	Weed density (% of control)	Weed biomass (% of control)
LTRF 2008				
100	52.9	37.5	61.3	31.5
75	52.4	37.09	59.3	28.9
50	48.6	28.9	48.6	15.1
Hoe Weeding	22.4	37.5	22.4	37.5
Weedy check	0.0	0.0	0.0	0.0
OFS 2008				
100	76.2	43.9	74.3	42.6
75	77.6	38.7	82.0	40.8
50	68.3	35.8	63.4	25.7
Hoe Weeding	8.8	41.4	8.8	41.4
Weedy check	0.0	0.0	0.0	0.0
LTRF 2009				
100	80.5	69.6	71.2	69.6
75	77.6	67.6	59.3	67.6
50	50.2	69.4	59.5	62.1
Hoe Weeding	-2.2	58.7	-2.2	58.7
Weedy check	0.0	0.0	0.0	0.0
OFS 2009				
100	81.8	57.0	78.2	61.8
75	80.3	55.0	64.3	40.4
50	73.3	50.9	56.6	47.6
Hoe Weeding	6.0	52.4	6.0	52.4
Weedy check	0.0	0.0	0.0	0.0

Table 29: Summary of effects of S-metolachlor and Pendimethalin on weed biomass (g) (per $6.25x10^{-6}$ha) 56 days after planting in the Ogbomoso area

Application rate (l/ha)	Weed weight±SD	Weed control (% of control)
S-metolachlor		
1.6	26.6±7.87	52.85
1.2	27.92±6.95	50.51
0.8	29.67±10.34	47.40
Pendimethalin		
2.0	27.24±7.23	51.71
1.5	30.95±8.32	45.13
1.0	34.51±10.43	38.82
Weedy check	56.41±13.50	0.00
Hoe weeded	33.0±8.30	

SD = Standard deviation

control over hand weeding.. Table 29 showed the summary of the weed weight and weed control 56 DAP in the zone. Weed biomass for S-metolachlor at 1.2 l/ha (26.6±7.87g) and pendimethalin at 2.0 l/ha (27.24±7.23 g) were lower compared with weedy check (56.41±13.50 g). The weeds were thus less vigorous than weedy check. Table 29 shows that weed biomass generally increased with reduction in concentration of the herbicides.

4.4.7 Maize yield in kg/ha as affected by the two herbicides

In 2008 at both LTRF and OFS, weedy check gave significantly lower yield (784kg/ha and 563.3kg/ha) respectively at 5% level of probability compared with the herbicide sprayed and hoe weeded plots (Tables 30 and 31). At LTRF in 2009 cropping seasons, 75 and 100% rates of the herbicides gave higher and significantly different yield (2046.7kg and 2273.3kg) compared with 50% (1736.7kg) (Table 30). This same trend was observed at OFS for 2009 growing season. No significant difference was observed among the rates at LTRF and OFS during the 2008 cropping season. Yield of maize was generally higher in 2008 than 2009 at both sites. However, the percentage increase in yield revealed that LTRF recorded the highest yield in 2009 while OFS gave the lower percentage yield in the same cropping season (Table 32). This can also be seen in the lower yield (326.7 kg/ha) from the weedy check at LTRF than OFS (734.7kg/ha). Lower rates of both herbicides gave lower yield. Significant difference was observed in treatment at both sites (Table 30).

4.5. Treatments effects on worm cast weight (ton/ha)

Worm cast weight per unit area was significantly higher at weedy plot than all other treatments at sites LTRF and OFS during both planting seasons (Tables 33 & 34). The toxic chemical, Mancozeb used also recorded low worm cast like the herbicides and the hoe weeded plots.

Earthworms were scarce on the ploughed and hoe weeded plots thus little or no exposure to chemicals. The mean values for worm cast weight per unit area were insignificant at LTRF during the 2008 and 2009 planting seasons. At OFS in 2008, the mean value for worm cast was significantly lower for 100% rate when compared with 50% and 75%. The same trend occurred during the 2009 growing season at OFS. Reduced worm cast weight was observed with increase in herbicide concentration, and more weight was recorded in Dual gold than the Pendimethalin. Significant different was observed in treatment at LTRF while OFS had significant difference in both treatment and rate. More worm cast weight was generally recorded in 2009 than 2008.

4.6 Response of *Eisenia fetida* (SAV) to the herbicides

Earthworm sampling done on the plots before herbicides application revealed that there were low populations of *E. fetida*. No significant difference was observed among all the plots. The surrounding bush gave higher number of *E. fetida* which was significantly different from records got from the ploughed plots. This observation was true for both site A and B, and the two growing seasons. The herbicides and their rates have no significant effects on the population and weight of *E. fetida* at both site A and B one month after spraying. The same observation was true for the two growing seasons of 2008 and 2009.

The noticeable and significant difference at 5% level of probability was observed between the surrounding bush and herbicide treated plots with the surrounding bush containing more earthworms. The sites and the growing seasons followed the same trend one month after spraying the herbicide (Table 35).

Table 30: Yield of maize±SD (kg/ha) at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2008)

Treatments	Percentage Rate (%)			Treatment Mean±SD
	50	75	100	
	LTRF			
Dual Gold	2224.0±1172.4	2266.7±762.0	2486.7±1095.7	2325.8±1010.0
Pendimenthalin	2437.3±1044.4	2537.3±767.0	2392.0±1164.5	2455.6±992.0
Hoe Weeding	2913.3±968.4	2913.3±968.4	2913.3±968.4	2193.3±968.4
Weedy Check	784.0±397.4	784.0±397.4	784.0±397.4	784.0±397.4
Rate Mean±SD	2325.1±895.7	2353.6±723.7	2368.5±906.5	
LSD(Trt.)	1076.3			
LSD(Rate)	ns			
LSD(TxR)	ns			
	OFS			
Dual Gold	1333.3±549.9	1690.0±655.7	1556.7±828.0	1526.7±677.9
Pendimenthalin	1753.3±726.7	1873.3±332.9	1880.0±955.0	1835.6±671.5
Hoe Weeding	2193.3±890.5	2193.3±890.5	2193.3±890.5	2193.3±890.5
Weedy Check	563.3±307.3	563.3±307.3	563.3±307.3	563.3±307.3
Rate Mean±SD	1638.0±618.6	1733.3±546.6	1708.0±745.2	
LSD(Trt.)	950.6			
LSD(Rate)	ns			
LSD(TxR)	ns			

ns = not significant at 5% level of probability

Table 31: Yield of maize±SD (kg/ha) at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2009)

Treatments	Percentage Rate (%)			Treatment Mean±SD
	50	75	100	
	LTRF			
Dual Gold	1736.7±302.4	2046.7±273.0	2273.3±360.2	2018.9±311.9
Pendimenthalin	1903.3±341.2	2266.7±110.2	2353.3±241.9	2174.4±231.1
Hoe Weeding	1040.0±1646.9	1040.0±1646.9	1040.0±1646.9	1040.0±1646.9
Weedy Check	326.7±271.5	326.7±271.5	326.7±271.5	326.7±271.5
Rate Mean±SD	1468.7±572.6	1603.3±575.4	1666.0±630.1	
LSD(Trt.)	1820.2			
LSD(Rate)	136.1			
LSD(TxR)	ns			
	OFS			
Dual Gold	1198.7±115.5	2441.3±157.0	2010.7±479.1	1883.6±250.5
Pendimenthalin	1674.7±748.1	1774.7±736.9	2353.3±241.9	1934.2±575.6
Hoe Weeding	2044.0±278.6	2044.0±278.9	2044.0±278.9	2044.0±278.9
Weedy Check	734.7±115.5	734.7±115.5	734.7±115.5	734.7±115.5
Rate Mean±SD	1752.5±314.4	2021.1±322.1	2050.7±278.9	
LSD(Trt.)	1488.5			
LSD(Rate)	154.4			
LSD(TxR)	ns			

ns = not significant at 5% level of probability

Table 32: Yield (Yd) of maize and percentage yield over weedy check at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2008 & 2009)

	LTRF				OFS			
	2008		2009		2008		2009	
Treatment (%)	Yd (kg/ha)	%Yd	Yd (kg/ha)	%Yd	Yd (kg/ha)	%Yd.	Yd (kg/ha)	%Yd
S-metolachlor								
100%	2486.7	68.5	2273.3	85.6	1556.6	63.8	2010.7	63.5
75%	2266.7	66.4	2046.7	84.0	1690.0	66.4	2441.0	69.9
50%	2224.0	64.8	1736.7	81.2	1333.3	57.8	1198.7	38.7
Pendimethalin								
100%	2392.0	67.2	2353.3	86.1	1880.0	70.0	2353.3	68.7
75%	2537.3	69.1	2266.7	85.6	1873.3	69.9	1774.7	58.6
50%	2437.3	67.8	1905.3	82.8	1753.3	67.9	1674.0	56.1
Hoe Weeding	2913.3	73.1	1040.0	68.6	2193.3	74.3	2044.0	64.1
Weedy check	784.0		326.7		563.3		734.7	

The mean population estimated during the field work were 0.83±0.14, 0.83±0.14 and 0.78±0.15 for 0.8, 1.2 and 1.6L/ha S-metolachlor respectively, and 0, 0.80±0.1and 0 for 1.0, 1.5 and 2.0L/ha pendimethalin respectively, mancozeb had 0.76±0.43 and weedy check 0.85±0.28 before herbicide application. Population estimated one month after application were 0.93±0.15, 0.92±0.31 and 2.33±0.46, for 0.8, 1.2 and 1.6L/ha S-metolachlor respectively, and 0, 0.83±0.14 and 0.78±0.15 for 1.0, 1.5 and 2.0L/ha Pendimethalin respectively; mancozeb had 0.81±0.2; hoe weeding and weedy check had 0.75±0.09 and 0.86±0.17 respectively.

Earthworms were not encountered on the treated plots, hoe weeding, weedy check and the surrounding bush three months after spraying the herbicide.

4.6.1 Herbicide effects on *Lumbricus terrestris*

After ploughing and pegging, just before herbicides applications, the plots were devoid of *L. terrestris* at both sites and throughout the two growing seasons except 2.0L/ha pendimethalin which recorded 0.57±0.29 and 0.78±0.15 before herbicide application and one months after application respectively. but significantly higher ($p \leq 0.05$) numbers were obtained from the surrounding vegetation (Table 36). Throughout the two growing seasons and from sites A and B, *L. terrestris* were not recorded on the plots including the control one month after herbicides application except two small ones (0.75±0.09) recorded one from 1.6L/ha S-metolachlor and from the hoe weeded plot (0.75±0.09). The surrounding vegetation gave significantly higher ($p \leq 0.05$) number of *L. terrestris* compared to the ploughed plots one month after spraying (Table 35). Just like *E. fetida*, no *L. terrestris* was recorded from the two sites and surrounding bush and the two seasons three months after spraying the herbicides.

Table 33: Effect of treatments on worm cast weight±SD (ton/ha) per unit area at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2008)

Treatments	Percentage Rate (%)			Treatment Mean±SD
	50	75	100	
	LTRF			
Dual Gold	2.410±3.9	1.48±2.6	0.92±1.6	1.603±2.7
Pendimethalin	1.447±0.5	1.063±0.7	1.55±2.68	1.353±1.3
Hoe Weeding	0.480±0.8	0.480±0.8	1.480±0.8	0.480±0.8
Weedy Check	4.607±4.1	4.607±4.1	4.607±4.1	4.607±4.1
Mancozeb	1.223±1.3	1.223±1.3	1.223±1.3	1.223±1.3
Rate Mean±SD	2.03±1.7	1.72±1.9	1.76±2.1	
LSD(Trt.)	3.739			
LSD(Rate)	ns			
LSD(TxR)	ns			
	OFS			
Dual Gold	0.627±0.7	0.507±0.9	0.147±0.3	0.4267±0.6
Pendimethalin	0.690±0.6	1.330±1.3	0.093±0.1	0.7044±0.7
Hoe Weeding	0.017±0.0	0.017±0.0	0.017±0.0	0.017±0.0
Weedy Check	1.260±1.2	1.260±1.2	1.260±1.2	1.26±1.2
Mancozeb	0.057±0.1	0.057±0.1	0.057±0.1	0.067±0.1
Rate Mean±SD	0.53±0.5	0.634±0.7	0.148±0.5	
LSD(Trt.)	1.101			
LSD(Rate)	0.234			
LSD(TxR)	ns			

ns = not significant at 5% level of probability

Table 34: Effect of treatments on worm cast weight±SD (ton/ha) per unit area at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2009)

Treatments	Percentage Rate (%)			Treatment
	50	75	100	Mean±SD
	LTRF			
Dual Gold	5.072±3.3	3.056±3.2	2.400±3.5	3.509±3.3
Pendimenthalin	2.571±2.2	1.973±1.8	3.040±3.2	2.528±2.4
Hoe Weeding	1.050±9.5	1.050±9.5	1.050±9.5	1.050±9.5
Weedy Check	10.87±3.8	10.87±3.8	10.87±3.8	10.87±3.8
Mancozeb	2.144±2.0	2.144±2.0	2.144±2.0	2.144±2.0
Rate Mean±SD	4.342±4.2	3.819±4.1	3.901±4.4	
LSD(Trt.)	4.018			
LSD(Rate)	ns			
LSD(TxR)	ns			
	OFS			
Dual Gold	1.429±1.3	1.877±2.0	1.530±**0.**8	6.203±1.4
Pendimenthalin	4.165±5.0	1.589±1.2	3.040±3.2	2.932±3.1
Hoe Weeding	3.163±2.9	3.163±2.9	3.163±2.9	3.163±2.9
Weedy Check	2.352±2.6	2.352±2.6	2.352±2.6	2.352±2.6
Mancozeb	2.587±2.6	2.587±2.8	2.587±2.8	2.587±2.8
Rate Mean±SD	2.739±2.9	2.314±2.3	5.289±2.5	
LSD(Trt.)	ns			
LSD(Rate)	1.287			
LSD(TxR)	ns			

ns = not significant at 5% level of probability.

Table 35: *Eisenia fetida* population and weight (g) estimated before and 1month after herbicide spraying at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) during the 2008 and 2009 growing seasons

	LAUTECH TEACHING & RESEARCH FARM								OGBOMOSO FARM SETTLEMENT								
	2008				2009				2008				2009				
	BHS		1MAS		BHS		1MAS		BHS		1MAS		BHS		1MAS		
TRT	No.	wt.	No.	wt.	No.	wt.	No.	wt.	No.	wt.	No.	wt.	No.	wt.	No.	wt.	LSD (p≤5%)
S-metolachlor																	
100%	0.71	0.00	0.71	0.00	1.00	0.11	0.88	0.09	0.71	0.00	0.71	0.00	0.71	0.00	1.00	0.06	ns
75%	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.88	0.59	1.26	0.93	1.00	0.15	1.00	0.15	ns
50%	0.88	1.49	1.00	0.59	0.71	0.00	1.00	0.12	1.00	0.49	0.71	0.00	0.71	0.00	1.00	0.11	ns
Pendimethalin:																	
100%	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	1.00	0.38	0.71	0.00	0.71	0.00	ns
75%	0.88	0.38	0.71	0.00	0.71	0.00	1.00	0.15	0.88	0.55	0.71	0.00	0.71	0.00	0.88	0.08	ns
50%	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	ns
Manc.	0.71	0.00	0.71	0.0 0	0.50	0.13	0.71	0.00	0.71	0.00	0.71	0.00	1.10	0.14	1.10	0.15	ns
HW	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.88	0.09	ns
H0	0.71	0.00	0.71	0.00	0.71	0.00	1.00	1.73	1.26	1.02	0.71	0.00	0.71	0.00	1.00	0.12	ns
Sur.Vg.	1.86	7.86	2.11	7.23	1.76	0.26	1.56	0.49	2.03	7.86	2.11	7.24	1.68	0.52	1.77	0.55	ns
LSD	0.24	1.14	0.20	0.55	0.47	0.19	0.52	0.29	0.23	0.78	2.29	0.62	0.53	0.34	0.74	0.32	

HW = Hoe weeding | BHS = Before herbicide spraying

H0 = Weedy check | 1MAS = One month after spraying

Sur. Vg. = Surrounding Vegetation | BHS = Before herbicide spraying

Manc = Mancozeb | 1MAS = One month after spraying.

4.6.2 Effect of herbicides on *Libyodrilus violaceus*

Before herbicide application (BHA), surrounding bush gave significantly higher population with variable weights of *L. violaceus* than all the plots including control ones. (Table 37) *Libyodrilus violaceus* was recorded at a very low rate during 2008 survey (Table 37) from both sites, surrounding bush gave significantly higher population when compared with treated and control plots. The same observation was recorded in 2009 at the two sites (Table 36) one month after spraying. *L. violaceus* was also not encountered three months after spraying the herbicides. The average populations of the worms encountered during the experiment at S-metolachlor plots BHA were 0.0, 0.89±0.16 and 0.75±0.09 for 0.8, 1.2 and 1.6L/ha respectively. Pendimethalin had the corresponding values 0, 0.80±0.1 and 0 for 1.0, 1.5 and 2.0L/ha respectively. Mancozeb had 0.83±0.14. One month after herbicide application, the following average populations were recorded: S-metolachlor 0, 0.78±0.15, and 0.78±0.15 for 0.8, 1.2 and 1.6L/ha respectively; Pendimethalin 0, 0.83±0.14 and 0.87±0.12 for 1.0, 1.5 and 2.0L/ha respectively. Hoe weeding and weedy check had 0.81±0.2 and 0.94±0.07.

4.7 Disappearance of S-metolachlor and Pendimethalin from the soil

Regression plots in Figures 10 – 33, and appendix III and IV show the disappearance time of S-metolachlor and Pendimethalin with time. The data in the two appendices were obtained from the graphs. In general, there was a decrease in the concentrations of the two herbicides residues in the soil from the day of application irrespective of the rate, revealing no apparent initial lag phase during which no appreciable loss of the herbicides occur. At the end of the experiments, thirteen weeks after application, the remaining herbicide residues and their percentages were shown respectively in the last two columns of appendix I and II.

Table 36: *Lumbricus terrestris* population and weight (g) estimated before and 1month after herbicide spraying at the two sites during the 2008 and 2009 growing seasons

	LAUTECH TEACHING & RESEARCH FARM								OGBOMOSO FARM SETTLEMENT								
	2008				2009				2008				2009				
	BHS		1MAS		BHS		1MAS		BHS		1MAS		BHS		1MAS		
TRT	No.	wt.	No.	wt.	No.	wt.	No.	wt.	No.	wt.	No.	wt.	No.	wt.	No.	wt.	LSD ($p \leq 5\%$)
S-metolachlor:																	
100%	0.71	0.00	0.71	0.00	0.71	0.00	0.88	0.04	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	ns
75%	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	ns
50%	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	ns
Pendimethalin:																	
100%	0.71	0.00	0.71	0.00	0.71	0.00	1.00	0.00	0.14	0.71	0.71	0.00	0.71	0.00	0.71	0.00	ns
75%	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	ns
50%	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	ns
Manc.	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	ns
HW	0.71	0.00	0.71	0.00	0.71	0.00	0.88	0.08	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	ns
H0	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	ns
Sur.Vg.	1.34	6.90	1.68	7.21	1.46	0.52	1.17	0.39	1.46	6.90	1.77	7.21	1.77	0.62	1.39	0.52	ns
LSD	0.15	0.63	0.12	0.47	0.15	0.09	0.45	0.31	0.15	0.63	0.12	0.47	0.12	0.04	0.45	0.34	

HW = Hoe weeding

H0 = Weedy check

Sur. Vg. = Surrounding Vegetation

Manc = Mancozeb

BHS = Before herbicide spraying

BHS = Before herbicide spraying

1MAS = One month after spraying

1MAS = One month after spraying

Table 37: *Libyodrilus violaceus* population and weight (g) estimated before and 1month after herbicide spraying at the two sites during the 2008 and 2009 growing seasons

	LAUTECH TEACHING & RESEARCH FARM								OGBOMOSO FARM SETTLEMENT								
	2008				2009				2008				2009				
	BHS		1MAS		BHS		1MAS		BHS		1MAS		BHS		1MAS		
TRT	No.	wt.	No.	wt.	No.	wt.	No.	wt.	No.	wt.	No.	wt.	No.	wt.	No.	wt	LSD (p≤5%)
S-metolachlor																	
100%	0.88	0.68	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	1.00	1.27	0.71	0.00	0.71	0.00	ns
75%	0.71	0.00	0.71	0.00	1.10	0.19	1.00	0.09	0.88	0.12	0.71	0.00	0.88	0.09	0.71	0.00	ns
50%	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.71	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	ns
Pendimethalin.																	
100%	0.71	0.00	0.71	0.00	0.71	0.00	0.88	0.05	0.71	0.00	1.00	0.13	0.71	0.00	0.88	0.07	ns
75%	0.71	0.00	1.00	1.14	0.88	0.09	0.71	0.00	0.71	0.00	0.88	0.07	0.88	0.08	0.71	0.00	ns
50%	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	ns
Manc.	0.88	0.59	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	1.00	0.13	0.71	0.00	ns
HW	0.71	0.00	0.71	0.00	0.71	0.00	1.10	0.19	0.71	0.00	0.71	0.00	0.71	0.00	0.71	0.00	ns
W0	0.71	0.00	0.88	1.18	0.71	0.00	1.00	0.15	0.71	0.00	0.88	0.77	0.71	0.00	1.00	0.14	ns
Sur.Vg.	1.95	5.78	1.86	5.70	1.68	0.48	1.65	0.37	1.68	5.78	1.95	5.70	1.76	0.53	1.95	0.62	ns
LSD	0.21	0.83	0.34	1.15	0.21	0.13	0.61	0.29	0.13	0.88	0.27	1.19	0.46	0.20	0.40	1.15	

HW = Hoe weeding

Ho = Weedy check

Sur. Vg. = Surrounding Vegetation

Manc = Mancozeb

BHS = Before herbicide spraying

BHS = Before herbicide spraying

1MAS = One month after spraying

1MAS = One month after spraying

The disappearance time for S-metolachlor was initially very fast with the highest concentration except in 2009 at Ogbomoso Farm Settlement where the reverse was the case. As the concentration got reduced with days, the disappearance time no longer follow the level of application. Generally, about 90% of S-metolachlor applied at their respective concentrations disappeared between 80-100 days. Fifty percent of the herbicide disappeared between 44-59 days, that is, about 6th to 8th weeks after application. 10% of S-metolachlor had disappeared in less than 15 days after application. Between 0-28 days after soil application, about 4.5 mg/kg to 5.7 mg/kg had disappeared and the rate of disappearance kept decreasing as the concentrations in the soil were decreasing until 85 – 98 days when less than 1mg/kg of the herbicide disappeared.

The initial disappearance of Pendimethalin did not follow the trend of higher concentrations disappearing faster than lower ones except at LAUTECH Farm in 2008 and 2009 10% of Pendimethalin disappeared between 3.5 to 12 days (less than 2 weeks) after application. Between 35.3 to 61.2 days (about 5-9 weeks) after application, 50% of Pendimethalin had disappeared. On the average, 90% of Pendimethalin had disappeared by about 94 days after application. The rate of disappearance of Pendimethalin followed the same trend as S-metolachlor by decreasing with decreasing concentration of residue in the soil. Thus, between 3.58 – 6.2 mg/kg Pendimethalin disappeared within 0 -28 days.

Between 85 – 98 days after application, less than 1.6mg/kg disappeared. The lowest rate of Pendimethalin applied, 1.0 l/ha, had almost disappeared completely by the thirteenth week of the experiment (Appendix V and VI).

The meteorological data during the 2008 and 2009 cropping seasons revealed higher temperature, evapo-transpiration, sunshine and rainfall in 2008 than 2009 (Table 44)

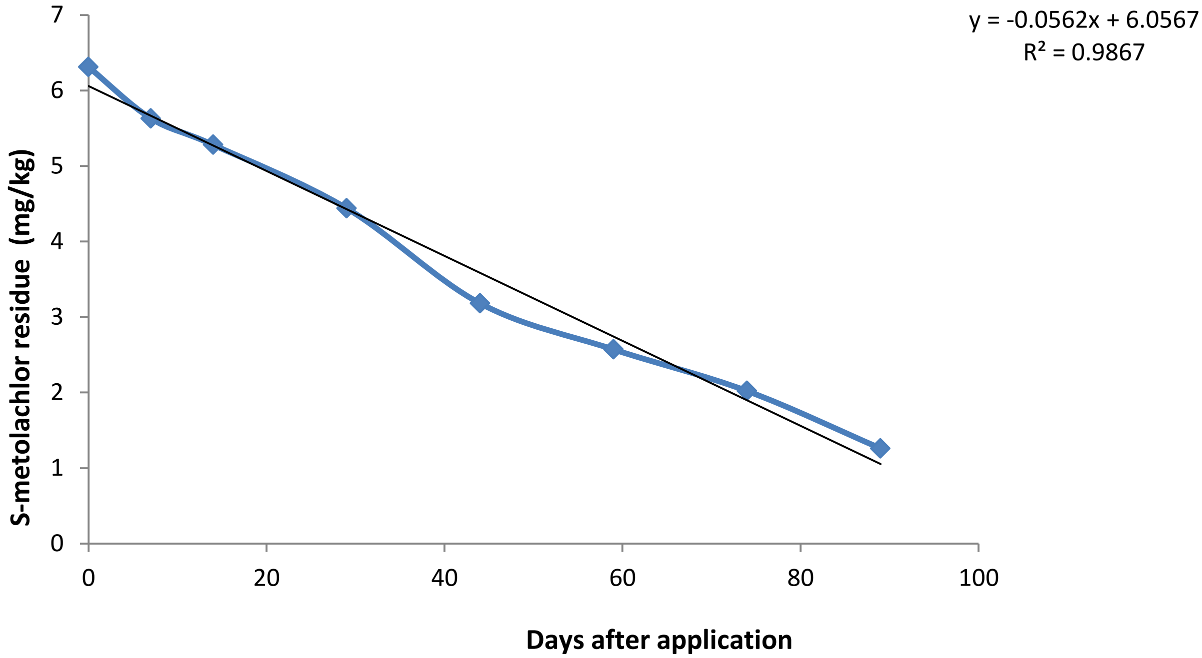


Figure 13: Disappearance of 1.6 l/ha S-metolachlor at LAUTECH Farm in 2008

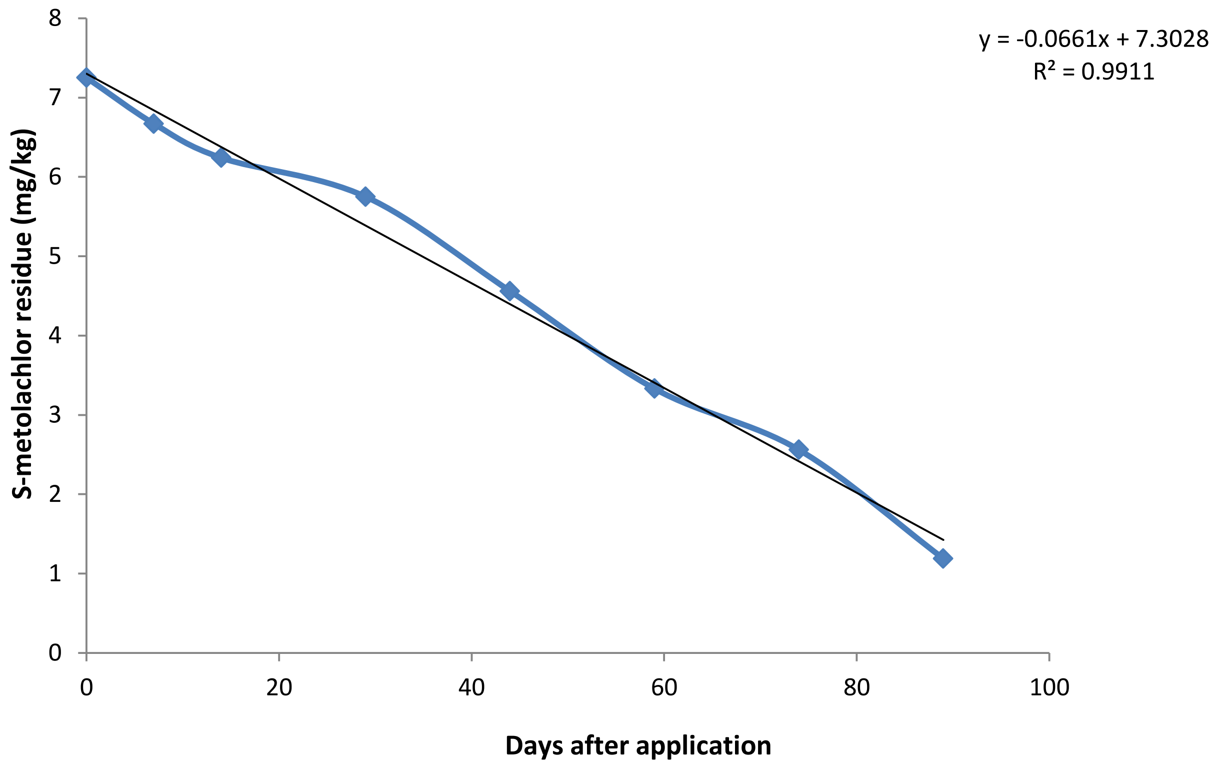


Figure 14: Disappearance of 1.6 l/ha S-metolachlor at Ogbomoso Farm settlement in 2008

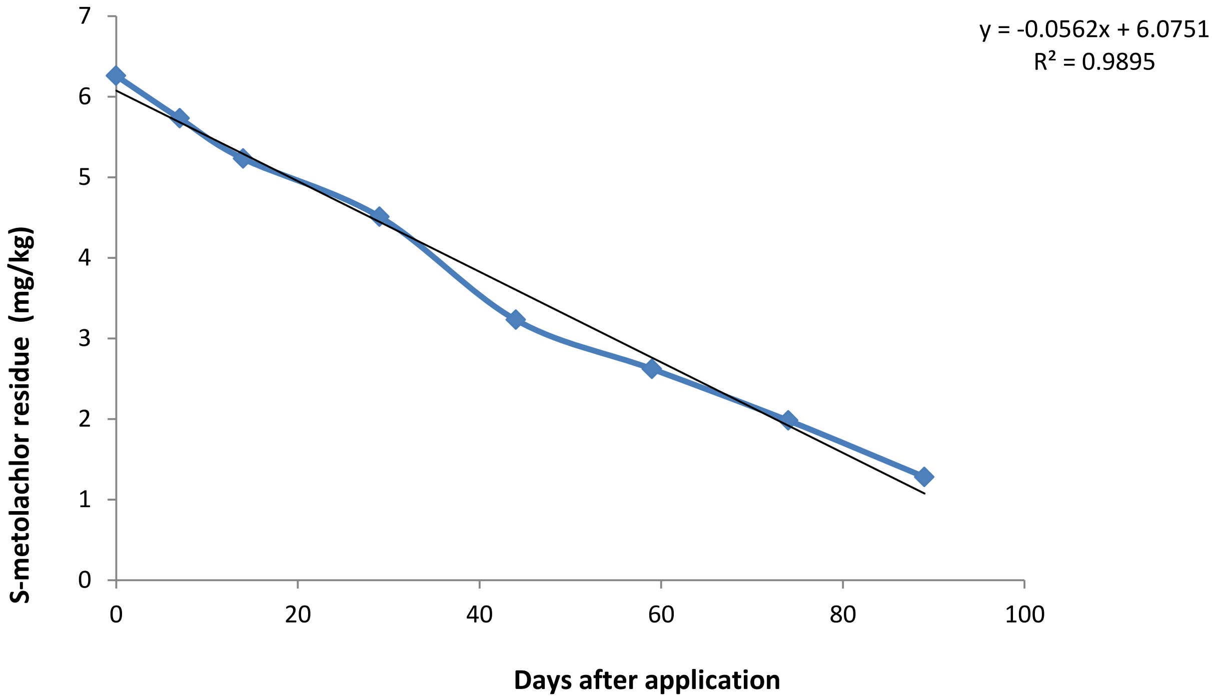


Figure 15: Disappearance of 1.6 l/ha S-metolachlor at LAUTECH Farm in 2009

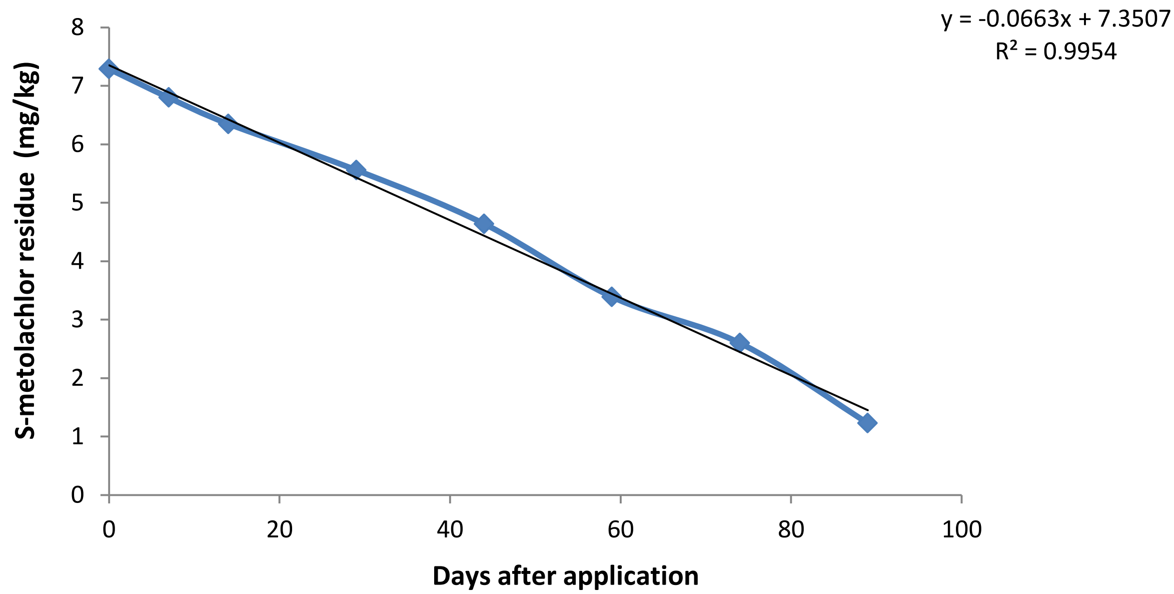


Figure 16: Disappearance of 1.6 l/ha S-metolachlor at Ogbomoso Farm settlement in 2009

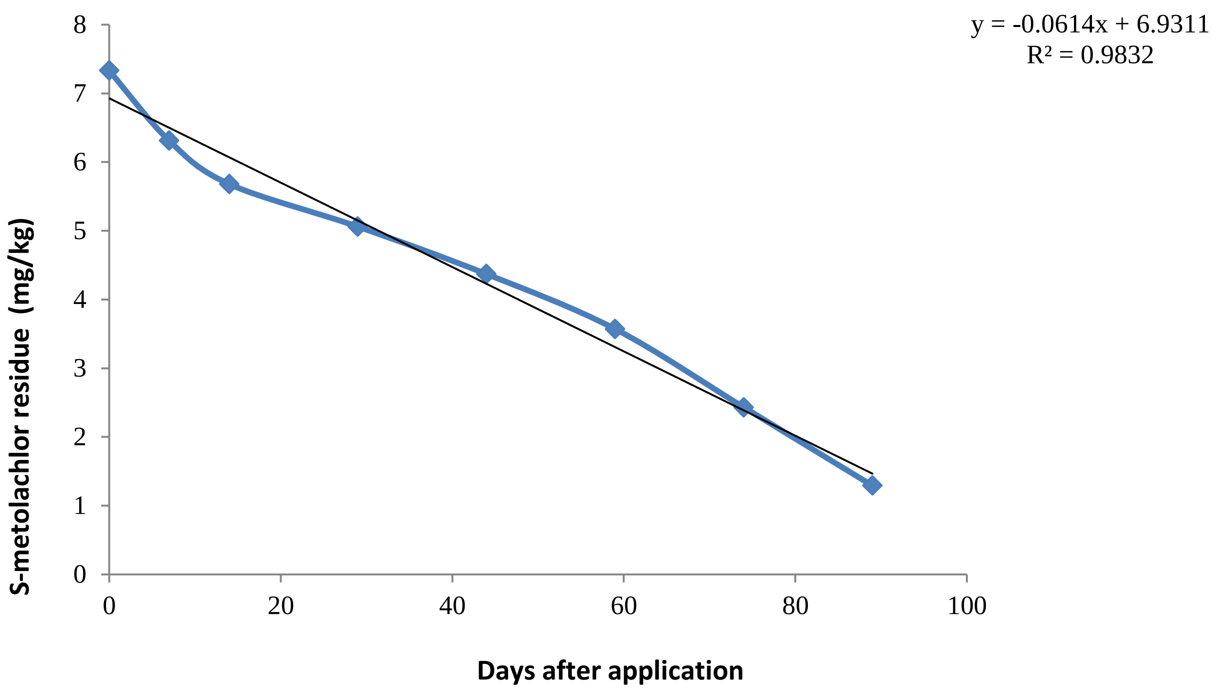


Figure 17: Disappearance of 1.2 l/ha S-metolachlor at LAUTECH Farm in2008

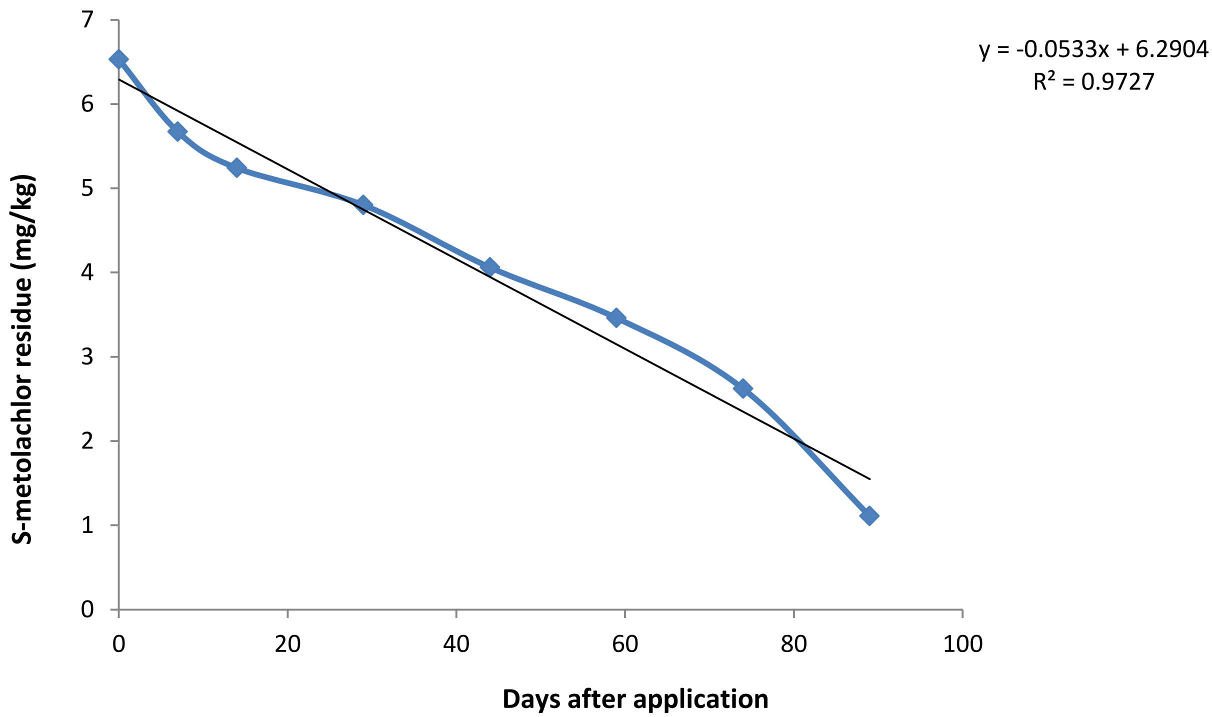


Figure 18: Disappearance of 1.2 l/ha S-metolachlor at Ogbomoso Farm settlement in 2008

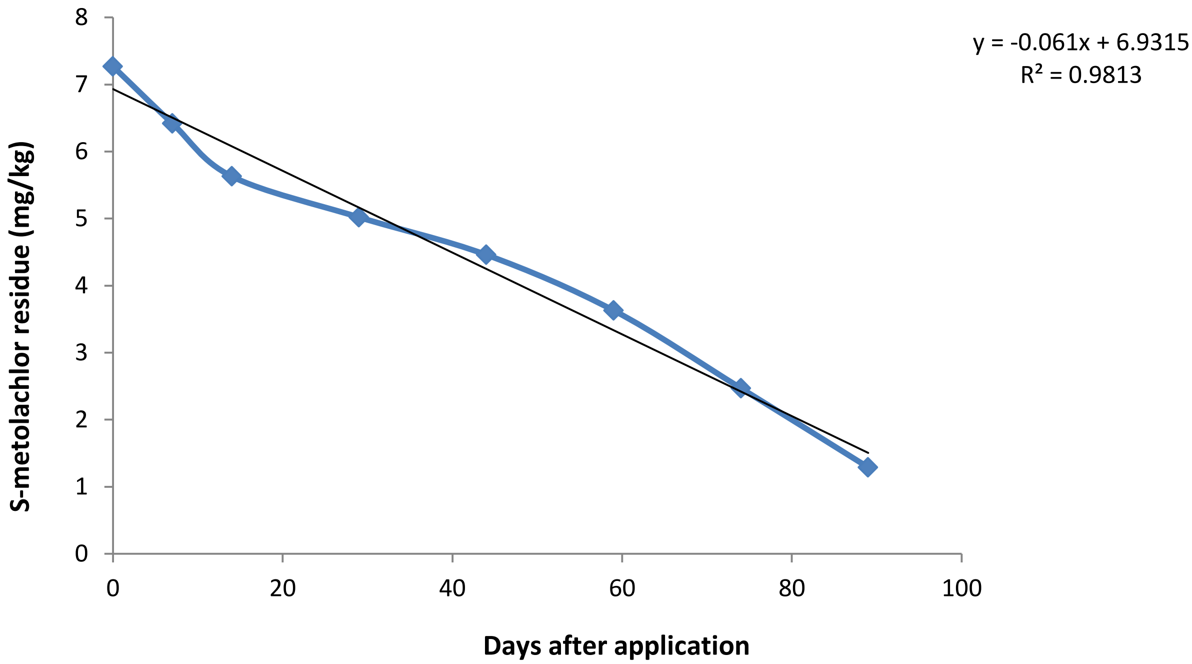


Figure 19: Disappearance of 1.2 l/ha S-metolachlor at LAUTECH Farm in 2009

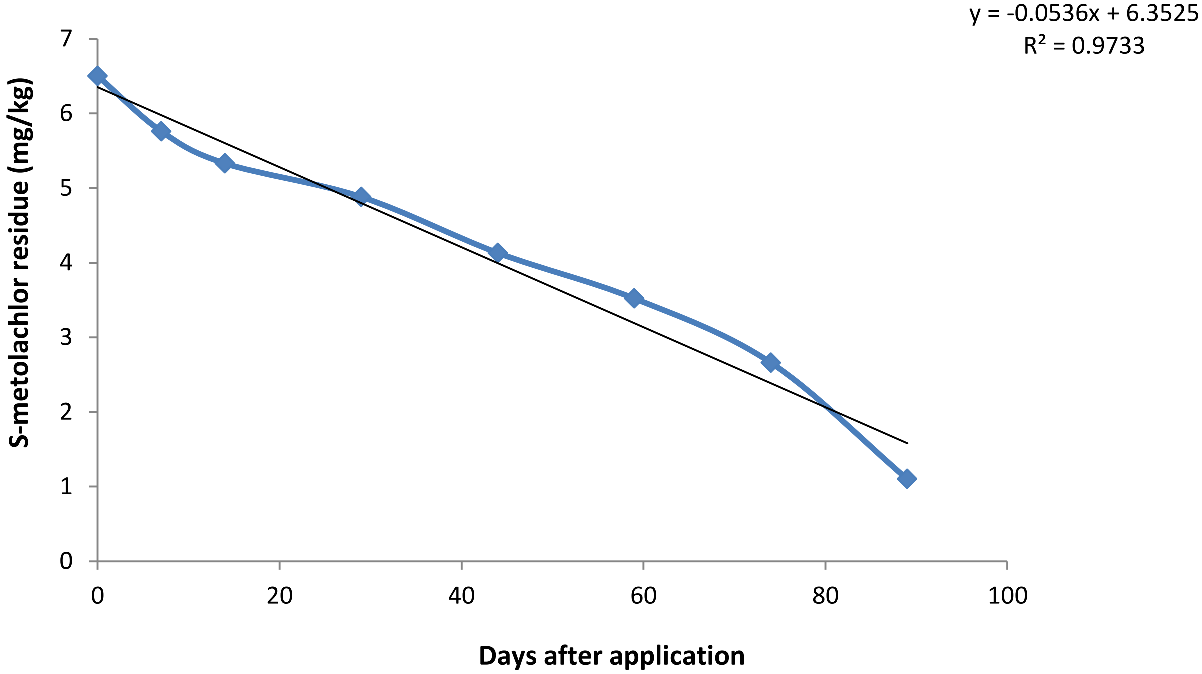


Figure 20: Disappearance of 1.2 l/ha S-metolachlor at Ogbomoso Farm settlement in 2009

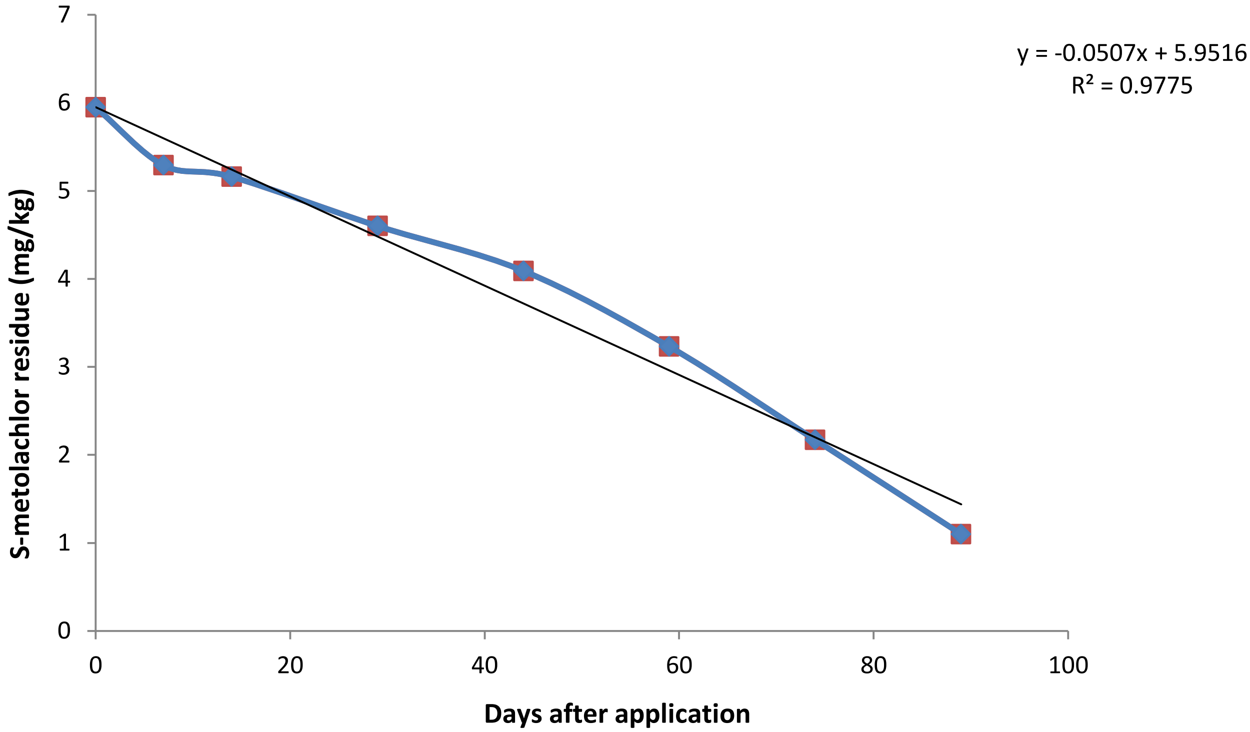


Figure 21: Disappearsnce of 0.8 l/ha S-metolachlor at LAUTECH Farm in 2008

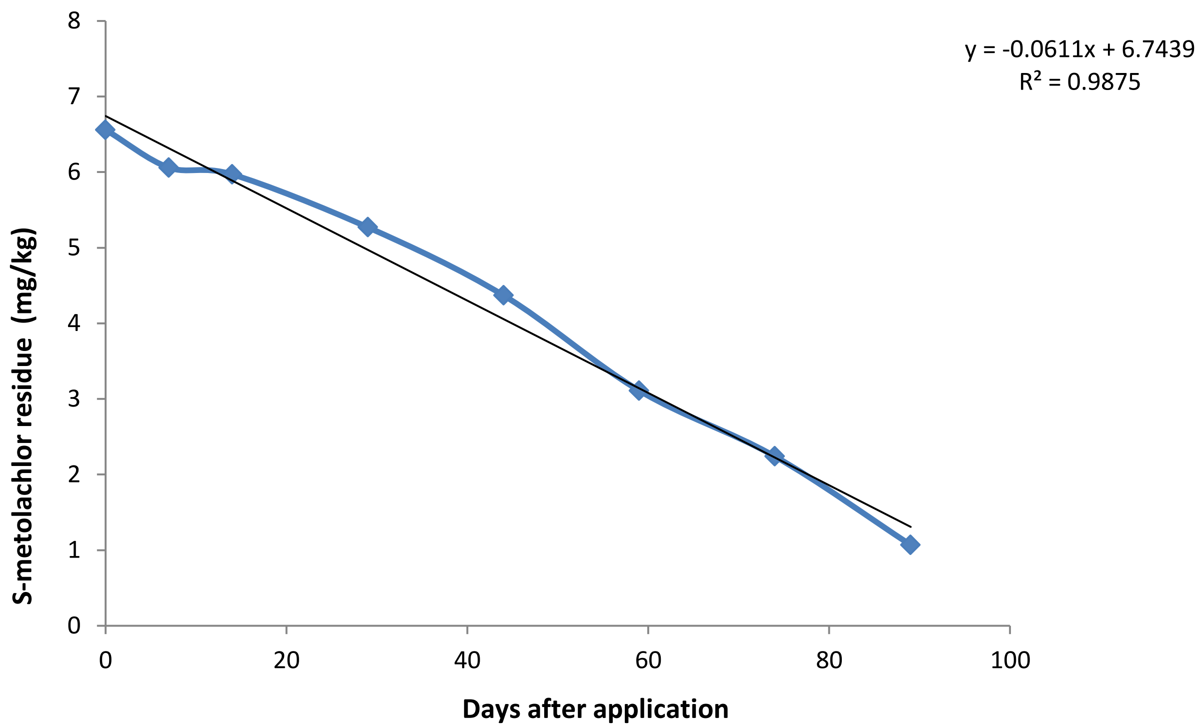


Figure 22: Disappearance of 0.8 l/ha S-metolachlor at Ogbomoso Farm settlement in 2008

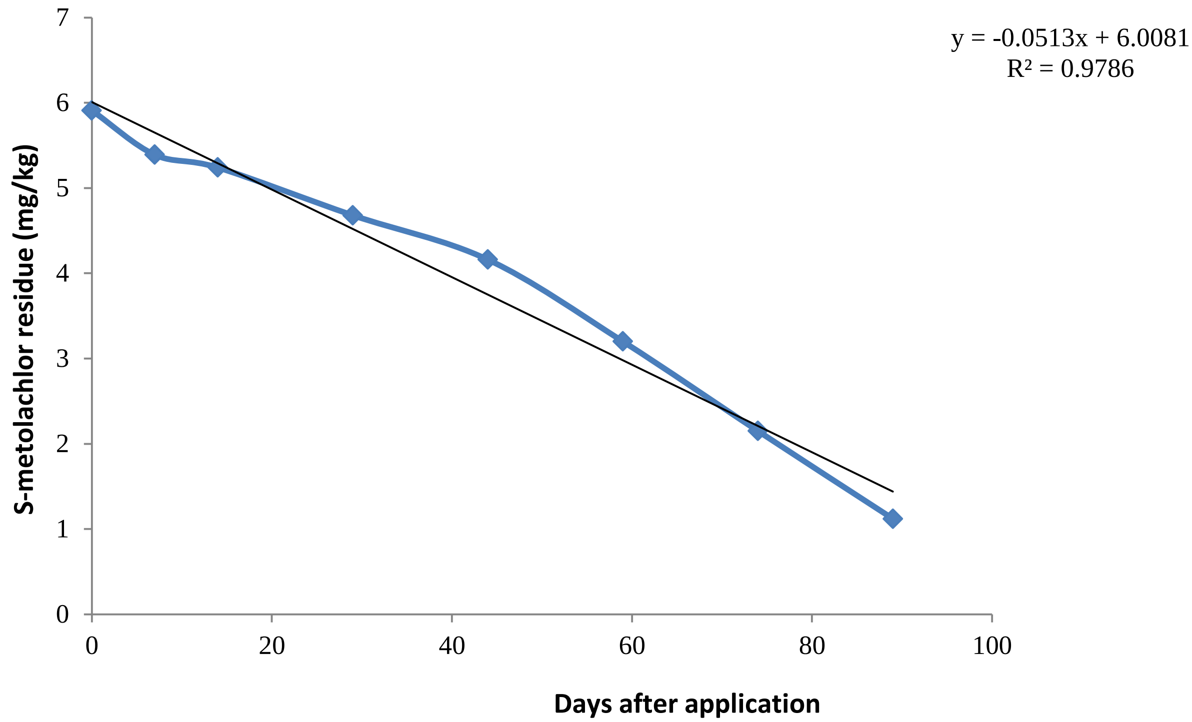


Figure 23: Disappearance of 0.8 l/ha S-metolachlor at LAUTECH Farm in 2009

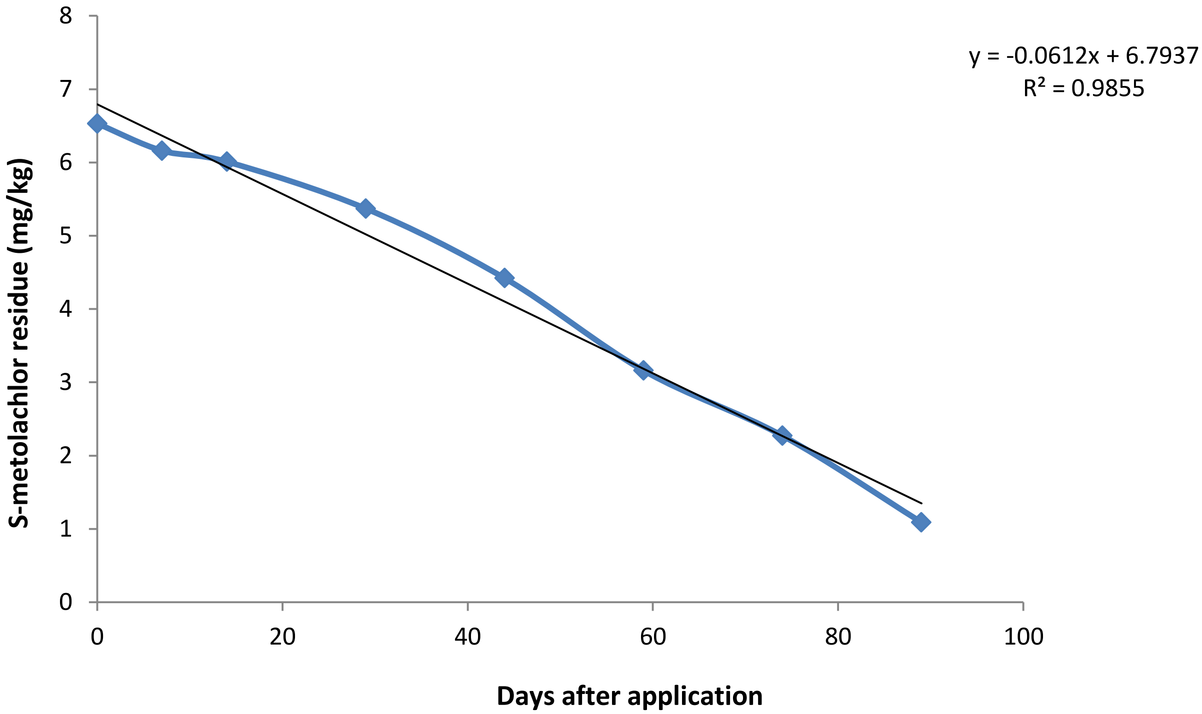


Figure 24: Disappearance of 0.8 l/ha S-metolachlor at Ogbomoso Farm settlement in 2009

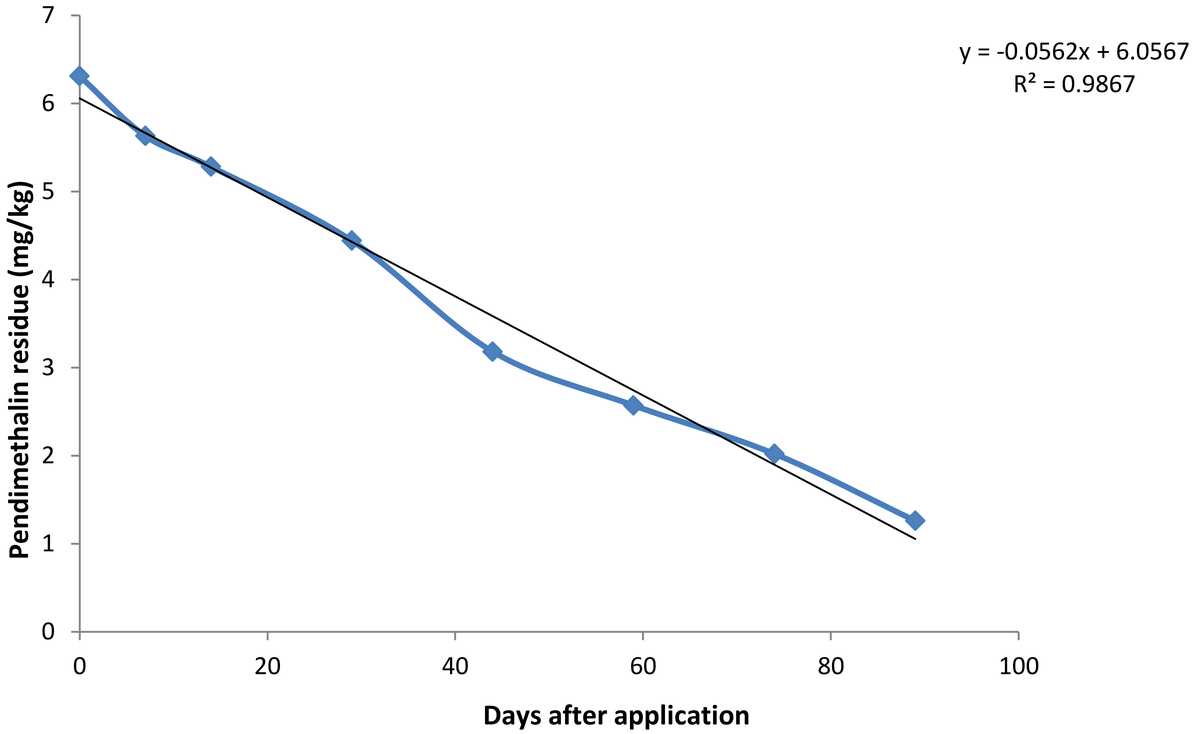


Figure 25: Disappearance of 2.0 l/ha Pendimethalin at LAUTECH Farm in 2008

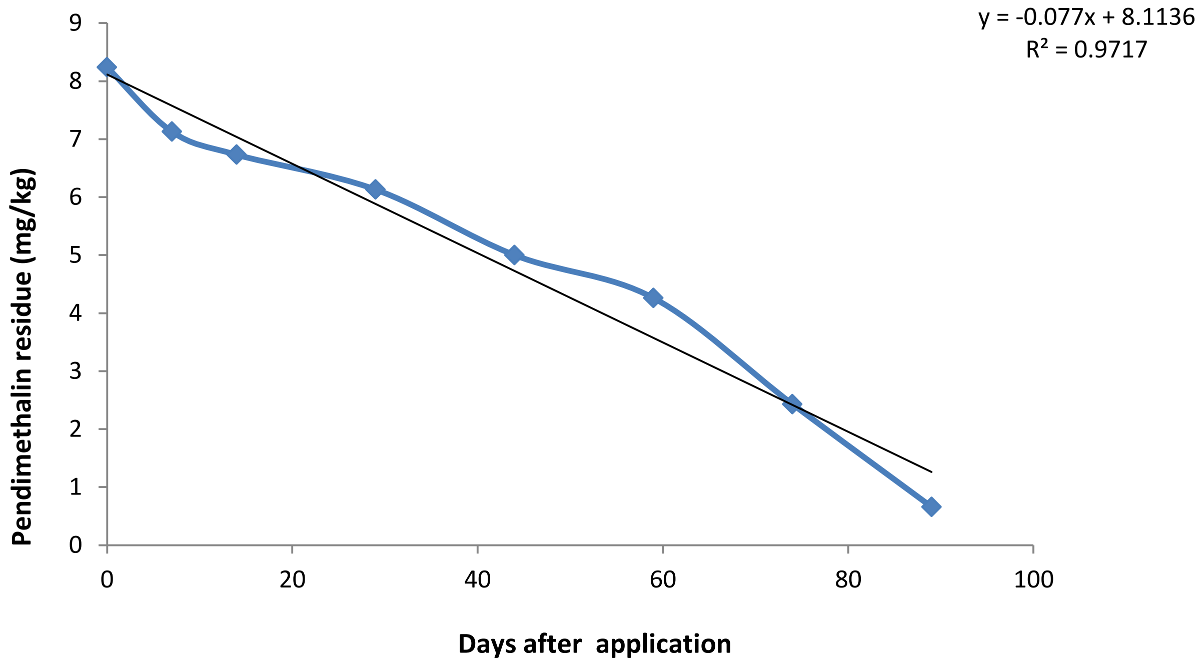


Figure 26: Disappearance of 2.0 l/ha Pendimethalin at Ogbomoso Farm settlement in 2008

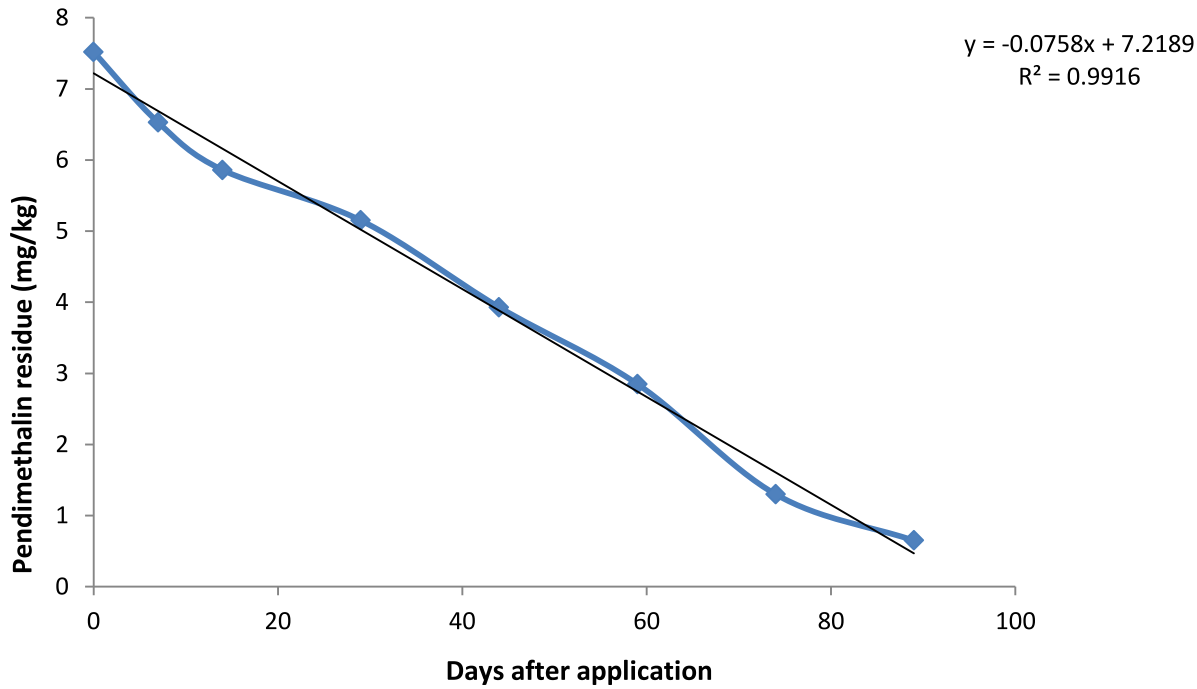


Figure 27: Disappearance of 2.0 l/ha Pendimethalin at LAUTECH Farm in 2009

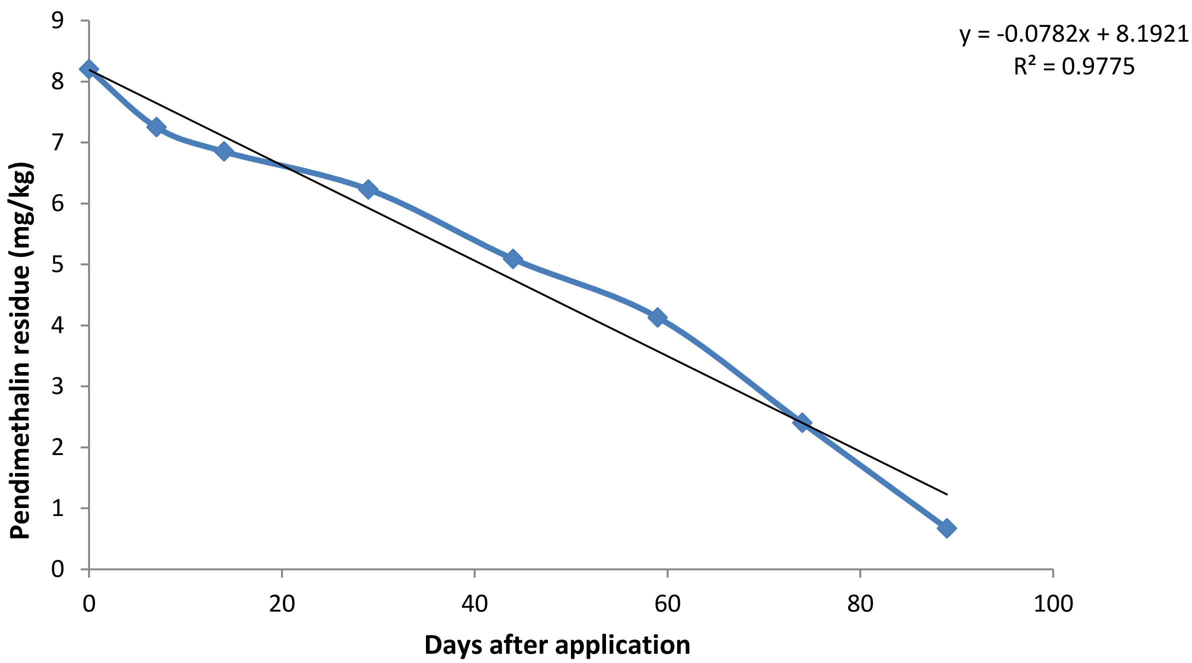


Figure 28: Disappearance of 2.0 l/ha Pendimethalin at Ogbomoso Farm settlement in 2009

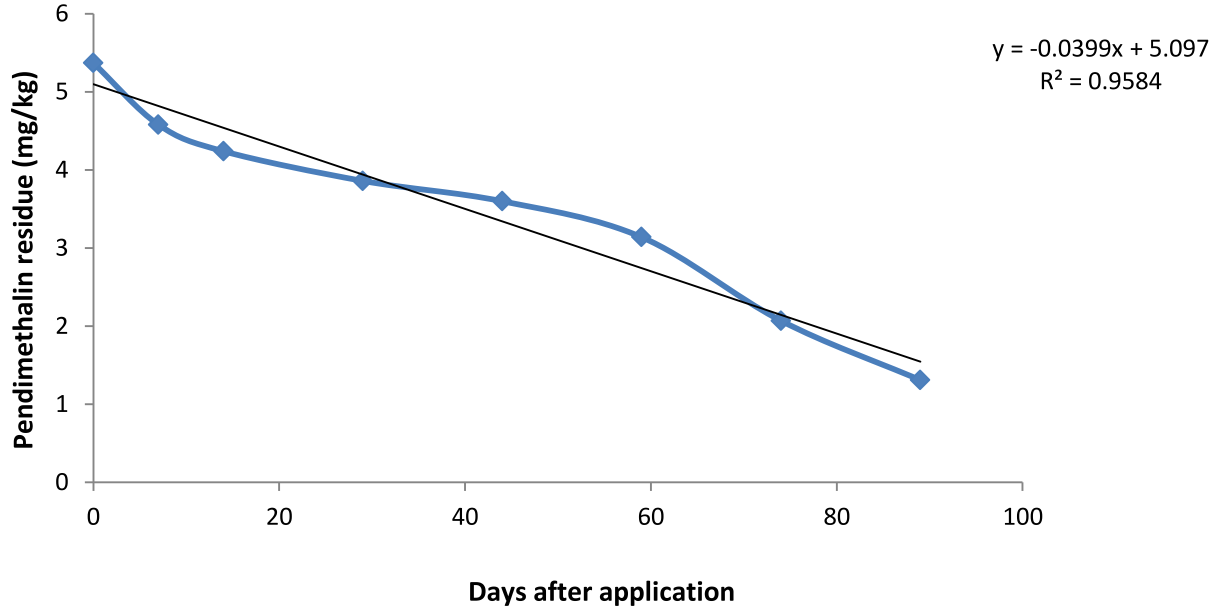


Figure 29: Disappearance of 1.5 l/ha Pendimethalin at LAUTECH Farm in 2008

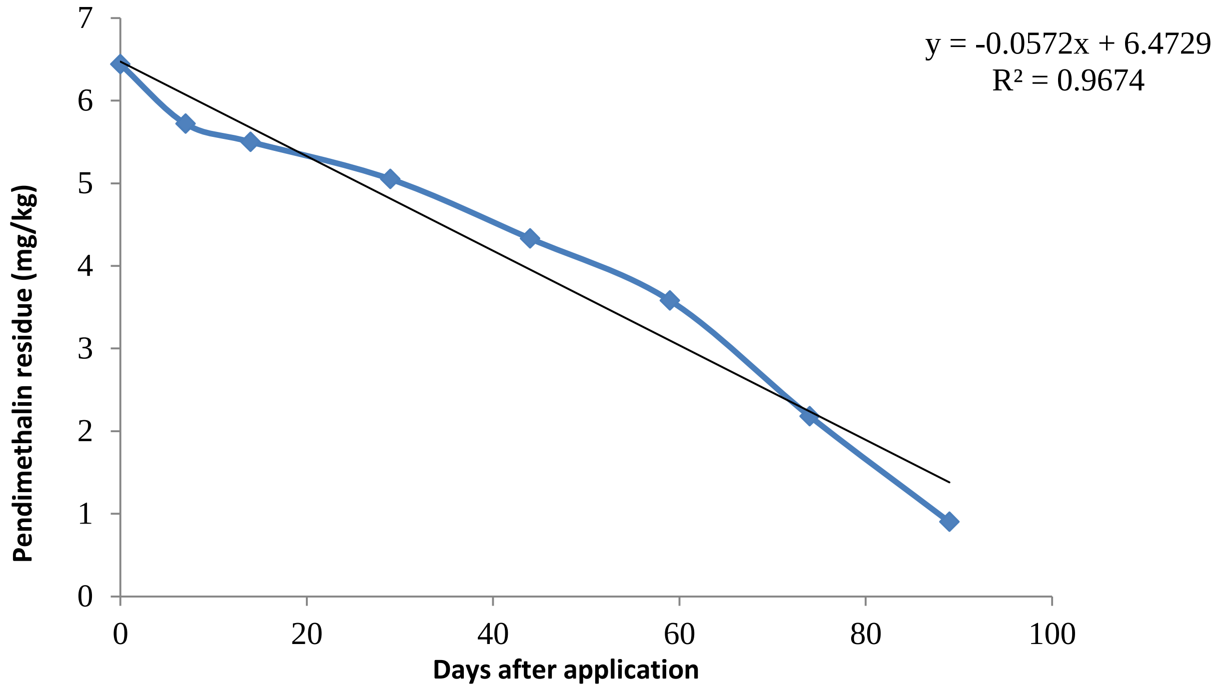


Figure 30: Disappearance of 1.5 l/ha Pendimethalin at Ogbomoso Farm settlement in 2008

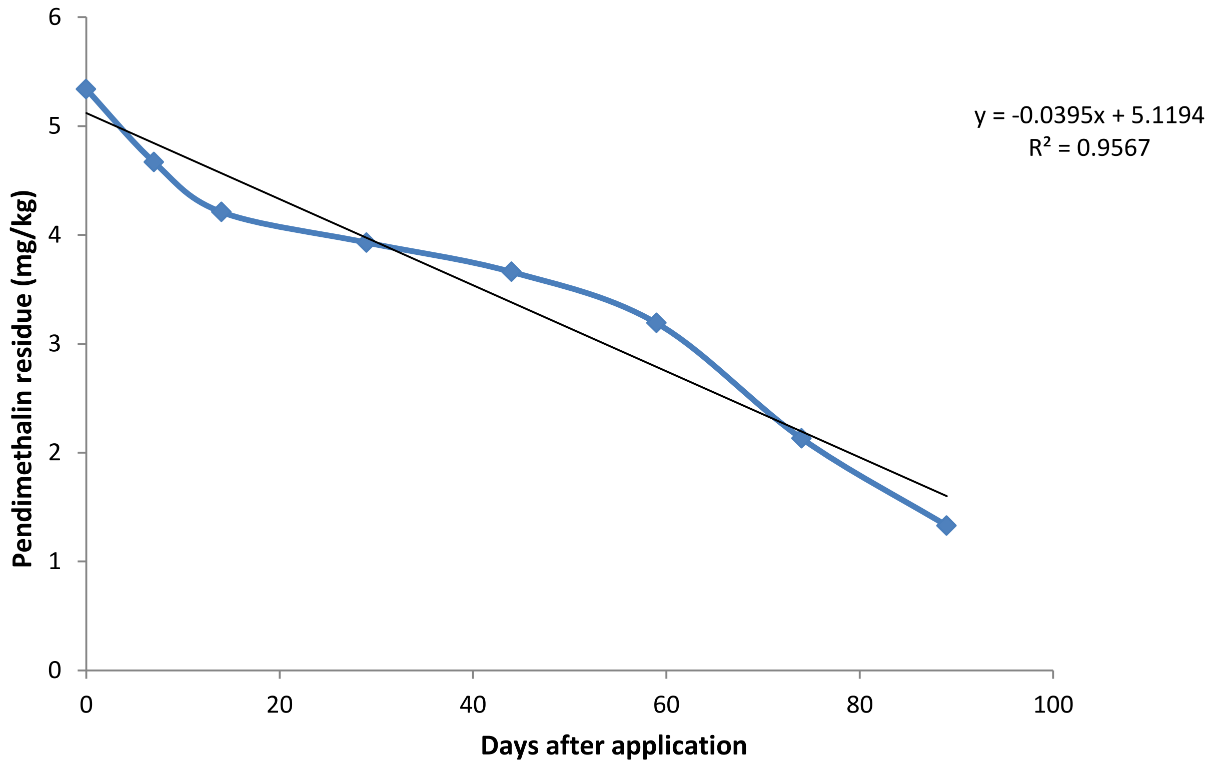


Figure 31: Disappearance of 1.5 l/ha Pendimethalin at LAUTECH Farm in 2009

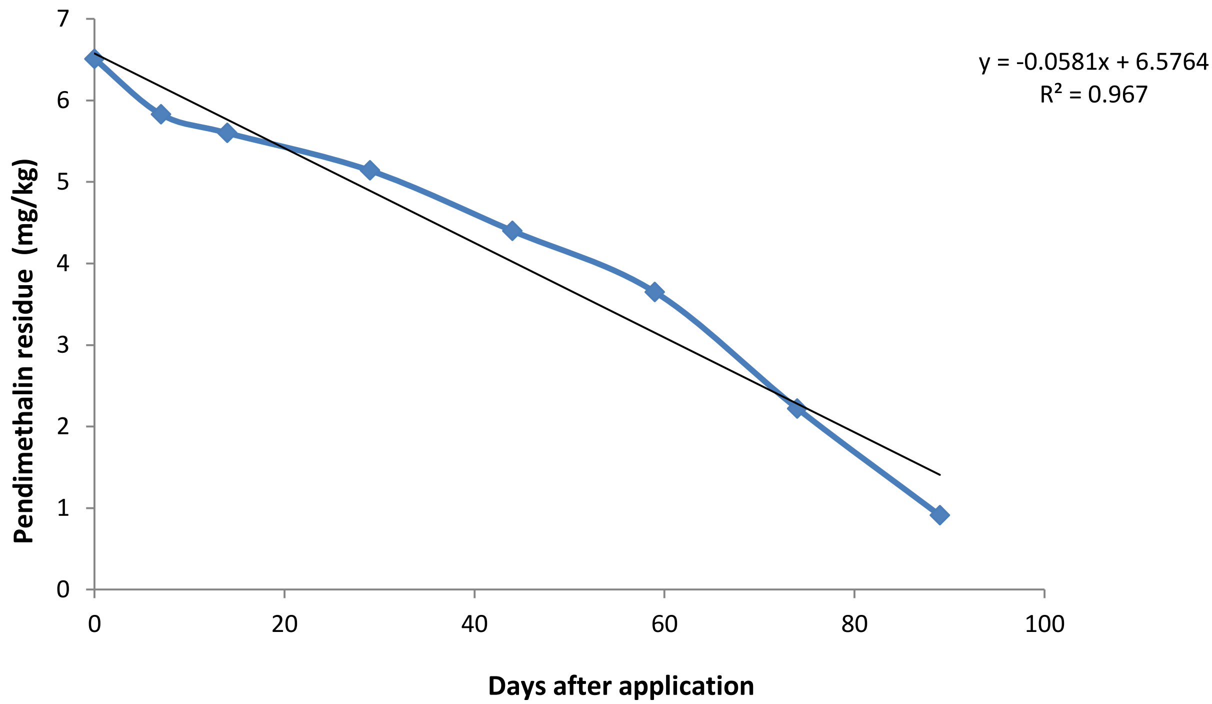


Figure 32: Disappearance of 1.5 l/ha Pendimethalin at Ogbomoso Farm settlement in 2009

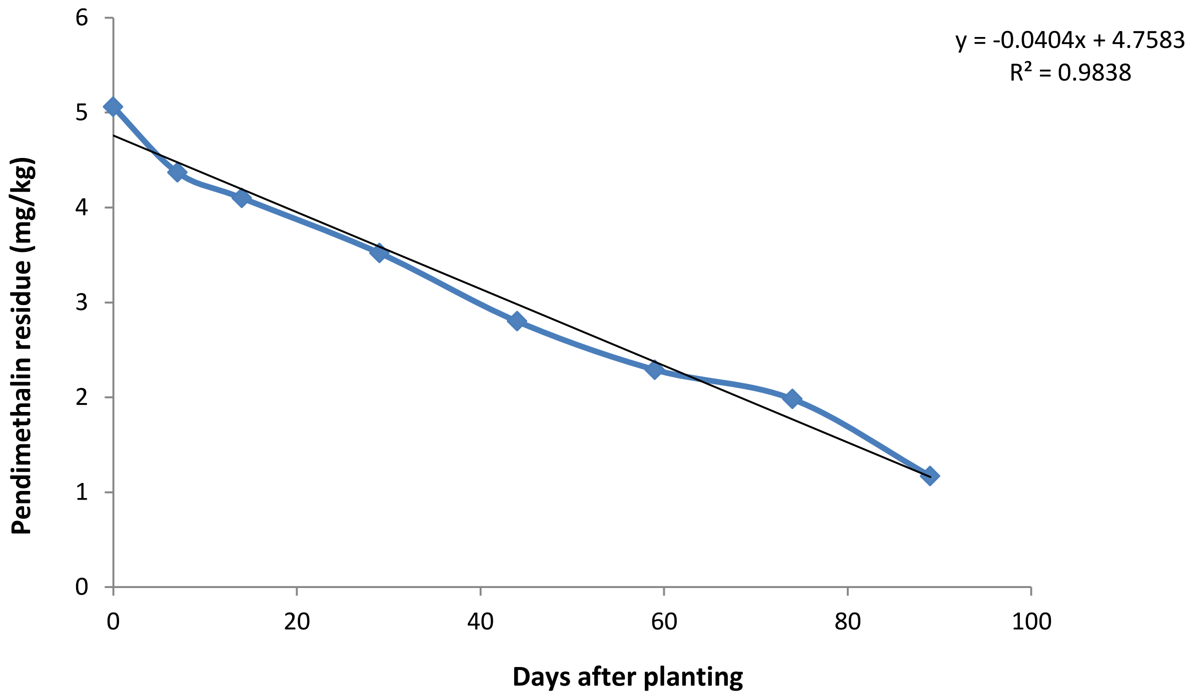


Figure 33: Disappearance of 1.0 l/ha Pendimethalin at LAUTECH FARM IN 2008

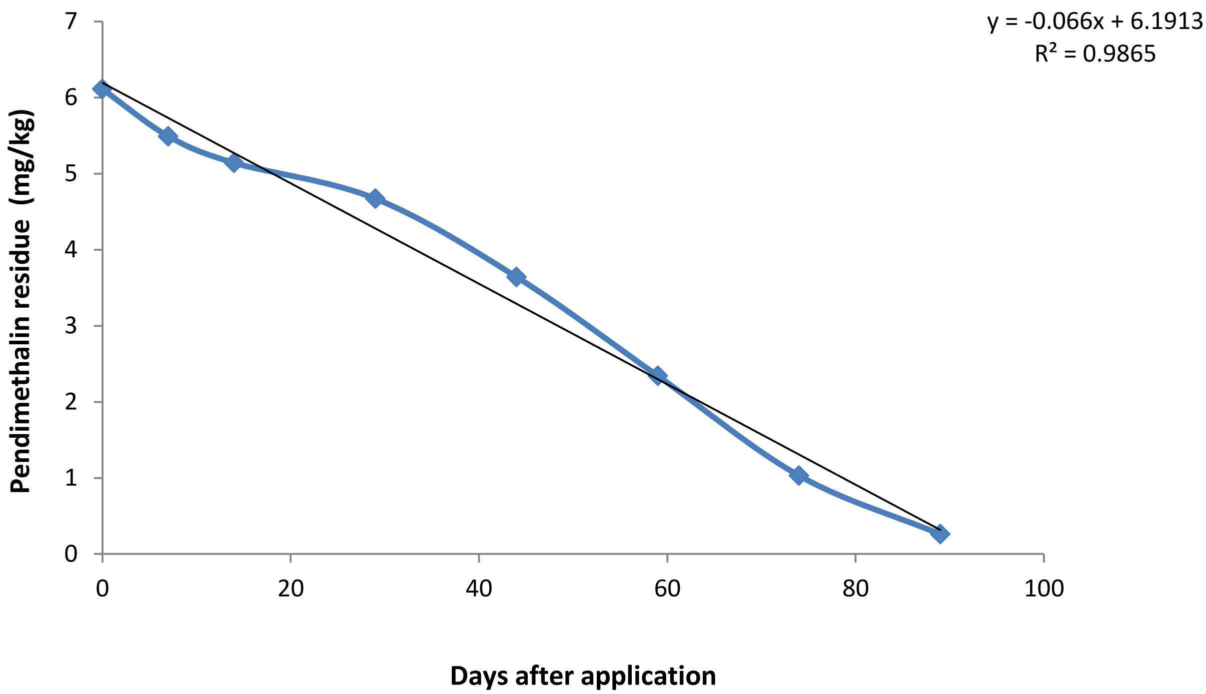


Figure 34: Disappearance of 1.0 l/ha Pendimethalin at Ogbomoso Farm settlement in 2008

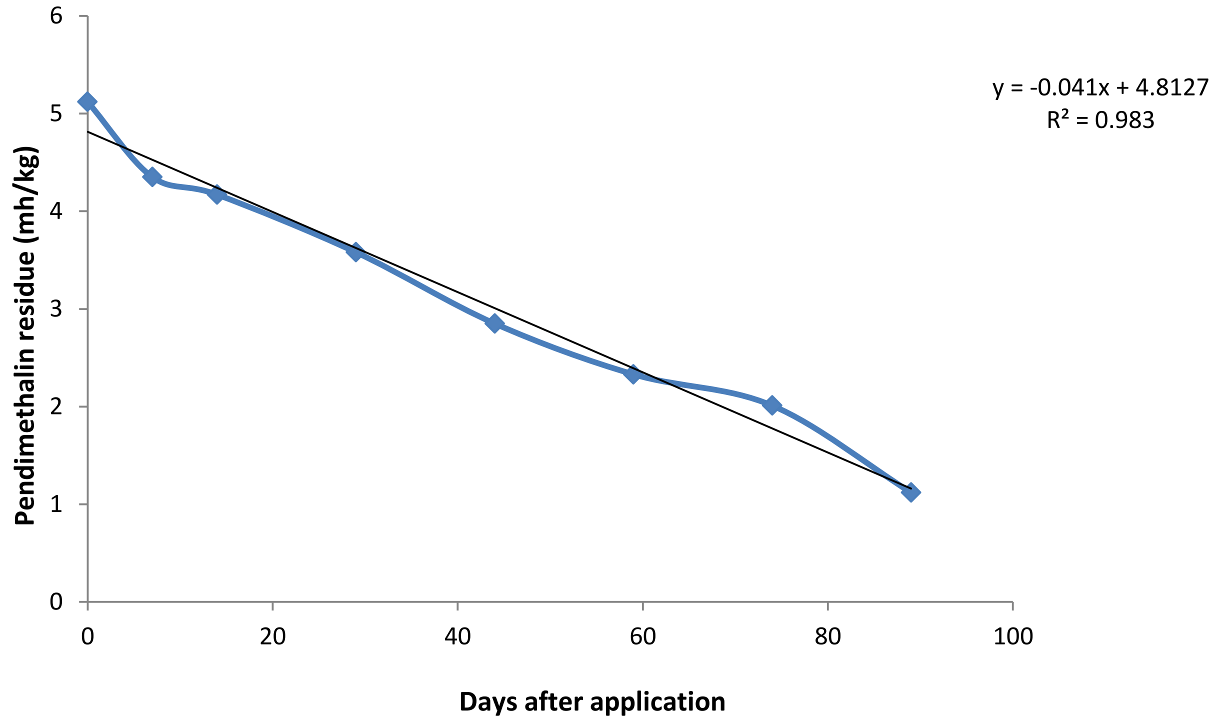


Figure 35: Disappearance of 1.0 l/ha Pendimethalin at LAUTECH Farm in 2009

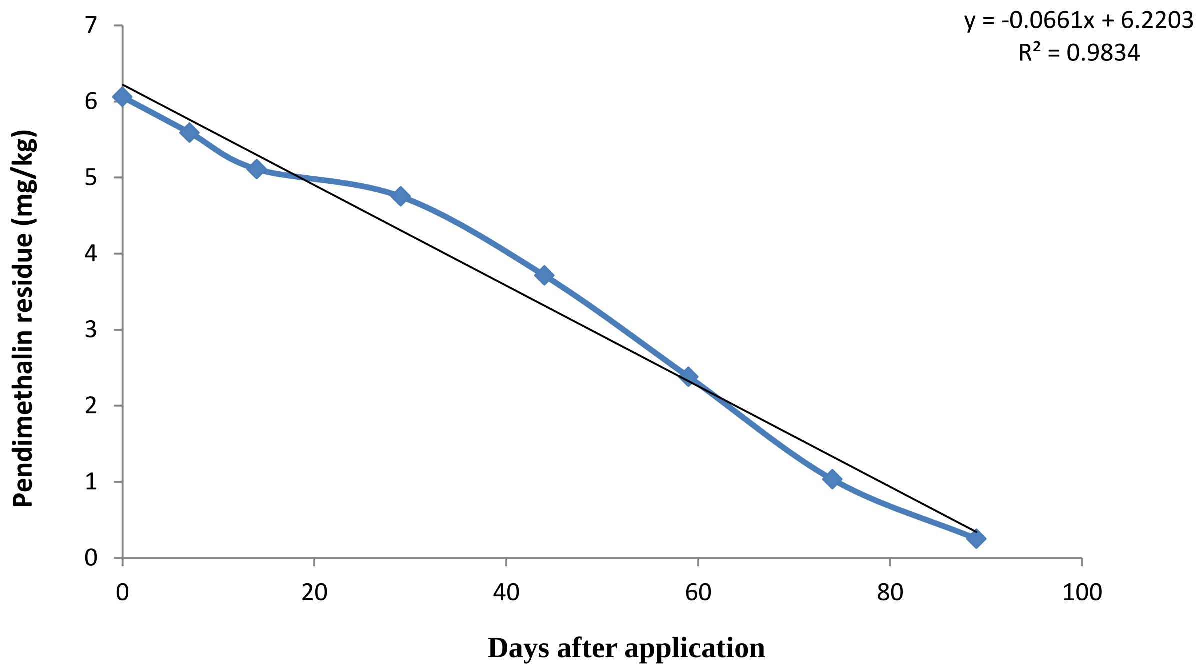


Figure 36: Disappearance of 1.0 l/ha Pendimethalin at Ogbomoso Farm settlement in 2009

Table 38: Monthly weather data of Nigerian Meteorological Agency, Ilorin Airport Meteorological data during the experiment (2008 & 2009)

Date (months)	Temp(°C) Min	max	Mean T (°C)	Relative Humidity (%)	Sunshine (Hrs)	Rainfall (mm)	No of rain days	Pitch Evapo0rimeter
2008								
January	32.9	18.2	25.6	46	7.5	0	nil	12
February	36.1	20.7	28.4	45	5.7	0	nil	12.3
March	36.8	23.5	30.2	72	7.6	20.5	3	8.1
April	33.9	23.5	28.7	76	6.5	106.1	9	5.6
May	33.5	22.9	28.2	76	6.7	42.3	11	5.0
June	31.3	22.1	26.7	69	6.9	241.1	15	3.4
July	29.8	21.8	25.8	87	5.4	318.6	18	2.6
August	28.9	21.7	25.3	89	4.8	226.3	19	2.8
September	30.1	21.7	25.9	88	4.5	270.3	21	2.3
October	32.3	21.8	27.1	83	7.5	224.5	11	3.4
November	34.9	21.3	28.1	75	8.1	4.8	1	7.2
December	38.4	20.8	29.6	68	7.9	14.0	2	7.7
2009								
January	34.2	20.8	27.5	67	7.5	11.1	2	8.1
February	36.3	23.4	29.9	77	7.6	1.2	1	6.9
March	37.0	24.3	30.7	72	7.1	179.5	2	7.7
April	33.5	22.9	28.2	79	7.2	223.9	13	4.9
May	32.8	23.0	27.9	79	7.2	76.0	10	4.1
June	31.3	22.6	27.0	89	6.2	177.0	12	3.4
July	30.0	21.8	25.9	90	4.7	313.4	16	2.7
August	27.3	22.0	24.7	90	3.8	209.1	13	2.4
September	30.5	21.9	26.2	86	2.3	185.7	19	2.3
October	31.4	22.0	26.7	85	5.3	122.8	13	2.7
November	33.4	20.2	26.8	67	7.5	4.4	2	3.7
December	33.2	19.2	26.2	-	-	0	nil	-

4.8 Lethal and sub-lethal toxicity tests

The average daily temperature range under the shade of the woodlot through the duration of the experiment was (22.4 – 28.5^{o}C). The average moisture content of the air-dried soil was 1.47% while the average moisture content of the soil after the experiment was 13.39%. The average pH of the soil was 7.2.

The results from lethal toxicity test of S-metolachlor and Pendimethalin were shown in Table 39. The LC_{50} value of S-metolachlor for *Eisenia fetida* in Contact Filter Paper (CPF-test) test was 1.57 L/ha compared with soil test value of 1.45 L/ha. The LC_{50} of Pendimethalin for *E. fetida* in CPF-test was 1.93 L/ha while the value is 1.77 L/ha for soil test. Based on their respective 95% Confidential interval (CI) around the LC_{50} values, CPF-test indicated relatively higher acute toxicity to *E. fetida* of S-metolachlor and Pendimethalin than the soil test.

The LC_{50} values of S-metolachlor for *Libyodrilus violaceus* in CPF-test was 0.46 L/ha while the soil equivalent was 1.41 L/ha. The CPF-test also showed higher acute toxicity to *L. violaceus* than soil test. Pendimethalin gave a contrary lethal toxicity value with CPF-test (2.56 l/ha) portrayed Pendimethalin as being more toxic in the soil (1.83 L/ha).

The overlapping confidential intervals (CI) for both soil tests and the two earthworms' species indicated that there was no significant difference between the LC_{50} of S-metolachlor and Pendimethalin. *L. violaceus* was more sensitive to S-metolachlor in CPF-test than *E. fetida* comparing their respective LC_{50} values of 0.46 L/ha and 1.57 L/ha. However, *E. fetida* was more acutely affected by Pendimethalin in CPF-test than *L. violaceus* as indicated by their LC_{50} values of 1.93 L/ha and 2.56 L/ha respectively.

All the application rates of both herbicides influenced the growth rates of the two earthworms' species negatively (Table 40). The weight of worms in the control treatments did not change significantly at 7 day of incubation and was always greater than the initial weight, indicating that the experimental conditions were satisfactory. *E. fetida* recorded highest growth rate reduction (0.47) at 1.2 L/ha S-metolachlor and (0.98) at 2.0 L/ha Pendimethalin. *L. violaceus* had 0.49 growth rate reduction at 1.6 L/ha S-metolachlor and 0.5 at 2.0 L/ha Pendimethalin. There was no significant difference ($p \geq 0.05$) in the growth rates reduction of the two earthworms' species in all the concentrations of the two herbicides considering the common chi square values although; there were significant differences when all the rates were compared and the control.

Table 39: Toxicity of S-metolachlor and Pendimethalin to earthworms as determined by two different methods

	LC50 (l/ha) (95% CI)			
	S-METOLACHLOR		PENDIMETHALIN	
Earthworm sp.	CFP-test	Soil-test	CFP- test	Soil-test
E. fetida	1.57 (0.75-1.83)	1.45(1.21-1.70)	1.93(0.39-2.40)	1.77(1.48-2.05)
L. violaceus	0.46 (n/a)	1.41(1.17-1.65)	2.56(n/a)	1.83(1.51-2.16)

CI = Confidence interval.

Table 40: Effect of S-metolachlor and Pendimethalin on the Growth rate (r*) of earthworms in the soil test

Herbicide	Conc. (L/ha)	Earthworm spp. Growth rate (r*) *E. fetida*	Growth rate (r*) *L. violaceus*	% Weight loss *E. fetida*	% Weight loss *L. violaceus*
S-metolachlor	0.8	0.21	0.42	18.5	34.5
	1.2	0.47	-	37.5	-
	1.6	-	0.49	-	39.0
Pendimethalin	1.0	0.16	0.33	13.7	28.1
	1.5	0.5	0.36	35.4	29.9
	2.0	0.98	0.5	62.5	39.4
	2.5	0.34	0.1	11.4	9.4
	3.0	0.63	-	46.7	-
Control	0.0	0.00	0.03	0.3	2.96
χ^2		0.42	0.42		
P		0.23	0.23		

- == Dead earthworm

$$r^* = \log_e \frac{\sum \text{mass day 7}}{\sum \text{mass day 0}}$$

χ^2 = Chi square

P = probability

CHAPTER FIVE

5.0 DISCUSSION

The larger proportion of young men (over 46% were below the active age of 45 years) involved in the agricultural activities is good for the future of farming in the study zone (Ogunsumi, 2005). The older farmers, who will be recalcitrant to adopting new agricultural innovations, were being succeeded by large number of younger ones who will be receptive to new innovations. Only about 12% of the farmers in the zone were illiterate while others acquired variable proportions education from adult education to the tertiary education level. This will definitely ease the work of the extension agent which is evident in the proportion of the active age involved in farming. These people were active in farming activities as over 60% of the farmers interviewed cultivated 9 acres and above. Similarly, greater than 81% of the farmers cultivated both arable and permanent crops, and this is likely to reflect in the consumption of farm inputs such as fertilizers and herbicides.

The large proportions of the farmers received information about herbicides use through extension agent, friends and family, and radio. This is indicated in the over 99% of the respondents that were aware of herbicides' use. This would enhance herbicide usage and more land area put under cultivation. Unfortunately the greater numbers of farmers were not aware of good and current herbicides in the market. The respondents were familiar with 12 herbicides in different groups, and greater percentages of the farmers were familiar with the old and probably persistent ones, some of which have been banned in Nigeria. This is shown by the 78% of the respondents knowing atrazine which is already being labeled in certain parts of the world for restricted use among the pre-emergent herbicides. Pre-emergent ones like Pendimethalin, Diuron, Igran Combi gold and S-metolachlor with relatively brief persistence were hardly known by few farmers. Among the constraints put forward by respondents was the lack of knowledge about some good herbicides. This and the other factors may have contributed to their adherence to the use of old herbicides like gramoxone and atrazine at the expense of good substitute although more expensive and less persistent ones like s-metolachlor, Pendimethalin and glyphosate. Abalu and Yayock (1980) reported that the low rate of agricultural technology adoption was usually due to two main reasons: inappropriateness and limited access to recommended technologies. The farmers need to be regularly put through refresher training by the extension agents. There is the need to further strengthen the socialization of modern technologies into farming systems and practices of subsistence crop production (Ogunyemi, 2000). Despite the constraints and the hazards experienced by the farmers, less than 12% of the respondents used herbicides at least twice or even more per growing season depending on the severity of the weed problem. Ogunsumi (2005) reported that over 51% of the cost incurred on one hectare of maize/cassava production was for weed control. With this, the quantity of herbicides use is likely to increase in the zone considering the number of acres of land cultivated. The attitude of the farmers as they responded to the assertions supported the fact that herbicide-use will continue to increase in the foreseeable future.

The results of the worm cast and soil analyses showed that worm cast has greater potential to support crop production than the ordinary soil from the two sites. The particle size analyses indicated higher silt and clay and less sand in worm cast when compared with the corresponding soil from the two sites. Top soil layer reduce leaching and enhance higher water retention capacity, as well as moderate drainage compared with the soil with high sand and hence poor water retention capacity. The nutrient loss will be higher in ordinary soil compared with worm cast. In the same way, the pH range of the worm cast (6.3-7.4) fell within the recommended range that support crop production in the tropics compared to the slightly acidic nature (6.3-6.9) of the ordinary soil.

Percentage organic carbon, nitrogen, phosphorus and potassium were higher in worm cast compared with the ordinary soil which was very low. Worm casts had been referred to as finely divided peat-like material with excellent structure, porosity, aeration, drainage and moisture holding capacity (Dominguez *et al*., 1997). It has been shown that worm casts will not burn when applied directly to even the most delicate plants. They are very water soluble, making their nutrient immediately available as plant food. Worm casts rival chemical fertilizers in their nutrient composition, providing a concentrated source of calcium, magnesium, nitrogen, phosphates and potash (http://louisvllehydroponics.com/organics.html). Earthworms change the phosphorus into a form that the plant roots can easily absorb. With the worm cast weight recorded in the two sites during the two growing seasons, it can be said that the two sites were moderately fertile. The yield of maize in the two seasons (2008 and 2009) indicated lower yield in 2009 than in 2008 whereas, the worm cast density was higher in 2009 sites than in 2008.This could probably be attributed to burying of the worm cast during the ploughing deep down beyond the root zone of maize which is a shallow feeder.

The two herbicides, S-metolachlor and Pendimethalin moderately supported maize seedling establishment during the two growing seasons of 2008 and 2009 at the two locations. Though, the 100% rates of the two herbicides slightly showed some effect on seedling establishment, the population of the maize seedlings on the plots was far above average. The slight variation in number of leaves at 28 days after planting at the two locations and the two growing seasons supported the fact that the two herbicides at the three rates adequately supported the establishment of the seedlings.

Seedlings of maize were generally not so much affected by the two herbicides except that 100% rate appear to have slightly affected the seedling plant height in the two locations. Stem diameter 4 weeks after planting showed more robust plant vigor for 2008 and 2009 at site A which was observed for OFS during the two growing seasons

The two herbicides adequately controlled the weeds 21DAP at both sites and during the two growing seasons. In 2008, the sites recorded serious weed problem as the weed density of the unsprayed plots (weedy check) indicated. In 2008 at LTRF, the three rates of herbicides used controlled the weed the same way such that at OFS, and LTRF and OFS in 2009, 50% rates recorded a significantly lower weed control than the 75% and 100% rates which were in turn not significantly different in their weed control ability. The 50% rate may be the optimum or most effective dosage.

The weed control assessment eight weeks after herbicides' application revealed that though the weedy check recorded significantly higher weed biomass than the herbicide sprayed plots, the weed control was not so adequate. In 2008, at the sites, the three rates of the herbicides and even the hoe weeded plots gave less than 40% weed control. This suggests that the herbicides might have lost some of their efficacies before 56 DAP. This could be attributed to loss of herbicides from the soil due to adsorption, degradation, leaching, runoff, volatilization, and soil (and related meteorological) characteristics. The lower weed control recorded at 21 and 56 DAP in 2008 at the two sites could be linked to higher number of weed species recorded during this season. The

2009 was a bit better as the herbicides recorded between 40.44% to 69.41% weed control. OFS recorded a worse percentage weed control than LTRF in 2009.

Despite the poor weed control recorded at both sites in 2008, the yield was higher in 2008 than in 2009. This could be due to higher meteorological conditions such as sunshine, rainfall and number of raining days during the duration of the experiment. Hoe weeding recorded higher yield than the herbicides treated plots particularly in 2008. Imoloame *et al*. (2010) reported that although hoe weeding resulted in the highest yield and percentage yield increase over weedy check in sesame, it recorded the highest cost of production per hectare.

The results of worm cast weight taken at 3 months after planting indicate that only the weedy plots gave significantly higher weight than all other plots at both seasons and the two sites. This indicated that the weedy plots which were minimally disturbed by tillage operation showed some earthworm activities. This could be as a result of weediness of the plots providing cover for the earthworms. Edward and Bohlem (1996) reported that although most herbicides are considered to exert little direct impact on earthworms, the reduced weed cover resulting from their application may render the habitats less hospitable to earthworms. Researchers have shown that earthworms are not favoured by tillage, and the greater the intensity and frequency of disturbance, the lower the population density or biomass of earthworms (Gerard and Hay, 1979; Edwards, 1980; Mackay and Kladivko, 1985; Haukka, 1988). Bostrom, (1986) observed that soil compaction caused by agricultural traffic can decrease earthworm population. Paoletti (1999) observed that most large earthworms usually disappear from intensively tilled rural landscape. The haphazard numbers of the three earthworm species, *E. fetida*, *L. terrestris*, and *L. violaceus* encountered on the plots before and after herbicides' treatment, with the surrounding unperturbed vegetation suggests that the herbicides played little or no role in the variations observed in the earthworm population. Edwards and Brown (1982) stated that herbicides tend to have low toxicity for earthworms, but can cause population reduction by decreasing organic matter input and cover from weed plants. The third months after spraying of both seasons of 2008 and 2009 fell within dry season and harmattan period (November) which was presumed to be too dry for earthworm activities. Sims and Gerard (1985) stated that during dry periods, worms are at the resting phase or period of quiescence and remain there until the rain fall and conditions become more favourable which cause the worms to become active again. Earthworms were said to find much better living conditions on grassland than on arable sites (Heyer *et al.*, 2003). Earthworm populations are usually significantly reduced in cropped field relation to pasture or undisturbed lands. Their abundance increased in plots that received disk cultivation or no-tillage treatment. Earthworm abundance doubled in no tillage soybeans as compared with ploughing (Mackay and Kladivko, 1985).

The loss in phytotoxicity and inability of S-metolachlor and Pendimethalin at the recommended rate of 1.6 L/ha and 2.0 L/ha respectively, to control weeds adequately beyond eight weeks after application was due to the low level of the herbicides in the soil at this period. This suggested that the herbicide might have lost some of its efficacy before 56 DAP due to factors such as degradation, leaching, runoff, volatilization and soil (and related meteorological) characteristics.

The meteorological data during the 2008 and 2009 cropping seasons revealed higher temperature, evapo-transpiration, sunshine and rainfall in 2008 than 2009. There are many reports of herbicides and other pesticides dissipating more rapidly in tropical than in temperate climates (Helling, 1997; Racke *et al.,* 1997*;* Laabs *et al.* 2002). This is more likely to be related to higher mean soil temperature in tropical and subtropical areas. Metolachlor is a herbicide for which vapour phase loss can be large during the first 48 h after application, depending on the climatic conditions. S-metolachlor with a vapour pressure of 2.8×10^{-5}mmHg at 25^{o}C and Pendimethalin with vapour pressure of 1.94×10^{-3} Pa at 25^{o}C are likely to have vaporized more during 2008 than 2009.

Health Canada (2004) reported that leaching may occur under conditions of excessive rainfall or irrigation, thus S-metolachlor and Pendimethalin could have been leached seriously during 2008 heavy rain. Such leached chemical no longer contribute to weed control and has lessen persistence in the zone relevant to crop production. S-metolachlor and Pendimethalin were moderately persistent in the ecozone with respective average DT_{50} of 53.4-55.8 and 45.8-57.5. There is direct correlation between persistence and the potential for runoff loss, particularly when the chemical remains within the upper 1 cm of surface soil. Runoff is triggered by rainfall, and the highest pesticide loss occurs during the first major runoff-producing event (Waucope, 1978, Leonard, 1988; 1990). While herbicide transport by runoff represents an important mechanism for potential environmental contamination of surface waters, the process itself generally removes <5% of total applied chemical and for most pesticides, <0.3% (Waucope, 1978).

About 50% of the two herbicides had disappeared at about eight weeks after application. By the 8th week of herbicide application, 1.6 L/ha S-metolachlor gave 37.45% weed control while 2.L/ha Pendimethalin gave 31.45% at LAUTECH farm in 2008. The percentage weed control of less than 45% was recorded for the two herbicides in 2009 at Ogbomoso Farm settlement. The weed control was better in 2009 in which at both plots location 56% to about 70% weed control was recorded.

There was difference in weed control ability of the two herbicides between 3 and 8 weeks after spraying. At the three weeks after spraying when weed density was estimated, more than 75% of the two herbicides remained in the soil while more than 50% of the herbicides have disappeared before the eighth week of the experiment during which the weed biomass was taken. The remaining concentration in the soil from this period was probably not enough to appreciably control the weeds hence the weediness observed at eighth week and the need for a supplementary weeding. The diminishing rate of herbicides in the soil in the zone will definitely translate to yield reduction in maize. The percentage weed control at LTRF was the best in 2009 for the two herbicides and there was corresponding best yield during this year at the site. Generally, 100% (recommended) rates of the two herbicides gave the best percentage yield all over including the hoe weeded plots.

Therefore, earthworms are a standard test species to analyze the impact of a substance on the soil compartment. Testing is always required when substances are applied on soil or when a contamination of soil is possible. Currently, a number of laboratory tests for the assessment of the toxicity of pesticides to earthworms have been described (Stringer and Wright, 1973; 1976; Lord *et al*., 1980; Stenersen, 1981; Bostrom and Lops-Holmin, 1982; Heimbach, 1984; Pizl, 1988), but most of them were found to be unsatisfactory for various reasons. Contact tests in which the test compound is deposited on filter paper over which the test earthworms move (Goats, 1981) are comparatively simple to conduct and their results showed good reproducibility, but they are difficult to interpret and to apply to field practice. Soil testing methods have often used various artificial soil media (Haque and Ebing, 1983), some consisting of completely inert compounds e.g. silica flour (Bouche, 1984). These substances allow a high degree of standardization and reproducibility but still are difficult to relate to field conditions. Thus, if the results of these types of experiments are to be useful for predicting the field situation, natural test medium and conditions and relevant modes of pesticide application should be used in the tests (Pizl, 1988).

The results of these tests indicated as confirmed by others (e.g. Vaclav, 1988) that herbicides are directly toxic to earthworms in contrast to Edwards (1980) who reported that herbicides are not directly toxic to earthworms. The toxicity varied with earthworm species and type of pesticides. Discrepancies between the LC_{50} values obtained by the two test procedures could be due to a number of factors, and it may be concluded that CFP-tests did not reflect the hazards of herbicides to earthworms in soil. The degree of adsorption of the herbicides to natural soil must be considered as well as the possible degradation of herbicides by microorganisms in the non-sterile substrate of the soil test. Earthworms react to herbicides due to an even distribution of sensitive receptors all over the body (Pizl, 1988). Various kinds of behaviour may strongly influence the degree of contact with herbicide such as foraging and escape behavior. In the soil, they may escape into deeper layers and the toxic effect of herbicide on them may be partly reduced. For example, the escape behaviour was demonstrated by some of the earthworms in the soil test in that, the worms that were already acclimatized and remained in the soil for seven days came to the soil surface and some even attached to the lid when the herbicides were sprayed on the soil. This behaviour partly explained the reason for the sparse population of, and lowered activities as indicated by worm cast production by the earthworms recorded in the field studies.

The LC_{50}-test is the most common way of estimating the toxicity of herbicides. However, it is hard to conclude from such mortality test what kind of latent ecological effects a pesticide might have when it is used under field conditions. Sub-lethal effects such as retarded growth or development, lowered fertility, etc. might cause population changes in the field although the animals do not suffer from acute toxicity. Report had it that the herbicide acetochlor caused adverse effect on sperm count and DNA in *E. fetida* (Xiao *et al*., 2006). The growth rate of *E. fetida* measured in this test was high and varied for the two herbicides from 0.16 --0.98 for the period of the test. *L. violaceus* suffered reduced growth rate in the range 0.1 - 0.49 for the two herbicides for the same duration of the study.

L. violaceus suffered less weight lost from the two herbicides than *E. fetida.* This reflects the biological and ecological differences between the earthworms' species. *L. violaceus* can burrow into deep soil layer than *E. fetida* which is coprophagic. Tomlin and Gore (1974) have concluded from the results of their field experiments that population reduction of earthworms was correlated with biomass reduction.

These tests, especially the CFP-test, indicated differences in susceptibility of the two earthworm species to the two herbicides which means that the toxicity of one herbicide cannot be simply extrapolated from one earthworm species to the other.

E. fetida has been suggested by many authors for toxicity testing since it is easy to rear in large numbers (Goats, 1981; Stenersen, 1981; Heimbach, 1985). Since this test, particularly the soil test showed that the results with *E. fetida* are comparable with those obtained with *L. violaceus;*

this earthworm species can also provide solid information about potential toxicity of chemicals to earthworms if studies were conducted on its biology and cultural requirements.

5.1. SUMMARY AND CONCLUSION.

The farmers in Ogbomoso were familiar with herbicide use except that the new and effective, less persistent ones were not much in use as a result of dearth of their supply and information on them. Majority of the farmers in the area used less than recommended rates of the two herbicides (S-metolachlor 1.6L/ha and Pendimethalin, 2.0L/ha).

Worm cast was found to have higher exchangeable cations, exchangeable acidity, pH, and organic carbon with better ratio of sand, silt and clay to support crop production than the soil from which it was produced.

The two herbicides, S-metolachlor and Pendimethalin at their used rates supported maize seed germination and seedling survival with percentage seedling survival in the range of 81.2-96.1.

The higher rates of the two herbicides controlled the weeds effectively up to 3weeks after spraying (48.6-81.8%) but kept diminishing up to 56 days after spraying (less than 45%).

Higher rates of the two herbicides gave optimum yield with higher yield recorded at LTRF in 2008.

Worm cast weight was higher at weedy plots (minimally disturbed and contained plant cover) and surrounding vegetation (undisturbed) than all other plots on the ploughed fields.

Earthworms were not affected by the sprayed chemicals at their rates but by the tillage operation and herbicidal removal of vegetation cover. This was evidenced by the irregular distribution of the sparse population of the worms on the plots and significantly higher and regular population in the vegetation.

About 90% of S-metolachlor and Pendimethalin applied at their respective concentrations disappeared between 80-100 and 94 days respectively. 50% of the respective herbicides on the average disappeared between 53.4 - 55.4 days and 45.8 - 57.2 days and they were said to be moderately persistent. The rate of disappearance decreased with decreasing residue concentration in the soil. The two herbicides were moderately persistent in the zone at the rates applied.

The herbicides were directly toxic to earthworms. The toxicity varied with earthworm species and type of pesticides.

The growth rate of *E. fetida* measured in this test was high and varied for the two herbicides from 0.16 - 0.98 for the period of the test. *L. violaceus* suffered negative growth in the range 0.1 -0.49 for the two herbicides for the same duration of the study.

L. violaceus suffered less weight loss from the two herbicides than *E. fetida.*

5.2. RECOMMENDATIONS.

The extension agents should be empowered to be able to show-case new farm inputs to farmers on regular basis so that they would be abreast of new agricultural innovations.

The farmers need to be regularly put through refresher training by extension agents so as to reduce the major constraints to the use of herbicides.

Worm casts can be collected from fallowed and forest soils, grind and applied directly to crops instead of inorganic fertilizers.

Minimum or zero tillage is recommended so that earthworms will be available to produce casts.

Bare soils or clean cultivation should be avoided as much as possible since bare soil is not conducive for earthworms' activities.

Supplementary weeding may be necessary after eight weeks of S-metolachlor and Pendimethalin application considering their short disappearance time, and the fact that majority of the farmers used less than recommended rates of the two herbicides.

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APPENDIX I

Concentration (mg/kg) of S-metolachlor extracted from the soil at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2008 & 2009)

Application Rate (l/ha)	Days after application								
	0	7	14	29	44	59	74	89	**P***
LTRF 2008									
1.6	**6.31**	5.63	5.28	4.44	3.18	2.57	2.02	**1.26**	**20.0**
1.2	**7.33**	6.31	5.68	5.06	4.37	3.57	2.43	**1.29**	**17.6**
0.8	**5.95**	5.29	5.16	4.60	4.09	3.23	2.17	**1.10**	**18.5**
OFS 2008									
1.6	**7.25**	6.67	6.24	5.75	4.56	3.33	2.56	**1.19**	**16.4**
1.2	**6.53**	5.67	5.24	4.80	4.06	3.46	2.62	**1.11**	**17.0**
0.8	**6.56**	6.06	5.97	5.27	4.37	3.11	2.24	**1.07**	**16.3**
LTRF 2009									
1.6	**6.26**	5.73	5.23	4.51	3.23	2.62	1.98	**1.28**	**20.5**
1.2	**7.27**	6.42	5.63	5.02	4.46	3.63	2.47	**1.29**	**17.7**
0.8	**5.91**	5.39	5.24	4.68	4.16	3.20	2.15	1.12	19.0
OFS 2009									
1.6	**7.29**	6.80	6.35	5.56	4.64	3.39	2.60	**1.23**	**16.9**
1.2	**6.50**	5.76	5.33	4.88	4.13	3.52	2.66	**1.10**	**16.9**
0.8	**6.53**	6.16	6.01	5.37	4.42	3.16	2.27	**1.09**	**16.7**

P* = percentage of herbicide residue

APPENDIX II

Concentration (mg/kg) of Pendimethalin extracted from the soil at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2008& 2009)

Application rate (l/ha)	Days after application								
	0	7	14	29	44	59	74	**89**	**P***
LTRF 2008									
2.0	**7.39**	6.42	5.74	5.06	3.87	2.80	1.27	**0.63**	**8.5**
1.5	**5.37**	4.58	4.24	3.86	3.60	3.14	2.07	**1.31**	**24.4**
1.0	**5.06**	4.37	4.10	3.52	2.80	2.29	1.98	**1.17**	**23.1**
OFS 2008									
2.0	**8.24**	7.13	6.73	6.13	5.00	4.26	2.43	**0.66**	**8.0**
1.5	**6.44**	5.72	5.50	5.05	4.33	3.58	2.18	**0.90**	**14.0**
1.0	**6.11**	5.49	5.14	4.67	3.64	2.34	1.03	**0.26**	**4.3**
LTRF 2009									
2.0	**7.52**	6.53	5.86	5.15	3.93	2.85	1.30	**0.65**	**8.6**
1.5	**5.34**	4.67	4.21	3.93	3.66	3.19	2.13	**1.33**	**25.0**
1.0	**5.12**	4.35	4.17	3.58	2.85	2.33	2.01	**1.12**	**21.9**
OFS 2009									
2.0	**8.20**	7.25	6.85	6.23	5.09	4.13	2.40	**0.67**	**8.1**
1.5	**6.51**	5.83	5.60	5.14	4.40	3.65	2.22	**0.91**	**14.0**
1.0	**6.06**	5.59	5.11	4.75	3.71	2.38	1.03	**0.25**	**4.1**

P* = percentage of final to initial residue

PPENDIX III

Disappearance time (DT) for 10%, 50%, 75%, and 90% of the soil extraction of S-metolachlor from LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) in 2008 and 2009 growing seasons

Rate of S-metolachlor (l/ha)	Disappearance Times (DT) Days							
LTRF 2008	10%	DT_{10}	50%	DT_{50}	75%	DT_{75}	90%	DT_{90}
1.6	0.63	4.6	3.16	51.8	4.73	81.2	5.68	88.9
1.2	0.73	6.6	3.67	52.5	5.5	79.8	6.6	96.2
0.8	0.60	13.10	2.98	57.8	4.46	84.9	5.36	102.9
OFS 2008								
1.6	0.73	11.2	3.63	55.3	5.44	82.6	6.53	99.4
1.2	0.65	11.0	3.27	55.3	4.90	82.6	5.88	98.02
0.8	0.66	15.3	3.28	55.7	4.92	73.5	5.90	98.7
LTRF 2009								
1.6	0.63	10.2	3.13	59.1	4.70	78.4	5.63	91.0
1.2	0.73	10.8	3.64	53.9	5.45	73.5	6.54	97.2
0.8	0.59	14.4	2.96	55.1	4.43	82.2	5.32	98.0
OFS 2009								
1.6	0.73	13.1	3.65	55.2	5.47	81.0	6.51	96.2
1.2	0.65	11.8	3.25	55.3	4.88	83.8	5.88	98.9
0.8	0.65	9.8	3.27	44.8	4.90	66.8	5.88	80.5

APPENDIX IV

Disappearance time (DT) for 10%, 50%, 75%, and 90% of the soil extraction of Pendimethalin at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) in 2008 and 2009 growing seasons

Rate of Pendimethalin (l/ha)	Disappearance Times (DT) Days							
LTRF 2008	10%	DT_{10}	50%	DT_{50}	75%	DT_{75}	90%	DT_{90}
2.0	0.74	8.2	3.70	35.3	5.54	73.5	6.65	80.5
1.5	0.54	11.6	2.69	57.9	4.03	85.9	4.83	103.8
1.0	0.51	11.9	2.53	47.6	3.80	72.8	4.55	87.0
OFS 2008								
2.0	0.82	9.6	4.12	50.8	6.18	77.4	7.42	92.4
1.5	0.64	10.8	3.22	55.6	4.83	81.6	5.80	99.4
1.0	0.61	8.8	3.06	42.4	4.58	71.6	5.50	86.8
LTRF 2009								
2.0	0.75	5.6	3.76	45.5	5.64	72.1	6.77	88.1
1.5	0.53	5.6	2.67	61.2	4.01	88.6	4.81	117.2
1.0	0.51	3.5	2.56	55.1	3.84	87.2	4.61	97.1
OFS 2009								
2.0	0.82	10.1	4.10	51.6	6.15	77.7	7.38	92.6
1.5	0.65	12.4	3.26	55.3	4.88	84.0	5.86	100.1
1.0	0.61	9.10	3.03	48.1	4.55	72.8	5.45	87.5

APPENDIX V

Rate of disappearance at 0-28, 29-56, 57-84, and 85-98 days after soil application of S-metolachlor at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2008 & 2009)

Rate of application	Rates of disappearance			
LTRF 2008	0-28	29-56	57-84	85-98
1.6	4.55	2.90	1.39	0.63
1.2	5.26	3.53	1.58	0.64
0.8	4.50	3.50	1.66	0.85
OFS 2008				
1.6	5.45	3.57	1.78	0.85
1.2	4.88	3.22	1.60	0.78
0.8	5.70	3.30	1.54	0.74
LTRF 2009				
1.6	4.52	2.75	0.98	-
1.2	5.38	3.48	1.6	0.67
0.8	4.58	3.20	1.48	0.72
OFS 2009				
1.6	5.54	3.58	1.72	0.65
1.2	4.87	3.20	1.55	0.73
0.8	5.05	4.55	0.40	-

APPENDIX VI

Rate of disappearance (mg/kg) at 0-28, 29-56, 57-84, and 85-98 days after soil application of Pendimethalin at LAUTECH Teaching and Research Farm (LTRF) and Ogbomoso Farm Settlement (OFS) (2008 & 2009)

Rate of application	Rates of disappearance.			
LTRF 2008	0-28	29-56	57-84	85-98
2.0	4.95	2.68	0.40	-
1.5	5.56	2.75	1.46	0.84
1.0	4.58	2.10	0.66	-
OFS 2008				
2.0	5.88	3.75	1.55	0.80
1.5	4.80	3.15	1.55	0.75
1.0	4.28	2.45	0.64	-
LTRF 2009				
2.0	5.50	3.20	1.60	0.50
1.5	3.95	2.88	1.80	1.26
1.0	3.65	2.75	1.44	0.87
OFS 2009				
2.0	6.20	3.77	1.54	0.44
1.5	4.88	3.22	1.60	0.80
1.0	4.39	2.55	0.87	0.00

APPENDIX V1I

QUESTIONNAIRE

RESEARCH TOPIC

Level of farmers' participation in the use of herbicides in the southern guinea savanna zone of Southwestern Nigeria

INTRODUCTION

The use of herbicides for weed control in the tropics is on the increase following the need to increase food production to meet the ever increasing demand for food. However, the choice of herbicides depends, amongst others, on cost, availability, persistence cropping system, weather, soil types etc. Herbicides should be chosen with caution so as to allow sustained soil productivity as some have been known to be deleterious to soil organisms due to phytotoxicity, persistence etc. Most farmers are illiterate and may not be able to make appropriate selection and use rates, they in most cases rely on blanket recommendation. In order to ascertain the herbicides commonly used by farmers, the rates of application, problems facing herbicide use etc. the following questionnaire was designed to elicit response from farmers and thereby making inferences concerning the issues raised earlier.

1. **AGE**:

How old are you? (Please tick one that approximates your age in years).

25-30yrs:…………………………………………………………………

31-35yrs:………………………………………………………………...

36-40 yrs:………………………………………………………………...

41-44 yrs:……………………………………………………………...

45-49 yrs:……………………………………………………………...

Above 49 yrs:…………………………………………………………...

2. EDUCATION:

What is your level of education? (Please tick one)

Did not attend school …………………………..………………………………

Attended adult education classes………………………………………………..

Attend primary school but did not complete ………………………………...……

Completed primary school…………………………………………………………

Completed modern III…………………...……………………………………….

Did not complete secondary school…………………………………………….

Completed secondary school………………………………………………………..

Tertiary education…………………………………………………………………

Others (Please specify)……………………………………………………………

3. FARMING ACTIVITIES:

In all, how many acres do you farm? ……………………acres.

4. What crops do you grow on your farm?

(a). Food crops cultivated: Maize ( ), Cassava ( ), Cowpea ( ), Yam ( ), Groundnut ( ),

…………….., …………………… , ……………………….

(b). Permanent crops cultivated: Cashew ( ), Cocoa ( ), Kola nut ( ),

Oil palm ( ), Mango ( ),

(c). Any others (Please specify): …………………………………………………..

5. HERBICIDE KNOWLEDGE:

(i). Do you know anything about the use of herbicides? Yes ( ), No ( ). (ii). If yes, where did you learn about it?

(Choose as many as apply).

Extension agents………………………………………………..

Friends and neighbors……………………………………………

Advisory bulletins………………………………………………..

Herbicides dealers and agents…………………………………….

Announcement on radio and television……………………………

Farmer organization………………………………………………

Pages of news papers……………………………………………..

Radio………………………………………………………………

Television…………………………………………………………

6 Which of the following herbicides are you familiar with?

(a). Please tick as many as you are familiar with.

(i) Atrazine…………………………………….

(ii) Lasso/atrazine…………………………….

(iii) Primextra………………………………….

(iv) Round up (Glyphosate)……………………..

(v) Gesaprim……………………………………

(vi) Pendimethalin……………………………….

(vii) Diuron ……………………………………

(viii) Galex………………………………………..

(ix) Igran Combi Gold……………………………..

(x) Basagran……………………………………..

(xi) S-metolachlor (Dual Gold)……………………………………

(xii) Fusilade………………………………………..

(xiii) Gramoxone……………………………………

7 Which crops do you use herbicides to cultivate?

……………………………………………………………………………………

…………………………………………………………………………………….

…………………………………………………………………………………….

8. (i) Do you have problems in obtaining your herbicides? Yes ( ), No ( ).

(ii) If yes, what are the problems?

(1)……………………………………………………………………………

(2)……………………………………………………………………………

(3)……………………………………………………………………………

(4)……………………………………………………………………………

(5)……………………………………………………………………………..

(6)……………………………………………………………………………..

(7)…………………………………………………………………………….

(8)……………………………………………………………………..

(9)…………………………………………………………………….

(10)…………………………………………………………………

9 Please, state those herbicides you use this growing season and their rate of use.

(1)……………………………………………………………………

(2)……………………………………………………………………

(3)……………………………………………………………………

(4)……………………………………………………………………

(5)……………………………………………………………………

(6)……………………………………………………………………

(7)……………………………………………………………………

(8)…………………………………………………………...................

(9)……………………………………………………………………

(10)…………………………………………………………………

10 How often do you use the herbicides? Please tick.

(i). Once in the growing season. ( )

(ii). Twice in the growing season. ( )

(iii). Depending on weed problem. ( )

11. What are the constraints encountered in the use of herbicides? (Please tick as many as apply).

(i) Lack of knowledge about some good herbicides…………………

(ii) Lack of suitable herbicide applicator………………………………

(iii) Irregular supply of herbicides……………………………………..

(iv) Herbicide packs usually too large to handle………………………

(v) The fear of herbicide misuse………………..……………………

(vi) Fear of handling herbicides………………………………………

(vii) Availability of cheap labour relative to herbicide cost…………..

(viii) No money to buy expensive but good herbicide…………………..

(ix) Herbicides require technical know how to use……………………

Cost of herbicide is too high for me……………………………

12. Hazards experience since the adoption of herbicide.

(i) Accidental oral ingestion of the herbicide………………………

(ii) Accidental pouring on the skin or eye…………………………

(iii) Killing of untargeted plants……………………………………..

(iv) Killing of animals……………………………………………….

(v) Other hazards (specify)……………………………………..

13. FARMERS ATTITUDES TO HERBICIDES

Statement	SA	A	U	D	SD
Government subsidy will encourage the use of herbicides.					
Use of herbicides reduces stresses associated with weed control					
Crops cultivated with herbicides are both high yielding and gives more profit					
Adequate information will facilitate the use of herbicide by most farmers					
Herbicides are too dangerous to handle by most farmers					
Herbicides are too costly to give reasonable profit from farm produce					
Undesirable side effects of the use of herbicides discourage most Farmers from its use					

Key:
SA = Strongly agree. D = Disagree

SD = Strongly disagree A = Agree U = Undecided