ABUNDANCE AND DISPERSAL OF THE AFRICAN BLACK BEETLE, (*HETERONYCHUS ARATOR* F.) (COLEOPTERA: SCARABAEIDAE) IN NJOMBE REGION

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EXTENDED ABSTRACT

The invasive African black beetle *Heteronychus arator* F. is a serious pest of crops in Tropical and sub Tropical regions, including East Africa. Literature on ecology of this pest in Sub Saharan Africa is scarce. Abundance and dispersal of *H. arator* were determined in maize fields in Njombe Region, Southern highlands of Tanzania, from December 2013-May 2014. Soil sampling was done monthly to determine larvae abundance of *H. arator.* Similarly adults *H. arator* were collected monthly by hand picking and pitfall traps. Results showed that larvae were present throughout the growing season, with low population at planting and peak period coinciding with optimum soil moisture. The abundance of adults varied with sampling time, high peaks recorded during the onset of rainfall. Abundance of both larvae and adults were significantly ($P < 0.001$) affected by fertilizer type. High populations were observed in farmyard manure. Dispersal of *H. arator* was significantly ($P < 0.001$) affected by fertilizer type. A high number of beetles moved significantly longer distances in bio slurry than farmyard and inorganic fertilizer. The number of beetles significantly decreased with increase in rainfall ($e = -0.011$, $P < 0.001$, Exp $[\beta] = 0.989$). On the contrary, average temperature was positively associated with number of beetles [$e = 0.748$, $P < 0.001$, Exp $(\beta) = 2.11$]. Larval abundance was significantly associated with rainfall [$e = 0.0045$, $P < 0.03$, Exp $(\beta) = 1.004$]. To study damage and control of *H. arator, a* separate experiment was set up with un treated, strip tillage, trap crop and insecticides. Results showed that damage by *H. arator* progressed from seedling to milk stage of maize in all plots. *H. arator* significantly ($P < 0.001$) affected above ground biomass, cob length, seed weight and grain yield but not cob weight of maize. Damage however differed significantly among treatments ($P < 0.001$) and across seasons ($P < 0.001$). Least damage was recorded in insecticide treated plots, and highest in untreated plots. The interaction between control method and time affected damage significantly ($P < 0.001$). The results provide useful input into management of *H. arator* under different fertilizer practices and weather conditions.

DECLARATION

I, MUSSA ABDALLAH, do here by declared to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has neither been submitted nor concurrently being submitted for a degree award in any other institution.

22/09/2016

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The above declaration is confirmed;

22/9/2016

Prof. M.W. Mwatawala Date

(Supervisor)

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DEDICATION

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
AU	African Union
%	Percentage
^0C	Degrees Celsius
cm^3	Centimeter cubic
df	Degrees of freedom
EPINAV	Enhancing Pro-poor Innovation in Natural Resources and Agricultural Value Chains
EPPO	European and Mediterranean Plant Protection Organization
FAO	Food and Agriculture Organization of the United Nations
Fig	Figure
iAGRI	Innovative Agricultural Research Initiative
K_20	Potassium oxide
LSD	Least Significant Difference
Masl	Meters above sea level
Max.	Maximum
MgO	Magnesium oxide
Min.	Minimum
mls	Milliliters
Mt/ha	metric tons per hectare
N	Nitrogen
P_20_5	Phosphorus pentaoxide
P^H	Hydrogen ion concentration
RH	Relative Humidity

S	Sulphur
t/ha	Tonnes per hectare
WEMA	Water Efficient Maize for Africa
Zn	Zinc

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Maize (*Zea mays* L.) is an important crop grown as staple food which serves more than 300 million people in Sub-Saharan Africa where it is grown by small holder farmers. It is one of the most important cereal crops in Africa and the developing world in general. Maize production is estimated at 158 million hectares worldwide. The chief maize producer in the world is the United States while Nigeria is the largest producer in Sub Saharan Africa followed by Tanzania (FAO, 2011).

Maize has become a major staple and cash crop for small scale farmers due to its increasing demand. The crop is most widely cultivated, covering about 45% of the area under annual crop cultivation in Tanzania. The Southern highlands comprising Iringa, Njombe, Ruvuma, Mbeya and Rukwa regions, are chief maize producers in Tanzania. The Regions contribute up to 90% of maize for the national strategic grain reserve (Lyimo, 2005).

Maize production is hindered by biotic and abiotic factors. Insect pests are the most important biotic causes of damage and yield loss in maize crop. Lepidopterans and Coleopterans are the most damaging insects of maize worldwide. These insects attack the crop at various stages from seedling to maturity (Ahad and Bhagat, 2012). *Heteronychus arator* F. is known to be a serious insect pest in maize. In south Africa (its country of origin), *H. arator* causes damage to maize seedlings as they migrate from grass land and attack maize fields (Matthiessen *et al.*, 1997). Generally, losses caused by insects that attack maize in Africa are not well established but are estimated to reach millions metric tonnes, equivalent of million US dollars annually (Ahad and Bhagat, 2012).

1.2 Justification

Maize is the major cereal and most preferred staple food and cash crop in Tanzania (RATES, 2003). Despite of its importance as the main staple food crop in the country, yield is still low. Average yield per hectare is estimated to be 1.2 mt/ha compared to the estimated potential yields of 4–5 mt/ha (WEMA, 2010). Low yield is attributed to several factors, which include crop pests. Maize is attacked by several types of beetles starting right from emergence to physiological maturity (Ahad and Bhagat, 2012).

Heteronychus arator F. is one of the most important pests of maize in the field. This beetle is an extremely devasting insect on maize seedling (EPPO, 1999). *Heteronychus arator* has been reported in many countries Africa, South America and Oceania (EPPO, 1999: Bell *et al.*, 2011). The pest threatens many outdoor crops, and its host range is well documented (King *et al.*, 1981).

Losses inflicted by *H. arator* are also known in some crops. Management of *H. arator* is done using insecticides (Drinkwater, 2002). Much of what is known is confined to Australia and South Africa. Farmers in Njombe region of Tanzania reported serious losses caused by *H. arator* an emerging serious constraint on maize production. However, damage and actual losses have never been quantified. Furthermore, spatial and temporal abundances of the beetle are not known. Dispersal of the beetle in maize fields is yet to be determined in Tanzania. This information is important in designing an economically sound management programme of this insect pest.

1.3 Objectives

1.3.1 Overall objective

To generate information needed in formulating an integrated management of *H. arator*

1.3.2 Specific objectives

i. To determine effects of fertilizer types on abundance and dispersal of *H. arator* in maize fields.

ii. To establish damage and control of *H. arator*.

1.3.3 List of papers

The present Dissertation is based on the following studies (Manuscripts) which will be referred to in the text by the Roman numerals:

PAPER I: Abdallah, M. Mwatawala, M. W. and Kudra, A. B. (2016) Abundance and dispersal of *Heteronychus arator* (Coleoptera: Scarabaeidae) in maize fields under different fertilizer treatments (Published under *Springer Plus*).

PAPER II: M. Abdallah, M.W. Mwatawala, A. B. Kudra, N.A. Urio, and P. W. Mtakwa (2016). Damage and control of the invasive African black beetle (*Heteronychus arator* F) (Coleoptera: Scarabaeidae) in Southern highlands of Tanzania. (Accepted in peer reviewed Scientific Journal as International Journal of Pest Management under Taylor and Francis).

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Geographical distribution of *H. arator*

Heteronychus arator which is indigenous to Africa, is an important pest of maize, sugarcane, potatoes and other cereals in the tropical region (Cackett, 1992; Makaka, 2008). It causes damage by feeding on the roots and tubers. The pest is widely distributed in the Oceania, South America and Africa. In Oceania, the pest is distributed throughout the coastal region of New South Wales, coastal south of Australia, northern Waikato and northern Taranaki (EPPO, 1999). In South America, the pest was reported in Brazil in Santa Catharina and Rio de Janeiro (EPPO, 1999). In Africa, *H. arator* is distributed in eastern, central and southern parts including Tanzania and Kenya. The pest was recently reported to cause high yield losses in maize in Njombe Region Southern Highlands of Tanzania.

2.2 Biology of *H. arator*

Previous studies indicated that all life stages are subterranean, though adults can fly. Adults generally overwinter in free-draining soils (King and Watson, 1982). Most of the overwintering populations can be third-instars larvae (Ortega, 1987). Adults lay eggs singly in soil at a depth of about 10-15 mm (Sidebottom *et al.*, 1998).

Depending upon soil temperature, eggs hatching can take place within 6 weeks. Young larvae feed on soil organic matter, while more mature larvae attack plant roots. There are three larval instars. The final instars burrows to a depth of 100 mm to pupate. In Australia, development from egg-laying to adult emergence takes about three months (King and Watson, 1982). Temperatures above 15°C are most favourable for development and survival of *H. arator* with optimum larval development occurring at 20-25°C (King and Watson, 1982).

2.3 Spatial and temporal abundance of *H. arator*

Populations of *H. arator* tend to be favored by sandy, peaty, or free draining loam sandy soils. Although loamy soil may also be favorable, but the amount of organic matter contained is very crucial (Bell *et al.*, 2011). Larvae and egg development are favored by sandy loam soils with a moisture content of 15-25%. Diagne (2004) reported that choice of habitat and abundance of beetle species may be influenced by organic matter and moisture content of the soil. High level of abundance for many beetles was observed in soil fertilized with organic manures. The deeper burrows were associated with high organic matter content of the soil (Diagne, 2004). However, there is no clear evidence on the effects of manure on abundance of this insect pest.

2.4 Dispersal of *H.arator*

The distribution pattern and abundance are the important biological parameters for insect pest management. King and Watson (1982) reported that dispersal of *H. arator* during autumn and spring potentially plays a crucial role in infesting new pasture during outbreak periods. Under well conserved soil, a large diversity of white grubs species can be established as organic matter consumers (Rincon *et al.*, 1997; Oliveira *et al.*, 2000). Diagne (2004) asserted that organic manure is often overlooked as the important parameter which may affect subterranean behaviour and dispersal of many beetles. The initial flight of *H. arator* is known to be triggered by the first significant rainfall as the adults emerge from pupae (Ortega, 1987). Although *H. arator* affects maize, little is known about factors influencing their dispersal and dispersal mechanisms.

2.5 Signs of damage and loss due to *H. arator*

Heteronychus arator primarily a pest of grass land and pasture. Most of the attacked plants are generally close to grass family such as maize or cereal crops cultivated on land that has recently been under pasture, fallow land or near fallow land since ovipositing beetles prefer weedy fields to locate food for newly hatched larvae. Oviposition usually occurs nearby host trees in which adult beetle prefer to feed (Knodel, 2006). Larvae feed on roots, resulting in wilting, poor absorption of nutrients, crop lodging and stunted plant growth. The stem of attacked plants usually has ragged, teased out appearance. Under severe damage the plant become stunted or may develop multiple tillers (EPPO, 1999). In India, losses of up to 80% have been reported (Makaka, 2008).

The attacks by root feeding insects differ depending on prevailing weather condition of a particular year. In a period of conducive environment, feeding of maize roots by rootworm larvae usually takes several weeks (Ortman and Fitzgerald 1964; Gavloski *et al.*, 1992). Continuous root feeding by larvae for a long period of time may affect compensatory growth (Whitfield, 1992). Severe damage of root system by larvae over a period of time may affect the growth of aerial parts, and grain filling and seed weight. Mechanical root pruning by larvae affect fresh and dry weight, Stalk weight and plant height (Gavloski *et al.*, 1992).

2.6 Field control of *H. arator*

2.6.1 Cultural control

Research on Pasture has shown that the ability of the beetle to survive and reproduce is reduced if grasses such as rye grass and Paspalum are absent in the area. In Australia, Kikuyu and Couch grass areas are excellent reservoir for the beetle. The findings by Oliveira (2000) have indicated that the larvae stage is very sensitive to disturbance.

Therefore, partial suppression of insect numbers might be obtained by cultivation during summer as the larvae are subjected to damage by desiccation since this period in most region is characterized by low moisture levels (Bell *et al.*, 2011). Tillage systems especially during the dry and sun seasons is known to play essential role in population reduction of white grubs in the field. However, to achieve high mortality the depth of larvae localization on the soil at the time of tiling practices should be the key factor (Ortega, 1987). Trap crops such as African marigold (*Tagetes minuta*) and sunflower (*Helianthus annuus* L.) reduced the ability of adult beetles from infesting the main crop grown such as maize (Bell *et al.*, 2011).

2.6.2 Physical control

Light and pitfall traps offer the most useful tools for prediction, monitoring of *H. arator* on the field (Musikavanhu, 1996). Deciduous trees bordering the field usually harbour adult beetles in large quantity i.e. pruning of branches or shaking and killing of beetles could be one way of reducing their numbers for the following season (Sidebottom *et al.*, 1998).

2.6.3 Biological control

Birds such as guinea fowl and chicken can be used to control beetle especially during land preparation which exposes beetle above the ground (Diana and Learmonth, 2001). Matthiessen and Learmonth (1991) reported nematode (*Heterorhabditis zealandica*) native to New South Wales in Australia is used to control *H.arator* in pasture. It is commercially available in Australia for beetle control. However their likely cost and moisture requirement limits their applicability (Diana and Learmonth, 2001). Endophytes are fungus that lives in symbionts with certain pasture grass. However, during black beetle outbreak, the adult deterrence conferred by even the best selected Endophytes may be insufficient to prevent damaging population of larvae from building up (Bell *et al.*, 2011).

2.6.4 Chemical control

In previous years a range of Insecticides has been investigated for their use in controlling *H. arator* in pasture and field crops. Research in Australia recommended the use of Dursban (48 % emulsifiable concentrate of Chlorpyrofos) as effective chemical for control of *H. arator*. Drinkwater (2002) affirmed that in South Africa *H. arator* can be controlled controlled by seed dressing. Some limitation for chemical control includes the age of larvae, soil mobility and pattern of infestation which is usually sporadic. Mature larvae are robust and mobile as they move deeper as they continue to develop thus contact insecticides such as Dursban (48 % EC Chlorpyrofos) could be sprayed to the foliage trees where adults beetles crowd. Similarly in the affected field young larvae can be controlled through soil treatment (Drinkwater, 2002).

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CHAPTER THREE

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Abundance and dispersal of *Heteronychus arator* (Coleoptera: Scarabaeidae) in maize fields under different fertilizer treatments

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3.1 Abstract

The invasive African black beetle *Heteronychus arator* F. is a serious pest of crops in Tropical and sub Tropical regions, including East Africa. Literature on ecology of this pest in Sub Saharan Africa is scarce. Dispersal and abundance of *H. arator* were determined in maize fields in Njombe Region, in the Southern highlands of Tanzania, from December 2013 to May 2014. Adults of *H. arator* were collected monthly by hand picking and pitfall traps. Results showed that larvae were present throughout the growing season, with low population at planting and peak period coinciding with optimum soil moisture. The abundance of adults varied with time, with high peaks recorded in January. Abundance of both larvae and adults were significantly affected by fertilizer type, with high populations in farmyard manure. The type of fertilizer significantly affected dispersal of *H. arator*. A high number of beetles moved significantly longer distances in farmyard and inorganic fertilizer compared to bio slurry a day after release. Abundance of beetles was negatively correlated with rainfall but positively correlated with average temperature, while abundance of larvae was positively correlated with rainfall. The results provide useful input into management of *H. arator* under different fertilizer practices and weather conditions.

Keywords: *Heteronychus arator* Spatial Temporal Fertilizer

3.2 Introduction

The African black beetle *Heteronychus arator* F. is a polyphagous insect attacking a wide range of cultivated crops, with a high preference for pastures (King *et al.,* 1981; Matthiessen *et al.,* 1997). Preferred hosts include potato, (*Solanum tuberosum* L.), maize (Zea *mays* L.), pineapple (*Ananas comosus* (L.) Merr.) and vegetables such as pea (*Pisum sativum* L.) and tomato (*Lycopersicon esculentum* Mill) (Venter and Louw197 8; Smith *et al.,* 1995; Sinclair *et al.,* 1997; Toit *et al.,* 1997; Matthiessen and Learmonth 1998).

Heteronychus arator originated from South Africa (Venter and Louw 1978) and invaded South America and the Oceania. In Africa, *H. arator* has been recorded in Eastern and Southern countries, including Namibia, Zambia, Malawi, Mozambique, Botswana, Democratic Republic of Congo and Tanzania.

Heteronychus arator attacks various crops during various stages of growth, from seedling to maturity (Ahad and Bhagat, 2012). All life stages of *H. arator* are subterranean but adults can fly (King *et al.,* 1981). The larvae feed on soil organic matter, while more mature larvae attack plant roots. Losses of up to 20–30 % of sown maize (Drinkwater, 1987) and up to 70 % of potato (Venter and Louw 1978; Matthiessen and Learmonth, 1995) have been reported. Each adult *H. arator* can attack 2–5 tubers of potato (Matthiessen and Learmonth, 1995). It is a pest of phytosanitary significance and it has caused great losses where it has been introduced. Abundance, dispersal, distribution and damage by *H. arator* are dependent on various ecological factors, including soil temperature, moisture and diseases (King *et al.,* 1981). Temperatures above 15 °C are most favourable for development and survival of *H. arator,* with optimum larval development occurring at 20–25 °C (King *et al.,* 1981). Low temperatures limit larval survival (King and Watson, 1982). Phytophagous insects like *H. arator* are subject to many selective pressures, including the abundance and diversity of plants and their spatial and temporal fluctuations. Knowledge on dispersal and abundance of *H. arator* is limited to the Oceania and South Africa. In other east and central African countries such as Kenya and Uganda the information are lacking. Quantifying dispersal is key to understanding population dynamics of insects and tracking changes in environmental conditions (Roderick and Caldwell, 1992).

Insects' dispersal may be caused by deterioration of habitat, resource depletion, competition or combination of these (Dingle, 2001). Likewise, dispersal may be triggered by food availability, population density or environmental factors such as temperature, humidity and rainfall (Solbreck, 1988). Crops provide a temporal and spatial concentration of resources (Lombaert *et al.*, 2006), which can attract or arrest large number of insects from long distances. A homogeneous crop would provide a high-level of resources to consumers compared to mixed, patchy cropping (Lombaert *et al.,* 2006).

Heteronychus arator is an emerging serious pest of maize in Njombe Region, Tanzania. The pest has not been studied in Tanzania, although farmers have reported high damages. Various control methods have been tested in New Zealand (Potter *et al.*,1996; Ball *et al.,* 1997; Koppenhöfer *et al.,* 2000; Erasmus and Van den Berg 2014).

Farmers who use farmyard manure and bio slurry in maize fields reported high losses due to *H. arator* in Southern highlands of Tanzania. In this study, it was hypothesized that use of manure and bio slurry increased abundance and dispersal of *H. arator* in maize fields. However, this was not determined by research. To understand factors affecting dispersal and abundance of *H. arator* is important before formulating a sound management program. We studied dispersal spatial and temporal abundance of the beetle in patchy maize fields in Southern highlands of Tanzania in relation to fertilizer application.

3.3 Methods

3.3.1 Description of the study area

Experiments were conducted in Njombe and Wanging'ombe Districts, Njombe Region in the Southern highlands of Tanzania. Njombe is one of the major maize producing regions of Tanzania. Four locations were selected, one in Wanging'ombe and three in Njombe district, based on high incidence of *H. arator*. All the locations are characterized by a uni-modal rainfall pattern, with the rainy season starting from November / December to April / May. The area receives an average annual rainfall of 1500mm, while the average temperature is16°C per annum. The locations are described in Table 1.

Table 1: Description of study locations

District	Village	Location	Altitude (m a.s.l)
Wanging'ombe	Nyumbanitu	S09°14.970'; E034°40.822'	1994
Njombe	Nyombo	S09°3.038'; E034°48.845'	1809
	Mtwango	S09°02.697'; E034°48.648'	1800
	Ibumila	S09° 11.595'; E034°8.513'	1840

3.3.2 Larval abundance

The experiment was set in a Randomised Complete Block Design (RCBD) in four locations. The three treatments viz., inorganic fertilizer, bio slurry and farm yard manure (Table 2) were applied in individual plots replicated in three locations. The rates used are those recommended for use in maize. The size of the plot for each treatment was 10 x 5 meters (50 m^2) with 10 m strips between plots and blocks. The land was prepared in late November and sowing of maize variety PAN 691 (PANNAR Seed Co. Ltd) was done in early December 2013. The variety is widely grown by farmers in Njombe due to its ability to tolerate a wide range of disease including maize streak virus and grey leaf spot. A total of 266 plants /50 m^2 were established at a spacing of 75cm x 25cm giving a population of 53 200 plants/ha. All standard agronomic practices such as early weeding were followed in each location.

Table 2: Fertilizer treatments used in the trial

Treatment	Fertilizer type	Content	Application rate	Timing of application
Inorganic fertilizer	Yara Mila cereal	23 % N, 10 % P_2O_5, 5 % K_2O, 5 % MgO, 3 % S, and 0.3 % Zn	526 kg YMC/ha	At planting
	Yara Vera	46 % N	40 kg N/ha	4 weeks after planting
	Yara Mila Java	23 % N, 6 % S	74 kg YMJ/ha	12 weeks After planting
Bio slurry	Bio slurry manure	1.8 % N, 1.5 % P_2O_5, 1.7 % K_2O	8000 kg/ha	At planting
	Bio slurry leachate	1.8 % N, 1.5 % P_2O_5, 1 % K_2O	10 000 L/ha	4 weeks after planting
FYM	Farmyard manure	0.8 % N,0.5 % P_2O_5, 0.7 % K_2O	10 000 kg/ha	At planting

Larval abundance was determined from a soil sample extracted around the roots (20 x 20 x 20cm) of three selected plants in a plot (Ahad and Bhagat 2012). Sampling was done monthly, from December 2013 to May 2014. The larvae in each soil sample were counted and recorded. Mean number of larvae per plot per month were recorded.

3.3.3 Adult abundance and dispersal

Beetles used in this study were collected by hand picking and by trapping every sampling month from January to May 2014. Collection of insects was done in the morning and release was done between 1900 h to 2100 h (Nyundo and Yarro, 2007). Plastic pitfall traps (15 × 13 × 8 cm; length, top diameter, bottom diameter) were used half filled with partially decomposed farmyard manure. Collected insects were kept in semi-transparent plastic boxes (30 cm × 30.5 cm × 25 cm), filled with farmyard manure, germinated maize and beans seedlings as food. The elytra of beetles were marked by triangular notching on posterior end one day before the release as suggested by Guzman *et al.* (2011).

3.3.4 Abundance estimation

A capture - mark-recapture (CMR) study was conducted during the 2013 - 2014 cropping season, in uniformly established maize plots within Ibumila village (Table 1). Three plots of 40 m × 45 m were treated with fertilizers as described in Table 2 and replicated in three locations. Distance between plots was 50 m. A total of 3400 marked beetles were released at each instance for abundance estimation as described by Arakaki *et al.* (2008). Beetles were released in the night (Nyundo and Yarro, 2007) once per month and were recaptured for three consecutive days after each release. Adults were recaptured by hand picking and trapping. Numbers of recaptured beetles were pooled across distance for each plot, each month. We recorded, for each plot, number of released (marked) beetles, number of recaptured beetles and number of unmarked beetles. Lincoln index was used to determine absolute abundance which is the variation of Jolly-Seber (Bancroft, 2005). Where N is the population estimate, M is the number of marked beetles, U is the number of unmarked beetles and R is the number of recapture bugs that were marked. The population estimates depends on the ratio of marked to unmarked beetles that removes bias that might arise due to capture efficiency. To balance the sampling efforts each plot was measured by the total time taken. The effects of distance were corrected by pooling recaptures across distance for each month.

3.3.5 Dispersal estimation

A total of 1800 marked beetles were released once every month, for dispersal estimation. Release and recapture were done from January to May 2014, as described above. Beetles were recaptured at 2, 4, 16, and 32 m radii from the release point. We recorded and compared the number of beetles caught at each radius from the release point.

3.4 Data analysis

General Linear Model was used to analyse abundance and dispersal of beetles using R statistical package. Two-way analysis of variance (ANOVA) was used to analyse abundance of larvae and beetles, with fertilizer and month as factors. Dispersal was analysed by three factors ANOVA, with as fertilizer type, days after release as the sub factor and distance from release point as factors. Post Hoc Tukey Test was used to compare means. Correlation coefficients for adult and larvae counts with selected weather parameters were calculated using Pearson correlation method under SPSS version 16 and evaluated for significance as suggested by Ahad and Bhagat (2012).

3.5 Results

3.5.1 Larvae abundance

Temporal variation in larval abundance in maize plots under different fertilizer treatment is presented in Fig. 1. Two way ANOVA results showed that larval abundance was not significantly affected by fertilizer type ($F_{(2, 54)} = 2.93$, $P < 0.06$) or month $F_{(5, 54)} = 2.29$, $P < 0.058$).

However, the interaction between fertilizer type and month significantly affected abundance of larvae $F_{(10, 554)} = 2.88$, $P < 0.005$). Analysis of simple effects of fertilizers did not show significant variations in larval abundance in December ($F_{(2, 9)} = 1.48$, $P = 0.28$), January ($F_{(2, 9)} = 1.24$, $P = 0.33$), February $F_{(2, 9)} = 0.57$, $P = 0.58$) or March $F_{(2, 9)} = 1.91$, $P = 0.2$). Significant simple effects of fertilizers were observed in April $F_{(2, 9)} = 10.22$, $P = 0.004$) and May $F_{(2, 9)} = 4.98$, $P = 0.035$).

Multiple comparison of means (Tukey, 95 % CI) showed significant differences between bio slurry and farmyard manure ($P = 0.005$), as well as bio slurry and inorganic fertilizer ($P = 0.02$) in April. Farmyard manure and bio slurry were not significantly different ($P = 0.597$). Bio slurry also differed significantly with farmyard manure in May ($P = 0.04$) but not with inorganic fertilizer ($P = 0.088$). Farmyard manure and inorganic fertilizer were not significantly different ($P = 0.85$) in May (Fig. 1). Larvae were highly abundant in farmyard manure treated plots, peaking in March and April (Fig. 1).

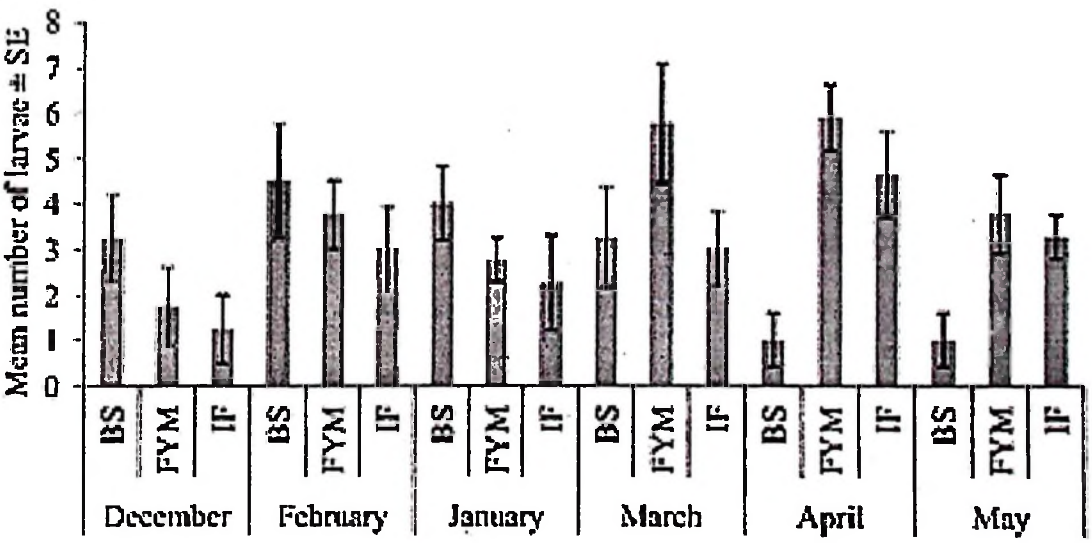

Figure 1: Abundance of larvae of *H. arator* in plots treated with different types of fertilizers

3.5.2 Adults abundance

Figure 2 presents temporal variation in beetles' abundance in maize plots under different fertilizer treatments. The number of collected adults of *H. arator* varied significantly among plots, depending on type of fertilizer ($F_{(2, 30)} = 9.31$, $P < 0.001$), and month ($F_{(4, 30)} = 14.12$, $P < 0.001$). The interaction between fertilizer type and month did not significantly affected beetles' abundance ($F_{(8, 30)} = 1.9$, $P = 0.09$) (Fig. 2). Significant main effects on beetles' abundance were observed among fertilizers ($F_{(2, 6)} = 5.66$, $P = 0.04$) and month ($F_{(4, 10)} = 10.35$, $P = 0.001$). Highest marginal mean (fertilizer effects averaged over months) was recorded in farmyard manure (274 ± 20), followed by bio slurry (196 ± 22) and inorganic fertilizer (130 ± 27). Post Hoc Tukey test (95 % CI) on marginal means revealed significant differences ($P = 0.04$) in beetles abundance between inorganic fertilizer and farmyard manure, but not between inorganic fertilizer and bio slurry ($P = 0.695$) or bio slurry and farmyard manure ($P = 0.11$).

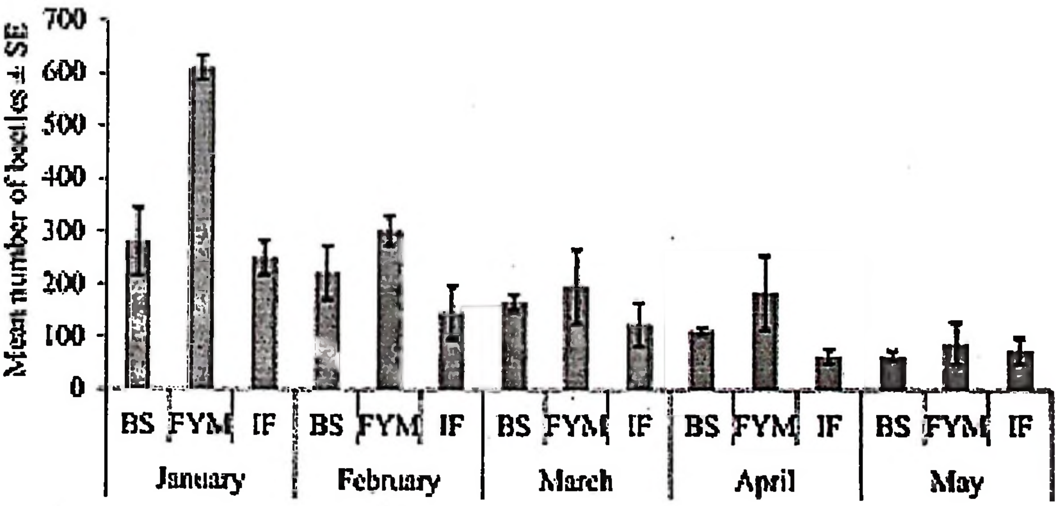

Figure 2: Mean number of adults of *H. arator* in plots treated with different types of fertilizers: (BS: bio slurry, FYM: farmyard manure, IF: Inorganic fertilizer)

3.5.3 Adults dispersal

Distance covered by beetles increased with time since release (Fig. 3). Three factors ANOVA results showed that number of recaptured beetles differed significantly with fertilizer type ($F_{(2, 90)} = 19.22$, $P < 0.001$), distance from point of release ($F_{(4, 90)} = 92.82$, $P < 0.001$) and days since release ($F_{(2, 90)} = 11.92$, $P < 0.001$). The interaction between fertilizer, days since release and distance from release point was also significant ($F_{(16, 90)} = 11.92$, $P < 0.001$). Analysis further showed significant simple interactions between fertilizer and distance from release point, after day 1 $F_{(2, 30)} = 32.5$), day 2 $F_{(2, 30)} = 24.98$, $P = 0.001$) and day 3 ($F_{(2, 30)} = 5.51$, $P = 0.001$) since release. Post hoc Tukey test (95 % CIs) showed that significantly less numbers of beetles were caught in bio slurry plots at longer distances from release point day after release. Significantly more beetles were caught within the release point in farmyard manure and inorganic fertilizer plots, a day after release (Fig. 3).

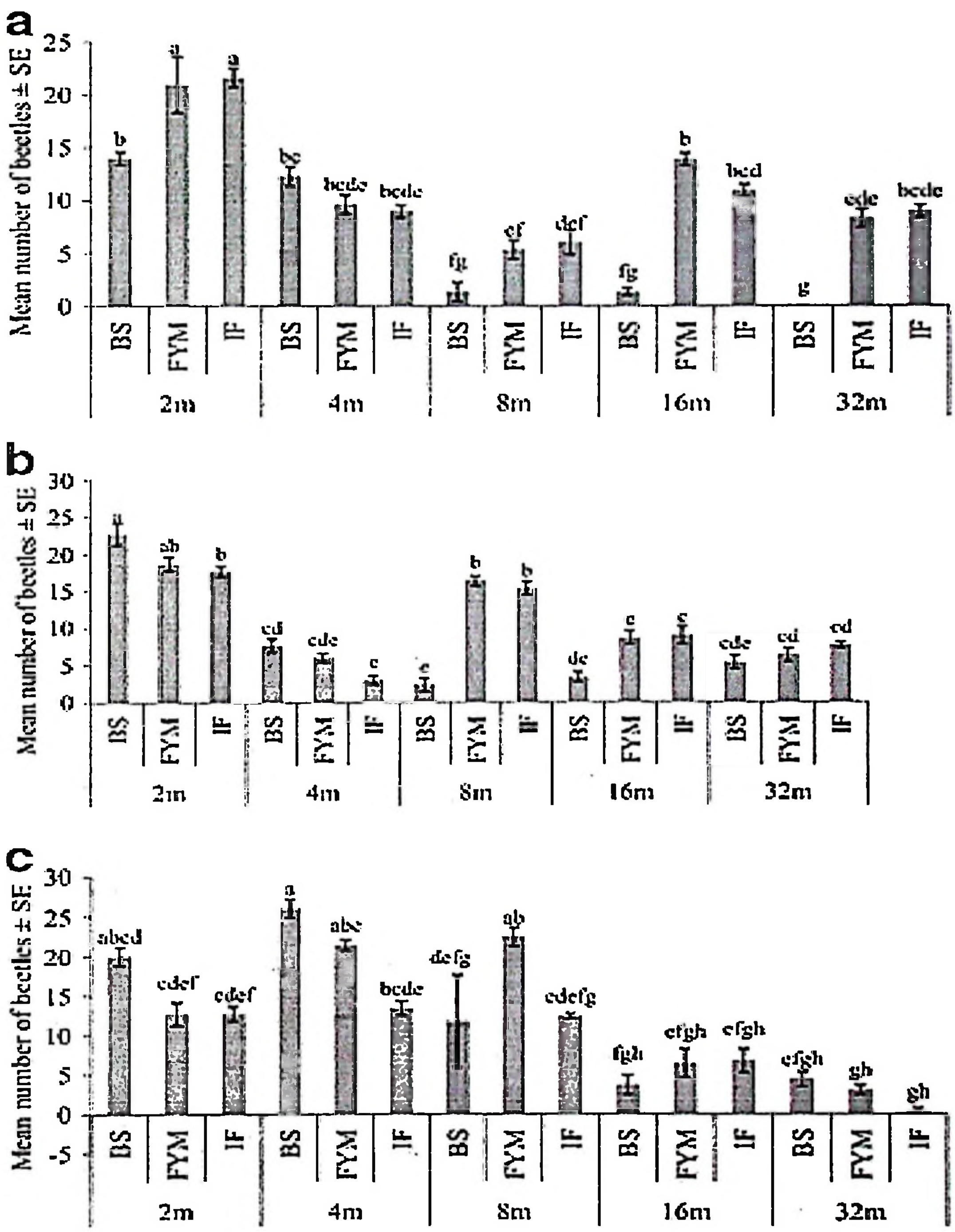

Figure 3: Mean number of beetles caught at various distances from release point in plots under different fertilizer treatments a day after release b 2 days after release c 3 days after release (BS: bio slurry, FYM: farmyard manure, IF: Inorganic fertilizer)

Poisson regression results showed significant associations between rainfall, average temperature and adults abundance (Table 3). The number of beetles significantly decreased with increase in rainfall (e = – 0.011, P < 0.001, Exp [β] = 0.989). On the contrary, average temperature was positively associated with number of beetles [e = 0.748, P < 0.001, Exp (β) = 2.11]. Relative humidity had no significant effect on beetles' abundance (Table 3). Larval abundance was significantly associated with rainfall [e = 0.0045, P < 0.03, Exp (β) = 1.004], but not with relative humidity and average temperature (Table 4).

Table 3: Correlation between adults and weather parameters

Parameter	e	SE	t (*)	Tpr	Exp (β)
RH	0.367	0.204	1.80	0.072	1.444
Rainfall	– 0.01112	0.00218	–5.10	<.001	0.9889
Av temperature	0.748	0.166	4.50	<.001	2.112

Table 4: Correlation between larvae and weather parameters

Parameter	e	SE	t (*)	Tpr	Exp (β)
RH	0.577	0.368	1.57	0.117	1.780
Rainfall	0.00449	0.00207	2.17	0.030	1.004
Av temperature	0.029	0.100	0.29	0.773	1.029

3.6 Discussion

This study presents the abundance and dispersal of the invasive *H. arator* in soils under different fertilizer management. The results revealed dependence of larval and beetles' abundance on fertilizer type. Temporal variations in larval and beetles abundance were also observed, with high numbers in farmyard manure treated plots. Sara *et al.* (2013) suggested that spatial activities of beetles are greatly influenced by change in habitat. Adults and white grubs of green jute beetle were reported to be attracted to the field fertilized with farmyard manure from cow and poultry (Diagne, 2004).

Dispersal of *H. arator* from the release point increased with time. Schumann and Vidal (2012) reported that dispersal of the Western Corn Borer larvae increased as they developed and the larvae moved off their original place of emergence and into deeper soil layers. Ross and Ostlie (1990) reported mean dispersal distance *Ostrinia nubilalis* (Hübner) increased linearly with time. Glogoza *et al.* (1998) observed a positive association between the probability of finding *Phyllophaga implicita* (Horn) (Coleoptera: Scarabaeidae) and the distance from the food source.

Results from the current study showed that temperature, and rainfall played a major role on temporal abundance of *H. arator*. Ahad and Bhagat (2012) reported that the population of larvae (white grubs) is determined by rainfall and soil moisture. East *et al.* (1981) reported that black maize beetle was a persistent problem during favourable environmental conditions such as rainfall, temperature, relative humidity and good soil types. Soil moisture also plays a significant role in burrowing depth of *H. arator*, with deeper burrows associated with high level of soil moisture. Further, both organic matter and soil moisture were reported to influence the selection of habitat for burrowing and oviposition by many beetles (Diagne, 2004). The abundance of adults was positively correlated with temperature, but negatively, correlated with rainfall. On other hand, the abundance for larvae was positively correlated with rainfall but not temperature and relative humidity. Temperature may be a key driver for spatial and temporal abundance of arthropods (Kearns and Stevenson, 2012). Survival and growth rate of *H. arator* are favoured by high temperature and rainfall, as most physiological responses could be triggered by the change in temperature (King and Watson, 1982). The influence of temperature on population dynamics of *H. arator* might be modified by other factors such as soil types, level of soil moisture, crop composition and management practices (East *et al.*, 1981). According to East *et al.* (1981) adults *of H. arator* can undergo extensive dispersal flights due to high mobility imposed for oviposition during dry season. Diagne (2004) pointed out that during the periods of mating the adults tend to avoid hard soils with little organic matter content and concentrate in areas with soft soils which are rich in organic matter, and this biological behaviour has influence on the extent of beetles dispersal. Early flights appear to be initiated by the first rainfall, as adults emerge from pupae (Bell *et al.*, 2011).

3.7 Conclusion and Recommendation

This study provided the basic information for *H. arator* on maize, in trials done in one season cycle. Abundance of black maize beetle is dependent on type of fertilizer as well as climatic factors, notably rainfall, relative humidity and temperature. Timely application of fertilizer is necessary to ensure growth of strong plants that can withstand attacks by the pest. Future multi seasonal studies are recommended.

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CHAPTER FOUR

4.0 Damage and control of the invasive African black beetle (*Heteronychus arator* F.) (Coleoptera: Scarabaeidae) in Southern highlands of Tanzania.

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4.1 Abstract

The African black beetle, *Heteronychus arator* F. is an invasive and a serious pest of maize distributed in Africa, South America and Oceania. Few studies on management of *H. arator* have been conducted in various parts of the globe. However, limited information on the pest is available from Sub-Saharan Africa, including Tanzania. Experiments were set up in Njombe Region, Southern highland of Tanzania, in 2013/2014 to evaluate effects of insecticide application, intercropping and strip tillage on reducing populations of *H. arator*. Treatments were laid in Complete Randomised Block Design replicated in three locations. According to results, damage by *H. arator* progressed from seedling to milk stage of maize in all plots. *Heteronychus arator* significantly ($P < 0.001$) affected above ground biomass, cob length, seed weight and grain yield but not cob weight of maize. Results also showed that percentage damage varied significantly among treatments ($P < 0.001$) and across locations ($P < 0.001$). Least damage was recorded in insecticide treated plots, while being highest in untreated control plots. The interaction between control method and time affected percentage damage significantly ($P < 0.001$). Highest damage was recorded in May, in untreated control plots. These results suggest sustainable integration of strip tillage, intercropping and insecticides for managing *H. arator*.

Key words: Maize damage, phenology, Sun flower, strip tillage, *Heteronychus arator*

4.2 Introduction

The African black beetle *Heteronychus arator* F. is a serious pest of maize in the field (EPPO, 1999; Sidebottom *et al.*, 1998). Destructive stages are both larvae and adults. The root-feeding larva is the most damaging stage. The outbreak of *H. arator* is caused by above average temperatures and availability of favourable food resources in the field. Adults usually migrate from grassland and can be damaging to maize (*Zea mays* L.) seedlings (Toit *et al.*, 1997; EPPO, 1999). However, adult outbreaks are sporadic in certain nuclear fields where they migrate from grassland. Warm (spring) temperatures encourage population increase, while wet conditions are unfavourable for early instar larval survival (Gerard *et al.*, 2013). African black beetle populations and damage are usually greatest on crops grown soils rich in organic matter content (Eden *et al.*, 2011). The successive loss in crop yield by *H. arator* can occur within a single year due to high fecundity rate of the beetle.

The attacks by root feeding insects differ depending on prevailing weather condition of a particular year. For example feeding of maize by rootworm *Diabotrica virgifera* (Le Conte) larvae usually takes several weeks in conducive environment (Ortman and Fitzgerald 1964; Gavloski *et al.*, 1992). Continuous feeding of roots by insects' larvae for a long period of time may affect compensatory growth of a crop (Whitfield, 1992). Similarly root damage affects fresh and dry stalk weight and plant height (Gavloski *et al.*, 1992). Management techniques of *H. arator* have been tested within limited scales and geographies. Insecticides fensulfothion and isazophos were reported to be effective and higher levels of control were achieved on moist organic peat soil than on drier mineral sand and clay soils (Blank *et al.*, 1982). Performance of insecticide however depends on season of application (Matthiessen and Learmonth, 1995). Biological control, on other hand, has not been very successful. Sutherland and Greenfield, 1978; Russell *et al.* (1982)

pointed out the potentials of using feeding deterrents, such leguminous plants. Similarly crop rotation and avoidance may work well in reducing insect pest populations. According to Ratnadass *et al.* (2012) plant species diversity in agro ecosystems can reduce the impact of pests and diseases through resource dilution and stimuli-deterrent diversion for pests; disruption of the spatial cycle and conservation of natural enemies.

Heteronychus arator is a serious constraint to maize production in many parts of Tanzania. Maize is the most important staple grain in Tanzania, accounting for about 70% of total cereal production (United Republic of Tanzania, 2012). Unfortunately maize yield has been declining due to, among other things, pests like *H. arator.* The Southern highlands of Tanzania comprising of regions of Iringa, Njombe, Ruvuma, Mbeya and Rukwa regions, are chief maize producers in Tanzania (Lyimo, 2005). Unfortunately these regions are infested by *H. arator.* High losses have been reported from Njombe region. However damage and actual losses due to *H. arator* have never been quantified. Furthermore, effective methods for controlling this insect pest have not been determined, and these were the main focus of this study.

4.3 Material and Methods

Control methods against *H. arator* were evaluated in Ibumila village ($09^0$11.595′S, and $034^0$85′E, 1840 masl) Njombe district, in the Southern highlands of Tanzania, from November 2013 to July 2014. The area receives up to 1600mm of rainfall per annum. The study area is characterised by sandy clay loam soil, with low pH (acidic), exchangeable potassium and phosphorous. Rainy season starts from early December to April. Land was prepared in late November and sowing of maize variety PAN 691 (PANNAR Seed Co. Ltd) was done in early December 2013. The variety is widely grown by farmers in Njombe due to its ability to perform better under high rainfall and tolerate a wide range of disease including maize streak virus and grey leaf spot. The sunflower crop was planted three weeks after the maize. The planting spacing of 75cm x 25cm was used for both maize and sunflower. Standard agronomic practices were carried out uniformly on all plots. These practices include land preparation, sowing, thinning and weeding.

4.3.1 Experimental design

The experiment was set up in a Randomised Complete Block Design (RCBD). Four farmers' fields, at least 1.5 km apart from each other, were selected. Each field was divided into plots of 5 m x 16 m. The plots were prepared in late November and maize variety PAN 691 (PANNAR Seed Co. Ltd) was sown in early December 2013, at a spacing of 75cm x 25cm. Each plot consisted of 21 rows of 5 m long, giving a total of 426 plants/80m^2 (53250 plants/ha. The effects of intercropping, strip tillage and insecticide application on suppressing the population of *H. arator* were tested. Maize, in each plot, was either (1) intercropped with sunflower (*Helianthus. annuus*, (variety Tumaini), at 2:1 pattern and a spacing of 75cm x 25cm inter row and intra row respectively (2) planted in a strip of 10cm wide, 30cm deep, at similar spacing as above or (3) sprayed with an insecticide Dursban (Chlorpyrofos 480 EC) at a rate of one litre product per hactare (Cackett, 1994; Musikavanhu, 1996). The insecticide was applied once at planting repeated after sixty days. One plot was left untreated in each location. Damage by *H. arator* was assessed visually by examining damage symptoms on the leaves and falling plants in a five 1m^2 quadrant in a plot (Diana 2001; Ahad and Baghat, 2012). The number and percent of plants damaged by *H. arator* was recorded. Damage was assessed every month starting from seedling to grain filling stage. The effect of damage on yield was assessed by determining weight of above ground biomass, cob length, cob weight, weight of seed and grain yield in tone per ha. The cobs were shelled to determine cob length and grain weight.

4.4 Data Analysis

Percentage damage was arcsine transformed (Alan *et al*., 2001) and then subjected to two - way analysis of variance (ANOVA) with control method being main factor and time being the sub factor. Data were analysed using Genstat 15 th edition version 15.1 (VSN International Ltd., UK). Furthermore, the effect of control method on each yield parameter was analyzed and the responses were compared across variables using the formula; Percentage loss reduction in relation to control method (%) = $T_I - T_0 / T_I * 100$ %. Where T_I and yield T_O be the mean yields for respective control method and untreated respectively (Oleveira *et al.*, 2000).

4.5 Results

4.5.1 Damage assessment

The results showed that larval damage was significantly different among treatments ($P< 0.001$, n= 4, df = 2, $LSD_{0.05}$= 0.039,) and across time ($P < 0.001$, n= 6, df = 5, LSD $_{0.05}$= 0.048). Similarly the interaction between treatment and time significantly affected larval damage ($p< 0.001$, df = 15, LSD $_{0.05}$= 0.096). Damage was lowest in insecticide treated plots and highest in untreated control. Damage increased with time, a gradual increase was observed in a period of February and March for untreated, strip tillage and trap crop. More damage was observed during the month of April and May for all treatments (Figure 1). Plates 1 and 2 shows mass collection of *H. arator* larvae and their damage on maize crop fields. Young larvae feed on plant roots (Plate 3) showing signs of damage on above ground plant parts. Tables 1 and 2 summarize the effects of larvae on maize yield. *Heteronychus arator* significantly affected above ground biomass ($P< 0.001$, n = 4, df = 3, $LSD_{0.05}$ = 1.640), cob length ($P < 0.001$, n = 4, df = 3, $LSD_{0.05}$ = 1.021), one thousand seeds weight ($P < 0.001$, n = 4, df = 2, $LSD_{0.05}$ = 1.640) as well as grain yield

Plate : Larvae (White grubs) responsible for causing damage

Plate : Effects of larvae damage on maize (a) Early damage symptoms (b) Severe damage symptoms

Plate : Root pruning by *H. arator* larvae

(P < 0.001, n = 4, df = 3, $LSD_{0.05}$ = 0.026). However, cob weight did not vary significantly among treatments (P = 0.001, n = 4, df = 3, LSD $_{0.05}$ = 0.808). Biomass, cob length per plant, cob weight, seed weight and total grain yield were generally higher in insecticide treated and intercropped maize. The percentage loss reduction was higher in insecticide treated maize than strip crop, and trap crop treated maize (Figure 1).

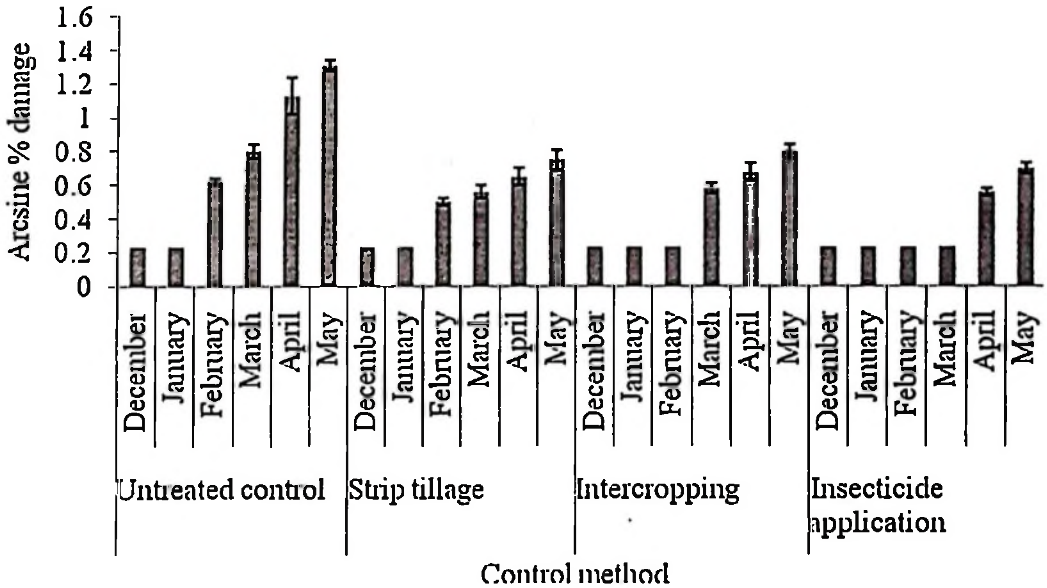

Figure 1: Mean damage by larvae for each control method across time

Table 1: Yield response of maize to larvae damage for each control method

Treatments	Biomass /4m^2 (kg)	Cob length /Plant (cm)	Cob weight /4m^2 (kg)	Thousand seed weight (kg)	Grain yield tone/ha
Un treated	$14.58^{c} \pm 0.300$	$14.75^{c} \pm 1.443$	$11.23^{c} \pm 0.335$	$0.244^{c} \pm 0.004$	$0.62^{d} \pm 0.010$
Strip tillage	$17.7^{b} \pm 0.388$	$15.5^{c} \pm 0.382$	$12.28^{bc} \pm 0.139$	$0.32^{b} \pm 0.003$	$0.86^{c} \pm 0.016$
Trap crop	$18.82^{b} \pm 0.348$	$17.01^{b} \pm 0.277$	$12.97^{ab} \pm 0.157$	$0.35^{b} \pm 0.029$	$0.91^{b} \pm 0.019$
Insecticides	$30.4^{a} \pm 0.622$	$19.58^{a} \pm 0.221$	$13.91^{a} \pm 0.177$	$0.49^{a} \pm 0.008$	$1.28^{a} \pm 0.015$
LSD ($_{0.05}$)	1.640	1.021	0.808	1.640	0.026
P	<.001	<.001	0.001	<.001	<.001
CV (%)	12	9	11	12	26

Means bearing the same letter within columns (superscripts) do not differ significantly (Tukey test: $P \leq 0.05$)

Table 2: Percentage (%) yield reduction as a result of larvae damage in three treatments

Parameters	Percentage (%) yield reduction in relation to control		
	Insecticides	Strip tillage	Trap crop
Biomass /4m^2 (kg)	52%	18%	23%
Cob length (cm)	25%	05%	13%
Cob weight (kg)	19%	09%	13%
Thousand seed weight (kg)	50%	24%	30%
Grain yield (tone/ha)	53%	28%	32%

Damage also varied significantly among treatments and phenological stages of maize. Damage was significantly higher in untreated plots compared to plots under control ($p<0.001$, $n = 4$, $df = 3$, $LSD_{0.05} = 0.046$). Damage differed significantly across phenological stages ($p < 0.001$, $n = 6$, $df = 5$, $LSD_{0.05} = 0.0563$). The interaction between control methods and phenological stages had significant effect on damage ($p<0.001$, $df = 2$, $LSD_{0.05} = 0.1127$). Damage increased from seedling stage, through vegetative stage, silk stage, to grain filling across all treatments (Figure 2). A gradual increase in damage was observed in intercropped and strip cropped maize, from flowering to milk stage. Increase of damage was noted from blister to grain filling stages.

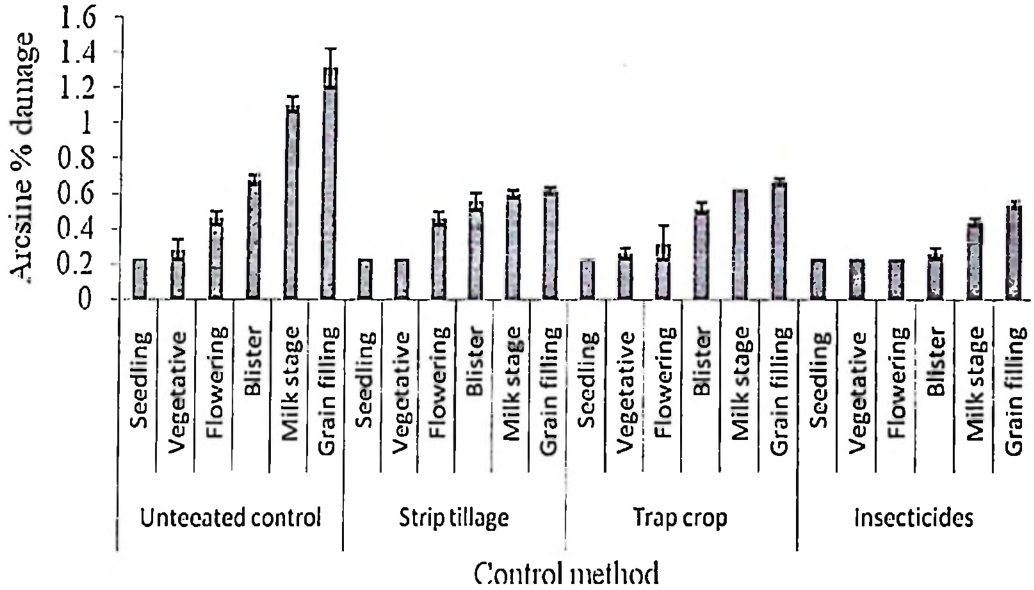

Figure 2: Mean damage at different phenological stages of maize

4.6 Discussion

Results of this study indicated that suitable control measures for *H. arator* are available. Insecticide application, intercropping and strip tillage reduced damage due to *H. arator* at varying levels. Insecticide application targeting early instars larvae has been reported to be effective (Cackett, 1992; Bell *et al.*, 2011; Taylor and Drinkwater, 2002). Fensulfothion and isazophos reduced larval population by 88% at 2 kg/ha, and 73% at i kg/ha rates (Blank *et al.* 1982). In some cases, the percentage of plants damaged by the beetle was a better criterion than the numbers of beetles killed. The best results in South Africa were obtained with carbosulfan EC, isazofos G, phoxim G and terbufos G (Drinkwater, 1987). Lindane and chlorpyrifos gave outstanding control of *H. arator* beetles on maize in South Africa when applied to the soil surface as a corrective measure after plant emergence (Drinkwater, 1982). Therefore, synchronization of the most susceptible larvae stage and insecticide application is necessary. The increase in maize damage from April to May observed in this study is probably due to degradation of pesticide used and population build up of the pest. The main limitation of Chlorpyrofos is that it degrades rapidly in sunlight.

The damage was lower in intercropped maize than in the control maize. Intercropping improve soil cover and reduce soil disturbance. The population growth of *H. arator* larvae was greater on rye grass (*Lolium perenne*) and paspalum (*Paspalum dilatatum*) than on white clover (*Trifolium repens*). The reduced growth of *H. arator* on T. repens was attributed to low consumption, probably due to the presence of feeding deterrents in the roots (King *et al.,* 1981). Rabary *et al.* (2011) reported decreased *H. arator* populations in rice (*Oryzae sativa*) and fodder radish *Raphanus sativus.* A compact (less disturbed soil) is a barrier to movement of larvae (Strnad and Bergman, 1987). Consequently, the survival of larvae is low in compact soils (Brown and Gange, 1990). Stinner and House (1990) reported a 43% decrease in the number of species and damage caused to crop with reduced soil management operations. On the contrary, mortality of larvae could be due to mechanical injury and exposure to adverse biotic (e.g. predators) and abiotic (sunshine) stresses after tillage operations. Studies by Oliveira *et al.* (2000) indicated that the effect of soil tillage on *H. arator* larvae was related to the depth reached by the equipment and the localization of larvae in the area. Strip cropping is a component of conservation agriculture, aiming at conserving soil and water by reducing run off, evaporation and erosion. Farmers in Tanzania use conservation agriculture with the aims of achieving viable and sustainable productivity According to Głowacka (2014), strip cropping as a component of conservation agriculture significantly increases maize yield and the percentage share of ears in the total biomass. Moreover, conservation agriculture practices such as strip cropping, also help to conserve natural enemies of plant pests and increase the diversity of flora and fauna in a form of habitat management. According to Landis *et al.* (2000), many agro ecosystems are unfavourable environments for natural enemies due to high levels of disturbance. Conservation agriculture facilitates habitat management by providing resources such as food for adult natural enemies, alternative prey or hosts, and shelter from adverse conditions (Landis *et al.* 2000). Furthermore, strip cropping modifies soil microclimate, nutrients conservation and moisture retention, which will then influence pest behaviour and plant growth.

According to Trenbath (1993), the presence of non-host plants in the intercropped plots can lead to attack escape in three ways; (i) the non-host plants cause plants of the attacked component to be less good hosts (ii) they (non-host plants) interfere directly with the activities of the pest and (iii) they (non-host plants) change the environment in the intercropped plots so that natural enemies of the attacker are favoured. According to the resource concentration hypothesis, the non-host plants may mask the effects of herbivore's host finding stimuli (visual and chemical) so that the colonization of the host plant is lower. Mono cropped plants are more visible than they would be in the natural ecosystems or in the systems based on intercrops (Feeny, 1976). Consequently, phytophagous insects are more likely to find and remain on host plants, growing in dense, nearly pure stands because the second plant species disrupts the ability of insects to efficiently attack their intended host (Asman *et al.*, 2001). The present study did not record natural enemies of *H. arator*. This study showed that the damage varies with the stage of maize growth, with the least damage at seedling and vegetative stages, and the highest damage during fertilization stage prior to grain filling stage. Early instar larvae were observed from December and January during this study. Such larvae preferred to feed on soil organic matter and organic manure, while late instars and adults attacked subterranean parts of the maize plants and grass. This reinforces previous findings by Abdallah *et al.* (2016) that in Tanzania larvae are the most damaging stage attacking maize. This contrast with maize grown in temperate regions where adult attack maize is the bigger problem (de Klerk, 2015; Matthiessen *et al.,* 1995).The occurrences of other insect pests of maize during this study were sporadic and minor.

4.7 Conclusion and Recommendation

Since the control methods applied in this study differed in their effects on yield, by affecting yield components. Therefore, the study concludes that a strip tillage system, intercropping and insecticides (Chlorpyrifos 480 EC) application should be integrated in controlling *H. arator*. Further studies should be conducted to test effects of intercropping maize e.g. with other crops. Good agronomic practices such as early planting, proper fertilization regime and proper weeding with additional of adult monitoring should also be tested for control and reduce damage by *H. arator.*

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CHAPTER FIVE

5.0 Conclusions and Recommendations

5.1 Conclusions

An understanding of pest biology such as their abundance and dispersal is important for developing an effective and sustainable pest management program which is economically viable. This study provide information that could be used as a sound base for selecting appropriate decision making in designing integrated control programme for African black beetle *Heteronychus arator* F. Weekly and monthly population are the useful source of information for various practices need to be carried out to reduce population build up and damage caused by this particular insect pest.

This study generated the basic information for *H. arator* on maize, in trials done in one season cycle. Abundance of black maize beetle is dependent on type of fertilizer as well as climatic factors, notably rainfall, relative humidity and temperature. Timely application of fertilizer is necessary to ensure growth of strong plants that can withstand attacks by the pest.

Despite the fact that the control methods employed in this study differed in their effects on yield, and yield component. The study concludes that a strip tillage system of strip of 10cm wide, 30cm deep, maize and sunflower, intercropping and insecticides application particularly Chlorpyrifos 480 EC at a rate of one litre product/ha should be integrated in controlling *H. arator*. This attempt to control should also consider larvae growth stage, climatic factors and timely application of fertilizer.

5.2 Recommendations

Since the trial for abundance and dispersal of *H.arator* were conducted within one cropping cycle, therefore Future multi seasonal studies are recommended to have more elaborative conclusion.

Although dursban has shown promising result in controlling of *H. arator* in this study, a substitute for this insecticide should be sought since it has been associated with health hazards especially among children. Further studies should be conducted to test effects of intercropping maize e.g. with other crops. This would provide a wide scale on choosing the IPM package in controlling *H. arator*.

Generally for the current situation and short term solution, the integration of trap crop, strip tillage using full protocol of zero tillage and insecticides with good agronomic practices such as early planting, proper fertilization regime and proper weeding with additional adult monitoring will be best practice for farmers as can ensure reasonable maize yields and also help to reduce beetles population at the same time as contribution to the long term reduction in population and damage.

APPENDIX

Appendix 1: Insect Capture - Recaptured data sheet

Month:...................................

Fertilizer type:..........................

Number of Beetles collected					
Distance	Total insect captured	Total insects marked	Total recaptured	Total Unmarked	Total insect captured
2m					
4m					
8m					
16m					
32m					
Total in a Plot					
Lincoln (N)					