African Journal of Agricultural Research

Volume 11 Number 13 31 March 2016
ISSN 1991-637X

Academic Journals

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Vol. 11(13), pp. 1110-1119, 31 March, 2016
DOI: 10.5897/AJAR2015.10381
Article Number: B44257C57812
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Seasonal challenges and opportunities for smallholder farmers in a mining district of Zambia

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Received 2 September, 2015; Accepted 12 November, 2015

Zambia's efforts to diversify from mining to agriculture have seen many interventions aimed at improving the productivity of smallholder farmers. These efforts have produced poor results, as productivity has remained low. This study used 121 semi structured interviews, two focus group discussions and several key informant interviews to investigate smallholder farmers' challenges over the course of a farming season, focusing on the main farming operations during different phases of the farming cycle. Results show that labour shortages during land preparation and weeding; and limited access to mineral fertilizer and hybrid seed constrain most households (83%) ability to increase total cultivated land. All the households engaged in rain-fed maize (*Zea mays*) production, while only 33% produced irrigated crops. The over dominance of maize production was a response to the opportunity provided by state subsidization of inputs and maize pricing, as well as the liberal macro-economic environment. Post-harvest losses due to pests were reported by 42.1% of the respondents; 25% cited high transport costs while 25% lamented the low market prices for farm produce immediately after harvest as important challenges. Proximity to an international border and an atmosphere that encourage private sector investment and cross border trade were important opportunities for the famers to sell off their production. Additionally, being in a relatively highly populated mining district provided local market opportunities not available to farmers in rural areas. It is concluded that understanding of challenges and opportunities over the course of a farming season would aid development actors in designing and implementing appropriate interventions.

Key words: Agricultural productivity, weeding, markets, rain-fed, farming inputs, Mufulira.

INTRODUCTION

The Southern African country of Zambia is renowned for its large copper deposits. Upon its attainment of independence from Britain in 1964, the country embarked on a very ambitious socialist development agenda

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financed by copper rents. The government formulated and implemented highly interventionist agricultural policies aimed at increasing the productivity of smallholder farmers, as well as increasing their sales and agricultural incomes. State interventions in the agricultural sector were mostly focused on maize (*Zea mays*) and included the provision of producer subsidies for maize seed and mineral fertilizers; the setting of pan territorial floor prices, and marketing of maize grain.

In the mid-1970s, the price of copper on the world market collapsed. During the same period, the price of oil on the world market quadrupled. Between 1974 and 1985, gross domestic product (GDP) growth rate averaged only 1% per annum, which was well below the population growth rate of 3.3% (Saasa, 1996). Zambia experienced an economic depression which the state tried to offset by borrowing heavily from international lenders, but only worked to push the country into a debt crisis. After several false starts, the state finally agreed to implement the International Monetary Fund’s Structural Adjustment Programme (SAP) in l989. SAP was premised on neo-liberal principles of a free market economy and hence *inter alia* demanded the removal of agricultural subsidies and privatisation of national parastatal companies.

Privatisation of mining parastatals led to retrenchments of mine workers and the collapse of many business firms that had been dependent on mining activities. The region hardest hit was the Copperbelt Province of Zambia, whose local economy was highly dependent on the economic health of the mines. With thousands of job losses, the residents of the Copperbelt province suffered. Poverty increased as households lost their stable incomes, and smallholder farmers’ production drastically reduced due to the abrupt removal of agricultural subsidies. Zambia’s real per capita GDP declined by more than 20%, between 1991 and 1995 (IMF, 1999). As a way of mitigating the adverse effects of SAP, several interventions were planned and aimed at diversifying away from mining into the agricultural sector. It was envisaged that by helping smallholder farmers-who now included former mine workers and their families improve their productivity, they could reduce household food insecurity, and poverty; and also make the Copperbelt economy less vulnerable to the vagaries of copper mining. Smallholder agriculture thus became a focal point for many development actors who employed diverse strategies and approaches but all with similar goals. Most approaches focused on the improvement of smallholder agricultural productivity and production through increased use of modern agricultural technologies. The state focused on provision of hybrid maize seed and mineral fertilizers to smallholder farmers through a nationwide subsidy programme known as the Farmer Input Support Programme (FISP). Smallholder farmers that were beneficiaries of FISP received a package of 200 kg of mineral fertilizer and 10 kg hybrid maize seed. This is sufficient for half a hectare and is expected to result in maize yield of 3 tons ha^{-1}. Public expenditure on FISP is large. In 2007, the FISP accounted for 35 to 60% of the overall public budget to Agriculture (Xu et al., 2009). Jayne et al. (2007: 6) reported figures of 63 and 80% in 2004 and 2005, respectively of agricultural ministry expenditure on FISP.

Significant resources and efforts have been expended on the smallholder farming sector as a means to improve its productivity and concomitantly reduce household food insecurity and poverty. These resources and efforts have been expended on interventions that are focused on improving smallholder farmers’ access to agricultural technologies, while FISP also links smallholder farmers to markets through the purchase of maize by the state. Despite all these efforts, smallholder farmers’ productivity has remained low (Scott, 2011; Nguleka, 2014) and their poverty levels remained high (Jayne et al., 2011). Low adoption levels of agricultural technologies that technocrats espouse as having the ability to greatly increase agricultural productivity seem to point to a complexity of factors mediating smallholder farming households’ low productivity. The technology focused approaches to agricultural productivity improvements ignore the local micro environments and wider structural challenges that characterise smallholder farmers’ environments.

The persistent challenge of low agricultural productivity and related challenges associated with smallholder farming households needs to be investigated so as to draw out lessons that could be useful for addressing the said challenges. Thus, this study had two objectives: To (i) explore what smallholder farming households consider to be salient challenges and opportunities that characterize their main farming operations over the course of an entire farming season; (2) investigate how wider macro-economic policies, the bio-physical environment and socio-cultural institutions influence smallholder farming households’ challenges and opportunities. The study finds that smallholder farmers’ challenges over the course of a farming season are interlinked and the constraints at any given phase of the farming cycle mediate the actions the farmers take at other phases later in the season. The larger macro-policy environment and location provide market opportunities and spur the production of rain-fed maize and irrigated crops. Access to resources at household level and wider structural challenges and opportunities must be considered in the design of agricultural interventions for smallholder farming households.

METHODOLOGY

Overview of the study area

The study was conducted in Mufulira District, one of the mining districts in the Copperbelt province of Zambia. The study sites were

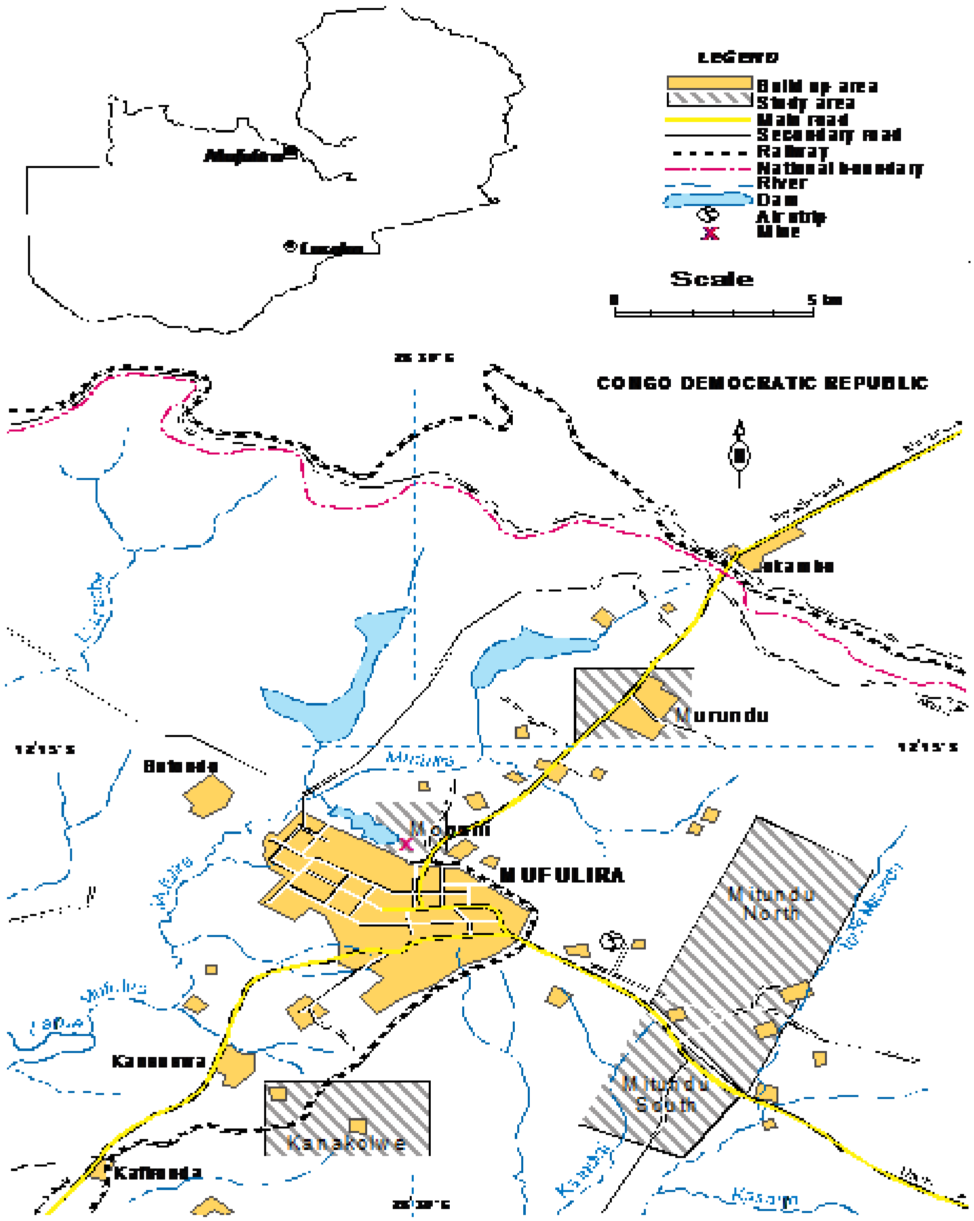

Figure 1. Map showing the location of Mufulira district and the study areas.

Mupena, Murundu, Mitundu and Kanakolwe areas (Figure 1). The district borders the Democratic Republic of Congo in the north, and is well connected to other districts in the province by road. The district's population was projected to be 183,268 in 2014 based on the 2010 National census results; and has a population density at 98.7 persons per Km^2 (Central Statistical Office (CSO), 2013). This is much higher than the national average population density of 17.3 persons per km^2. The district is located in the agro-ecological region that receives uni-modal seasonal rainfall of 1200 mm and above annually, has a crop growing season of 190 days and low probability of drought and cooler temperatures during the growing season (GRZ, 2002). Agricultural activities are common in its urban environs and dominant in the peri-urban areas, predominantly smallholder crop production. Smallholder crop production - which is mostly rain fed - is focused on crops such as maize, cassava (*Manihot esculenta*), groundnuts (*Arachis hypogaea*), sweet potatoes (*Ipomea batatas*), common beans (*Phaseolus vulgaris*), pumpkins (*cucurbitaceae spp*), and other cucurbits.

Research strategy and data collection tools

Fieldwork for this study was carried out between June and August 2014. Quantitative and qualitative research strategies were employed. A quantitative research strategy emphasizes quantification in the collection and analysis of data and embodies a view of social reality as an external, objective reality (Bryman, 2012). Conversely, Creswell (1998) observed that a qualitative research strategy emphasized the multiple dimensions of a problem or issue and displayed them in all of their complexity, including the ways in which individuals interpreted their social world. The quantitative strategy was used for conducting a household survey during which data was collected from a sample of 121 households in the study area on variables such as input use, tillage systems, crop and livestock production, challenges faced in farming, and associations with farming organizations and development agents. The 121 households were selected on the basis of their participation in a recent agricultural development project.

A qualitative strategy was employed to obtain in-depth and contextual information on aspects such as land tenure, and roles of development actors (both state and non-state) who were identified to be significant local players. In this vein, key informant interviews and focus group discussions (FDGs) were conducted. The key informant interviews were conducted with eight agricultural experts, three local political and business leaders, and four longtime residents known to have knowledge and experience on the research topic and study area. Two FGDs, each comprising ten women and men smallholder farmers were conducted. Combining many data collection tools is fruitful as it makes it possible to examine the same phenomena from different perspectives.

Data analysis

Thematic analysis was used to systematically examine the answers to each question from the household survey for themes. Categories were created to include the whole range of answers given to each question by all the respondents. Each response was then examined and placed in the relevant category. The qualitative data software QDA Miner 3.2 (Provalis Research, 2009) was employed to come up with categories. Frequencies and percentages were then calculated for each category, to determine how common certain views were. The FGDs - which had been recorded using digital recorders, were transcribed. The focus group discussants and key informant views were incorporated into the results and discussion section.

Literature review

Smallholder farmers in Sub-Saharan Africa face many challenges. The per capita growth rate of agricultural Gross Domestic Product (GDP) was negative during the 1980s and 1990s, though improvements have been noted since 2000 (Denning et al., 2009). The challenges are due to a multitude of factors which range from bio-physical (Mpandeli and Maponya, 2014), socio-cultural, economic and institutional to macro-policy environments. Given the great diversity among smallholder farming environments, the concomitant variations in agricultural systems and practices mean that various groups of factors interact in a myriad ways. Despite the diversity, smallholder farming systems are characterized by some common features and common challenges. Depletion of soil fertility, along with the related problems of weeds, pests, and diseases, is a major bio-physical cause of low per capita food production in Africa (Sanchez, 2002).

Although African soils present inherent difficulties for agriculture; analysts generally agree that a fundamental contributing factor has been the failure by most farmers to intensify agricultural production in a manner that maintains soil fertility (Morris et al., 2007).

Dependence by smallholder farmers on erratic rainfall under a patchy mosaic of agro climates and the vagaries of weather has prevented Sub-Saharan Africa (SSA) from experiencing the Green Revolution (Eicher, 1995; Enete and Amusa, 2010) and climate change poses a considerable challenge (Arslan et al., 2015). The projected combined impacts of climate change and population growth suggest an alarming increase in water scarcity for many African countries. This will curtail the ability of irrigated agriculture to respond to the expanding food requirements of tomorrow's Africa and much greater emphasis will have to be given to increasing the productivity of global rain-fed agriculture which currently provides 60% of the world's food (Cooper et al., 2008).

The seasonal nature of agricultural production causes peaks and troughs in labour utilization on the farm, and creates food insecurity due to the mismatch between uneven farm income streams and continuous consumption requirements (Ellis, 1999). Lean season or hunger periods, which are periods of severe food shortages and low consumption levels, are common (Norton et al., 2005). Low levels of mechanization (Nkamleu et al., 2003); minimal use of external inputs such as hybrid seed, mineral fertilizer, and herbicides; high transport costs and inadequate institutional support have precluded productivity increases (Denning et al., 2009; Mpandeli and Maponya, 2014). Evenson and Gollin (2003) noted that although large numbers of high yielding crop varieties were released in SSA in the 1960s and 1970s, adoption by farmers was low, and yield growth made only minor contributions to production growth. They attributed this in part to the agro-ecological complexities of the region and a lack of irrigation facilities. Generally, performance of irrigation projects has been disappointing globally (Valipour, 2014) and SSA is not an exception.

Poor infrastructure and related high transport costs (for both inputs and surplus production), inadequate institutional support (Enete and Amusa, 2010), slow development of input and output markets (Binswanger-Mkhize, 2009), political instability, price shocks and limited financing options (Fan et al, 2013), diverse agro-ecological complexities (Diouf 1989), low fertilizer use, and the limited availability of suitable high yielding varieties and other modern technologies have all contributed to low agricultural productivity growth in Africa. In 2002, fertilizer nutrient consumption in SSA was estimated at 8 kg ha^{-1}, much lower than other developing regions (Morris et al, 2007:2). Dependence on simple manual tools for performing major farming operations leads to drudgery (Ezeibe et al, 2015), low yields and low incomes, and perpetuates low productivity. Collier and Dercon (2014) summarized the smallholder African agriculture as a vast and only slowly changing number of poor smallholders contributing most of agricultural output, with low yields, limited commercialization, few signs of rapid productivity growth, and population–land ratios that are not declining.

From the late 1960s to the 1980s, many governments in SSA actively intervened in the agricultural sector in an effort to increase agricultural productivity. Strategies employed were varied and included state farms and irrigation programmes, collectivization, direct fertilizer subsidies and other agricultural input credit programmes (Denning et al., 2009) and output market pricing (Holmen, 2005; Banful, 2011). Other development actors such as international development organizations and international research organizations employed various development interventions to address the low agricultural productivity with a lot of enthusiasm about their benefits. However, agricultural technologies that had performed excellently on research stations were poorly adopted by farmers and failed to address farmer constraints. More commonly the lack of uptake occurred because farmers were constrained in resources, such that investment in a new technology not only influenced what must be done in one field, but involved trade-offs with other activities from which the farmers generated their livelihoods (Giller et al., 2009).

After the generally dismal performance of most agricultural interventions in SSA in the recent past, it has been recognized that incorporation of farmers' perspectives is critical. Smallholder farmers have an intimate knowledge of local soil and climate, often accumulated over generations that give them an advantage in tailoring management to local conditions and the flexibility to quickly adjust management decisions to site, seasonal and market conditions (Deininger and Byerlee, 2012). Incorporation of farmer perspectives in agricultural technology development has been espoused to contribute to the development of technologies suited to diverse environments in which smallholder farmers operate. This study therefore focused on investigating smallholder farmers' interpretation of their main constraints and opportunities during the main phases of the farming cycle. The phases considered over the course of a farming season were land preparation, sowing and fertilizer application, weeding, harvesting, post-harvest storage and marketing.

RESULTS AND DISCUSSION

Results from the semi-structured interviews showed that all the 121 respondents utilized hand held hoes as their main farming implement during tillage and weeding operations. The main tillage systems used in the area are ridges and flat culture. Being manual systems, both require high labour inputs which are mostly supplied by household members. About 60% complained about the high labour requirements for weeding and complained that they found weeding especially challenging as it has to be done within a short period characterized by many days of heavy rainfall which occasionally prevents them from working. Labour shortages during critical farming operations are a pervasive feature of smallholder farming in SSA. Ezeibe et al. (2015) reported labour shortages and drudgery experienced by smallholder cassava farmers in Nigeria. As observed by Nyamangara et al. (2014), labour limitations, especially for weeding, and low levels of mechanization for both land preparation and weeding have been reported to lead to a reduction in the area under cultivation by up to 50% in SSA. All the households interviewed produced rain fed maize while about 69% produced groundnuts (Table 1).

Maize production had a clear dominance and was cited to have the most challenges. When asked about crop production challenges, all the respondents gave responses related to maize production. The most cited challenge was the inability to access sufficient quantities of mineral fertilizers for their maize production (84.3%). This was either due to the quantities accessible through the state subsidy programme FISP being inadequate (10%) or their inability to access the subsidized inputs due to failure to meet their contribution towards the subsidized inputs (11%). Smallholder farmers contributed ZMW 100 (USD 16) for every 50 kg bag of mineral fertilizer accessed through FISP and received a free 10 kg bag of hybrid maize seed. In theory, each smallholder household with a member belonging to a registered farmer cooperative and cultivating up to 5 hectares can access 4 × 50 kg bags of mineral fertilizer and 10 kg of free seed. The fertilizer allocation must constitute two basal dressing (N: P_2O: K_20, 10:20:10) and two top dressing (46% N) bags of mineral fertilizer. In practice, not all qualified smallholder farmers are able to obtain them and even then not in the quantities stipulated. According to the agricultural officers in the district, the demand for FISP inputs outstrips the supply; The District Agricultural Committee allocates FISP packs to agricultural camps based on the number of farmer cooperatives in each camp. During the 2013/2014 farming season, 7837 FISP packs were received from central government. These comprised 7140 maize, 480 sorghum, and 217 groundnut packs. The district had a total of 440 registered cooperatives among which these packs were shared. The criteria for registering a farmer cooperative with the Ministry of Agriculture are: (i) cooperative must be located in a designated agricultural camp, (ii) cooperative must have a minimum of ten (10) members, and (iii) be registered as a business entity.

Other than being inadequate, the FISP inputs were delivered late as complained by 61% of the respondents. They narrated that the maize seeds and basal fertilizers where delivered several weeks after the first opportunity

Table 1. Rain fed and irrigated crop production in the study area.

Rain fed crops	Percentage of household producing crop n=121	Irrigated crop	Percentage of household producing crop n=121
Maize	100	Tomatoes	24.8
Groundnuts	68.6	Cabbage	23.1
Cassava	52.1	Egg plant	5.8
Sweet potatoes	51.2	Okra	4.1
Common beans	28.1	Rape	24
Pumpkins	12.4	Onions	4.1
Chickpeas	5	Others (chillies, green pepper, spinach, amaranthus)	5
Soya beans	9.9	-	-
Millet	5.8	-	-
Others (sunflower, pop corn)	3.3	-	-

Source: Field data (2014).

for planting had elapsed and occasionally when the growing period left was too short for the maize varieties delivered. The medium to late maturing maize varieties are recommended for the district. These require a growing period of 120 to 140 without which yields are adversely affected. One farmer complained as follows:

*"*The inputs are delivered late and at different times. They start by delivering the urea, then later they bring D-Compound (D-compound is a pre-emergence basal dressing fertilizer, to be applied before the seeds have germinated, while urea is applied when the maize is at knee height.) and seed. What can we do with Urea before seeds?" (Interview with respondent, August, 2014).

The FISP input delivery dates ranged from the first week of December to February. It was too late to use inputs received in February for the season under study and farmers kept these for the following season. Late delivery of FISP inputs results in most recipients sowing late. A few of the farmers sowed recycled (F1 generation) seeds which they complained gave very low yields. Late sowing "brings its own problems", said one respondent. These problems include rodents eating the seeds before they germinate. This happens because when sowing is delayed, weeds grow and harbour rodents. Farmers also complained of receiving expired maize seed and inappropriate varieties. Late sowed seeds also result in low yields. The low yields are inimical to the FISP's objectives of improving farmer productivity. Key informants cited several reasons for the pervasive inefficiencies characteristic of FISP input delivery nationwide and despite the state's rhetoric to the contrary. Procedures for importation of mineral fertilizers into the country and selecting transporters of FISP inputs annually are very bureaucratic. Even in the rare cases when FISP inputs are delivered to district agricultural offices on time, allocating to co-operatives also takes time. Smallholder farmers face constraints in raising the funds required as their contribution towards the FISP inputs and co-operatives wait until the last moment before submitting their monetary contributions in order to help as many of their members as possible. In the words of one key respondent, "sometimes the inputs stay for a month at the district agricultural office without being given to the farmers, all because of bureaucracy ".

Some respondents (22%) reported their need to perform weeding operations 2 to 3 times per season due to pernicious weeds. About a quarter hired-in labour to supplement household labour at USD 20 for a 50 m × 50 m area on average. It was observed that weeding is an important bottleneck and limited the acreage of land tilled as "tiling large areas resulted in them being abandoned after failing to weed". The mean land size tilled per season was 1.5 hectares (standard deviation =1.4) out of mean total land owned of 6.2 hectares. Thus just slightly less than a quarter of the total land owned was under cultivation. This is higher than the national average land size holding of 3.27 hectares (Tembo and Sitko, 2013). It is therefore argued that access to land is not a prime challenge, and other factors preclude expansion of cultivated land area.

The use of herbicides among the farmers was low. Household labour was mostly used for weeding, while some households hired-in labour at around USD 20 for a quarter hectare. Commonly used herbicides cost ZMW 90 (USD 14.4) per litre, which is sufficient for a quarter hectare, and lower than the cost of hired labour. Some farmers had reservations against using herbicides due to their perceived adverse effects on soils. As one farmer put it, "the [agricultural] plot belonging to [named] orphanage was scorched after herbicides were applied.

Table 2. Crop sales by farming households in study area, Mufulira.

Crop sale patterns by households	Percentage (n=119)
Sold maize only	8.4
Sold maize and other crops	56.3
Households that sold maize	**64.7**
Did not sell maize but sold other crops	17.6
Did not sell any crops	17.6
Sold some crops	**82.4**

Source: Field data (2014).

Up to date, nothing grows there, just a bare batch of soil remaining". Another farmer believed that herbicides scorch the soil when they are continuously used for five years. Others complained of having had challenges in following the herbicide application instructions, while the women farmers observed that it was men's work to spray herbicides and thus outside their domain.

Transporting crops from the fields to homes upon harvest was a challenge for 30.6% of the farmers. The harvest was ferried from the fields to homes by carrying on the head, using own or hiring bicycles; and hiring vehicles. The farmers paid up to USD 80 per trip using hired vehicles. Labour shortages were experienced by 25.6% while 9.9% lacked the funds to hire-in labour to help with the harvesting of crops. Those that hired-in labour paid USD 0.8 for every 50 kg bag of maize harvested. Efforts were made to harvest crops as quickly as possible, as delays resulted in pest attacks (by rodents, weevils and termites) and thefts, according to the farmers. Over a third (36.4%) reported not facing any challenges with harvesting their crops.

Post-harvest challenges were experienced with storage of maize and pest infestations. 15% complained of not having adequate storage facilities for their maize while 42.1% said their stored crops were attacked by pests. Use of insecticides was common although some reported pest infestations despite using insecticides. Common crop pests were weevils, termites and rats. One farmer lamented that the insecticides stop working after six months and weevils infest the stored maize while others asserted that wrong application of insecticides reduces their efficacy. One woman respondent explained that most farmers used a wrong method of drying maize of putting in on the roof tops of their houses and exposing it to direct sunlight instead of air drying it in the shade. Ten percent of the respondents reported that they could not afford to buy post-harvest insecticides while those that purchased them spent an average of USD 6 on their purchases annually.

Crop marketing went on smoothly for 35.6% of the respondents while the rest faced challenges. A quarter (24.8%) complained about the high costs of transporting produce to markets while 20.7% bemoaned the highly fluctuating prices for farm produce. They observed that due to over-supply at harvest time, prices of farm produce were low and variable. Prices improve a few months after harvest (around December to February) when food stocks are low for most households, that is, during the hunger or lean period. Processing of farm produce such as vegetables would help extend their shelf life and farmers would be able to earn more income from the value addition. Most farmers sale their surplus harvest immediately after harvest as they do not have storage facilities. The majority (82.4%) of the farmers interviewed sold part of their produce (Table 2).

Maize sales dominated immediately after harvests. The maize was mostly sold to the local milling company and not to the state maize buying agency, the Food Reserve Agency (FRA). The farmers explained that they preferred to sell to the privately owned milling company because they did this at a price higher than that offered by FRA and they were paid cash on delivery whereas with FRA they had to wait for weeks or months to get their money. The local milling company purchased a 50 kg bag of maize at ZMW 70. A total of 18,764 metric tonnes of maize were purchased by the local milling company from farmers. The maize is milled into flour and the by-product, maize bran (Marketing manager, pers. com). The presence of the privately owned milling company is a good opportunity for the smallholder farmers as it provides a good steady market. Respondents also reported selling their farm produce to traders from the neighbouring Democratic Republic of Congo (DRC). Their location near the DRC which is a huge market is thus another important opportunity.

Irrigated crop production was engaged in by 33.1% of the respondents. This is an increasingly important activity for farmers that have agricultural plots adjacent to perennial streams as they draw the irrigation water from such streams. Crops commonly produced under irrigation (Table 3) are on high demand from urban residents. Irrigated crop production has great potential in the district due to the relatively large urban population, proximity of peri-urban areas to the central business district and roads

Table 3. Average market prices of irrigated crops during the 2013/2014 farming season.

crop	Price during rainy season (zmw)	Price during dry (off) season (zmw)	Averag amounts sold per household annually
Tomatoes (box)	200	70	76
Cabbage (50 kg sack)	80	40	83
Rape (50 kg sack)	150	100	20
Chinese cabbage (50 kg sack)	150	70	20
Okra (25 kg)	70	120	3
Amaranthus (50 kg sack)	20	50	10
Egg plant (50 kg sack)	120	120	30
African egg plant (25 kg sack)	25	60	-
Sweet potato leaves (50 kg)	30	80	50

1 USD = ZMW 6.25 in July 2014. Source: Field data (2014).

that remain passable throughout the year. Farmers with irrigated plots complained that it was very hard work for most of them as they have to ferry water in buckets to irrigate their crops. They also complained about soil diseases and pollution from the local mine which releases sulphur dioxide fumes that scorch their crops.

Extension services provided by public extension officers were perceived to be adequate by 61.7% of the respondents, while the rest had complaints. Some (26.1%) thought extension officers were not available to provide services such as trainings in crop management and provision of advice. A few (7%) felt the extension officers were selective in their provision of services for example, allocation of FISP inputs to farmer cooperatives while some (3.5%) complained that the veterinary extension officers were inaccessible and expensive as they demanded the farmers to offset their transportation costs. Others complained that extension officers did not provide enough training sessions annually, and the few times that they did, it was to groups with no follow up to individual farms. A key informant from the veterinary department explained that due to very low staffing levels, it was challenging for the department to attend to all livestock farmers when needed. They had sought to overcome this challenge by training a selected group of locals in basic veterinary to work as community veterinary assistants. These veterinary assistants provide services such as vaccinations, de-worming, birthing, and diagnosis of common livestock diseases.

The results reveal major bottlenecks and opportunities at different phases of the farming cycle in a single season experienced by households (Figure 2). As observed by Jayne et al. (2010) there appears to be a vicious cycle in which low surplus production constrains smallholders' ability to use productive farm technologies in a sustainable manner, reinforcing semi-subsistence agriculture.

Other than the household level environment, smallholder farmers also have to deal with wider processes due to policies. These include the national agricultural policy on farming inputs and support for maize prices. Zambia's agricultural policy is highly maize-centric and has historically been dominated by maize for political-economic reasons. This study observes that the farmers focus on mineral fertilizers for nutrient amendments and ignore other nutrient sources such as leguminous crops and trees. This seems to be a reflection of the state's focus on external inputs for agricultural productivity improvements. Farmers also focus on maize production in response to the policies targeting maize production and marketing.

Farmers also have to contend with bio-physical factors such as the high seasonal rainfall, high temperatures and low inherent soil fertility. The high temperatures cause leaching of nutrients and subsequent low soil fertility (Kapungwe, 2013). The high rainfall also limits the weeding opportunities available for farmers dependent on manual weeding. The high temperatures during the hot dry season are associated with poultry diseases. Outbreaks of new castle diseases were cited as responsible for a large reduction in the local population of free ranging chickens.

Unlike most smallholders in Zambia whose land rights are held under customary tenure, the smallholders in the study area access land that is held under leasehold tenure. This entails secure and private land rights. It also means that there are no communally owned grazing areas. This restricts livestock farmers to either stall feeding or tethering the livestock within their yards. Such livestock farmers face challenges of securing sufficient quantities of fodder. Livestock husbandry is not common in the area.

Zambia's liberalized market economic policies have spurred the development of private agro companies which provide various agricultural services. These policies have provided both opportunities and challenges

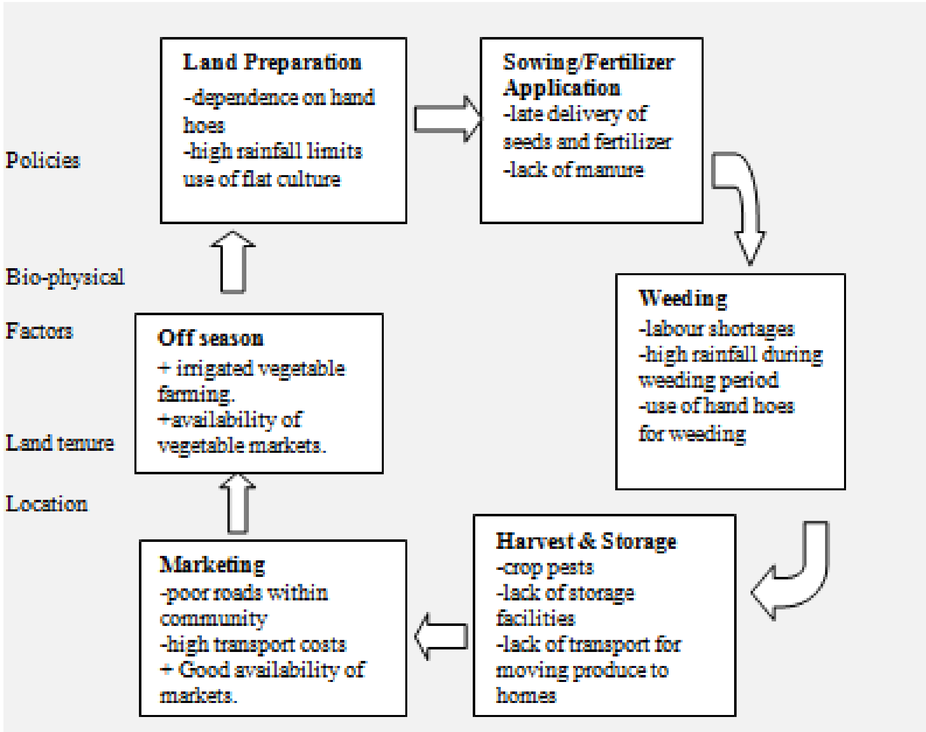

Figure 2. Opportunities (+) and challenges (-) at different phases of the farming cycle in the smallholder farming sector.

for the local smallholder farmers. For instance, the existence of a private milling company that purchases maize from farmers and pays them cash on delivery has provided a very welcome option for smallholder farmers who hitherto sold their maize to the Food Reserve Agency and endured months of hardship as they waited to be paid.

Conclusion

This study has shown that smallholder farmers in Mufulira, Zambia face challenges throughout the farming season, during every major phase of the farming cycle. These challenges range from limited access to external inputs, use of manual tillage methods and shortages of post-harvest storage facilities. Other challenges result from the bio-physical, policy environment, and the location of the study area. The high rainfall has resulted in leached and highly acidic soils which require annual nutrient amendments. The maize-centric agricultural policy mediates the decisions made at household level, which reveal a propensity for maize production and focus on mineral fertilizer utilization. The location of the study area in a relatively densely populated mining district and in very close proximity to the international border with the Democratic Republic of Congo presents a good and steady market for both rain-fed and irrigated crops throughout the year. The study concludes that consideration of locally important factors and the myriad ways in which they interact to mediate farmers' decisions is an important consideration in any development intervention aimed at addressing smallholder farmers' productivity challenges. The findings also point to the need to consider the entire farming cycle when planning interventions, as bottlenecks at all major phases of the farming cycle influence the decisions that are made at any one point. In addition to this, wider policies and institutions also affect farming households decisions and their choices about agricultural productivity enhancing technologies.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

This publication is part of the author's research work at Umeå University, thanks to a Swedish Institute Post-Doctoral Guest Researcher Scholarship.

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academicJournals

Vol. 11(13), pp. 1120-1125, 31 March, 2016
DOI: 10.5897/AJAR2015.10638
Article Number: A7B977557815
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Current banana smallholder farmers' farming practices and knowledge on plant-parasitic nematodes associated with banana (*Musa* spp.) in Rusitu Valley, Zimbabwe

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Received 10 November, 2015; Accepted 10 February, 2016

Plant-parasitic nematodes are economically important pests of banana (*Musa* spp.) and compromise its productivity. Controlling nematode populations and good agronomic practices are pre-requisites for a good yield. A survey of farmers in the Rusitu Valley, Zimbabwe, was conducted to assess their current banana production practices and knowledge of plant-parasitic nematodes associated with banana. Respondents were selected using systematic sampling from three wards. Most farmers (61.9%) grew bananas as a monoculture, and 38.1% intercrop banana with other crops. All the farmers neither rotated banana with other crops nor practiced pest and disease control measures, and only 11.4% apply a fertiliser to their banana crops. Most (82.9%) farmers in Rusitu Valley had little or no knowledge of plant-parasitic nematodes that damage bananas. Sound extension programme in Rusitu Valley should educate farmers on the importance of managing plant-parasitic nematodes and using better banana crop production practices.

Key words: Plant-parasitic nematode, banana, production practice, Rusitu Valley.

INTRODUCTION

Rusitu Valley is one of the principal banana-producing areas of Zimbabwe and they grow well in its low-lying areas (Mudyazvivi, 2010). The smallholder communal farmers of the Rusitu Valley produce a large portion of the yield, although these statistics are not available (Mwashayenyi, 1995; Svotwa et al., 2007). The crop is sold on the fresh market and due to its continuous fruiting habit, it is an important, reliable source of food and

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income to this banana-dependent community (Chitamba et al., 2013; Chitamba et al., 2014). Banana production has been declining over the years, and this has been attributed to poor agronomic practices, poor soil fertility and inadequate pest control. In many fields, individual plants have too many pseudostems for optimum production and are stunted, wilted, or have toppled (Mudyazvivi, 2010), possible indicators of poor production practices and plant-parasitic nematodes.

Plant-parasitic nematodes are a major pest of bananas worldwide (Gowen and Quénéhervé, 1990; Kashaija et al., 1994; Pattison, 2011) and thus a great threat to food security globally. Mwashayenyi (1995) reported that nematodes are a problem in the banana production parts of Zimbabwe and if control measures are not implimented, yield losses of up to at least 30% can occur. Cumulative losses due to a reduction in bunch weight and toppling may reach 75% in three cycles of production (Sarah et al., 1996). Most growers are unaware that nematodes are a cause of banana production problems and it is important to inform them (Brooks, 2004). There is a need, therefore, to assess the famers' current knowledge of plant-parasitic nematodes and banana production practices and provide extension services to improve nematode management and good cultural practices before and after crop establishment.

Extension players from the government and non-governmental organisations (NGOs) have played roles in farmer training on banana production in these communities (Mudyazvivi, 2010), but no emphasis has been put on the management of the nematodes, the major pest of the crop. The present study would close this gap thereby creating an opportunity for sound extension services to improve yield of the crop through good nematode management. The findings from this research survey will create a platform for determination of the actual plant-parasitic nematodes associated with banana in major banana production areas of the country, thereby opening up the application of suitable nematode control and management options accordingly.

Though more work has been done on the management of plant-parasitic nematodes as well as on cropping systems, not much was recorded on the application of the findings in practical situations in the farmer's fields. Banana farmers need to be trained about nematodes as major pests of the crop and be aware of the options available for good management of the pest to reduce yield loses. The present study also sought to find out the level of farmers' knowledge on plant-parasitic nematodes associated with their cash crop as well as their knowledge on the crop's production systems. This would help in coming with solutions by interested stakeholders (both government and NGOs) through extension services and necessary inputs required for good crop production and management. Moreover, this would in turn improve the well-being of these banana-dependent communities through enhanced food security and increased income from surplus banana sales. The present study will also create a platform for further agronomic research surveys on determination of the actual plant-parasitic nematodes associated with banana in these major banana production areas of the country.

Considering the economic importance of banana in Rusitu Valley, the importance of proper agronomic practices and the destructive nature of nematodes to the crop, the present study was carried out with the main objective of assessing farmers' knowledge on banana plant-parasitic nematodes as well as their current banana production practices in the area.

MATERIALS AND METHODS

Study site

Rusitu Valley falls under Chimanimani District, Manicaland Province of Zimbabwe, located at an altitude ranging from 460 to 2000 m above sea level and latitude of 19°59'S and 32°49'E (Figure 1). The area is under Natural Region I of Zimbabwe's Agro-ecological Zones, receiving an annual rainfall ranging from 1000 to 2000 mm and 635 mm effective rainfall. Generally, 70 to 80% of the rain falls from November to March and rainfall is also observed in the dry winter season. Cool season winter temperatures range from 12 to 15°C, while summer temperatures range from 18 to 20°C. Soils are podzols derived from the quartzite and schist as parent materials.

Sampling

An informal survey was first done and it included interviews with key informants as well as focus group discussions with the smallholder banana producers (farmers). Secondary information was reviewed from Agricultural Technical and Extension Services (Agritex) annual reports. Individual surveys were then conducted in March 2012 with smallholder banana farmers in Rusitu Valley using structured questionnaires. The survey population was made up of farmers in Wards 21, 22 and 23. From each of these wards, 35 farmers were sampled using systematic sampling technique, where every tenth homestead was interviewed using a pre-tested structured questionnaire. The face to face interaction with each respondent, allowed the enumerator to explain questions to the respondents to probe for more information. This was done to probe for information from smallholder farmers, the target group which was suspected of having low literacy levels. A total of 105 farmers, which approximately represented 10% of all smallholder farmers in Rusitu Valley, were interviewed in this study.

Data analysis

Data from survey was coded and analysed for both descriptive and quantitative statistics using Statistical Package for Social Sciences (SPSS) Version 16.0. Chi-square test ($p<0.05$) was used to determine the relationship/association among variables.

RESULTS

Out of the 105 farmers interviewed, 57.1% were males while the other 42.9% were females (Table 1). Three education levels (primary, secondary and

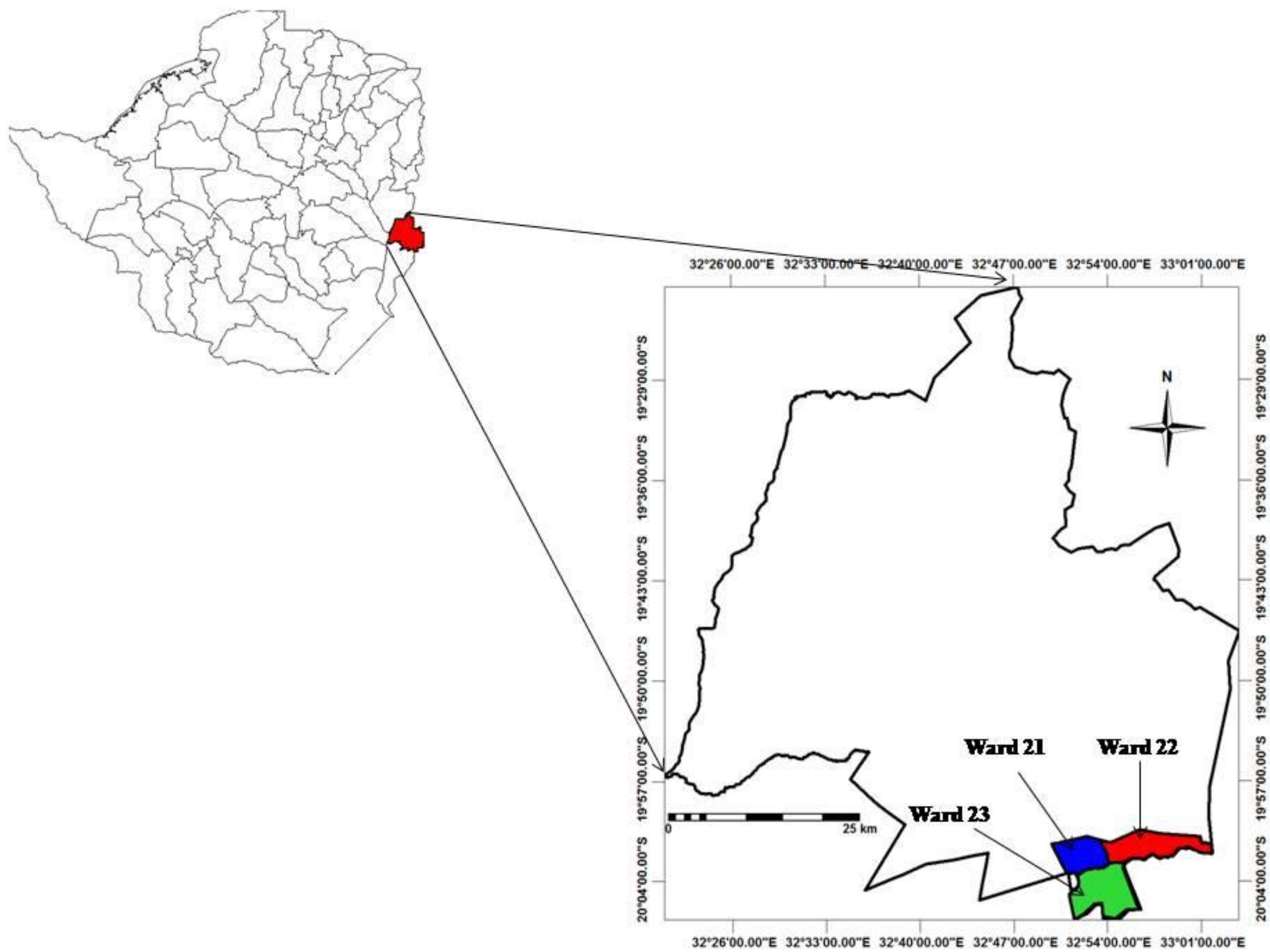

Figure 1. Map of Rusitu Valley Wards studied, Chimanimani District, in relation to Zimbabwe.

Table 1. Frequency and percentage of sex of the respondents (farmers) interviewed in Rusitu Valley.

Sex of respondents	Frequency (n)	Percentage
Female	40	57.1
Male	65	42.9

college/university) were considered. The highest proportion (64.8%) of the farmers attained secondary education level whilst only a few (4.8%) farmers attained College/University education level. 30.5% of the farmers attained only primary education level (Table 2).

Most of the farmers (82.9%) interviewed in Rusitu Valley had no knowledge of plant-parasitic nematodes associated with bananas. Only a small proportion (17.1%) of the farmers had knowledge about plant-parasitic nematodes associated with banana in the area (Table 3).

χ^2 test revealed that the farmers' level of knowledge on banana plant-parasitic nematodes was positively associated (p=0.01) with their education level; the educated were more knowledgeable than the less educated. However, the farmers' level of knowledge on banana plant-parasitic nematodes was negatively associated (p=0.53) with their sex (Table 4).

The study revealed that in Rusitu Valley, 61.9% farmers grow banana under the monoculture system while 38.1% intercrop it with other crops like pineapple, sugarcane, yams, and beans. None of the farmers interviewed practiced crop rotation or pest and disease control (Table 5). Only 11.4% of farmers among the interviewed apply fertiliser/manure to their banana crop while the rest do not (Table 5).

Agritex, Agricultural and Rural Development Authority (ARDA) and NGOs were the extension services in Rusitu

Table 2. Rusitu Valley farmers' level of education.

Education level	Frequency (n)	Percentage
Primary	32	30.5
Secondary	68	64.8
College/University	5	4.8

Table 3. Farmers' knowledge level on plant-parasitic nematodes associated with banana.

Knowledge level	Frequency (n)	Percentage
Has knowledge	18	17.1
Has no knowledge	87	82.9

Table 4. Association of farmers' level of knowledge on plant-parasitic nematodes with farmers' sex and education levels

Variable	d.f.	χ^2	p-value
Farmers' education level	2	9.63	0.01
Sex	1	0.39	0.53

Table 5. Farmers' current banana production practices in Rusitu Valley.

Production practice	Frequency (n)	Percentage
Monocropping	65	61.9
Intercropping	40	38.1
Rotation	0	0
Disease/pest control	0	0
Fertiliser/manure application	12	11.4

Table 6. Extension players in Rusitu Valley that farmers know.

Extension players	Frequency (n)	Percentage
Agritex	26	24.8
ARDA	4	3.8
NGOs (SNV/Fintrac)	3	2.9
Agritex and NGOs	41	39
Agritex and ARDA	22	21
Agritex, ARDA and NGOs	9	8.6

Valley who trained farmers on banana production practices (Table 6).

Agritex was found out to be the major extension player in the area. However, the majority of the farmers (39%) interviewed indicated that they were trained by both Agritex and NGOs while only a 2.9% indicated that they were trained by NGOs alone. Most of the farmers (62.9%) interviewed also indicated that they were not satisfied with extension services offered by the extension players while others (37.1%) were satisfied (Table 7).

The course content covered in banana production training by the extension players ranged from land preparation through to harvesting and marketing as shown in Table 8.

Table 7. Satisfaction with extension services by farmers in Rusitu Valley.

Satisfaction with extension services	Frequency (n)	Percentage
Satisfied	39	37.1
Not satisfied	66	62.9

Table 8. Course content covered in banana production training by extension players in Rusitu Valley.

Extension players	Areas covered in training
Agritex	Land preparation, planting and spacing, soil fertility management, irrigation, weed control, harvesting
ARDA	Land preparation, planting and spacing, soil fertility management, irrigation, weed control, harvesting, ripening, marketing
NGOs	Land preparation, planting and spacing, soil fertility management, irrigation, weed control, harvesting, ripening, processing, marketing through Growers Associations (e.g. Rusitu Valley Growers Association)

DISCUSSION

Lower percentage of female respondents from the survey indicates that most households in Rusitu Valley are headed by men. The findings on the farmers' level of education are inconsistent with Boonstoppel and Mudyazvivi (2010) who reported that in Rusitu Valley, only 50% of the household heads completed primary education and a little over 30% had achieved secondary education.

Lack of knowledge on banana parasitic nematodes by the majority of the farmers can be attributed to poor extension services given by the extension players in Rusitu Valley, as most farmers indicated dissatisfaction with the extension services provided by the extension players (Table 7). This might be due to the fact that banana farmers in Rusitu Valley are scattered across mountainous terrain where accessibility and transport costs cause challenges in the provision of extension services (Mudyazvivi, 2010; SNV Zimbabwe, 2008) and hence causing a poor extension linkages between farmers and extension workers. Inadequate extension in Rusitu Valley can also be attributed to a very high farmer to extension worker ratio of 500:1 which is well above the recommended one of 200:1 (AGRITEX officer, personal communication). This will result in poor extension services being delivered to the farmers by the extension players.

Moreover, all of the extension workers interviewed have insufficient knowledge on pest management/crop protection, and nematodes are not emphasised as major banana pests of economic importance. Non-governmental extension players in the area like SNV trained farmers and pupils on banana production and emphasised on other agronomic practices, but never gave emphasis on nematode pests as shown in Table 8. This is evident in some of the banana production training manuals by SNV for farmers and pupils; for example, a training manual by Dzitiro (2010) does not have detailed coverage on control measures for banana pests like nematodes. The manual just identified and suggested the control measures of semi-loopers, red spider mites, thrips and slugs as the only important banana pests without mentioning plant-parasitic nematodes. This might have contributed to the lack of knowledge on banana parasitic nematodes by the majority of the farmers in Rusitu Valley. From the survey, most farmers indicated that the areas covered by the extension players were mainly land preparation, fertilisation, irrigation, harvesting, postharvest handling and marketing, hence no knowledge on banana parasitic nematodes as pests.

Improper banana production practices like failure to apply fertiliser or implement pest and disease control measures by the farmers in Rusitu Valley can be attributed to inability to adequately acquire the required inputs such as fertilisers and pesticides by the farmers. This could be due to the fact that farmers tend to allocate the little available resources they have to maize, their staple food. Unavailability of farmer organisation as well as market access constraints also discourage farmers from investing much on banana. The status quo in the area is that bananas are fetching very little income, with most middlemen paying US\$0.10 kg^{-1} (SNV Zimbabwe, 2008), while others only pay US\$2 per bunch (1 bunch ≈ 15 kg). Farmers are therefore, not very keen to learn much about bananas and hence are not willing to invest much on them in terms of the required inputs.

Of the farmers who practice intercropping, most use crops like sugarcane, pineapple, yams, and beans. This could be mainly attributed to land maximisation as farmers have smaller allocation of land in the valley area (Mudyazvivi, 2010). Failure of the farmers to practice crop rotation on bananas can be attributed to the perennial nature of the crop as well as the labour involved in clearing/destroying the entire banana plantation in order to put an annual crop like maize. Replanting the banana crop in a new field also mean that farmers will have to wait for at least 12 months before they get something for subsistence from the crop. Furthermore, the banana crop rejuvenates its own stand through suckering hence no labour for replanting is needed. Thus farmers prefer to grow the banana under monoculture system to cut on unnecessary labour.

Conclusion

Most of the farmers in Rusitu Valley grow bananas under monoculture system; about one-third of the farmers intercrop banana with other crops; all the farmers neither rotate banana with any other crop nor practice disease and pest control measures. Very few farmers apply fertiliser/manure to their banana crop. Most of the smallholder farmers have low knowledge level on banana plant-parasitic nematodes as major pests of economic importance. The findings from the present study provide a foundation for implementation of sound extension services to the farmers in the banana-dependent community of Rusitu Valley on good production practices and basic integrated pest management for improved productivity.

Conflict of interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENT

This research was supported by the International Development Research Centre (IDRC), Canada, through the Bentley Cropping Systems Fellowship 2010. The authors thank all the farmers and extension officers who participated in the study. Special acknowledgement is accorded to Mr. and Mrs. Robert Mudada as well as Ms. Rumbidzai Mudada for the good hospitality during the entire period of this study.

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Vol. 11(13), pp. 1126-1133, 31 March, 2016
DOI: 10.5897/AJAR2014.9233
Article Number: FD85D9257820
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Impact of tillage type and soil texture to soil organic carbon storage: The case of Ethiopian smallholder farms

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Received 12 October, 2014; Accepted 20 August, 2015

Soil organic carbon is a fundamental soil resource base. However, there is limited information on soil organic carbon storage due to influence of tillage type and soil texture under smallholder production systems in Ethiopia. The objective of this study was therefore to quantify soil organic carbon in different soil textures and tillage types; and to the contribution of livestock in improving soil carbon, soil structure and soil fertility. Fifteen sample sites were selected for soil chemical analysis details on crops, soil and land management practices for each sample site was collected through household interviews, key informants discussion and literature review. The carbon storage per hectare for the four soil textures at 0 to 15 cm depth were 68.4, 63.7, 38.1 and 31.3 t/ha for sandy loam, silt loam, loam and clay loam; respectively. Sand and silt loams had nearly twice the organic carbon content than loam and clay loam soil. The soil organic carbon content for tillage type at 0 to 15 cm was 8.6, 10.6, 11.8 and 19.8 g kg^{-1}for deep tillage, minimum tillage, shallow tillage, and zero tillage; respectively. Among tillage types soil organic carbon storage could be increased by using the minimum and shallow tillage. Carbon saved due to shallow cultivation as practiced by Ethiopian smallholders using oxen drawn plough contributed to carbon trade off of about 140 million ton per year. At current levels of carbon saving shallow tillage would generate $4.2 billion of revenue per year for Ethiopian smallholders.

Key words: Carbon budget, crop residue, manure, smallholder farming, soil texture, tillage.

INTRODUCTION

Soil carbon storage is defined as “the process of transferring carbon dioxide from the atmosphere into the soil through crop residues and other organic solids, and in a form that is not immediately reemitted”. This transfer or “storage” of carbon helps to off-set emissions from fossil fuel combustion and other carbon-emitting activities, while enhancing soil quality and long term agronomic productivity (Sundermeier et al., 2005). Under mixed crop and livestock production systems in Ethiopia, crop production is the major cash income earner (IPMS, 2004), while livestock production plays an important role as a source of draught power for crop production, organic

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fertilizer, for crop production as well as serve as a living bank; and for household income generation and for human nutrition (Hadera, 2001).

Although livestock production was associated with environmental degradation and ecological devastation and irreversible desertification (FAO, 2006); there is an ample evidence to show that livestock production contributed positively to environmental stability in terms of carbon balance into the soil. Under smallholders management, the positive aspects of livestock production contribution to carbon storage is attained when farmers use animal power for farm operations such as ploughing, disking, ridging, weeding, threshing and transporting agricultural inputs and outputs; which is a carbon zero operation compared with mechanized agriculture (de Hann et al., 1998). The addition of animal manure and livestock waste into the soil is an alternative management option as carbon input for soil carbon storage (FAO, 2001; Lal, 2002, 2004).

Soil texture plays an important role in carbon storage in the soil and strongly influences nutrient availability and retention. Whendee et al. (2000) reported that sandy soils stored approximately 113 t/ha carbon to 100 cm depth versus 101 t/ha carbon in clay soils in a forest ecosystem in the Amazon. Fine-textured soils prevent organic matter against decomposition by stabilizing with minerals and clay surfaces; and physical protection of organic matter within aggregates (FAO, 2004).Carbon and nitrogen mineralization rates are often lower in clay soils than in coarse-textured soils because of the holding capacity of organic molecules onto surface minerals, which seems to be a major mechanism of soil organic-matter preservation (Christensen, 2001). Soils with less than the protective capacity are potentially capable of sequestering soil organic carbon in their clay and silt fractions (FAO, 2004).

Soil organic carbon content of cropping soils is well below the potential protective capacity, because they have been subjected to conventional tillage and burning practices, which cause substantial carbon losses (Lal, 2004). Therefore, tillage types have important impacts on soil organic carbon including controlling residue placement in soils (FAO, 2004). Deep tillage buries crop residue, but the residue is not mixed uniformly throughout the tillage depth (Lal, 2004). Moreover, tillage brings subsoil to the surface where it is exposed to atmospheric cycles (Lemus and Lal, 2005) and increases the decomposition of soil organic carbon. However, zero tillage provides minimum soil disturbance and promotes soil aggregation through enhanced binding of soil particles (FAO, 2004).

Depletion of soil organic carbon stocks has created a soil carbon deficit that represents an opportunity to store carbon in the soil through a variety of land management approaches (Franzluebbers et al., 2000). Increase in soil organic carbon can be achieved by increasing carbon inputs and decreasing the decomposition of soil organic matter or both (Rosenberg et al., 1999). Sundermeir et al. (2005) observed that the rate of organic carbon sequestration in the soil increase by each ton of residue applied was more for zero tillage than for plough-tilled cultivation.

Therefore, it is important to study the impact of different land tillage practices under mixed crop and livestock production systems on carbon storage as well as the contribution of livestock to carbon storage through shallow tillage.

Previous research studies on carbon storage were related to natural resource management, forestry and soil perspective (Lal, 2004), whereas the current study was related to the contribution of livestock to improving soil organic carbon, soil structure and soil fertility; and the role of animal draught power in decreasing soil organic carbon decomposition due to tillage.

In this article, the relationships of soil organic carbon with both soil texture and tillage types was evaluated and discussed. The hypothesis that soil carbon content depends on the soil texture and tillage types was also tested. We also assessed the contribution of livestock and crop residues in improving soil structure, soil organic carbon and fertility. The investigation was based on soil samples collected in 2009 for chemical analysis as well as in the same year land; livestock and a crop management history of the study sites were captured through interviews with farmers and key informants who had a good knowledge of the study area.

MATERIALS AND METHODS

Study area

The study was conducted in central Ethiopian highlands that represent 90%of the farming system in Ethiopia. In the highlands, the main agricultural activity is smallholder mixed farming systems dominated by crop production and livestock keeping (Constable, 1984), livestock play a key role in crop farming in ploughing the soil, threshing, transporting and adding manure to the soil.

The highland further subdivided into three zones based on the development potential and resource base at: the high potential cereal/livestock zones, the low potential cereal/livestock zone; and high potential perennial crop/livestock zone (Amare, 1980; FAO, 1988).

The current study area falls under the high potential cereal/livestock production zone (IPMS, 2004), which is located southeast of Addis Ababaat latitude 8°46’ 16.20’’ to 8°59’ 16.38’’ N and longitude 38°51’ 43.63’’ to 39°04’ 58.59’’ E, on the western margin of the Great East African Rift Valley. The altitude of the area ranges from 1500m to 2000m above sea level. Two major agro-climatic zones were identified in the study area: the mountain zone >2000meter above sea level, which covers 150km^{2}or 9% of the area; and the highland zone at 1500 to 2000 m above sea level, which covers >1600 km^{2}or 91% of the area (IPMS, 2004).

The agro-ecology of the study area is best suited for diverse agricultural production systems. The area is known for its excellent quality Teff grain, which is an important staple food grain in Ethiopia that is used for making bread (Enjera). Wheat is the second most abundant crop, while pulses especially chickpeas grow in the bottom lands and flood basins. Livestock production is an integral part of the whole agricultural production system.

Table 1. Description of soil texture and tillage type of sample sites.

Site No.	Description(Crop history and ecology)	Tillage type	Soil texture At 0 to 15 cm	Soil texture at 15to 30 cm
1	Fenced and resting land. This site has been undisturbed and unploughed for over 30 years.	ZT	SL	SL
2	A commercial farm where farmyard manure was applied for seven years.	DT	L	SAL
3	This site had experience of crop rotations of cereals with pulses.	ST	L	L
4	The land was ploughed once and then herbicides were applied during or just before sowing of cereals	MT	L	CL
5	This site was a smallholder backyard manure application plot closer to the homestead.	ST	SAL	CL
6	Compost was applied to this site.	ST	L	L
7	This site was a field where crop residues were well managed.	ST	CL	CL
8	This site was overgrazed, degraded and eroded land.	UT	SL	SL
9	This site was degraded, fenced for more than 15 years.	UT	SAL	L
10	This site experienced continuous deep cultivation with heavy machinery.	DT	L	L
11	This site was a farm plot near plastic factory effluent.	ST	SAL	CL
12	This site was a farm plot near detergent factory effluent.	ST	CL	CL
13	This site was a farm plot near steel factory effluent.	ST	SL	SL
14	This site was an animal waste disposal plot for 40 years without cropping.	ZT	SAL	SAL
15	This site was a swamp where runoff from the mountains leached away nutrients from the farms and deposited them in the swamp.	ZT	SL	SL

Key for tillage: ZT=Zero tillage, DT= deep tillage, ST= shallow tillage, MT=minimum tillage, Key for texture: L= loam, SL= silt loam, SAL= sandy loam, CL= clay loam.

Study methods

The study was designed to quantify soil organic carbon in different soil textures and tillage types and to determine the contribution of livestock in improving soil carbon, soil structure and soil fertility. The study combined socioeconomic surveys with laboratory chemical analyses. The laboratory data were complemented by land management histories and the current land management practices. Sample sites were selected purposely in consultation with farmers, experts and reviewing of secondary data. The selected sample sites had 15 characteristics, which were further subdivided into soil textures and tillage types to estimate carbon stock. Sample sites were described as shown in Table 1 based on world overview of conservation approaches and technology categorization system for conservation measures and land use management (WOCAT, 2013). The soil textures were subdivided into four classes based on the AOAC (2000) and Asnakew (1988) as loam, sandy loam, silt loam and clay loam.

The tillage types were classified as described by Abiye and Firewe (1993) as follows: deep tillage uses mechanized tractors with disc ploughs at a soil depth 30 cm and above. Minimum tillage involves the removal of weeds first by using herbicides followed by ploughing only once by oxen at the depth of 8 to 10 cm before sowing. Shallow tillage uses a traditional ox-drawn plow at the depth of 15 to 20 cm. Zero tillage is where an area has never been ploughed for a long period of time.

Soil sampling and analysis

In June 2009, soil samples were taken from the above 15 sites samples were collected to determine the impacts of different land management practices and conservation measures such as slopes, degradation level, crop history, tillage type, level of fertilization, residue management and compost or manure application. Crops, soil and land management practices for each site were described based on detailed interviews with farmers, key informants and literature review. At each site, the auger was used to take samples from the top soil at 0 to15 cm and 15 to 30 cm soil depths at four points spaced within 30 to 50 m intervals through a transect walk. Soil extracted at these points was pooled to make up a single sample for analysis and mineralization assays. Prior to the soil sample collection, coarse organic matter (leaves, wood, and roots) was removed by hand. The samples were mixed and homogenized, and the pooled sample was stored in a plastic bag and transported to Debrezeit research centre soil laboratory within two hours of collection. Immediately after the arrival, soil samples were air dried ground with mortar and pestle, and sieved through a 2mm sieve. Soil organic carbon content was determined by using the procedure described by Walkely and Black (1934). Particle size analysis was carried out as described by Bouyoucos (1951).

Soil moisture analysis was done by oven drying of 15 samples for 24 hat 105°C. Samples were weighed and the amount of carbon per unit area was calculated using the formula described by Pearson et al. (2005) as: C (t/ha) = [(soil bulk density, (g/cm^3) x soil depth (cm) x % c)] x 100. The carbon content was expressed as a decimal fraction that is, 2.2%C was expressed as 0.022. Soil bulk density was estimated by using the Adams equation (Adams, 1973) as shown below:

$$BD = \frac{100}{\frac{OM\,\% + (100 - OM\,\%)}{0.244\,MBD}}$$

Table 2. Analysis of variance for soil organic carbon at soil textures 0 to 15 and 15 to 30 cm.

Variables	Sum of squares	df	Mean square	F	Sig.
Soil texture 0 to 15 cm	8.39	3	2.80	4.719	0.02
Soil texture15 to 30 cm	1.79	3	0.60	1.156	0.37

Table 3. Soil organic carbon for soil textures at 0 to15 and 15 to 30 cm depth.

Soil texture	Soil carbon at 0 to 15 cm depth (g kg^{-1})	Soil carbon at 15 to 30 cm depth(g kg^{-1})	Soil organic carbon storage at 15 to 30 cm (t/ha)
Clay loam (n=4)	7.9 ± 4.0	6.6 ±3.3	31.3
Loam (n=6)	13.1 ± 7.4	8.1 ±4.4	38.1
Sandy loam (n=3)	28.1 ± 9.5	15.1 ± 5.6	68.4
Silt loam (n=2)	7.4 ± 3.7	14.0 ±7.5	63.7
Total (n=15)	14.0 ± 10.3	9.9 ±7.3	

Where; BD = bulk density, OM = organic matter, MBD= mineral bulk density

A typical value of 1.64 was used for MBD (Mann, 1986).

Statistical analysis

Detailed statistical analysis of the data was carried out by SPSS Version 17.0.1 (2008). A post hoc multiple comparison tests of means were done by univariate least significant difference.

RESULTS AND DISCUSSION

Effect of soil texture on soil organic carbon content

Haque et al. (1993) noted that chemical properties of vertisol type of Ethiopia showed low organic matter and total nitrogen, while Ali (1992) observed that at 0 to 25 cm depth soil organic carbon content was 18.6 g kg^{-1}in a similar site in the present study area. In the current study the average soil organic carbon content across all soil textures was 14.0 g kg^{-1}in 0 to 15 cm and 10.0 g kg^{-1}at 15 to 30 cm, which were well below the value reported by Ali (1992). The reason for these differences could be due to the effect of human anthropogenic factors such continuous ploughing, removal of crop residue, and change in traditional practices (such as use of manure for energy source than for soil fertilization) for the last 30 years. The soil textures in the study area were categorized into four groups, namely: clay loam (27%), loam (40%), sandy loam (20%) and silt loam (13%). At P-value<0.05, there was a significant difference in soil organic carbon content between these soil texture groups at 0 to 15 cm soil depth which is probably attributed due to organic inputs and land use history, but there was no significant difference at 15 to 30 cm depth (Table 2). Post and Kwon (2000) reported that the amount of decomposition rate and placement of carbon inputs above and below ground differed between ecosystems, soil texture and land uses.

Sandy Loam had the highest carbon content at both soil depths, estimated to be 28.1±9.5 6 g kg^{-1} for 0 to 15 cm soil depth and 15.5±5.6 g kg^{-1} for 15 to 30 cm soil depth. Mengistu and Fassil (2010) reported that in Northern Ethiopia the total organic carbon (TOC) ranged from 7.3 to 17.4 g kg^{-1}. The highest 17.4 g kg^{-1} was found at the depth of 0 to 15cm in the forestland and the lowest 7.3 g kg^{-1} was observed in the farmland. In the current study the average carbon content ranged from 6.6 ± to 28.1±9.5 6 g kg^{-1} which was a wide range of variation because of differences in agriculture management practices.

From the mean results in Table 3, at the depth of 15 to 30 cm sandy loam texture had 15.1 ±5.6 g kg^{-1} carbon content and silt loam had 14.0±7.5 g kg^{-1}. Both textures maintained better carbon contents than loam and clay loam which had soil organic carbon of 8.1±4.4 g kg^{-1} and 6.6±3.3 g kg^{-1}; respectively. Organic carbon content was higher at 0 to 15 cm depth than at 15 to 30 cm depth for all soil texture types (Table 3). The result indicated that sandy loam and silt loam had twice more soil organic carbon content than loam and clay loam. Similarly, Tilahun and Asefa (2009) reported that in south east Ethiopia the soil dominated with clay in texture was negatively correlated with SOC stocks.

This implied that porosity and particle size had an effect on soil organic carbon accumulation (Whendee et al., 2000; Lal, 2004). However, Christensen (2001) and Milne and Heimsath (2012) suggested that soils with high clay content tend to have higher soil organic carbon than soils with low clay content under similar land use and climate conditions. In the current study the variation could be accredited mainly due to differences in land use type and crop history.

In the current study the carbon storage was calculated per hectare based on the average soil organic carbon percentage. The carbon storage for the four soil textures at 15 to 30 cm soil depth were 68.4, 63.7, 38.1 and 31.3 t/ha for sandy loam, silt loam, loam and clay loam, respectively, as shown in Table 3.

From the data of carbon storage in Table 3 the difference between sandy loam (68.4 t/ha) and that of clay loam (31.3 t/ha) was 36.7 t/ha. Using FAO(2001) plotting unit of carbon to wheat yield a difference of 36.7 t/ha for sandy loam would enable to produce 734 to 1468 kg more wheat per hectare than would have been produced by clay loam under the assumption of similar weather and management condition. In order to translate the impact of increase in crop yield because of carbon storage and subsequent repercussion on livestock it is useful to mention the use of crop residues as animal feed. To estimate the amount of crop residues produced from increased storage, the use of extrapolation of grain to straw ratio is important. In a study conducted in Ethiopian highlands wheat grain to straw ratio 1:1.8 and positively correlated (Kahsay, 2004). That meant the increase in grain productivity consequently results in an increase in straw production, which eventually add value to livestock feed.

The study area was dominated by Vertisols (IPMS, 2004; Kahsay, 2004), and this soil type is characterized with low organic carbon content and poor response to chemical fertilization (Haque et al., 1993; Srivastava et al., 1993). Thus under traditional soil management practices vertisols produce low crop yield. However, there was ample proof to show that this type of soils was capable of producing much more food and feed than they were producing, provided that they were adequately and properly managed (Mesfin and Jutzi, 1993).

Abate et al. (1993) reported that with proper drainage of vertisols using oxen drawn broad bed makers, cereal grain yield increased by 106% and that of straw increased by 78% compared with traditional hand used drainage systems. The effect of improved drainage on fertilizer use efficiency of cereal was investigated by Abate et al. (1993) who found that grain and straw yield were increased by 30%. They also noted that different crops and soil husbandry practices increased grain and straw yield; for example, sequential cropping increased by 60%; mixed cropping of legumes and cereals raised by 40%; row intercropping of forage legumes with cereals boosted by 30%; and forage grass and legume mixed cropping improved by 40%. All this resulted in high biomass production of both grain and straw. These results showed that through proper soil drainage and agronomic management practices it is possible to increase soil organic content and land productivity.

In smallholders farming livestock contributed to soil drainage by drawing broad bed markers for better aeration, nutrient uptake and improve storages. Therefore, livestock had a role in generating power for the improvement of soil structure and fertility under smallholder mixed agriculture, too.

It should also be noted that nitrogen is the most limiting nutrient in vertisols. The use of forage and grain legumes enhances nitrogen fixation which leads to increased productivity of grain and straw (Desta, 1988; Haque, 1992). Hence, animal feed production can be integrated with soil structure and fertility improvement. Animal manure and other animal wastes increase soil organic carbon content, total nitrogen and water retention capacity (Jutzi et al., 1987) which increase both grain and straw storage, and meet livestock nutrient demand for better milk and meat production.

The contribution of livestock in soil organic carbon storage in tilled land

The depth of ploughing has a significant impact on carbon storage in the soil, where organic matter and minerals are mechanically mixed with the top layer (Lal, 2009). Sundermeier et al. (2005) reported that sub-soiling at 35.6 cm depth caused the loss of more carbon than ploughing at 20.3 cm depth. They also reported that sub-soiling caused the loss of more carbon than strip-tillage and zero tillage. In a 40-yearexperimentation in Ohio State University, Sundermeier et al. (2005) found that continuous zero tillage nearly doubled the organic matter content in the top 5 cm, while ploughing reduced it by a third. In another study conducted in Brazil, Barreto et al. (2009) found that soils under natural vegetation and conservation tillage systems generally had higher aggregation indices and total organic carbon stocks in the surface layer than soils under conventional tillage. It showed that zero tillage had an effect on carbon stabilization between the natural ecosystem and conventional tillage.

Hernanz et al. (2009) studied different tillage practices such as conventional tillage, minimum tillage and zero tillage in an experimentation which combined the rotation of cereals with pulses for 20 years. They found that the average soil organic carbon content was 14% higher in zero tillage than in minimum tillage and conventional tillage. They also reported that in zero tillage, stocked soil organic carbon content increased in the top layer but declined systematically in the bottom layer.

In the current study tillage types were categorized into four groups: deep tillage, minimum tillage, shallow tillage and zero tillage. The analysis of variance showed that there was no significant difference in carbon content between tillage types at both 0 to 15cm and 15 to 30 cm depth as shown in Table 4.

Soil organic carbon content of 0 to 15 cm depth was 8.6, 10.6, 11.8 and 19.8 g $kg^{-1}$for deep tillage, minimum tillage, shallow tillage, and zero tillage; respectively. A similar trend was found at 15 to 30 cm depth for different tillage types as shown in Table 5. A land that had never been cultivated had soil carbon storage of 87.55 t/ha at 0 to 15 cm compared with 40.34 t/ha of deep tillage. That

Table 4. Analysis of variance of soil organic carbon in tillage types at 0 to 15 and 15 to 30 cm soil depth.

Variables		Sum of squares	Df	Mean square	F	Sig.
	Between groups	2.74	3	0.91	0.8	0.51
Tillage type at 0 to15 cm	Within groups	12.19	11	1.11		
	Total	14.95	14			
	Between groups	2.14	3	0.71	1.5	0.28
Tillage type at 15 to 30 cm	Within groups	5.33	11	0.49		
	Total	7.48	14			

Table 5. Soil organic carbon content for tillage types (Mean ± SD).

Soil tillage	Soil carbon at 0 to 15 cm depth ($g\ kg^{-1}$)	Soil carbon at 15 to 30 cm depth (%)	Soil organic carbon storage at 0 to 15 cm (t/ha)
Deep	8.6 ±5.6	4.9 ±3.4	40.34
Minimum	10.6	3.0	48.87
Shallow	12.8 ±7.6	8.8 ±6.1	54.28
Zero	19.8 ± 13.7	14.7 ±8.7	87.55
Total (n=15)	14.0 ±10.3	9.9 ± 7.3	

was twice the carbon storage capacity. Shallow tillage under traditional farming methods using oxen-drawn ploughs had carbon storage capacity of 54.28t/ha (62% of the zero tillage). Higher amount of soil organic carbon in zero tillage soils could have been occurred due to the protection of carbon from decomposition (Sundermeier et al., 2005). In contrast, conventional tillage causes oxidation of soil organic carbon because of the disruption of macro aggregates and exposure of soil organic carbon to microbial oxidation and decomposition (Hernanz et al., 2009).

The results of the current findings were in agreement with the findings by Edwards et al (1992), who reported that after 10 years of experimentation comparing conventional mould board plough tillage with conservation tillage, the latter had increased surface carbon and nitrogen to 67% and the former had decreased by 66%. Jastrow (1996) also reported that the storage of soil organic carbon in shallow soil depth (<7.5 cm) was usually greater with zero tillage than with conventional tillage when sweep (<10 cm), chisel (15 cm) or mould board Plough (15 to 30 cm depth) were the primary tillage tools. Assuming a linear increase in soil organic carbon with time, Jastrow (1996) found that the rate of soil organic carbon storage at 0 to 50 cm depth in zero tillage was 84.44 g/m^3C per year. He also reported that the carbon stock of continuously cropped and conventionally tilled soils was also 25% lower than the carbon stock in conservation tillage.

In the current study the amount of carbon saved by using shallow tillage with ox-driven plough instead of deep ploughing with mechanized tractors was estimated at 140 million tons of carbon per year, calculated based on the assumption that the difference of 54.28 for shallow tillage to 40.34 t/ha for deep tillage equals to 14 t/ha carbon saved due to tillage type and multiplied by 10 million hectares land annually ploughed by smallholder farmers using animal draught power in Ethiopia (MoFED, 2009). In addition to the carbon saving, shallow tillage fostered carbon-free non-fuel consuming draught power farm operations. For example, a wheat farm required about 5 tractor hours per hectare to complete all farm operations equivalent of 160 kg of carbon per hectare (FAO, 2004). When this figure was multiplied by 10 million hectares of land annually ploughed by smallholder farmers traditionally using draught power in Ethiopia, the total amount of carbon saved in Ethiopia due to tillage type estimated to be to 1.6 million tons of carbon per year.

One of the anticipated benefits for smallholder farming in carbon credit schemes was financial gain that could be achieved from carbon trading. Carbon credits create a market for reducing greenhouse emissions by giving a monetary value to the cost of polluting the air. Nordhaus (2008) has suggested that an optimal price of carbon is around $30/ton based on the social cost of carbon emissions and will need to increase with inflation. In general carbon saved due to shallow tillage contributed to carbon trade off of 140 million tons per year. At the current level of carbon saving and a tax of $30/t of carbon, shallow tillage could generate $4.2 billion revenue per year.

In addition to more carbon release into the atmosphere from the disturbed soil, mechanization breaks soil structure and contributes to wind and water erosion. Mechanization also releases carbon monoxide, carbon dioxide and other greenhouse gases from fuel combustion. Hence, shallow ploughing with draught power is a positive farm operation from an environmental point of view because it uses an energy source which is renewable and reasonably non-polluting. In addition, draught power (oxen, donkeys, horses, camels and mules) serves as a means of transport which is also relatively pollution free, unlike gasoline that releases too much carbon emissions. This indicated that livestock plays a key role in reducing carbon emissions to the atmosphere and global warming. However, it is not realistic to continue with traditional farming given the current increase in human population and the need for increased food production.

Conclusion

Loss of soil organic carbon can lead to a reduction in soil fertility, and an increase in land degradation and desertification when activities such as tillage type and land management practices were not properly applied. The natural soil texture characteristics in terms of carbon storage will would possibly changes as result of change in land use and crop management.

Livestock had a significant role in the improvement of soil structure and increased fertility through the provision of manure and draught power in smallholder mixed agriculture. It was noted that nitrogen was the most limiting nutrient in vertisols, while the use of forage and grain legumes enhanced nitrogen fixation which led to increased carbon absorption. Hence, animal feed production could be integrated to land care for improved soil structure and fertility. Animal manure and other animal wastes increased soil organic carbon. Livestock reduced carbon emissions when draught power was used for ploughing and transportation. As there are several evidence on the negative contribution of livestock towards global warming, there are also ample information where livestock can contribute positively towards environmental management and climate change through carbon storage reduction of carbon emission.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

We gratefully acknowledge (ILRI) International Livestock Research Institute for the research fund support and use ILRI facilities.

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academicJournals

Vol. 11(13), pp. 1134-1140, 31 March, 2016
DOI: 10.5897/AJAR2015.10511
Article Number: 66324A057825
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Effects of traditional practice of soil burning (*guie*) on soil physical properties at Sheno areas of North Shoa, Oromia Region, Ethiopia

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Received 12 October, 2015; Accepted 12 November, 2015

The study was conducted in the Kimbibit District, which is located at the North Shoa Zone of Oromia National Regional State, with the objective of investigating the effects of traditional practice of soil burning (guie) on physical properties of soils of the study area. Both disturbed and undisturbed soil samples were collected from farmers' burned fields and normal fields in three peasant associations. The burned soils samples were collected from the bottom, middle and top of the heap. Soil parameters were analyzed using standard procedures and the results were subjected to analysis of variance (ANOVA). Mean separation was done using the least significant difference (LSD). Except silt content, total porosity, percentage base saturation, all the other parameters considered in this study were significantly affected by soil burning. The burning reduced clay content (71.9, 78.4 and 75.8%), total porosity (20.3, 21.7 and 0.1%), water retained at FC (26.0, 58.4 and 33.8%) and PWP (19.7, 55.5 and 25.0%) and available water holding capacity (42.9, 67.1 and 57.1%), of the bottom, middle and top of the heap, respectively. Burning increased sand content (31.0, 38.0 and 34.5%), bulk density (19.7, 30.3 and 9.2%), particle density (7.7, 16.3 and 9.5%), water repellency (84.0, 149.4 and 95.1), on the bottom, middle and top of the heap, respectively. The soil attributes due to soil burning showed an overall change towards the direction of the loss of its physical fertility as compared to unburned soils. Therefore, strategies to feed the expanding population in the study areas will have to seek a sustainable solution that better address integrated soil management.

Key words: Guie, heap, Kimbibit district, soil burning.

INTRODUCTION

Soil fertility maintenance is a major concern in tropical Africa, particularly with the rapid population increase, which has occurred in the past few decades. In traditional farming systems, farmers use bush fallow, plant residues, household refuse, animal manures and other organic nutrient sources to maintain soil fertility and soil organic

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matter (OM). Although this reliance on biological nutrient sources for soil fertility regeneration is adequate with low cropping intensity, it becomes unsustainable with more intensive cropping unless fertilizers are applied (Mulongey and Merck, 1993). Without maintaining soil fertility, one cannot talk about increment of agricultural production in feeding the alarmingly increasing population. Therefore, to get optimum, sustained-long lasting and self-sufficient crop production, soil fertility has to be maintained.

The vast majority of soils around Kimbibit District are burned annually for cropping of virgin and fallowed land. This specialized form of shifting cultivation is practiced in almost all peasant associations in the District. Traditionally, farmers in the area sow crops to mature on residual moisture, fallow the land in the main rainy season, and burn, or "*guie*" the soil (Berhanu, 1985). Land that is plowed early for late planting of crops is exposed to soil erosion due to high and intense rainfall, hence diminishing soil fertility. This indigenous technical knowledge (ITK) is used mainly for production of barley (local variety), which is a major food crop. The traditional method of growing barley involves opening virgin and fallowed land by digging slabs of soil. The slabs are spread in order to dry the grass. After drying, they are stacked upside down in conical shapes in various spots of the field and burned. The burning is not rapid and is similar to the method used for charcoal production. The burned brown soil is then spread on the dug area, mixed to make a fine seedbed and barley is planted (broadcast). According to farmers, high yields and quality of barley are obtained by using this indigenous technical knowledge. After one season of barley growth, the land is abandoned for at least more than 4 (Berhanu, 1985) years. The practice of soil burning before planting crops is not unique to Ethiopia. The same practice is done in Kenya and locally known as "Belset ab Tindinyek ".

Soil burning can have a marked effect on the OM stock because almost all OM is consumed during burning which affects long term crop productivity and soil fertility. Since burning removes OM and their colloids fractions, and since such materials furnish most of the microbiological activities and the base exchange capacity of the soils thereby providing ample storage for plant food, the removal of such essential particles and their colloids decrease the fertility of the soils (Assefa, 1978).

This exacerbates soil quality decline due to soil burning leading to soil degradation which may ultimately lead to complete loss of land values. The consumed soil OM during soil burning affects soil physical quality of soil. These variations of soil physical properties due to soil burning indicate the risk to the sustainable crop production in the area. However, in the study areas, the effects of soil burning (*Guie*) on soil physical properties are not well studied. Therefore, this study was initiated to investigate the effects of traditional practice of soil burning (*Guie*) on soil physical properties.

MATERIALS AND METHODS

Location and description of the study area

Geographically, Sheno is located in the Oromia Regional State, Central highlands of Ethiopia at distance of 78 km north of the national capital, Addis Ababa (Figure 1). Geographically, the District extends from 90°12'-9°32' N latitude and 39°04'-33°0' E longitudes (Figure 1) at an altitude ranging from 1950 to 2918 m above sea level (masl). The agro ecology is highlands *(Baddaa)* with flat topography. Soils of the district are moderately fertile black, red and brown clay soils. Sheno areas are characterized by bimodal rainfall pattern with erratic distribution. There are four main seasons: the long rainy season *Genna* (June to August), the short rains *Arfassa* (March to May), harvesting period *Birra* (September to November) and dry season *Bona* (December to February). The mean (1996-2007) annual rainfall is 1366.7 mm. The annual mean minimum and mean maximum temperatures at the study area for the periods from 1996 to 2007 are 12.9 and 19.9°C, respectively (Data from Kimbibit District of Agricultural Office).

Vegetation and land use

Except very few and scattered bushes, grasses and small trees, the natural vegetation has been cleared for expansion of agricultural land. Only patches of artificially planted Eucalyptus tree species are found on the peripheral sides of the farm lands. Much of the land is used for crop production and a few parts as pasture (grazing) lands. The main category of livelihood is mixed farming focusing on crop and livestock production. Crop production is entirely rain fed. The livelihood zone is best known for barley, wild oats, wheat, horse beans, linseed and lentils. Barley, wild oats, wheat and horse beans are the main crops grown for home consumption. The main crops sold are wheat, linseed, lentils and horse beans. Cattle, sheep and equines are the main types of livestock (Personal Communication and Data from Kimbibit District of Agricultural Office).

Site selection and soil sampling

The assessment of the effects of traditional soil burning, *Guie*, on soil physical was conducted under laboratory conditions. From the whole of Sheno District, three representative peasant associations (PAs) farm lands known for practicing *Guie* for barley and other crops production and that are relatively similar in their agroecology and soil type were selected through reconnaissance survey and discussion with development agents and the Office of Agriculture of the District.

From the selected PAs (Golelcha, Garechatu, Tuka Abdola**)**, one representative farm was selected and disturbed soil samples were collected from burned heaps and unburned fields that are adjacent to each other. The disturbed samples were collected using auger from the plow layer (0-20 cm) while undisturbed soil samples were collected using core sampler from the same depth for unburned soil. For burned soil, both disturbed and undisturbed soil samples were collected by manually forcing auger and core sampled into the soil. Soil samples were collected from the bottom, middle and top of the heaps.

The height of most of the heaps was 60 cm during soil sampling. Accordingly, soil samples were collected from 0-20 (the bottom of the heap), 20-40 (middle of the heap) and 40-60 cm (top of the heap). The major criteria used for selection of the height for the bottom, middle and top of the heap were colors transition from the bottom to middle, middle to top and the expected difference in the soil properties. In the case of the height variation for the heaps, colors transition were used as major sampling criteria from the bottom, middle and top of the heap.

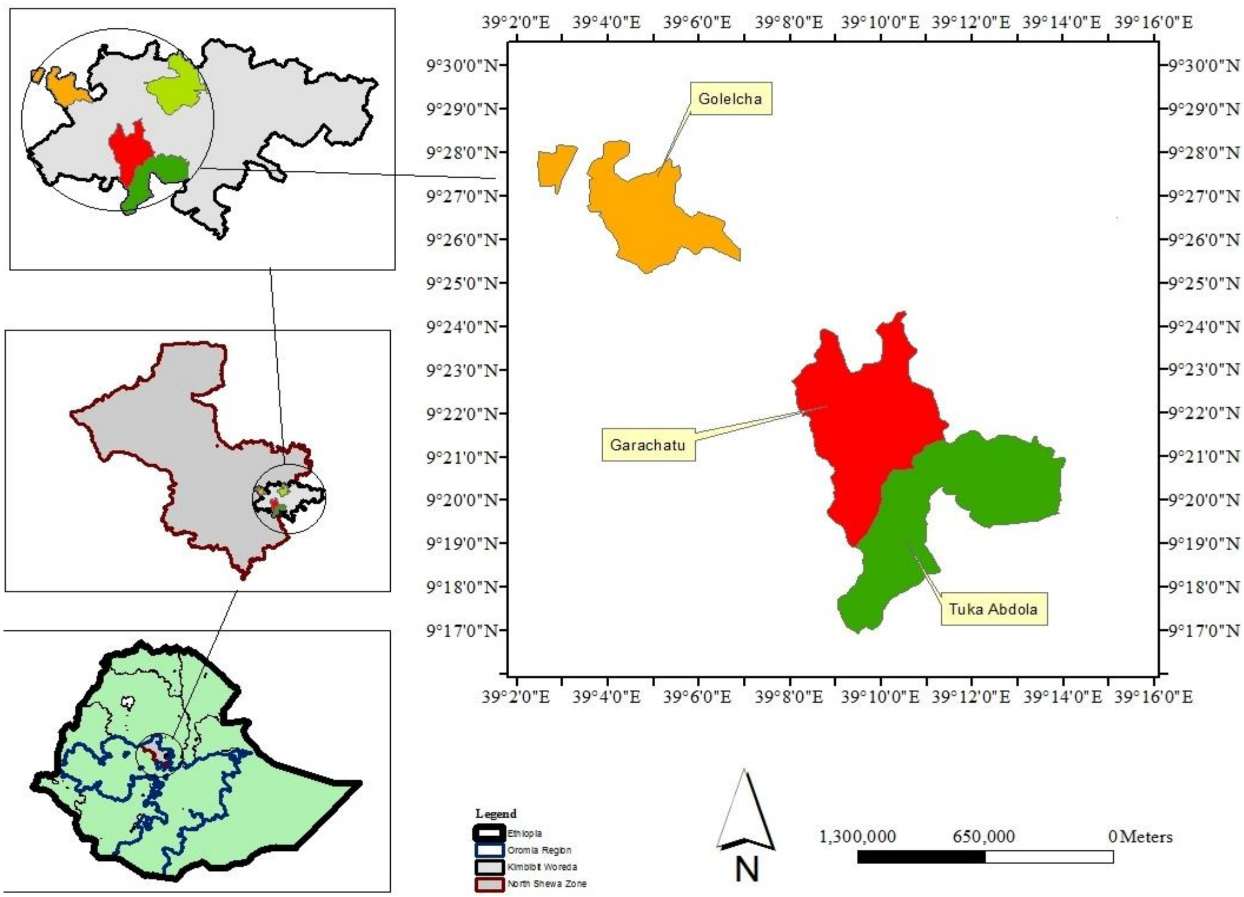

Figure 1. Map of study areas.

The sub-samples collected from different points of each field at different points of the field and heaps were composited to make one composite sample per field. One composite soil sample was then prepared from the fifteen sub samples for each treatments (control, the bottom, middle and top of the heap). In this way, a total of 12 composite samples were collected from the three PAs (replications) and analyzed for their physical properties to see the effects of soil burning under farmers' practice. The composite soil samples were labeled and transported to the laboratory in plastic bags for further processing and analysis at Haramaya University laboratory.

Soil sample preparation and laboratory analysis

Soil sample preparation

The disturbed samples collected from the field were air-dried and crushed to pass through a 2 mm sieve for analysis of all properties of interest. The disturbed samples prepared in this way were used for laboratory analysis of particle size distribution (sand, silt and clay), particle density and water repellency. Undisturbed soil samples were used for the determination of soil bulk density and water retention capacity at field capacity and permanent wilting point.

Laboratory analysis of soil physical properties

Soil colors were determined with the help of the Munsell soil color chart. Soil particle size distribution was determined by the Boycouos hydrometer method (Bouyoucos, 1962) after destroying OM using hydrogen peroxide (H_2O_2) and dispersing the soils with sodium hexameta phosphate. Soil bulk density (BD) was measured from undisturbed soil samples which were weighed at field moisture and after oven drying the pre-weighed soil core samples to constant weight (105°C) as per the procedure described by Black (1965). Particle density (PD) was determined by the pycnometer method (Devis and Freitans, 1984). Total porosity was estimated from the bulk and particle densities.

The soil-water holding capacity (WHC) values were measured at -1/3 bars for field capacity (FC) and -15 bars for permanent wilting point (PWP) using the pressure plate apparatus (Hillel, 1980). Soil water repellency can only be measured at the point scale, and this was done by measuring the water drop penetration time (WDPT). In this test, one or more drops of water were placed on the soil surface and the time required for the water to penetrate the soil was recorded (Letey, 1969).

Data analysis

Soil data generated through laboratory analysis were subjected to analysis of variance (ANOVA) using the general linear model procedure of the statistical analysis system (SAS, 2004). Mean separation was carried out using least significant difference (LSD). Pearson's simple correlation coefficient was executed to reveal the magnitudes and directions of relationship between different soil properties.

Table 1. Patterns of soil color (dry soil) as affected by soil burning and position in the heap.

Treatment	Golelcha	Garechatu	Tuka Abdola
Control	Weak red (7.5YR 4/2)	Weak red (7.5YR 4/2)	Dark red (10YR 3/6)
Bottom	Dark reddish gray (10YR 3/1)	Pale red (2.5YR 6/2)	Light red (7.5YR 4/3)
Middle	Light red (2.5YR 6/8)	Light red (10YR 6/6)	Light red (2.5YR 6/6)
Top	Black (5Y 2.5/5)	Black (5Y 2.5/5)	Black (5Y 2.5/5)

Table 2. Changes in texture of the soils studied.

Treatment	Golelcha	Garechatu	Tuka Abdola
Control	SL (56, 28 and 16)	SL (60, 26 and 14)	SL (58, 26 and 16)
Bottom of heap	LS (77, 19 and 4)	SL (71, 24 and 5)	LS (80, 16 and 4)
Middle of heap	LS (81, 16 and 3)	SL (73, 23 and 4)	LS (86, 11 and 3)
Top of heap	LS (81, 15 and 4)	SL (71, 25 and 4)	LS (82, 15 and 3)

Figures in parenthesis are percentage of sand, silt and clay, respectively; LS= loamy sand; SL= sandy loam.

RESULTS AND DISCUSSION

Soil color

The color of the soil samples studied were found to belong to 4 hue groups, namely 5Y (3 samples), 7.5YR (3 samples), 10YR (3 samples) and 2.5 YR (3 samples) (Table 1). The values in the soil of Tuka Abdola were 3 in the control, 4 in the bottom, 6 in the middle and 2.5 in the top of the heap. The soils from the Garechatu site had the values of 4 in the control, 6 in the bottom, 6 in the middle and 2.5 in the top of the heap. Golelcha site had soil color values of 4 in the control, 3 in the bottom, 6 in the middle and 2.5 in the top of the heap (Table 1).

Generally, increase in temperature had different influences on the chroma and values of the soil. Red color values are formed with constant depletion of soil organic matter (OM) which may be due to increase in oxidation level and other chemical changes. These results were in agreement with Ulery and Graham (1993) and Certini (2005) who stated that the redder hue which appears in the burned soils is apparently because of transformation of Fe-oxides and complete removal of OM. The redder colors on the middle of the heaps were the indication of occurrence of higher fire intensity in that position of the heap while the black color of the top of the heap is due to charred organic matter and total organic matter is not combusted. Color of the burned soil can be used as an indicator of fire severity.

Soil texture

The highest average sand content (80.00%) was observed at the middle of the burned heap and the lowest (58.00%) was recorded in the unburned soil or the control. The average clay fraction of the unburned soil, the burned soil at the bottom, middle and top of the heap were 15.30, 4.30, 3.30 and 3.70%, respectively (Table 2). Sand contents were increased by 31.0, 38.0 and 34.5% on the bottom, middle and top of the burned heap, respectively as compared to the control. On the contrary, soil burning reduced clay contents by 71.9, 78.4 and 75.8% in the bottom, middle and top of the heap, respectively, as compared to the control treatment.

The observed variation in soil separates may be related to the exposure of the soils to high temperatures resulting in the fusion of clay and silt particles into sand-sized particles. Thus, soil burning increases the coarser particles by decreasing the contents of finer particles. Similar results were reported by Oguntunde et al. (2004) that in severely burnt soils, the decrease in clay fraction and corresponding increase in sand content were observed.

Despite the fact that texture is an inherent soil property, soil burning contributed to the changes in particle size distribution. The textural class of the soils from Golelcha and Tuka Abdola changed from sandy loam to loamy sand as a result of soil burning while the textural class of the soil from the Garechatu site remained sandy loam both before and after the soil burning treatment (Table 2). In this study, sand was negatively but significantly ($r = -0.93^{**}$) correlated with clay (Table 4).

Soil bulk and particle densities

With exception to silt contents, the results of the analysis of variance (Table 5) showed that all soil physical properties studied were significantly ($P \leq 0.05$) affected by soil burning.

The highest (1.85 g cm^{-3}) and lowest contents (1.42 g

Table 3. Mean values of soil physical properties and relative change (%) due to soil burning.

Soil properties	Control	Bottom of heap	Middle of heap	Top of heap
Sand (%)	58.00^b	76.00^a (31.0)	80.00^a (38.0)	78.00^a (34.5)
Silt (%)	26.70	19.70 (-26.2)	16.70 (-37.5)	18.30 (-31.5)
Clay (%)	15.30^a	4.30^b (-71.9)	3.30^b (-78.4)	3.70^b (-75.8)
BD (g cm^{-3})	1.42^c	1.70^{ab} (19.7)	1.85^a (30.3)	1.55^{bc} (9.2)
PD (g cm^{-3})	2.21^c	2.38^b (7.7)	2.57^a (16.3)	2.42^b (9.5)
TP (%)	35.79	28.53 (-20.3)	28.03 (-21.7)	35.78 (-0.1)
FC (%)	25.67^a	19.00^b (-26.0)	10.67^c (-58.4)	17.00^b (-33.8)
PWP (%)	18.67^a	15.00^b (-19.7)	8.30^c (-55.5)	14.00^b (-25.0)
AWHC (%)	7.00^a	4.00^b (-42.9)	2.30^b (-67.1)	3.00^b (-57.1)
WR (Second)	27.00^c	49.67^b (84.0)	67.33^a (149.4)	52.67^b (95.1)

*Means with in a row followed by the same letter (s) are not significantly different from each other at P ≤ 0.05; Figures in the parenthesis are relative change (%) due to soil burning; BD = bulk density; PD = particle density; TP = total porosity; FC = field capacity; PWP = permanent wilting point; AWHC = available water holding capacity; WR = water repellency.

Table 4. Pearson's correlation coefficient (r) among soil physical properties.

Soil properties	Sand	Clay	BD	PD	TP	AWHC	WR
Sand	1						
Clay	-0.93**	1					
BD	0.71**	-0.69*	1				
PD	0.71*	-0.65*	0.96**	1			
TP	-0.63*	0.69*	-0.88**	-0.72**	1		
AWHC	-0.71**	0.88**	-0.69*	-0.67*	0.62*	1	
WR	0.69*	-0.71**	0.92**	0.89**	-0.78**	-0.80**	1

* and ** = Significant at P ≤ 0.01 and < 0.05, respectively; ns = Not significant; BD = bulk density; PD = particle density; TP = total porosity; AWHC = available water holding capacity; WR = water repellency.

cm^{-3}) soil bulk density were recorded in the middle of the burned heap and the unburned soil, respectively (Table 3). Due to soil burning, the increase in soil bulk density by 19.7, 30.3 and 9.2% in the bottom, middle and top of the heap was observed, respectively, as compared to the control or unburned soil. Firstly, the increase in the bulk density of the soil may be attributed to the combustion of soil OM leading to deterioration of soil structure. The binding agents such as humic substances are deeply affected by fire temperature and, in connection with clays, promoting important changes in soil structure which is in agreement with the findings of Choromanska and DeLuca (2002) who reported that as a result of the loss of OM in heated soils, soil structure was destroyed which led to increase in the bulk density of the soil.

Secondly, the other reason for the increase in the soil bulk density is the decreases in the soil porosity. The increase in the sand and decrease in the clay fractions due to soil burning might have contributed to the increase in soil bulk density on the burned soil samples. As indicated in Table 4, correlation analysis showed a positive and significant (r = 0.71**) relation between bulk density and sand content while a negative and significant (r = -0.69*) relation was obtained between bulk density and clay content.

The average values of soil particle density of the unburned soil, the burned soil at the bottom, middle and top of the heap were 2.21, 2.38, 2.57 and 2.42 g cm^{-3}, respectively (Table 3). The results of this study revealed an increment of soil particle density by 7.7, 16.3 and 9.5% due to soil burning in the bottom, middle and top of the heap, respectively, as compared to the control. These higher particle density values in the middle of the burned heap could be because of the decrease in OM and expected iron oxide transformation in the burned soil.

The other reason for the higher values of particle density obtained in the middle of the burned heap might be due to the presence of heavy mineral Mn in the middle of the burned heap as indicated by the higher Mn contents which is in agreement with past reports by Hillel (1980) and Wakene (2001).

Total porosity

The average values of total porosity of the unburned soil,

Table 5. Results of analysis of variance for soil physical properties.

Soil properties	Treatment MS (3)	Error MS (8)	LSD (0.05)	CV	SE
Sand (%)	308.00**	26.25	9.65	7.0	5.07
Silt (%)	58.00^{ns}	21.83	ns	22.9	2.20
Clay (%)	100.67**	0.58	1.44	11.5	2.89
BD (g cm^{-3})	0.39**	0.02	0.28	13.2	0.18
PD (g cm^{-3})	0.38**	0.03	0.31	8.7	0.18
TP (%)	190.71*	36.29	11.34	14.7	4.00
FC (%)	114.53**	3.42	3.50	10.2	3.09
PWP (%)	54.89**	2.17	2.77	10.5	2.15
AWHC (%)	12.75**	0.83	1.72	22.4	1.04
WR (Second)	833.88**	38.75	11.72	12.7	8.34

*, ** = Significant at P ≤ 0.05 and P ≤ 0.01, respectively; (8 and 3) = Treatment and error degree of freedom, respectively; CV = coefficient of variation; LSD = least significant difference; ns = not significant; MS = mean square; SE = standard error; BD = bulk density; PD = particle density; TP =total porosity; FC = field capacity; PWP = permanent wilting point; AWHC = available water holding capacity; WR = water repellency.

the burned soil at the bottom, middle and top of the heap were 35.79, 28.53, 28.03 and 35.78%, respectively, which reveals a reduction of total porosity by 20.3, 21.7 and 0.1% in the bottom, middle and top of the heap, respectively, as compared to the control or unburned soil (Table 3).

Firstly, the increase in sand content and the decrease in clay content are also likely to decrease the total porosity by decreasing the amounts of soil micropores. Sandy soil has larger pore (macropore) but small total porosity while clay has smaller pores (micropores) but higher total porosity which is in agreement with the findings of Landon (1991) who stated that the fine textured soils especially those without a stable granular structure may have a dominance of micropores, thus allowing relatively slow gas and water movement, despite the relative large volume of total pore space. Correlation analysis (Table 4) showed a positive and significant (r = 0.69*) relationship between total porosity and clay with a negative and significant (r = -0.63*) relationship between total porosity and sand contents.

Secondly, the reduction in soil OM content which acts as binding agent of soil particles leading to stable aggregate formation is heavily affected by fire temperature during the process of soil burning leading to decrease in soil total porosity.

Soil water holding capacity

The mean AWHC contents decreased considerably from 7.00% on the unburned soil to the values of 4.00, 2.30 and 3.00% on the bottom, middle and top of the burned heap, respectively which reveals a reduction by about 42.9, 67.1 and 57.1% in the bottom, middle and top of the heap of the burned soil, respectively, as compared to the control.

The variation in water contents both at FC and PWP may be due to differences in their particle size distribution (sand, silt and clay fractions). The increases in sand sized particles and corresponding decreases in the clay sized particles after soil burning have led to the lower water contents at both FC and PWP which in turn reduced the soil AWHC. Similar results were reported by Emerson (1995) that increases in clay content increases the soil water holding capacity both at the FC and PWP. Similarly, the results obtained from the correlation analysis also indicated that AWHC has a positive and significant (r = 0.88**) relationship with clay content, whereas sand fraction has a negative, however, significant (r = -0.71**) relationship with AWHC (Table 4).

The reduction of soil water retention after soil burning may also be due to the reduction in the total OM of the soils which is burnt off during burning. This may be attributed to the fact that OM improves water retention through its positive effects on aggregate formation and stability leading to a well-structured soil of relatively low bulk density as a result of increased total soil porosity. Similar results were reported by Assunta et al. (2004) that most OM within the soil contains 50-90% water.

Moreover, the increase in soil bulk density is also another reason for the decrease in soil AWHC because bulk density is the measure of soil porosity which is the indicator of soil water content which is in agreement with the findings of Barauah and Barthakulh (1997) who concluded that soil bulk density is an indicator of soil aeration status and soil water content. In harmony with this, the analysis of the Pearson's correlation coefficient (Table 4) also revealed that AWHC was negatively and significantly (r = -0.69*) related with soil bulk density. In general, the observed changes in the AWHC, FC and PWP in the present study indicate that the water retention properties of the soils in the study area have been disturbed significantly by soil burning.

Water repellency

The mean values of soil water repellency increased considerably from 27.00 (second) on the unburned soil to the values of 49.67, 67.33 and 52.67 (second) in the bottom, middle and top of the heap, respectively due to soil burning which reveals an increment of about 84.0, 149.4 and 95.1% in the bottom, middle and top of the heap, respectively, as compared to the control or unburned soil (Table 3).

The highest value of soil water repellency in the middle of the burned heap could be due to the highest fire intensity expected and the highest sand content (80.00%) observed at the middle of the heap which is supported by the findings of Huffman et al. (2001) who concluded that soil water repellency is strengthened with increasing burn severity and sand content. Accordingly, the results of correlation analysis also revealed that water repellency is significantly (r = 0.69*) and positively related with sand content (Table 4).

Conclusion

The results from this study showed that as compared to normal or unburned soil, burning reduced available water holding capacity (42.9, 67.1 and 57.1%) and total porosity (20.3, 21.7 and 0.1%) in the bottom, middle and top of the heap, respectively. On the other hand, soil burning increased water repellency (84.0, 149.4 and 95.1%), bulk density (19.7, 30.3 and 9.2%) and particle density (7.7, 16.3 and 9.5%) in the bottom, middle and top of the heap, respectively, as compared to the unburned soil. The soil attributes due to soil burning showed an overall change towards the direction of the loss of its physical fertility as compared to unburned soils.

These variations of soil physical properties due to soil burning indicate the risk to the sustainable crop production in the study area. Therefore, strategies to feed the expanding population in the study areas will have to seek a sustainable solution that better addresses integrated soil management. In addition, improvement in the management of the soil resources for sustainable agricultural use would be one of the most useful strategies. The huge emission of carbon dioxide, that is, greenhouse gas during soil burning is also a problem of global warming.

Conflict of Interests

The authors have not declared any conflict of interests.

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academicJournals

Vol. 11(13), pp. 1141-1149, 31 March, 2016
DOI: 10.5897/AJAR12.1610
Article Number: E75B51D57828
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Yield performance of East African highland banana hybrids on farmers' fields under high disease pressure

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Received 30 July, 2012; Accepted 17 February, 2016

The production of the East African highland cooking banana is constrained by pests, diseases and narrow genetic base amongst others. Research to develop resistant / tolerant genotypes has been on going at Kawanda. 18 promising banana hybrids have been identified. The hybrids were planted on farmers' fields in Kasangombe Sub-county in central Uganda for evaluation against black Sigatoka and yield. Data were collected on some of the agronomic traits, banana weevil damage and response to black Sigatoka disease on the plant and first ratoon crops. The data were analysed using mixed model procedures on SAS software. Means within each crop cycle were separated by comparing hem to Mbwazirume using adjustment to Dunnett's Test at 5% level of significance. The hybrids had more functional leaves (at least 9) compared to Mbwazirume (approximately 8 leaves). Youngest leaf spotted was significantly higher in the hybrids. All the hybrids except 2734K-1 retained significantly higher number of leaves at harvest (approximately 3 leaves). Most of the hybrids produced bigger bunches (at least 16 kg and 19 in the plant crop and first ratoon respectively) and the yield (t/ha/yr) of the banana hybrids was also higher compared to Mbwazirume. A Bi-plot of principal component analysis 1 against principal component analysis 2 showed that banana hybrids 12419S-13, 2625K-1 and 7798S-2 displayed very good agronomic traits in terms of plant height, girth and bunch weights. They also appeared to be tolerant to black Sigatoka disease as compared to Mbwazirume. These could be recommended for further evaluation with farmers to establish their culinary qualities and acceptability.

Key words: East African highland banana hybrids, black Sigatoka disease.

INTRODUCTION

The East African highland cooking banana (*Musa* spp., AAA-EA) is an important food crop as well as a source of income for over 20 million small scale farmers in the Great Lakes region of Eastern Africa. In Uganda, over 7

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Million people including 65% of the urban population depend on banana as their staple food (Tushemereirwe et al., 2003).

Annual production is estimated at 8.45 million tons, accounting for 15% of the total banana /plantain output. The popularity of this perennial crop has spread throughout the country because of its multiple uses and ability to provide food and cash all year round. Most people in Uganda and the great lakes region use the term 'food' and 'matooke', (cooked banana) interchangeably (Karugaba and Kimaru, 1999). However, the production of East African highland bananas is declining due to declining soil fertility, pests and diseases, poor planting materials, post-harvest handling, poor husbandry practices, socio-economic issues, marketing constraints and poor rural road networks (Karugaba and Kimaru, 1999).

Banana weevil (*Cosmopolitis sordidus, Gemar*) and black Sigatoka are some of the major banana pests and diseases. Banana weevils cause premature death of the plant, delayed maturation of fruits and production of small bunches of low economic value. This accounts for 45% of yield loss in bananas (Rukazambuga, 1996). On the other hand, black Sigatoka has been reported to cause yield decline of 30 to 50% on plantains (Mobambo et al., 1993), while Tushemereirwe (1996) reported a yield loss of 37% on East African Highland bananas.

A number of control options have been used to manage banana weevils and black Sigatoka disease. For instance habitat management, trapping, use of clean planting materials, natural enemies and pesticides were employed in the control of banana weevils. While management of black Sigatoka disease was mainly through the use of fungicides and de-leafing.

In general, these control options have been less efficient or they are not user friendly due to socio-economic reasons (Craenen, 1998, Gold et al., 1999). Therefore, National Agricultural Research Organisation (NARO) has opted for use of host plant resistance.

Through convectional breeding, National Banana Research Programme and International Institute of Tropical Agriculture (IITA) developed some promising hybrids derived from East African highland banana crosses at National Agricultural Research Laboratories (NARL), Kawanda. Therefore, this study aims to evaluate banana hybrids response to black Sigatoka and yield on farmers' fields.

MATERIALS AND METHODS

Study site selection

The study sites were selected in Kasangombe Sub-county; Nakaseke District in Central Uganda. The sub-county is at an altitude of 1311metres above the sea level, about 0°56'N of latitude and longitude 32°42'E; with mean annual rainfall range between 1200 to 1375 mm, and average temperatures of 17.5 and 28°C minimum and maximum respectively.

This is one of the 'hot-spots' of black Sigatoka disease and banana pests.

Farmer selection and banana hybrids

A multistage stratified sampling method was used to select 15 farmer fields for the study. A list of Parishes within the sub county was produced, out of which three parishes were randomly selected. A total of 15 farmers that is, 6 farmers from Nakaseeta Parish, 5 farmers from Bulyake Parish and 4 farmers from Bukuku Parish were randomly selected. The number of farmers per parish was based on the number of banana farmers per parish.

Eighteen (18) East African highland banana hybrids namely; 2729K-1, 2729K-2, 2625K-1, 2734K-1, 11777S-6, 9540S-2, 9494S-36, 12478S-13, 12419S-13, 9509S-5, 365K-1, 2409K-3, 7798S-2, 8386S-19, 9187S-8, 9494S-10, 9750S-13 and 2695K-4 were evaluated against two local checks (Mbwazirume and Kisansa). These derived hybrids were triploids which were a product of first crossing land races (East African highland bananas triploids, AAA) with either Calcutta 4 or *Musa acumiunata burmanica* (diploids) to get the tetraploid hybrid bananas. The tetraploid hybrids were further crossed with the male diploid bananas to obtain the triploid hybrids.

The bananas hybrids were planted in the farmers' fields in September, 2005. An augmented incomplete block experimental design was used. Each of the farmer's field per parish was randomly assigned four different hybrids and two local checks (Mbwazirume and Kisansa) used as controls. Each hybrid and the local checks comprised of 12 plants. These were planted in holes of 60 cm wide by 60 cm deep dug manually at a spacing of 3 x 3m between and within the plants. A total of 72 plants per farmer's field were established.

Data collection

Agronomic traits

A data collection sheet was designed and used in collecting growth and yield (agronomic) data for two consecutive plant cycles (plant crop and first ratoon crop). The dates on which the plantlets were planted and when the sucker for the next cycle emerged from the soil were recorded. These dates were taken to be the planting dates for the plant crop and first ratoon crop respectively, and they were used to calculate the yields in the plant crop and first ratoon crop.

Agronomic traits of the banana hybrids were recorded at flowering and harvest. On the day of flowering, the pseudostem height and circumference (girth) was gotten. The pseudostem height was determined using a calibrated pole of 3 m at a precision of 5 cm interval from ground level up to the level of inflorescence (point where the unfurled leaf forms a V-shape with the last open leaf). While the girth was measured and recorded on fully round part of the pseudostem, 100 cm above the ground using a standard tape measure.

On the day of harvesting, the following parameters were recorded: harvest date, the weight for each harvested bunch was taken using a Spring-Dial Host scale. The physiological maturity of bunches was established when the colour of one of the fingers on the first hand begun to turn from green to yellow. The yield (tons/ha/year) for each banana hybrid was then calculated according to Noupadja and Tomekpé (2000) for each crop cycle (Plant crop and first ratoon crop):

Yield = (Plant density x 365 days x bunch weight (kg))/ 1000 / x period from planting to harvest (1)

Where period from planting to harvest (days) = Date of harvest –

Date of planting

Black sigatoka disease assessment

Assessing the response of banana hybrids to black Sigatoka disease, data were collected on the following parameters: number of functional leaves (NSL) and youngest leaf spotted (YLS) at flowering, and the number of functional leaves at harvest of the plant crop and the first ratoon crop. The number of functional leaves were physically counted and recorded for each plant on the date of its flowering. Leaves with more than 50% of non-functional surface area were considered dead. YLS was determined by physically counting down from the first unfurled leaf. For instance in the resistant plants, it will be on the older leaves and the opposite is true for susceptible plants. The YLS had at least ten discrete, necrotic lesions or one large necrotic area with ten light coloured dry centres. YLS and NSL were used to calculate the index of non-spotted leaves (INSL) (Carlier et al., 2003).

$$\text{INSL} = 100 - 100x\left[\left(NSL - YLS + 1\right)/NLS\right] \qquad (2)$$

This index, provide an estimation of available photosynthetic leaf area prior to fruit filling and it is a measure of resistance (Carlier et al., 2003).

On the date of harvesting, the number of functional leaves were also physically counted and recorded on every harvested plant, since there is no leaf replacement after flowering of bananas. The numbers of functional leaves at harvest indicate how fast the disease progresses in the plant. According to Barekye et al. (2002), the disease progresses fast in susceptible plants causing rapid loss of leaves so that by harvest time only few leaves or none remain on the banana plant.

Weevil damage assessment

Weevil damage assessment was done according to Rukazambuga (1996), two cross sections were made at pseudostem base or the collar region (upper cross- section) and 5 cm below the pseudostem (lower cross-section). The percentage of tissue consumed by the weevils was estimated by consolidating the consumed area in each cross section. To obtain the inner section damage (central cylinder, XI); the upper and lower inner damage were averaged. Also, the average of the upper and lower outer portions gave percentage corm damage in the outer (cortex) section (XO). Calculating the total cross-sectional damage (XT), the inner (XI) and outer (XO) percentage corm damage were added together and then divided by 2 for every harvested plant.

Data analysis

Response variables for growth parameters, yield components, and disease scores were checked for normality and found to be relatively normally distributed necessitating no transformation. Exploring the effect of farms on genotype performance was done by exposing the data to analysis of variance (ANOVA) using a general linear model (GLM) using SAS software (SAS Institute Inc., 2008) with genotype, crop cycles and their interactions being fixed while farms nested in sites were taken as random. This analysis was based on assumption that farms are a random sample of many possible farms. Means within each crop cycle were separated by comparing to a standard check (Mbwazirume) using adjustment Dunnett's Test at 5% level of significance.

Multivariate analysis

Prior to the stepwise regression analysis, corm damage scores were first transformed using arcsine-transformation to reduce non-normality and heterogeneity of variance. All the data collected on the agronomic variables (height, girth, bunch weight and yield), weevil damage (XI, XO and XT) and black sigatoka disease scores (NSL at flowering, YLS, NSL at harvest and INSL) were then subjected to stepwise regression analysis. This was to remove variables that were highly correlated and carried similar information. To enhance the dispersion of banana hybrids to the agronomic traits, principal component analysis (PCA) was done on the variables that were retained by stepwise regression. The principal component axis was then plotted on a bi-plot to this effect.

RESULTS

Agronomic traits

Plant height, girth at 100 cm above the ground at flowering and the bunch weight of the banana hybrids are presented in Table 1. The height of banana hybrids at flowering was significantly different from that of Mbwazirume (286.33 cm) with hybrids12419S-13 and 7798S-2 being significantly taller in both the plant crop and first ratoon. Plant crop of Kisansa was also significantly taller than Mbwazirume, while banana hybrids 2729K-1, 9509S-5, 2409K-3, 9187S-8, 9494S-10, 2695K-4, 9540S-2, 9494S-36 and 12478S-13 and first ratoon crop of banana hybrids 9509S-5, 2409K-3, 9494S-36 and 12478S-13 were significantly shorter .

In general, most of the banana hybrids had small girths in both the plant and first ratoon crops. The pseudostem circumference (girth) for the banana hybrids ranged from 34.27 to 69.70 cm over the two seasons. The plant and first ratoon crops of banana hybrids 2729K-1, 9509S-5, 365K-1, 2409K-3, 8386S-19, 9187S-8, 9494S-10, 9750S-13, 2695K-4, 2729K-2, 2734K-1, 11777S-6, 9540S-2, 9494S-36 and 12478S-13 had significantly smaller girths compared to that of Mbwazirume (54.8 cm). Banana hybrids 7798S-2 and 12419S-13 had the largest pseudostem circumference amongst the hybrids in both the plant and first ratoon crops but they were not significantly different from Mbwazirume (Table 1).

The bunch weights of all the banana hybrids except the plant crop of banana hybrids 9509S-5, 2409K-3, 9540S-2 and 12478S-13 and the ratoon crop of 9540S-2 were heavier than that of Mbwazirume. The plant crop of banana hybrids 2625K-1, 9494S-36 and 12419S-13 were significantly heavier than that of Mbwazirume (13.9 kg). Banana hybrid 12419S-13 had the biggest bunch (24.3 kg). The plant crop of Kisansa was also heavier than Mbwazirume but it was not significantly different from it. In the first ratoon crop banana hybrids produced bunches that ranged from 17.3 to 26.3 kg. Banana hybrid 2729K-2 had the biggest bunch (26.3 kg). But they were not significantly different from that of Mbwazirume (17.8 kg) (Table 1).

The yield (t/ha/yr) of most banana hybrids was higher

Table 1. Means (n=1080) of the agronomic and yield parameters for East African highland banana derived hybrids by crop cycles compared to Mbwazirume in Kasangombe Sub County, Nakaseke District.

Genotype	Plant crop				First ratoon			
	Height (cm)	Girth (cm)	Bunch Weight (kg)	Yield (Tones/ha/yr.)	Height (cm)	Girth (cm)	Bunch weight (kg)	Yield (Tones/ha/yr.)
Mbwazirume	286.3	54.8	13.9	10.2	332.4	66.6	17.8	14.2
Kisansa	311.2*	51.9	15.8	11.5	343.4	58.3*	17.6	13.5
2729K-1	244.3*	42.7*	18.9	13.5	293.2	51.2*	21.8	16.3
9509S-5	217.1*	34.3*	11.1	8.8	272.8*	44.1*	20.4	16.9
365K-1	254.8	44.6*	14.4	11.2	307.5	54.0*	20.0	16.9
2409K-3	222.6*	35.2*	11.9	9.7	278.4*	45.6*	19.6	16.3
7798S-2	336.7*	57.4	17.6	13.1	402.6*	69.7	-	-
8386S-19	280.4	46.7*	16.3	12.4	347.7	58.5*	24.9	19.9
9187S-8	252.6*	42.4*	16.5	12.2	307.4	54.9*	23.3	18.5
9494S-10	246.3*	39.6*	17.9	13.6	279.2*	47.0*	24.1	18.6
9750S-13	275.3	42.6*	19.5	15.2*	326.4	51.5*	22.7	18.4
2695K-4	249.1*	46.0*	18.1	13.4	306.9	56.7*	23.7	19.2
2729K-2	269.5	44.3*	18.9	14.8	318.4	53.3*	26.3	20.7
2625K-1	300.4	49.1	21.3*	16.5*	343.3	58.7*	23.2	18.3
2734K-1	257.9	43.7*	16.4	12.6	318.4	52.3*	19.9	16.3
11777S-6	292.1	44.6*	17.9	13.4	345.4	53.8*	19.8	15.4
9540S-2	254.0*	36.7*	13.0	10.2	302.0	43. 5*	17.3	14.5
9494S-36	249.0*	45.8*	20.7*	16.4*	280.6*	50.8*	22.0	18.3
12478S-13	230.9*	40.3*	13.4	10.4	286.3*	51.5*	19.0	15.3
12419S-13	342.6*	56.0	24.3*	17.0*	381.9*	63.1	25.9	18.6

*Means within the same column are significantly different from Mbwazirume, - missing data.

than that of Mbwazirume in the two cycles. But only the plant crop of banana hybrids 9750S-13, 2625K-1, 9494S-36 and 12419S-13 had significantly higher yield (Table 1).

Response to black Sigatoka disease

Table 2 shows the number of functional leaves at flowering, harvest and the scores for the youngest leaf spotted. The plant crop of banana hybrids 9509S-5, 365K-1, 2695K-4 and 9540S-2 displayed significantly higher number of functional leaves than the local check (Mbwazirume). Banana hybrid 8386S-19 had the highest number of functional leaves (approximately 12 leaves). While the first ratoon crop of banana hybrids 9509S-5, 2409K-3, 8386S-19, 9187S-8, 9494S-10, 9750S-13, 2729K-2, 2625K-1, 11777S-6, 9540S-2, 12478S-13 and 12419S-13 produced significantly higher number of functional leaves at flowering than Mbwazirume. Banana hybrid 12478S-13 had the highest number of leaves (approximately 13) on the day of flowering. But the local checks (Kisansa and Mbwazirume) had almost the same number of functional leaves at flowering (Table 2).

In addition to what was earlier mentioned all the banana hybrids displayed significantly higher scores of youngest leaf spotted when compared to Mbwazirume and Kisansa in both the plant and first ratoon crops. However, the ratoon crop of banana hybrid 2734K-1 was not significantly different from Mbwazirume. Banana hybrid 8386S-19 and 12478S-13 had the highest score of youngest leaf spotted in the plant crop and first ratoon crop respectively (Table 2).

Index of non-spotted leaf was also significantly higher for the banana hybrids in both the plant crop and the first ratoon crop than Mbwazirume (Table 2). Banana hybrid 9494S-10 and 8386S-19 had the highest index of non-spotted leaf in the plant crop and first ratoon crop respectively. Also the plant crop of Kisansa had significantly higher index of non-spotted leaf compared to Mbwazirume.

At harvest, all banana hybrids except 2734K-1 had significantly more functional leaves in both the plant and first ratoon crops. The plant crop of banana hybrids 12478S-13 and 2729K-2 retained the highest number of leaves (approximately 6 leaves). Banana hybrid 7798S-2 and 9540S-2 retained the least number of leaves (approximately 3 leaves). In the first ratoon crop banana hybrids 2729K-2, 12478S-13 and 9494S-10 retained the highest number of leaves (approximately 5 leaves). Banana hybrid 2625K-1 retained the least number of leaves (approximately 3 leaves) (Table 2).

Table 2. Mean (n=1080) number of functional leaves at flowering and harvest of East African highland banana hybrids and the scores for the youngest leaf spotted on the plant crop and first ratoon crop.

Genotype	Plant crop				First ratoon crop			
	Number of functional leaves at flowering	Youngest leaf spotted	Index of non-spotted leaf	Number of functional leaves at harvest	Number of functional leaves at flowering	Youngest leaf spotted	Index of non-spotted leaf	Number of functional leaves at harvest
Mbwazirume	7. 9	4.6	46.0	1.7	7.7	4.6	45.5	1.6
Kisansa	8.0	5.2	53.1*	1.3	7.6	4.7	48.6	1.5
2729K-1	10.2*	9.3*	82.6*	3.6*	9.5	9.1*	85.3*	3.9*
9509S-5	9.6	8.8*	79.1*	4.4*	11.4*	11.0*	85.9*	4.0*
365K-1	9.4	8.4*	77.8*	4.4*	8.9	8.0*	79.2*	4.3*
2409K-3	9.7*	8.7*	79.3*	4.0*	11.9*	9.8*	74.8*	3.5*
7798S-2	11.0*	9.1*	75.5*	3.3*	10.2	8.4*	69.3*	-
8386S-19	12.1*	10.8*	80.5*	4.4*	12.5*	12.1*	89.7*	3.5*
9187S-8	10.8*	10.3*	85.8*	3.7*	10.4*	10.1*	86.9*	4.4*
9494S-10	10.9*	10.5*	87.3*	5.2*	11.2*	11.0*	88.8*	5.4*
9750S-13	11.0*	10.2*	85.7*	4.7*	10.7*	10.5*	89.0*	4.1*
2695K-4	9.2	8.5*	82.4*	4.0*	9.5	8.7 *	80.9*	3.7*
2729K-2	11.4*	10.3*	83.3*	5.6*	11.7*	11.1*	86.1*	5.3*
2625K-1	10.0*	9.6*	85.3*	3.5*	10.2*	9.2*	80.7*	3.4*
2734K-1	10.1*	7.6*	65.0*	1.3	8.9	6.3	58.9*	1.3
11777S-6	11.8*	9.5*	72.9*	4.2*	10.6*	9.0*	76.7*	4.6*
9540S-2	9.2	8.6*	81.9*	3.3*	10.85*	9.3*	76.1*	3.5*
9494S-36	10.3*	9.5*	82.2*	3.5*	9.5	8.7*	81.4*	3.6*
12478S-13	11.2*	10.4*	84.1*	5.5*	12.7*	12.6*	89.0*	5.4*
12419S-13	11.9*	9.4*	71.6*	4.1*	11.1*	9.9*	79.7*	5.1*

*Means within the same column are significantly different from Mbwazirume, - missing data.

Multivariate analysis

From the stepwise regression analysis only plant height, girth and number of functional leaves at flowering, index of non-spotted leaf and total cross section damage greatly influenced the yield of the hybrids (Table 3). The principal component analysis (PCA) based on a correlation matrix between the agronomic variables and total cross section damage, showed that all variables except total cross section damage positively influenced bunch weight (Table 4).

PCA grouped the agronomic variables, disease and weevil total cross sectional damage variables into six components that together accounted for 100% of the original variation (Table 5). However, three principal components were retained as these accounted for 88.79% of the total variability in the data, where PCA 1 accounted for 48.42% of the total variation, while PCA 2 accounted for 31.93% and PCA 3 accounted for 8.44% of the total variation.

PCA components presented in Table 5 can therefore be interpreted as correlations between

Table 3. Parameter estimates of variables that affect banana yield (bunch weight) of East African highland banana derived hybrids using stepwise regression analysis

Variable	Parameter estimate	Standard error	Type II SS	F -Value	Pr > F
Intercept	-14.86121	1.49795	3070.89513	98.43	<.0001
Girth	0.32850	0.02873	4078.93230	130.74	<.0001
Height	0.01805	0.00517	379.66705	12.17	0.0005
Number of functional leaves at flowering	0.72701	0.07648	2818.96030	90.35	<.0001
Index of non-spotted leaf	0.07781	0.01051	1711.16966	54.85	<.0001
Total cross section damage	-0.08527	0.03311	206.94301	6.63	0.0101

Table 4. Correlation coefficient between agronomic and weevil damage variables of the data collected from East African highland banana derived hybrids in Kasangombe Sub-county, Nakaseke District.

Variable	Bunch weight	Girth	Height	Number of functional leaves at flowering	Index of non-spotted leaf	Total cross section damage
Bunch weight	1.00	-	-	-	-	-
Girth	0.31	1.00	-	-	-	-
Height	0.41	0.85	1.00	-	-	-
Number of functional leaves at flowering	0.36	-0.26	-0.02	1.00	-	-
Index of non-spotted leaf	0.39	-0.51	-0.36	0.71	1.00	-
Total cross section damage	-0.17	0.48	0.32	-0.57	-0.60	1.00

Table 5. Eigenvectors of principal component analysis using agronomic, disease and weevil damage variables.

Variable	PC1	PC2	PC3	PC4	PC5	PC6
Bunch weight	-0.07	0.62	0.59	-0.31	-0.39	0.10
Girth	0.46	0.39	-0.15	-0.04	0.50	0.60
Height	0.37	0.50	-0.34	0.05	0.01	-0.70
Number of functional leaves at flowering	-0.41	0.38	-0.41	0.57	-0.33	0.29
Index of non spotted leaf	-0.51	0.23	0.33	0.24	0.69	-0.23
Total cross section damage	0.47	-0.12	0.49	0.72	-0.11	-0.02
Percentage of total variation:	48.42%	31.93%	8.44%	6.83%	2.56%	1.82%
Eigen Value:	2.9	1.9	0.5	0.4	0.2	0.1

bunch weight, growth, disease and pest parameters with the components. The first PCA (PC 1) is about the performance for growth parameters; Girth (with 0.46 loading) and height (with 0.37 loading) and banana weevil damage scores (with 0.47 loading) contrasted by disease score parameters (functional leaves (with -0.41 loading) and index of non-spotted leaf (with -0.51 loading). The second PCA is about the performance of bunch weight and growth parameter both have large positive loadings (Table 5). This was then put on a bi-plot of PC1 and PC2 against the hybrids (Figure 1). Hybrids (12419S-13, 2625K-1 and 7798S-2) are grouped in the first quadrant. While hybrids (9509S-5, 9540S-2, 12478S-13 ,2409K-3, 2729K-1 and 9187S-8) in third quadrant. On the other hand, hybrids 2695K-4, 2734K-1 and 365K-1 were grouped together so are the local checks (Mbwazirume and Kisansa) but these two groups are in the second quadrant. Hybrids 9494S-36, 11777S-6, 9494S-10, 9750S13, 8386S-19 and 2729K-2 are grouped in the fourth quadrant.

Girth, index of non-spotted leaves and total cross sectional damage contributed higher in the first PCA (PC 1). Height and bunch weight had higher loading in the second PCA (PC 2). Bunch weight and total cross

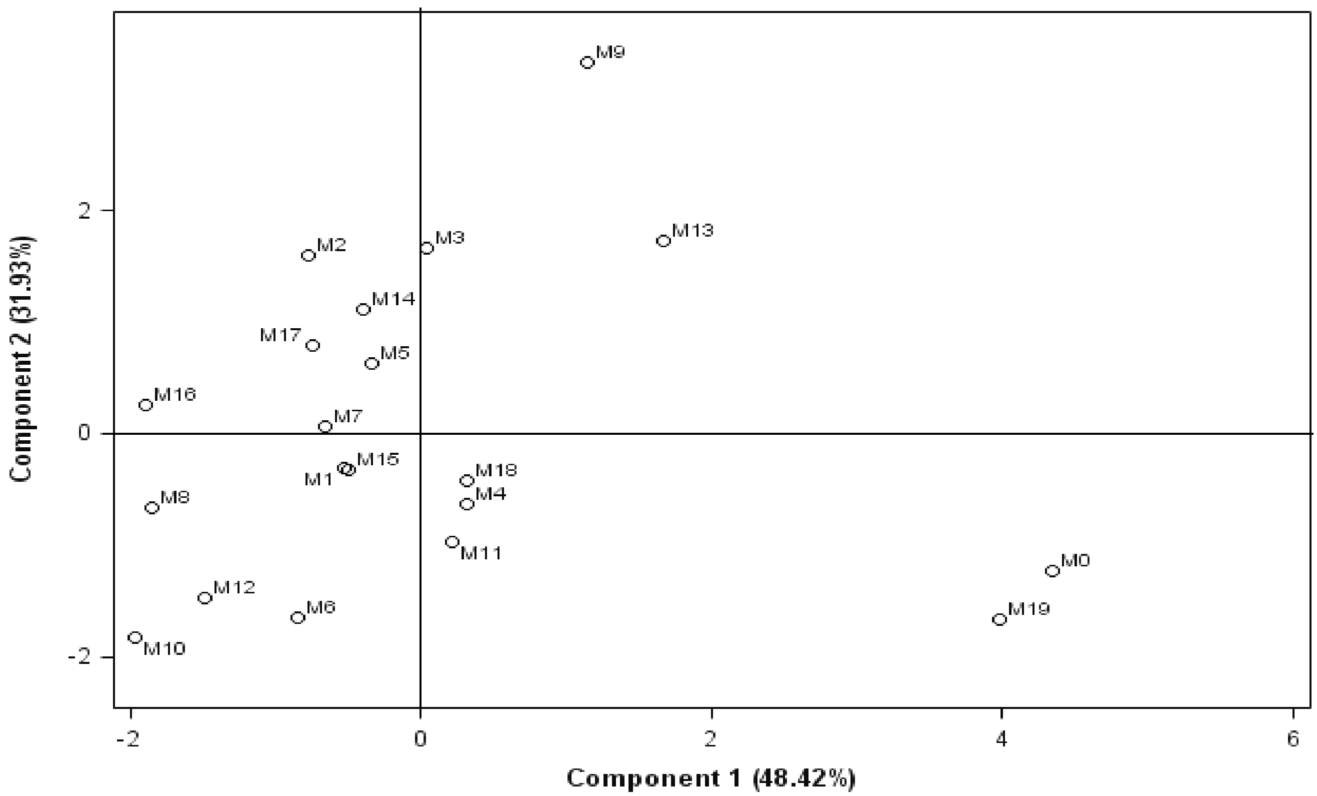

Figure 1. Plot of first (PC1) and second (PC2) principle components from a principal component analysis of agronomic, black Sigatoka disease and one weevil damage variables of East African highland banana derived hybrids in Kasangombe sub county, Nakaseke District. (Codes for the hybrids / genotypes: M0 = Kisansa M10 = 9509S-5; M1 = 2729K-1 M11 = 365K-1; M2 = 2729K-2 M12 = 2409K-3; M3 = 2625K-1, M13 = 7798S-2; M4 = 2734K-1, M14 = 8386S-19; M5 = 11777S-6, M15 = 9187S-8; M6 = 9540S-2, M16 = 9494S-10; M7 = 9494S-36, M17 = 9750S-13; M8 = 12478S-13, M18 = 2695K-4; M9 = 12419S-13, M19 = Mbwazirume.

sectional damage had higher loading in the third PCA (PC3) (Table 5). A bi-plot of PC1 and PC2 against the hybrids, grouped banana hybrids 12419S-13, 2625K-1 and 7798S-2 in the first quadrant . While hybrids 9509S-5, 9540S-2, 12478S-13, 2409K-3, 2729K-1 and 9187S-8 in third quadrant (Figure 1). On the other hand, banana hybrids 2695K-4, 2734K-1 and 365K-1 were grouped / clustered together so are the local checks (Mbwazirume and Kisansa) but these two groups are in the second quadrant . Banana hybrids 9494S-36, 11777S-6, 9494S-10, 9750S13, 8386S-19 and 2729K-2 are grouped in the fourth quadrant. These two groups are placed on the second axis (Figure 1).

DISCUSSIONS

All the banana hybrids except 7798S-2 and 12419S-13 were short but they were within the expected heights (≤ 3m) (Jones 1994). They also had smaller pseudostems, suggesting that only banana hybrids7798S-2 and 12419S-13 had an advantage of big support in the soil, and this could also make them more tolerant to snapping due to wind or storm, one of the causes of yield loss in banana plantations (Stover and Simmonds, 1987). Thus some of these losses are reduced and translated into economic benefits for commercial growers but also enhanced food security for subsistence farmers (Daniels, 2002). These hybrids can further support heavier bunches without any form of bunch support like wooden props (Alvarez, 1997; Daniels, 2002). Similarly, Mukasa et al. (2005) reported that for successful perennial establishment of *Musa* plants accompanied by high yields depends on good root and shoot development in combination with good suckering.

Bunches of most banana hybrids were generally heavier than Mbwazirume. The development of a big / heavy bunch in bananas depends on the photosynthetic potential of the leaves. An increase in banana leaf area results in an increase in fruit production but this parameter will have some location specificity as photosynthetic activity is a function of leaf area and incident solar radiation (Smithson et al., 2001). The size of a bunch would influence consumer preference and according to Thompson and Wainwright (2007) most banana producers and consumers prefer cultivars with big bunches. This probably puts the hybrids 12419S-13, 9494S-36, 2625K-1, 9750S-13, 2729K-1, 2695K-4 and 2729K-2 at an advantage of being preferred by consumers.

Yield of most banana hybrids in both the two cycles were above the national average yield (14.9 tonnes per ha.) for bananas (Uganda National Household Survey Report 1995-96; Bagamba, 2007). The high yields could be due to the big bunches produced coupled with short production cycle. This was in agreement with Bananuka et al. (2000) who reported that large bunch weight and yield in bananas is attributed to higher growth rate before flowering and high number of functional leaves at flowering and harvest.

Most of the banana hybrids had many functional leaves (at least 9) at flowering compared to local checks. To guarantee good development of the bunch and high quality fruits, a plant must have at least 8 functional leaves during its whole growth period and similar number of healthy at flowering (Ortiz and Vuylsteke 1994; Orjeda 1998; Tushemereirwe et al., 2003). The presence of many leaves in these hybrids may be explained by the fact that they were less susceptible to black Sigatoka disease at flowering. This was further supported by high scores of youngest leaf spotted (YLS) at flowering. Basing on Craenen (1998) levels of host response to black Sigatoka disease, banana hybrids can therefore be categorized as follows: 2734K-1 was susceptible hybrid (< 8 leaves without symptoms); 2729K-1, 9509S-5, 365K-1, 2409K-3, 7798S-2, 2695K-4, 2625K-1, 11777S-6, 9540S-2, 9494S-36 and 12419S-13 were less susceptible hybrids (between 8 – 10 leaves without spots) while 12478S-13, 2729K-2, 9750S-13, 9494S-10, 9187S-8 and 8386S-19 were partially resistant (>10 leaves without spots). The higher the number of youngest leaf spotted and functional leaves at harvest the better the tolerance to black Sigatoka (Barekye et al., 2002). It also correlates significantly with disease development time (Craenen, 1998). This implied that most of the banana hybrids (>8 leaves without spots) were less affected by the necrotic effect of the fungus (*Mycosphaerella fijiensis*), so the foliage of these plants remains green for long time hence less frequency of deleafing. Consequently, the banana hybrids had high index of non-spotted leaf because of high surface area to capture more radiant energy from the sun. They therefore had better potential of photosynthesizing and producing more assimilates which eventually turns into a big bunch. The opposite was true with the local checks (Mbwazirume and Kisansa).

In addition to what was earlier mentioned, the principal component analysis based on a correlation matrix between the agronomic and total cross section damage was in agreement with the study of Mukasa et al. (2005) who also reported that for successful perennial crop establishment of *Musa* plants, high yields depends on good root and shoot development in combination with good suckering. Pests and diseases also cause direct plant damage, hence affecting plant growth and yield (Gold et al., 2001).

Principal component (PC) 1 and PC2 were retained because they explained the largest proportion of the total variation (>70%) (Bartholomew et al. 2002). A plot of PC1 and PC2 showed that banana hybrids 12419S-13, 2625K-1 and 7798S-2 displayed very good agronomic traits (plant height and girth), and consequently bigger bunches but they appeared to be susceptible to black Sigatoka disease as compared to the banana hybrids in the third quadrant. This therefore implies that banana hybrids in the third quadrant were more tolerant to black Sigatoka disease but they produced smaller bunches. Heavier bunches are as a result of greater active leaf area as they lead to high total dry matter production or accumulation (Buah et al., 2000). But genotype could be a more critical factor in determining the yield potential of a given cultivar (Njuguna et al., 2008). This probably explains why some hybrids produced relatively smaller bunches even though they had many functional leaves both at flowering and harvest. On the other hand, on the second principal axis, Mbwazirume and Kisansa had good agronomic traits (girth and height) but they were more susceptible to black Sigatoka and thus produced smallest bunches compared to the hybrids that were also groupedin the fourth quadrant but they were more tolerant to black sigatoka disease. This also indicated that bigger bunches and higher yields in banana could be attributed to higher growth rate before flowering and high number of functional leaves at flowering and harvest (Bananuka et al., 2000).

Conclusion

Banana hybrids produced better bunches compared to the local check (Mbwazirume), and they also exhibited better response to black Sigatoka disease. Banana hybrids 12419S-13, 7798S-2 and 2625K-1 had outstanding big bunches and they also had better tolerance to black Sigatoka disease. They should therefore be recommended for sensory evaluation to establish the ones that would be preferred by farmers. Those with consumer desired traits can then be multiplied and distributed to other areas where black Sigatoka disease is still a production constraint.

ACKNOWLEDGEMENT

The authors wish to thank the Rockefeller Foundation for providing funds to develop the hybrids, and BMZ-IITA for the resources that supported this study. The authors are also grateful to Mulwana Felix, all the NBRP scientists and Technicians and the banana farmers in Kasangombe Sub county who participated in the study.

Conflict of Interests

The authors have not declared any conflict of interests.

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Vol. 11(13), pp. 1150-1158, 31 March, 2016
DOI: 10.5897/AJAR2015.9819
Article Number: 92C992A57833
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Yield of maize hybrids: Is there any association among nitrogen rate, *Azospirillum* inoculation and fungicide treatment?

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Received 16 April, 2015; Accepted 17 February, 2016

Optimization of land use can be attained by incorporating technologies to crop production, such as the use of diazotrophic bacteria, fertilizers, and pesticides. Seed inoculation with *Azospirillum* is an alternative that favors the incorporation of green agriculture in regions of conventional farming, such as the Brazilian savannah (Cerrado). However, limited information is available about this bacterium's contribution to agriculture when other technologies are also incorporated. This study evaluated the performance of maize hybrids inoculated, or not, with *Azospirillum brasilense*, with or without fungicide applications, and subjected to different nitrogen rates under Cerrado field conditions. Each factor analyzed contributes to the increased maize grain yield. The use of inoculants containing plant growth promoting bacteria is a good option to ensure high yield of maize. Still, nitrogen should not be replaced, neither totally nor partially, by seed inoculation with *Azospirillum*. Fungicide applications should be done, as required, during maize cycle. Moreover, specific maize breeding programs should consider the affinity between *Azospirillum* strains and maize hybrids, mainly for regions with nitrogen deficient soils, like Cerrado. Thus, by incorporating additional technologies, maize crop farmers can optimize land use and, consequently, reduce the expansion into new agricultural areas.

Key words: Foliar protection, nitrogen use, plant growth promoting bacteria, sustainability, *Zea mays* L.

INTRODUCTION

Optimization of land use has been the focus of international discussions for a long time. Recently, in RIO + 20, once again this aspect was addressed, now emphasizing the idea of "green economy" (Scarano et al., 2012). In fact, many farmers do not take advantage of the area's full potential (Silva et al., 2006; Brannstrom et al.,

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2008; Valipour, 2012, 2013; Sá et al., 2013). Thus, agriculture moves into new areas, turning it in an unsustainable business (Klink and Machado, 2005; Gallardo and Bond, 2011). Furthermore, the global area available for agricultural purposes is becoming increasingly scarce and many experts state that the Brazilian savannah (Cerrado), a biodiversity hotspot, is the last agricultural frontier of the world (CEPF, 2015).

One of the biggest granaries of the world, Cerrado is responsible for most of the Brazilian commodity production, especially soybean and maize (Trivedi et al., 2012; CONAB, 2015a). Current maize production with new hybrids has potential yield between 9 and 15 t ha^{-1}. However, in Brazil, the average production is approximately 5.1 t ha^{-1} (CONAB, 2015b), demonstrating that natural resources are poorly managed. Thus, questions about how to solve this problem and how to give maize a label of green agriculture product become important. The immediate answer is the use of technologies that maximize plant genetic potential. One of these technologies, which has been adopted for some time, is seed inoculation with *Azospirillum* (Bashan et al., 2004; Cavaglieri et al., 2009; Hungria et al., 2010; Hungria, 2011).

Since Cerrado soils are naturally nitrogen deficient (Lopes and Cox, 1977; Araújo and Haridasan, 1988; Haridasan, 1994; Bortolini et al., 2001; Ohland et al., 2005; Bustamante et al., 2006; Souza, 2006; Haridasan, 2008), seed inoculation with *Azospirillum* could result in increased maize production (Cavaglieri et al., 2009; Compant et al., 2010; Hungria et al., 2010). However, the incorporation of a new technology, in general, does not replace other practices used.

Pesticide spraying and fertilization are among the most common practices used in cropping systems. Still, the wide use of pesticides in modern agriculture may cause side-effects on non-target microbiota (Pereyra et al., 2009). In this perspective, seed inoculation with *Azospirillum* is controversial. Some authors state that interactions between pesticides and microbes are compatible, such as for tebuconazole and *A. brasilense* sp245 on wheat (Pereyra et al., 2009); while others assert that these interactions are incompatible, such as for carbofuran, chlormephos, terbufos and benfuracarb with *A. lipoferum* strain CRT1 on maize (Revellin et al., 2001). Similarly, another interesting and controversial issue is the use of fertilizers, especially nitrogen, together with *Azospirillum* inoculation. Although strains of *Azospirillum* can improve plant growth and development (Cassán et al., 2009; Hartmann and Bashan, 2009), some studies suggest that nutrient supplementation with mineral fertilizers is needed for greater grain yields (Díaz-Zorita and Fernández-Canigia, 2009), especially for maize (Mehnaz et al., 2010; Ferreira et al., 2013; Myresiotis et al., 2014), in which practices such as fertilization and pesticide application may impair efficacy of treatments with *Azospirillum*. Studies about the interaction among these practices in maize are restricted, mainly on field conditions. Thus, questions are raised by farmers and scientists involved in the maize chain. Therefore, the association of *Azospirillum* seed inoculation, with nitrogen fertilization, and with plant protection in maize production, their combination on yield, and the consequences of such combination in nitrogen use from the physiological point of view were evaluated.

MATERIALS AND METHODS

Site description

The study was done at 18°59'02'' S and 47°27'39'' W during the crop season of 2009/2010, under Cerrado field conditions. The region's climate is classified as humid subtropical (Cwa, according to Köppen's climate classification), with average temperature of 22.8°C and precipitation around 1539 mm per year. Weather was ideal for maize crop during the experiment conduction (Figure 1). Previously to the experiment, soil samples were taken arbitrarily from spatially distributed points, from the 0-20 cm layer, and chemically and physically analyzed. Chemical parameters evaluated were soil pH (in H_2O), exchangeable P (in $Mehlich^{-1}$), exchangeable K, Ca, Mg and Al. All parameters were analyzed according to the Committee of Soil Fertility of Minas Gerais State (CFSEMG) (1999). The main chemical and physical characteristics of the soil at the establishment of the experiment are shown in Table 1. The soil of the experimental area is classified as an Oxisol.

Experimental model design

A randomized block design was set up, with six replications, in a 4 × 2 × 2 × 6 factorial structure. Four maize hybrids inoculated, or not, with *Azospirillum brasilense*, with or without fungicide applications, and subjected to different nitrogen rates (50, 100, 150, 200, 250 and 300 kg N ha^{-1}) were evaluated.

Each plot consisted of six 5.2 m long rows, 0.6 m apart, covering an area of 18.7 m^2 per plot and an experimental area of 5,391.4 m^2. The four central rows were used for evaluations, discarding 1 m from each row end.

Seed inoculation

Maize seeds were inoculated with strains of the bacterium *A. brasilense* (Ab-V5 and Ab-V6) in a minimum concentration of 2×10^8 viable cells ml^{-1}. Mixture was carefully done, in plastic bags, to ensure a uniform distribution of the liquid inoculant on the seeds, at a dose equivalent to 100 ml ha^{-1}. Therefore, theoretical estimate of bacterium cells per seed was 285,714. Maize hybrids used in the study (coded 1 to 4) are genetically modified materials of high yield potential and belong to four different maize breeding companies. The hybrids were selected because they are recommended for Cerrado conditions.

Experiment conduction

Sowing was done immediately after seed inoculation with *Azospirillum*, in a no-tillage system and an approximate stand of 70,000 plants ha^{-1}. Basic fertilization was applied at sowing consisting of 625 kg ha^{-1} of the NPK formula 08-20-20 + 0.5% Zn. When maize plants were at V_6 stage (Ritchie et al., 1992), 78 kg K_2O ha^{-1} were applied broadcast, as well as different rates of urea

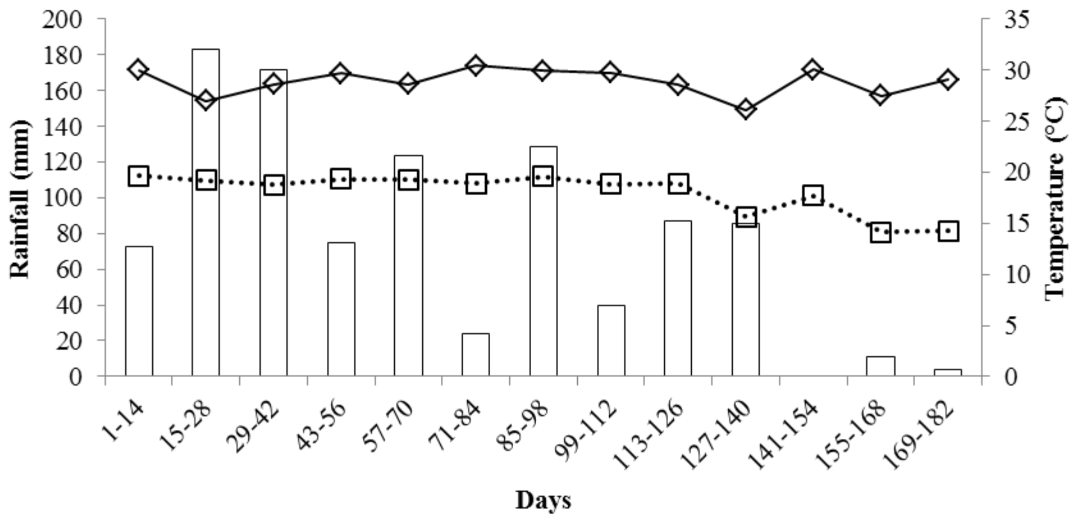

Figure 1. Pluvial precipitation, minimum and maximum temperatures from 17 Nov 2009 to 19 May 2010 at the site where the experiment was conducted (18°59'02'' S and 47°27'39'' W). Source: Laboratory of Climatology of the Federal University of Uberlândia, MG, Brazil.

Table 1. Soil chemical and physical properties (0-20 cm) at the experiment site.

Chemical											Physical
pH	P	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	Al+H	CEC[z]	T_{CEC}[z]	BS[z]	OM[z]	Clay
(H_2O)	(mg kg^{-1})	($mmol_c$ kg^{-1})							(%)	(dag kg^{-1})	(g kg^{-1})
5.5	15.1	4.0	24.0	6.0	0.0	36.0	70.0	34.0	48	3.4	411

[z]Cation Exchange Capacity (H+Al+Ca+Mg+K); T_{CEC} (Ca+Mg+K); Base Saturation (T_{CEC}/CEC) × 100; Organic Matter.

according to the treatment. Herbicides were used for weed control and insects were controlled with biological and chemical insecticides, according to technical recommendations for the crop, described by the pesticides' manufacturers. Fungicide applications were done at V_8, V_T and R_3 stages with a triazole + strobilurin-based product (in treatments with foliar protection). The dose of the commercial product and mineral oil used were 300 ml + 600 ml ha^{-1}, respectively, at the spray volume 150 L ha^{-1}.

Harvest

Ears from each experimental plot were mechanically harvested and processed when maize grains with 23% of moisture. Weight and humidity were determined on onboard scale and grain-moisture tester, in the harvester. Data were extrapolated to a one-hectare area and corrected to 13% moisture content, rendering productivity values in kg ha^{-1}.

Statistical analysis

All assumptions required for the analysis of variance (ANOVA) were confirmed. The error normality was evaluated by Kolmogorov-Smirnov and the variance of homogeneity by Levene, both at 0.01 significance level. Subsequently, the data set was submitted to the ANOVA (Table 2). When significant differences were detected ($P \leq 0.05$), averages of inoculation effect and of foliar protection were compared by the Tukey test and averages of nitrogen rates by polynomial regression. All analyses were done at 0.05 significance level.

RESULTS

Effects of nitrogen fertilizer, *Azospirillum* inoculation, and foliar protection on maize grain yield

Each factor analyzed contributed to the increase of maize grain yield. Besides isolated effects, productivity was affected by the inoculation with *Azospirillum* combined with the fungicide application, and by the latter factor with the hybrids studied (Table 2). However, the second interaction will not be addressed in this paper since the focus is not the recommendation of maize hybrids, neither the study of their performance in the field, considering that new hybrids are constantly developed and released on the market. Thus, the effects of technologies on maize crop production are emphasized, regardless of the hybrid used by farmers.

Nitrogen fertilization promoted greater maize yield. Crop production peaked up to 9.41 t ha^{-1} at 256 kg N ha^{-1}

Table 2. Analysis of variance.

Source of Variation	DF	Mean Square Grain Yield	*F*
Hybrid (Hyb)	3	48,365,385.94*	260.22
Azospirillum (Azos)	1	36,147,851.49*	194.48
Nitrogen (N)	5	2,495,142.77*	13.42
Fungicide (Fung)	1	273,671,648.58*	1,472.43
Hyb x Azos	3	216,316.95ns	1.16
Hyb x N	15	201,803.18ns	1.09
Hyb x Fung	3	24,523,347.17*	131.94
Azos x N	5	258,140.05ns	1.39
Azos x Fung	1	1,560,221.66*	8.39
N x Fung	5	317,722.49ns	1.71
Hyb x Azos x N	15	91,945.92ns	0.49
Hyb x Azos x Fung	3	191,265.04ns	1.03
Hyb x N x Fung	15	105,917.16ns	0.57
Azos x N x Fung	5	101,598.25ns	0.55
Hyb x Azos x N x Fung	15	41,968.96ns	0.23
Block	5	1,528,514.80	8.22
Error	475	185,864.27	260.22
CV (%)		4.64	

* and ns: significant and not significant by the *F* test (Snedecor statistics) at 0.05 significance level; DF: Degree of freedom; CV: Coefficient of variation.

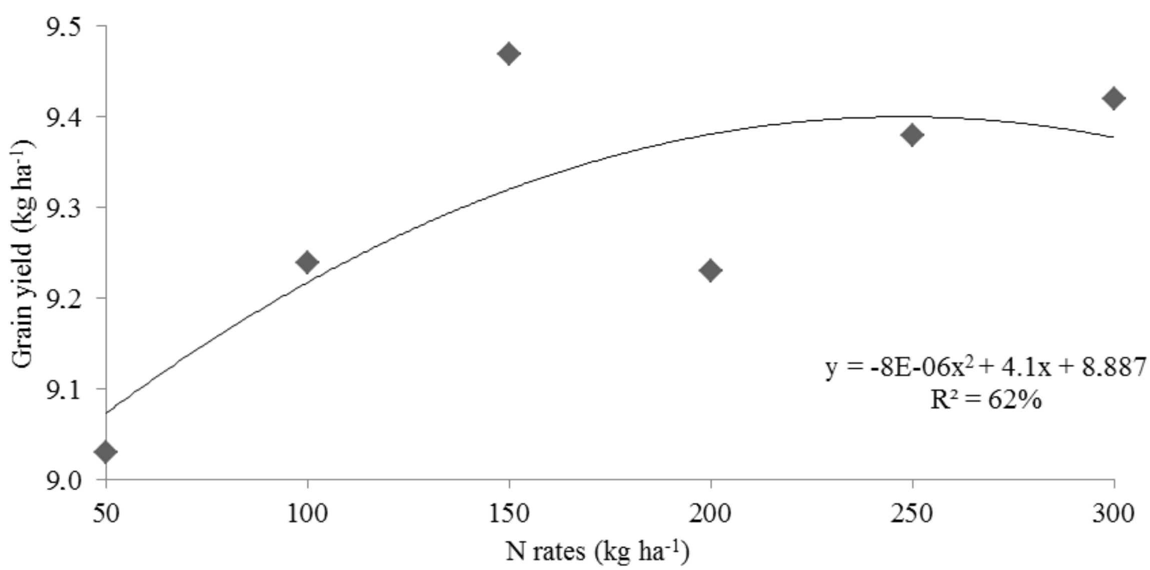

Figure 2. Grain yield of maize hybrids in response to nitrogen fertilization.

(Figure 2). In contrast, inoculation of maize hybrids with *A. brasilense* resulted in yield increases varying from 4 to 6% (approximately 400 to 600 kg ha^{-1}) (Figure 3). Fungicide applications also contributed to increased crop productivity, regardless of the hybrid tested. Foliar protection promoted an increment of 30% in maize production (Figure 4). Besides the isolated effects of inoculation and foliar protection on hybrids' yield, a noteworthy increase in maize productivity was obtained when both practices were associated (Table 3). This increase was 22% above the control (with neither fungicide spraying nor *Azospirillum* inoculation).

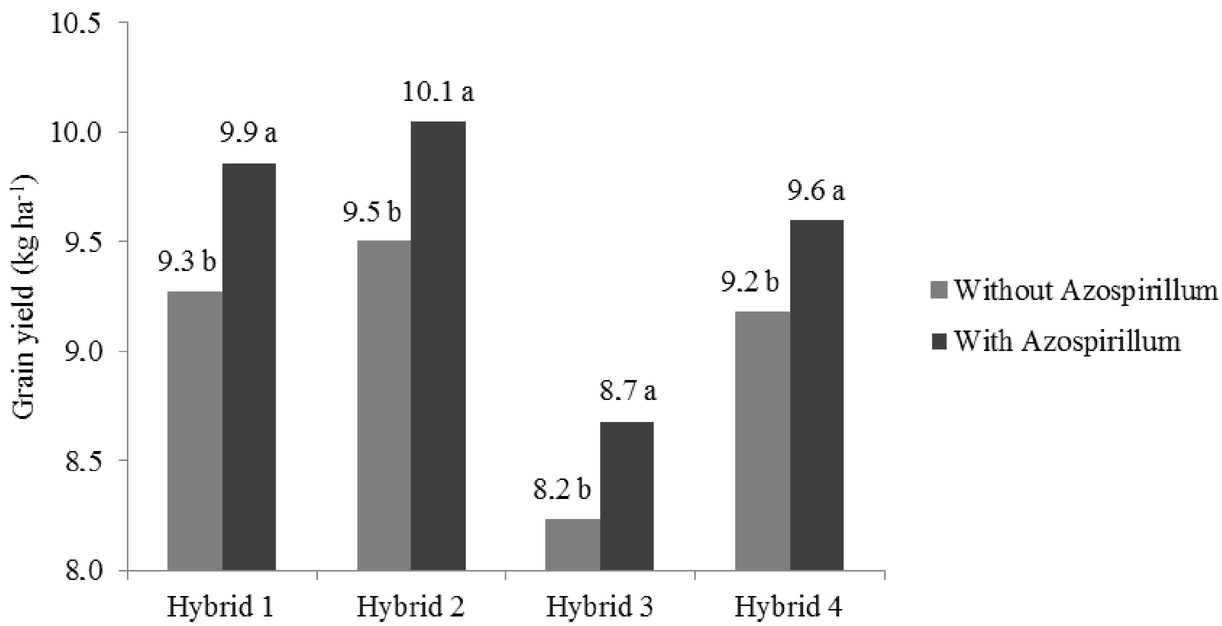

Figure 3. Grain yield of maize hybrids in response to *A. brasilense* inoculation*.*averages followed by different letters, for each hybrid, are statistically different by the Tukey test ($P \leq 0.05$).

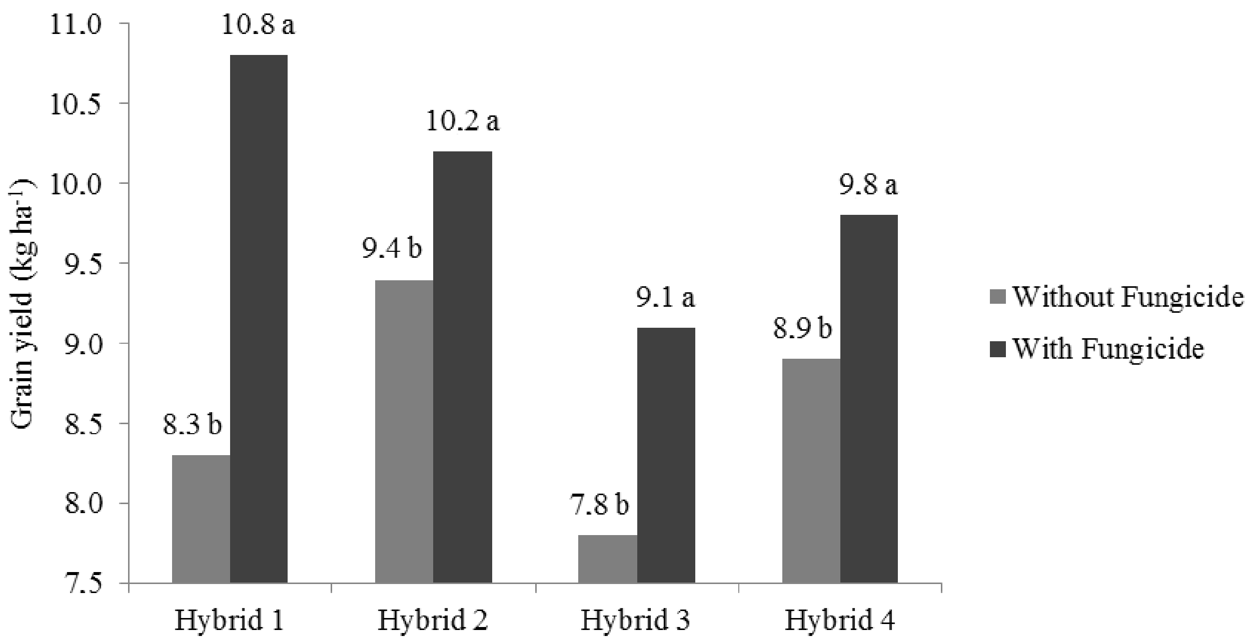

Figure 4. Grain yield of maize hybrids in response to fungicide applications*.*averages followed by different letters, for each hybrid, are statistically different by the Tukey test ($P \leq 0.05$).

Effects of A*zospirillum* inoculation and foliar protection on maize nitrogen use

Regardless of the rate of nitrogen applied, maize grain yield increased due to the inoculation with *A. brasilense* (Figure 5), indicating better nitrogen fertilizer use by the plants. Fungicide spraying also optimized nitrogen use by the hybrids (Figure 6). Analyzing each nitrogen rate (50, 100, 150, 200, 250 and 300 kg ha^{-1}), fungicide use led to increases of 14 to 17% in maize productivity,

Table 3. Grain yield of maize hybrids (kg ha^{-1}) in response to fungicide applications and *A. brasilense* inoculation*.

Azospirillum brasilense	**Foliar protection**	
	With	**Without**
Inoculated	10.3^{aA}	8.8^{aB}
Non inoculated	9.7^{bA}	8.4^{bB}

*averages followed by different letters, in lowercase in the columns and uppercase in the lines, are statistically different by the Tukey test ($P \leq 0.05$).

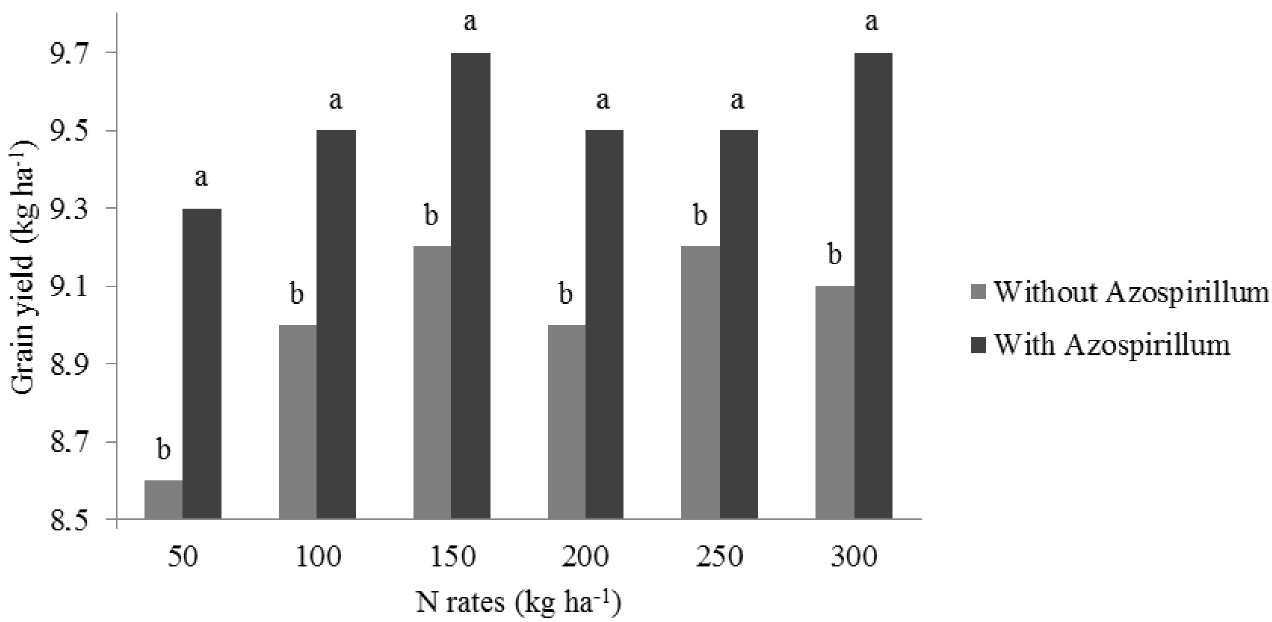

Figure 5. Grain yield of maize hybrids in response to *A. brasilense* inoculation and nitrogen fertilization*.*different letters, for each N dose, are statistically different by the Tukey test ($P \leq 0.05$).

corresponding to 1.2 to 1.5 t ha^{-1}.

DISCUSSION

The quadratic response of maize yield to increasing rates of nitrogen was also reported by Silva et al. (2005). This result could be explained by ammonia volatilization due to urea application to the soil. Urea hydrolysis raises the pH around the fertilizer granules and converts all of its N content into NH_4^+, which reacts with OH^- resulting in H_2O and volatile NH_3^+, which is phytotoxic. Thus, high nitrogen rates applied via urea can impair plant development, and, consequently, decrease production.

The inoculation of maize hybrids with *A. brasilense* led to greater yields. This increase varied among the hybrids tested due to their genetic constitution, which is consistent with several studies demonstrating affinity between *Azospirillum* strains and maize genotypes, altering their responses to inoculation (Salamone and Döbereiner, 1996; Salamone et al., 1996). This also emphasizes that research on selection of bacteria that are able to associate effectively to maize genotypes are essential in order to ensure investment return.

A wide range of responses of cereals to inoculation with *Azospirillum* is reported. Studies show yield increases varying from 5 to 30% (Okon and Labandera-González, 1994) and from 662 to 823 kg ha^{-1} in relation to non-inoculated controls (Hungria et al., 2010). In this study, grain yield increases varied from 4 to 6% (which represents 400 to 600 kg ha^{-1}), meaning that even highly productive maize genotypes, obtained from conventional and biotechnological breeding, can have yield increased by seed inoculation with *Azospirillum*.

Therefore, inoculation enabled yield increases of maize crops growing under Cerrado conditions, which resulted from the affinity between *Azospirillum* and hybrids recommended for the region. Thus, inoculation allowed optimization of land use and even small and medium farmers (in low investment production systems) can obtain greater yields with this technology.

Increased production of maize can be attributed to the

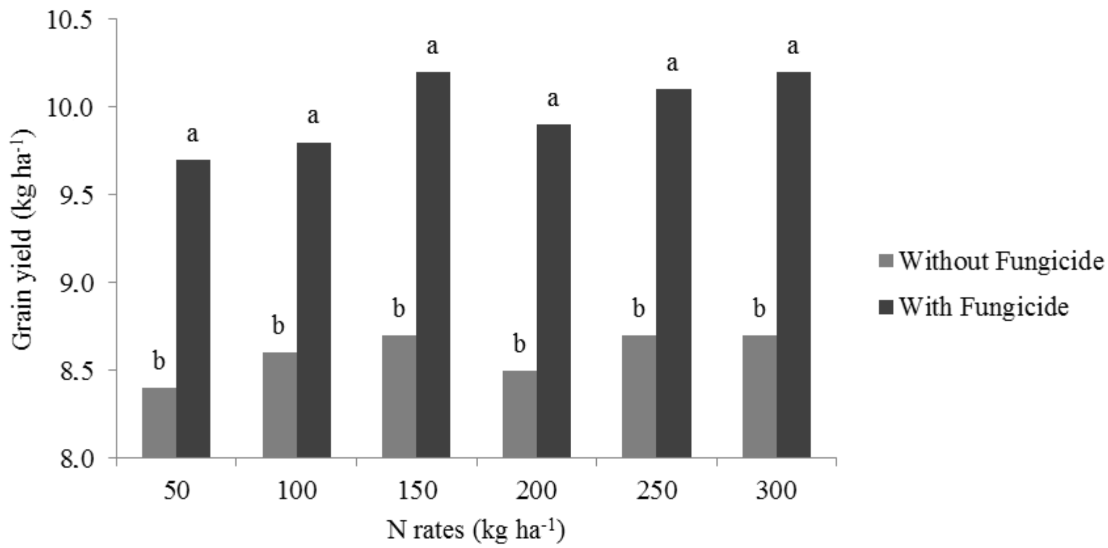

Figure 6. Grain yield of maize hybrids in response to fungicide applications and nitrogen fertilization*. *different letters, for each N dose, are statistically different by the Tukey test ($P \leq 0.05$).

phytostimulatory effects of inoculation with *Azospirillum*, due not only to biological nitrogen fixation in the rhizosphere, but also to plant's greater efficiency in water and nutrient uptake due to greater growth of root system provided by the production of plant growth promoting substances by the bacteria (Döbereiner, 1992; Reis et al., 2000; Cassán et al., 2008). Better nitrogen fertilizer use was observed when maize hybrids were inoculated with *Azospirillum*. From this result it can be inferred that *Azospirillum* inoculation enhances nitrogen use, although it does not replace it. Thus, even if part of the maize nitrogen demand is supplied by association with diazotrophic bacteria, reduction of nitrogen fertilizer rates is not recommended. This result, however, contrasts with the one reported by Hungria (2011), who found substantial reduction of nitrogen fertilization in maize plants inoculated with *Azospirillum*. Applying a nitrogen rate equivalent to half of that recommended for maize in Brazil (100 kg N ha^{-1}), the researcher obtained grain yield of 7.8 t ha^{-1} (Hungria, 2011). However, it must be stated that such production was achieved only with the strain Ab-V5 (+ 54 kg N ha^{-1}) in a single crop season. Besides the previously mentioned aspects, foliar protection affected maize yield as well. The hybrids obtained greater yield potential, reaching up to 10.2 t ha^{-1}, after fungicide applications. This is certainly related to treated plants health. In treatments without fungicide application, hybrid photosynthetic activity may have been compromised, resulting in lower production. This ratifies the idea that investment in plant nutrition is jeopardized if correct phytosanitary management is not adopted. This statement is consistent with studies about effects of fungicide use to increase plant yield (Köhle et al., 2003).

Besides the already known foliar protection, it has been postulated that strobilurin-based fungicides can interfere in the physiology of some crops, such as dry beans (Rava, 2002) and soybean (Fagan et al., 2010), promoting a better fertilizer use by the plants, significantly increasing yields. Therefore, regardless of the N rate applied, this nutrient uptake by maize plants was optimized due to foliar protection (control of diseases) and to physiological effects also provided by the fungicide. These physiological effects comprise an increase in the enzyme nitrate reductase activity (Kaiser and Brendle-Behnisch, 1995), a decrease in ethylene synthesis (Grossmann and Retzlaff, 1997) and a greater plant tolerance to abiotic stresses (Grossmann et al., 1999). This result confirms that of Ruske et al. (2003) while studying the effects of a strobilurin-based fungicide on N uptake, partitioning, remobilization, and grain N accumulation in winter wheat cultivars. Thereby, it is possible to state that foliar protection as well as physiological effects due to the fungicide application positively influenced nitrogen use by maize, increasing yield of the hybrids tested. It is important to emphasize that this better nitrogen use can reduce production costs of maize, avoid degradation of natural resources and increase crop productivity.

Foliar spraying with fungicide was not antagonistic to *Azospirillum* inoculation. Therefore, both technologies can be recommended for greater maize yields. This is important since *A. brasilense* is not restricted to organic crops and, therefore, will be exposed to a wide variety of pesticides commonly used in intensive agriculture.

Generally, agrochemicals have side-effects on non-target micro-organisms (Bashan et al., 2007). However, these authors recognize the lack of studies addressing this important issue and that most of them were performed under *in vitro* conditions. Research on the effects of agricultural pesticides on *Azospirillum* species are available, focusing on herbicides (Jena et al., 1990; Salmeron et al., 1991; Omar et al., 1992; Rivarola et al., 1992; Forlani et al., 1995) and insecticides (Langenbach et al., 1991; Buff et al., 1992; Sánchez et al., 1994).

As to the effect of the fungicide applied in this study, one could wonder whether its absorption and translocation in the plant could affect bacteria development in maize rhizosphere. However, strobilurins and triazoles have low systemic activity, often bound to the outer layers of plant cuticle, showing limited transport on the boundary leaf layer resulting in long-lasting residual effects on plant pathogens (Köhle et al., 1994). Therefore, *Azospirillum* cells do not come into direct contact even with fully systemic fungicides as all of these compounds are translocated acropetally into leaves and the shoot tip (Diedhiou et al., 2004). The low or inexistent basipetal transport may explain why foliar fungicide applications have no direct effect on micro-organisms in the root zone (Sicbaldi et al., 1997; Chamberlain et al., 1998). In addition, indirect effects like greater photosynthesis activity of strobilurin-treated plants (Beck et al., 2002) may also be involved, and should promote *Azospirillum* development due to improved carbohydrate supply to the roots. Those effects could explain the positive interaction observed between *Azospirillum* inoculation and foliar protection on maize yield.

Conclusions

Each factor analyzed contributes to an increase in maize average yield. Greater interest in the use of inoculants containing plant growth promoting bacteria has been observed and will probably increase in the coming years, due to fertilizer cost, awareness about pollution, and emphasis on sustainable agriculture. However, to ensure high yield, nitrogen rates should not be replaced, neither totally nor partially, by seed inoculation with *Azospirillum*. Fungicide applications should be done during maize cycle. In addition, specific maize breeding programs should consider the affinity between *Azospirillum* strains and maize hybrids, mainly for regions with N deficient soils, like Cerrado. Thus, by incorporating additional technologies, maize crop farmers can optimize land use and, consequently, reduce the expansion into new agricultural areas.

Conflict of Interests

The authors have not declared any conflict of interests.

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Vol. 11(13), pp. 1159-1163, 31 March, 2016
DOI: 10.5897/AJAR2014.9160
Article Number: 52B05AA57838
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Pruning of *Eucalyptus grandis* x *Eucalyptus urophylla* planted at low density in Southeastern Brazil

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Received 17 September, 2014; Accepted 13 July, 2015

Tree pruning is a silvicultural operation that aims to improve wood quality, but care must be taken regarding the timing and height of the lift to ensure that tree growth is not negatively affected. The objective of this work was to evaluate the effects of different pruning heights on height and diameter growth of *Eucalyptus grandis* × *Eucalyptus urophylla*. The experiment was done in a one year old stand which was planted at 9 × 3 m spacing, managed under a silvopastoral regime, and located in João Pinheiro, Minas Gerais, Brazil. Pruning treatments removed branches carrying the lower green crown as follows: 0% (unpruned), 20, 40, and 60% of total tree height. Diameter at breast height (DBH at 1.3 m) and total height of all trees in the sample plots were measured prior to pruning and one year after pruning. Compared to the unpruned control, pruning significantly reduced mean DBH and total height in the 40 and 60% treatments but not in the 20% treatment. Thus, it was concluded that when pruning operation is done before canopy closure not more than 20% of lower green crow should be removed to avoid tree growth reduction.

Key words: Silvopastoral regime, silvicultural intervention, forest management.

INTRODUCTION

Brazil houses 7.7 million hectares of planted forests, of which nearly 70% is composed of different *Eucalyptus* species. The main purpose of these plantations is for charcoal, fire wood and cellulose production. A smaller percentage of these eucalypt forests are grown for solid wood products production, a growing activity in the last few years. For instance, eucalypt roundwood consumption for solid wood products (mainly sawnwood, furniture, wood panels and plywood) has risen from about 3 million m^3 in 2006 to about 15 million m^3 in 2014

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(ABRAF, 2008; IBÁ, 2014).

Considering the silvicultural tools available to forest managers to grow trees for solid wood products, thinning and pruning are among the most important. While thinning allows target trees to grow to large diameters by means of stand competition reduction, pruning is associated with wood quality enhancement through clear wood production. An alternative to thinning is to plant trees at lower densities, such as in the case of silvopastoral regimes. These regimes combine trees, forage and livestock occupying the same plot of land (Cubbage et al., 2012).

Since early thinning operations are unnecessary when trees are planted at silvopastoral regimes, the main silvicultural operation to enhance wood quality is pruning. The ideal timing and severity of pruning should be planned in a way as to minimize the defect log by pruning as early and as high as possible without negatively affecting clear wood production, since wood that is free of defects achieve greater strength properties and yield lumber that earns a high grade (O'hara, 2007).

Pruning yields best results when applied to live green branches. For instance, Smith et al. (2006) found that while branch occlusion rates did not differ between pruned and unpruned dead branches, it was significantly lower for pruned live branches in comparison to unpruned live braches. This implies that pruning interventions must anticipate branch mortality, which occurs early for fast growing shade intolerant species, such as many *Eucalyptus* species. However, pruning should not be done in a way to reduce tree growth.

Eucalyptus plantations in Brazil have an important role in providing substitutes for native timber species as solid wood products providers (Teixeira et al., 2009). Changes have been undergoing *Eucalyptus* management for solid wood products, mainly in respect to wider initial spacing to take advantage of high initial diameter growth rates (Maestri, 2003; Nutto et al., 2006). It is important to understand how trees behave in relation to pruning operations when planted under wider initial spacing.

The objective of this work is to evaluate the effects of different pruning heights on diameter and height growth of a *Eucalyptus grandis* × *Eucalyptus urophylla* stand planted at low initial density.

MATERIALS AND METHODS

The present study was carried out in a *E. grandis* × *E. urophylla* (clone I144) stand (17º 44' 26" S and 46º 10' 27" O), located in the municipality of João Pinheiro, Minas Gerais, Brazil. The regional climate is tropical. The mean annual precipitation is 1,250 mm and rainfall is concentrated from October to March, mean annual temperature is 23.9ºC, mean altitude is 540 m.a.s.l. The soil in the stand is classified as an oxisol with sandy loam texture.

Before planting, the sub-soil was ripped to 50 to 60 cm depth with simultaneous addition of reactive rock phosphate to a depth of 30 cm at a rate of 600 g/plant. Post-planting fertilizer applications consisted of 120 g/plant of NPK (6-30-6) ten days after planting; and 180 g/plant of NPK (10-0-30 + 1% B + 0.5% Zn + 0.5% Cu) 8 and 20 months after planting. The post-planting fertilizer applications were applied at two opposite points about 15 cm away from the seedlings using a hand fertilizer machine.

The stand density at planting was 9 m between and 3 m within rows to meet the requirements of a silvopastoral regime. Four pruning treatments were applied when the stand was one year of age. These resulted in removal of the lower green crown to either 0% (unpruned control), 20%, 40%, or 60% total tree height; the mean pruned heights were 0, 1.2, 2.4, and 3.5 m, respectively. At the time of pruning, there had been no natural pruning or branch mortality, and as such the tested pruning heights represented total live branch removal only. A randomized complete block design was used with five replications. The sample plots consisted of five rows with fourteen trees per row, with a measurement area of 30 trees (ten trees per the three central rows), with a total of 175 measured trees per treatment. All trees of each plot had DBH and height measured prior to treatment installation and one year after pruning. At the time of the pruning intervention, mean stand DBH was 5.5 cm and stand mean height was 5.9 m.

Statistical analysis

The effects of pruning were assessed at stand and tree level. At stand level, plot means of DBH and height were examined using analysis of variance (ANOVA). Residual properties where checked using the Shapiro-Wilk test for normality and the Bartlett test for homogeneity of variances. The Scott Knott post hoc test (Scott and Knott, 1974) was applied to the separate significant differences between the pruning treatments. This test was chosen since it is considered robust in controlling Type I errors (Borges and Ferreira, 2003).

Linear regression models were used to evaluate pruning effects at tree level. One year DBH and height increments were related to tree size prior to pruning with treatment inserted as a factor variable (Model 1). To account for the lack of independence of trees belonging to the same blocks, linear mixed models were used. A random variable was inserted in the model to account for block variance.

$$ix_{lk} = \beta_0 + \beta_1 * x_{lk} + \beta_2 * T_k + \beta_3 * (x_{lk} * T_k) + u_l + e_{lk} \quad (1)$$

where ix is tree DBH or height increment one year after pruning; x is tree DBH or height at the moment of the pruning intervention; and T is a factor variable to account for treatment variability. Subscripts *l* and *k* refer to block and tree, respectively. u_l and e_{lk} are independent and identically distributed random between-block and between-tree factors with a mean of 0 and constant variances of σ^2_{bl}, and σ^2_{tr}, respectively.

All statistical inferences were performed using the program R (R Core Team, 2012) and the following packages: Jelihovschi et al. (2012) and Pinheiro et al. (2012).

RESULTS

Pruning affected mean stand DBH values (F(3, 12) = 3.91, p = 0.04, CV = 5.31%) and mean stand height (F(3, 12) = 3.87, p = 0.04, CV = 5.34%). Residuals were normally distributed with mean zero and there was homogeneity of variances between treatments. Both

Table 1. Influence of different pruning heights on mean stand diameter at breast height (DBH) and height (h) values one year after intervention.

T (%)	DBH (cm)*	h (m)
0	12.1 (0.4)[a]	12.4 (0.4)[a]
20	11.7 (0.4)[a]	12.1 (0.6)[a]
40	11.2 (0.3)[b]	11.5 (0.2)[b]
60	10.9 (0.3)[b]	11.2 (0.5)[b]

*Values followed by the same letter in the same column are statistically equal according to the Scott Knott test (p = 0.05). Numbers in parenthesis represent the standard error.

Table 2. Parameterization of the DBH and height increment models at tree level.

	DBH increment			Height increment		
Parameter	**Value**	**Std. Error**	***p*-value**	**Value**	**Std. Error**	***p*-value**
β0	9.4269	0.523	0.000	10.8216	0.668	0.000
β1	-0.5245	0.072	0.000	-0.7317	0.078	0.000
T20	-2.3459	0.547	0.000	-3.0305	0.610	0.000
T40	-2.1910	0.487	0.000	-1.7550	0.552	0.002
T60	-0.5082	0.581	0.382	-1.5752	0.664	0.018
T20*x	0.3458	0.096	0.000	0.4636	0.102	0.000
T40*x	0.2799	0.088	0.002	0.1653	0.094	0.079
T60*x	-0.1246	0.104	0.230	0.0555	0.111	0.617
σ^2_{bl}		0.556			1.175	
σ^2_{tr}		0.696			0.532	

mean diameter and height of trees in the 0 and 20% treatments were greater than those of the 40 and 60% treatments, one year after pruning (Table 1).

Regression analysis confirmed that tree growth loss due to pruning followed the same behavior as mean stand level growth reduction, with higher pruning heights reducing diameter and height increments. Table 2 presents the results of the parameterization of the diameter and height increment models. Visual analysis of residual dispersion of both models did not indicate any undesired trend that could negatively influence model performance.

The parameters of Table 2 where used to illustrate the influence of tree size and pruning height on one year diameter and height growth (Figure 1). The amount of growth reduction caused by the different pruning regimes varied according to initial tree size (Table 2, Figure 1). For instance, a tree with DBH of 5 cm that was pruned up to 40% of tree height would present a DBH increment 11% less than an unpruned tree (6.0 versus 6.8 cm/year). This reduction would be only of 4% if the initial tree size was of 7 cm (5.5 versus 5.8 cm/year). Height growth followed this same behavior.

DISCUSSION

The present paper relates the effects of pruning prior to canopy closure on growth of clonal *E. grandis* × *E. urophylla* trees planted at a low initial density (370 trees per hectare). Canopy closure can be defined as the moment when the crowns of adjacent trees touch each other. The results obtained from of this experiment come from a young stand, as such it is important to note that the impact of green crown pruning in tree and stand growth may vary as the stand approaches maturity and as successive pruning operations are applied.

The amount of lower green crown that can be removed from *Eucalyptu*s trees in pruning operations without resulting in growth loss have been reported by many authors (e.g. Brendenkamp et al., 1983; Pinkard and Beadle, 2000; Monte et al., 2009). A general consensus is that 40 to 50% of the lower green crown can be removed without affecting tree growth (Pinkard and Beadle, 1998; Alcorn et al., 2008; Forrester et al., 2010). The results found in this study indicated a stronger response of growth loss following pruning than usual, with mean stand attributes suffering reduction with the

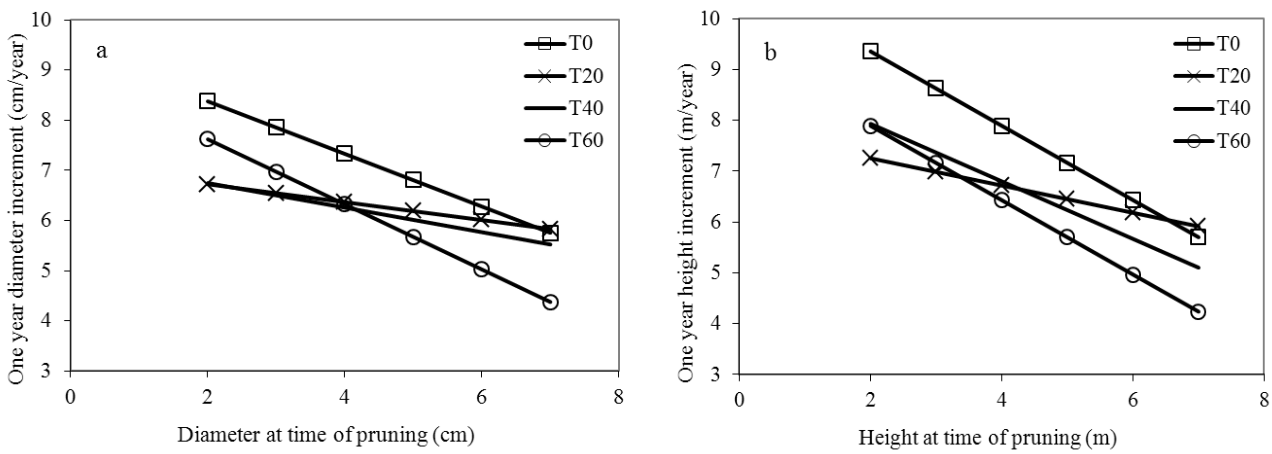

Figure 1. Behavior of one year DBH (a) and height (b) increment considering different tree sizes at the moment of the pruning intervention.

removal of 40% of lower green crown onwards. This probably occurred due to the canopy characteristics of the stand at the time of pruning application. The lower tree crowns were not undergoing mortality at the time of pruning. This was due to the early moment of pruning intervention and the wide spacing applied at installation. Thus, the lower crown of the trees was still contributing to tree growth, and its removal affected tree development. The moment of canopy closure is dependent on the planting density and growing conditions (Beadle, 1997; Montagu et al., 2003). For *Eucalyptus* species, canopy closure usually occurs between the ages of 1 and 4 years (Medhurst et al., 1999; Ryan et al., 2004). At the moment of canopy closure, the tree's lower crown does not contribute much in terms of carbon allocation and tree growth (Montagu et al., 2003), allowing high levels of green crown removal (up to 50%) without affecting tree growth.

The results of the present study are in conformity with other pruning trials in *Eucalyptus* species when conducted prior to canopy closure and planted at low density. For instance, Pinkard (2002) found that 20% leaf area removal of pre-canopy closure *Eucalyptus nitens* trees caused stem growth reduction. Fontan et al. (2011) reported diameter growth reduction for a *Eucalyptus camaldulensis* × *E. grandis* clone established in 9.5 × 4.0 m spacing when pruning all trees of the stand, removing 33% of live crown height plus removal of some thick branches above this height in three lifts. To avoid growth reduction in these stands, the aforementioned authors recommended pruning interventions removing 33% of live crown height plus removal of some thick branches above this height in four lifts (beginning at age 9 months with 6 month intervals) only for trees selected for final harvest (60% of the stand).

As for the tree level analysis, smaller trees presented the largest diameter and height increments, regardless of the pruning treatments. The tree level analysis also indicated that, for the two intermediate pruning treatments, growth reduction was mainly concentrated on the smaller trees of the stand, with larger trees presenting growth similar to unpruned trees (Figure 1). Thus, the more intensive treatments, probably removed amounts of leaf area that were too large for the smaller trees to recuperate, this way causing more pronounced growth reduction in these trees. This helps to explain why the 20% pruning treatment presented mean stand attributes statistically equal to the unpruned treatment, since the growth of the larger trees were able to compensate the growth loss of the smaller trees.

From a management perspective, the results found in this study suggests that it should be possible to implement a light pruning prior to canopy closure (e.g. removing up to 20% of lower green crown), and more severe pruning post-canopy closure (e.g. removing up to 50% of lower green crown), without affecting stem growth. However, an economic analysis of such a pruning regime is warranted to check for viability.

Conclusion

The tested pruning heights reduced eucalypt height and DBH development one year after intervention when more than 20% of the lower live green crown was removed.

Conflict of Interests

The authors have not declared any conflict of interests.

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academicJournals

Vol. 11(13), pp. 1164-1170, 31 March, 2016
DOI: 10.5897/AJAR2015.10408
Article Number: 18EDB2A57845
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Diversity and seasonal distribution of parasites of *Oreochromis niloticus* in semi-arid reservoirs (West Africa, Burkina Faso)

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Received 18 September, 2015; Accepted 17 February, 2016

This study aimed to investigate the diversity, abundance, intensity, and seasonal distribution of parasites of *Oreochromis niloticus*. A total of 254 specimens of *O. niloticus* was sampled in Loumbila and Ziga reservoirs in both rainy and dry season and examined for parasites. The total prevalence was 55.90% and the highest seasonal prevalence, abundance and intensity were observed during the rainy season. Recorded parasites were the myxozoan *Myxobolus tilapiae*, the copepode *Lamproglena monodi*, the monogeneans *Cichlidogyrus tilapiae*, *Cichlidogyrus halli*, the digenetic trematode *Clinostomum* species, the nematode *Paracamallanus cyathopharynx*, and the acanthocephalan *Acanthogyrus tilapiae*. The latter species had higher prevalence (45.67%) and high abundance. *L. monodi*, *C. tilapiae*, *C. halli*, and *P. cyathopharynx* were only observed in Loumbila reservoir. *A. tilapiae*, *Clinostomum* spp. and *M. tilapiae* were found in both reservoirs with a high abundance. In conclusion, it was found out that *O. niloticus* specimens were heavy infection with a broad number of parasites. This situation could eventually reduce performance and productivity of the species, especially in aquaculture.

Key words: *Oreochromis niloticus*, parasites, Loumbila reservoir, Ziga reservoir, Burkina Faso.

INTRODUCTION

Fish is an important source of protein to humans and other animals. The tilapias are freshwater fish in the family of Cichlidae and they were considered to be more resistant compared to other species of cultured fish. *Oreochromis niloticus*, *Sarotherodon galilaeus,* and *Tilapia ziilli* are the major species in Burkina Faso fisheries. *O. niloticus* is a fast growing fish and has a great importance for fisheries, aquaculture, and screen aquarium. It is also used extensively in biological and physiological research (Gómez-Márquez et al., 2003; Sandoval-Gío et al., 2008). The size and the stock of these species are decreasing in the Ziga and Loumbila

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reservoirs according to fishermen, suggesting that there are factors limiting their growth, among them are parasitic infections. Indeed, it has been shown that *O. niloticus* is the host of many parasites (Akoll et al., 2012).

The occurrence of disease conditions, particularly due to parasites, is a major burden in aquaculture (Bondad-Reantaso et al., 2005). Parasites cause direct losses of fish through mortal infections and have considerable impact on fish growth, resistance to other stressing factors, susceptibility to predation, and marketability. Besides, parasites pave the way for secondary infections (Scholz, 1999). Therefore, studies of fish parasites are ecologically important since abundance of fish parasites is likely to have a greater impact on the fish activities and shape of fish community and ecosystem structure through influences in trophic interactions, host fitness, and food webs (Hudson et al., 2006). Fish parasites are also potential biomarkers for ecology and trophic interactions (Cauyan et al., 2013). Different parasites have a variety of intermediate hosts and often depend on trophic interactions for transmission, so parasites within a vertebrate host may be excellent indicators of food-web structure and biodiversity (Marcogliese and Cone, 1996).

To date, few studies have been conducted on fish parasites of Cichlidae, including *O. niloticus* in West Africa semi-arid areas like Burkina Faso (Boungou et al., 2006a, b, 2008; Boungou, 2007; Coulibaly, 1995; Coulibaly et al., 1995, 1999; Kabré, 1997). These studies focused on ectoparasites diversity and endoparasites biology. However, there is no data about infection dynamic. In this study, *O. niloticus* was chosen as the model to investigate seasonal dynamic of parasites, using diversity, abundance, and intensity as indicators. The study is conducted in two reservoirs located in semi-arid areas in West Africa.

MATERIALS AND METHODS

Study area

Two study areas, Loumbila and Ziga reservoirs, were selected for this study. Loumbila reservoir was chosen because it is one of the oldest fisheries of the country. On the other hand, Ziga is one of the recent and developing fisheries. The second reason is that both sites are not so far from Ouagadougou. The Loumbila reservoir (12°29' N 01°24' W) was built in 1947. It is located in the North East of Ouagadougou, at about twenty kilometres. Its capacity is about 42.2 million m^3 in flood and its maximum surface is about 16.80 km². Ziga reservoir (12°37' N and 0°49' W) was built in 2000 and is located in the East of Ouagadougou. It has a capacity of 200 million m^3 and cover an area of 70 km² (AFD, 2015). These reservoirs are located in a Soudano-Sahelien climate type, characterized by one long dry season (October to May) and one rainy season (June to September). Both reservoirs are located at the outskirts of Ouagadougou, the city, capital of Burkina-Faso. Fishing and agriculture activities have developed around these reservoirs since their inception. The reservoir of Loumbila is the most impacted, mainly by activities such as agriculture especially gardening. During the dry season, the bed of this reservoir is used for crops and often more than chemicals are used.

Sample collection

Fish samples were collected monthly from March 2012 to August 2012. *Oreochromis* specimens were randomly selected by us among fisherman catch. Fish were captured using gill nets. All the fishes were transported in icebox to the laboratory for analyses. A total of 254 identified as *O. niloticus* according to Paugy et al. (2004) were sampled and transported to the laboratory.

In the laboratory, sexes of the specimens were determined by checking gonads. Each fish specimen was dissected; their gills as well as the different part of the digestive tract (esophagus, stomach, and intestines) were isolated, kept in different Petri dishes, and screened for parasites. The parasites found were collected, counted and kept in 70% ethanol for later identification.

Parasites species identification

According to the parasite taxa, different protocols were used for species identification. For Acantocephalans and Digeneans, specimens were stained with carmine, dehydrated through a gradient series of ethanol, cleared in clove oil and mounted in Canada balsam. For nematodes, lactophenol was used as the cleaning agent. Myxozoa were fixed and stained with fresh Giemsa stain. Parasites were observed by using a Zeiss microscope.

Data analysis

Data were analyzed under the Statview 5.0.1.0 version SAS Institute Inc. and Xlstat 2015 version.1.02 Addinsoft software. Prevalence, mean intensity, and mean abundance were calculated after Bush et al. (1997).

Proportions test was used to compare the prevalence between season and studies area, and non-parametric tests (Mann-Whitney and Kruskall-Wallis tests) to compare parasites intensity between season and study area. Results were considered significant if its corresponding p-value was less than 0.05 (at the 95% level).

RESULTS

Parasites diversity

Seven ectoparasites and endoparasites species were recovered from *O. niloticus* in Ziga and Loumbila reservoir. Recorded species were distributed among Acanthocephalan (*Acanthogyrus tilapiae*), Trematode (*Clinostomum* species), Monogenean (*Cichlidogyrus tilapiae* and *Cichlidogyrus halli*.), Nematode (*Paracamallanus cyathopharynx*), Copepod (*Lamproglena monodi*), and Myxosporeans (*Myxobolus tilapiae*).

Global prevalence, abundance, and intensity of parasites

Table 1 shows the prevalence, total, and mean abundance and infection intensity for the six groups of parasites found during this study. In total, 254 specimens of *O. niloticus* were examined for the two localities, 55.90% of them were found positive for various parasites.

Table 1. Prevalence, abundance and mean intensity of parasites observed in *O. niloticus*.

Factor	Parasite group	NES	NIS	P%	TA	MA	MI
Groups	Acantocephalan	254	116	45.67	1836	7.23	15.83
	Copepod	254	3	1.18	5	0.02	1.67
	Monogenean	254	1	0.39	68	0.27	68.00
	Myxosporea	254	10	3.94	49	0.19	4.90
	Nematode	254	1	0.39	1	0.00	1.00
	Trematode	254	45	17.72	212	0.83	4.71
Sites	Loumbila	112	73	65.18	1020	9.11	13.97
	Ziga	142	69	48.59	1116	7.86	16.17
All parasites and sites		254	142	55.90	2171	8.54	15.28

NES: Number of examined specimen, NIS: number of infected specimens, P%: prevalence, TA: total abundance, MA: mean abundance, MI: mean intensity.

The global mean abundance was 8.54 parasites per fish specimen examined with mean intensity up to 15.28 parasites per specimen infected. A total of 2171 parasites were identified as helminthes (n=2117), copepods (n=05) and Myxosporean spores (n=49) were collected from fish species. Helminthes are Acanthocephalans, Trematode, Monogenean, and Nematode. The Acanthocephalans, mainly larvae, were the most prevalent group (45.67%) (Figure 1). Among them, *Acanthogyrus* was the most prevalent and most abundant specie in the two localities. The Monogenean and Nematode showed the lowest prevalent. Higher prevalence was also reported for Trematodes (17.72), while the other groups show prevalence under 5%. However, this difference was not significant statistically (p=0.41).

There was little variation of prevalence according to sex (56 and 57%, respectively for male and female), indeed there was no statistical difference between these values (p<0.73). The same pattern was noticed with the mean intensity (mean intensity of male=17.52; female=12.27); the difference was not statistically significant between male and female (p<0.77, Mann Withney U test).

Parasite location

In this study, parasites were found in intestine and on gill of *O. niloticus.* Intestine was infected by two groups of parasite, Acanthocephala and Nematode. Adult Acanthophalans were observed in intestine posterior portion and their larva encysted in anterior intestine wall. Gill parasites were *L. monodi*, *C. tilapiae, C. halli*, *M. tilapiae*, and *Clinostomum* spp. *Clinostomum* spp. was met on gill and after oral cavity towards the pharyngeal region and beneath operculum. Intestine was the more infected organ (with high prevalence). The parasite *L. monodi* is firmly fixed in the gill arch.

Infection pattern between sites

Four species (*L. monodi*, *C. tilapiae*, *C. halli*, and *P. cyathopharynx*) were observed only in Loumbila reservoir; three others which were the most abundant species were common to both reservoirs.

Table 1 also presented the parasitic indices variations between sites. Around 112 fishes were examined for Loumbila reservoir and 142 fishes for Ziga. The nfection prevalence was 65.18% (n=73) in Loumbila and 48.59% (n=69) in Ziga. The analysis showed the infection prevalence was significantly higher in Loumbila reservoir than Ziga reservoir (p=0.008; Proportions test). The difference of intensity was also statically significant between the two localities (p<0.0003, Mann Withney U test). The prevalence, mean abundance, and mean intensity of infection of the species are summarized in Table 2. This table shows that at species level, the prevalence of *A. tilapiae* does not vary between the two reservoirs. But, the prevalence of *Clinostomum* spp. was higher in Loumbila reservoir.

Parasites distribution within season

Four species were found in dry season and six species in rainy season. Indices variations according to season and sites are shown in Table 3. In both reservoir, the prevalence of parasites were higher in rainy season than in dry season (p= 0.0001, proportion test). Prevalence of infection was higher in Loumbila reservoir than Ziga reservoir without regard to season. The prevalence of infection significantly varies also across seasons, with the

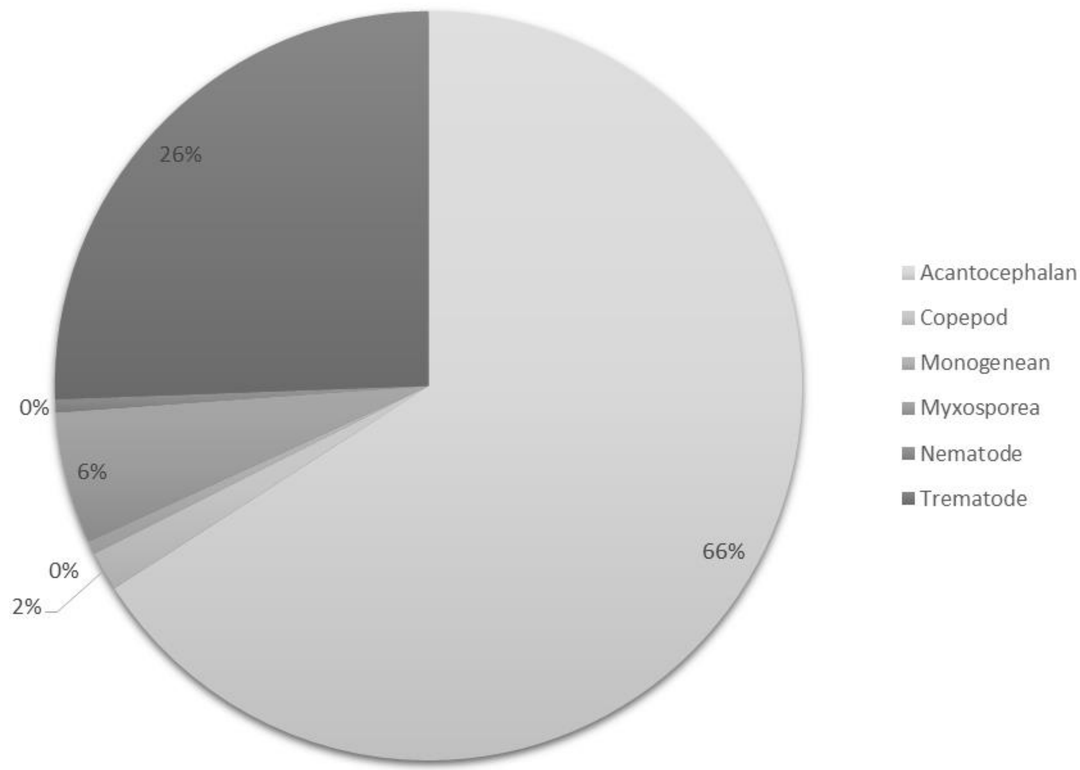

Figure 1. Pie chart presenting percentages of frequency of parasite occurrence.

Table 2. Prevalence, abundance and mean intensity of three species recorded in both localities.

Sites	Species	TA	MA	P%	MI
	Acanthogyrus tilapiae	1076	4.24	45.77	16.55
Ziga	*Clinostomum* spp.	37	0.15	5.63	4.63
	Myxobolus tilapiae	42	0.17	4.93	6.00
	Acanthogyrus tilapiae	760	2.99	45.54	14.90
	Clinostomum spp.	175	0.69	33.04	4.73
	Myxobolus tilapia	7	0.03	2.68	2.33
Loumbila	*Cichlidogyrus monodi*	5	0.02	1,18	1,67
	Cichlidogyrus tilapiae	23	0.09	0,39	23
	Cichlidogyrus halli	45	0.18	0,39	45
	Paracamallanus cyathopharynx	1	0.00	0,39	1

P%: Prevalence, TA: total abundance, MA: mean abundance, MI: mean intensity.

highest infection prevalence being observed in rainy season. The number of parasites was higher in rainy season than in dry season (p< 0.0001, Mann Whitney test,).

Concerning the seasonal dynamics in the examined *O. niloticus,* Table 4 revealed that the highest seasonal prevalence of parasite species was recorded in rainy season. The peak of seasonal dynamic of *A. tilapiae* in total examined *O. niloticus* was observed in rainy season. All examined fish in rainy season was infected with *A. tilapiae*. Figure 2 shows the parasitic indices of *O. niloticus* by month in the two reservoirs; months of rainy (June, July, August) record the higher indices. The month of July harbored higher prevalence, higher mean intensity and abundance. The lower prevalence was observed in month of April and the average lower intensity and abundance in March. Nonparametric test of Kruskall Wallis showed a difference of number of parasites

Table 3. Prevalence, mean abundance and intensity of parasite according to season in the two localities.

Season	Localities	NES	NIS	P%	TA	MA	MI
Rainy	Loumbila	55	46	83.64	699	12.71	15.19
	Ziga	40	30	75	785	19.62	26.17
Total rainy	-	95	76	80	1484	15.62	19.53
Dry	Loumbila	57	27	47.37	321	5.63	11.89
	Ziga	102	39	38.23	331	3.24	8.49
Total dry	-	159	66	41.51	652	4.10	9.88
General total	-	254	142	55.90	2136	8.41	15.04

NES: Number of examined specimen, NIS: number of infected specimens, P%: prevalence, TA: total abundance, MA: mean abundance, MI: mean intensity.

Table 4. Seasonal dynamics of different parasite species among examined *O. niloticus.*

Season	Parasite species	NES	NIS	TA	MA	MI	P (%)
Rainy	*Acanthogyrus tilapiae*	95	95	1563	16.45	16.45	100.00
	Clinostomum spp.	95	36	183	1.93	5.08	37.89
	*Cichlidogyru*s *monodi*	95	3	5	0.05	1.67	3.16
	Cichlidogyrus tilapiae	95	1	23	0.24	23.00	1.05
	*Cichlidogyru*s *halli*	95	1	45	0.47	45.00	1.05
	Myxobolus tilapiae	95	7	40	0.42	5.71	7.37
Dry	*Acanthogyrus tilapiae*	159	20	273	1.72	13.65	12.58
	Clinostomum spp.	159	9	29	0.18	3.22	5.66
	Myxobolus tilapia	159	3	9	0.06	3.00	1.89
	Paracamallanus cyathopharynx	159	1	1	0.01	1.00	0.63

NES: Number of examined specimen, NIS: number of infected specimens, P%: prevalence, TA: total abundance, MA: mean abundance, MI: mean intensity.

between months ($h = 14.84$, $p < 0.011$).

DISCUSSION

Parasites recorded in *O. niloticus* from Ziga and Loumbila reservoirs were dominated by acanthocephalan. The site of acanthocephalan infection was restricted to the fish intestine. Differences in physical environment in the gut, availability, nature, and amount of food supply were factors that most likely limit the distribution of parasites in different sections of alimentary tract (NKwengulila and Mwita, 2004). Hence, the preference of Acanthocephalans for intestinal region as site of attachment could be attributed to food availability in this region. Acanthocephalans do not have a gut. Nutrients from the lumen of the host gut are absorbed across the body wall of the parasites. Amin et al. (2008) reported that test results suggest that *A. tilapiae* was better adapted to some cichlid hosts than to others. Sanil et al. (2010) reported a heavy infection with Acanthophalan (*Tenuiproboscis* species) in posterior intestine of *Lutjunus argentimaculatus* in Southern India.

Clinostomum spp. larvae are the second dominated parasites species of *O. niloticus* observed in this study. It was observed beneath operculum, in pharyngeal region and on gill. This result is similar to those of Aloo (2002) and Ochieng et al. (2012) who observed *Clinostomum* spp. below the operculum and in the pharyngeal region in *Oreochromis leucostictus* in Lake Naivasha. *O. niloticus* is more receptive for larva of *Clinostomum* (Coulibaly, 1995). Digeneans (*Clinostomum* spp.) have complex life cycles involving 3 hosts: snail, fish or amphibian, and bird (Bonett et al., 2011). Snail is considered as first intermediate host, with fish acting as second intermediate host and aquatic birds as definitive host. *O. niloticus* feeds mainly on benthic materials, including detritus, by picking up larval stages of parasites. Maguza-Tembo and Mfitilodze (2008) reported that *Oreochromis shiranus* was susceptible to harbor trematodes (*Clinostomum*). The

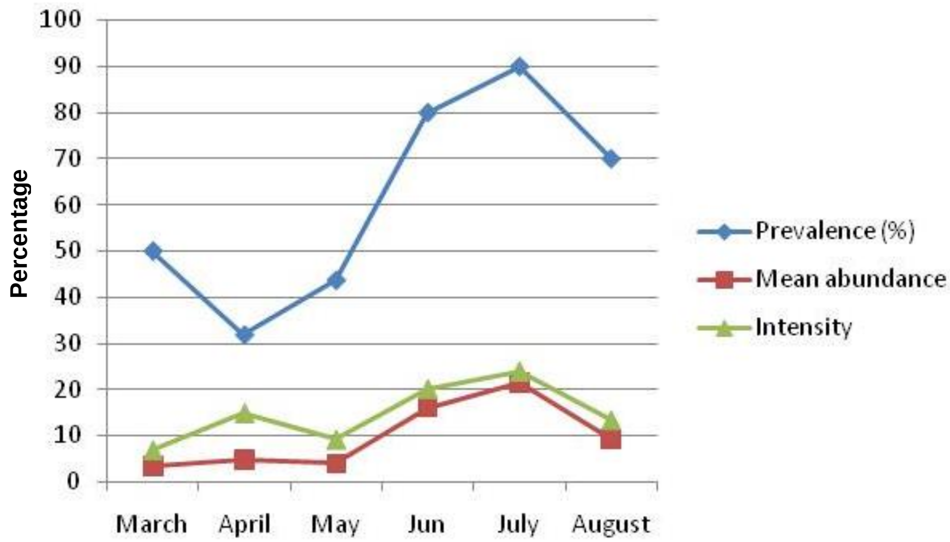

Figure 2. Prevalence, mean abundance and mean intensity of the parasites in *O. niloticus* in the two sites per month.

metacercariae of *Clinostomum* in the specimens of fish host suggested the presence of snails in the sites of study which are the first intermediate hosts of parasites (*Clinostomum*). The metacercariae of *Clinostomum* is known to damage the muscles of fish, making it degusting and unsalable (Coulibaly, 1995).

M. tilapiae was the myxosporean species recovered on gill in *O. niloticus* in this study. Most infections by Myxozoa in fish create minimal problems, but heavy infestations can be more prevalent, especially in young fish (Klinger and Francis-Floyd, 2013).

Gill parasites (*L. monodi*, *C. tilapiae*, and *C. halli*) were recorded in low prevalence. *L. monodi* was found in *O. niloticus* in three sites (Bazèga, Bagré, and Loumbila) in Burkina Faso with prevalence 3.60% (Boungou et al., 2013). *L. monodi* was fixed deeply in the gill arch. It could create damage in gill tissue.

Nematodes *P. cyathopharynx* was recorded with prevalence 0.39% in fish intestine. Eissa et al. (2011) recorded in Egypt *P. cyathopharynx* and *Procamallanus laeviconchus* in stomach of *O. niloticus*. Moyo et al. (2009) found *P. cyathopharynx* (prevalence = 11.1%) in *O. mosambicus* in Zimbabwe. *P. cyathopharynx* was recorded and described in Burkina Faso for first time by Kabré (1997) in Siluriform fish. The prevalence of *P. cyathopharynx* was low for *O. niloticus* (0.39%), which could be a post cyclic or accidental host.

Analysis of the results shows that the prevalence is higher in the reservoir of Loumbila. This could be due to difference in intensity and numbers of human impact in the two reservoirs. The reservoir of Loumbila is an old reservoir (established since 1947) when compared with the reservoir of Ziga (created in 2000). In addition, this reservoir faced more and longtime impact from human activities, including: silting, accumulation of chemical product from agriculture (over time) and eutrophication which promotes the proliferation of algae and the intermediate hosts. Therefore, the proliferation of intermediate hosts may increase the chance of contamination.

The results showed that male fish recorded higher mean abundance and intensity of parasites than female fish, although both sex have the same chance to be infected (no significant difference of prevalence and intensity between the sex). Most researchers have reported that male fish are usually more infected than female (Aloo, 2002; Idris et al., 2013) and these same researchers observed a higher incidence of parasites in males than in females. That could be due to certain ecological factors emanating probably from feeding differences between the males and females. Males are always in movement, but females are in egg-laying period, keeping eggs in their mouths and feeding less during that period. Male eat more and accumulate parasite in their organism.

The higher prevalence, abundance and intensity of parasites in July and June could be explained by the season. It means that in July, the rainy season is well established and food is available for fish. This period also corresponds to the period of reproduction and proliferation of intermediate hosts. The increase of intermediate hosts could explain the increased rate of infection in the rainy season observed in the results during this period. This result confirms the result of Usip et al. (2010) in Nigeria, who had reported that during the rainy season, most species of cichlids had a high level rate of infection. *A. tilapiae* appear to be recruited in the summer (Amin et al., 2008). The high number of parasites species in rainy season could be explained by the presence of their intermediates hosts in this season.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

This study was supported by the “Agence Universitaire de la Francophonie” that financed a grant for the first author through the "Programmes Horizons Francophones". The authors would like to thank them for this valuable contribution.

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Vol. 11(13), pp. 1171-1180, 31 March, 2016
DOI: 10.5897/AJAR2015.10684
Article Number: 830BE3B57851
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Utilization of nitrogen (^{15}N) from urea and green manures by rice as affected by nitrogen fertilizer rate

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Received 24 November, 2015; Accepted 10 February, 2016

The use of green manures (GMs) in combination with nitrogen (N) fertilizer application is a promising practice to improve N fertilizer management in agricultural production systems. The main objective of this study was to evaluate the N use efficiency (NUE) of rice plant, derived from GMs including sunn hemp (*Crotalaria juncea* L.), millet (*Pennisetum glaucum* L.) and urea in the greenhouse. The experimental treatments included two GMs (sunn hemp-^{15}N and millet-^{15}N), absence of N organic source (without GM residues in soil) and four N rates, as urea-^{15}N (0, 28.6, 57.2 and 85.8 mg N kg^{-1}). The results showed that both rice grain and straw biomass yields under sunn hemp were greater than that of millet or without the application of GM. The NUE of rice under sunn hemp was greater than that under millet (18.9 and 7.8% under sunn hemp and millet, respectively). The urea N application rates did not affect the fertilizer NUE by rice (53.7%) with or without GMs. The NUE of GMs by rice plants ranged from 14.1% and 16.8% for root and shoot, respectively. The study showed that green manures can play an important role in enhancing soil fertility and N supply to subsequent crops.

Key words: *Oryza sativa* L., sunn hemp, millet, isotopic diluition, nitrogen mineralization.

INTRODUCTION

Rice is a staple food for more than 50% of the world population (Fageria et al., 2010). Nitrogen (N) is the main nutrient that affects the rice yield, because it increases the percentage of filled spikelets, increases the leaf

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surface and contributes to improvement of the quality of the grain (Cazetta et al., 2008).

Brazil is the world's largest producer of upland rice, but upland rice yield is much lower than lowland-flooded rice (Fageria et al., 2010, 2011; Conab, 2015). Nitrogen is one of the most important nutrients in determining upland rice yield in Brazil, since low level of N fertilizers is used by farmers due to high cost of these fertilizers (Fageria, 2007; Fageria et al., 2010).

The efficiency of N fertilizers is usually low, with a recovery estimated, on average by the shoots of about 50% of the N applied (Dobermann, 2005; Chien et al., 2009). The importance of green manures (GMs) in crop systems is increasing in recent years due to concern for reducing chemical inputs and improving soil quality (Fageria et al., 2005). The application of N chemical fertilizer in combination with GM may be an effective method to enhance fertilizer N use efficiency and crop yield in dryland (Li et al., 2015).

In addition, the association of GM to N fertilizer is a promising approach to improve N fertilizer management, soil fertility and organic matter, reduce N losses from the readily available sources, increase the use of green manure N and yield of grain crops, and in the case of legume GM, incorporate biologically fixed N to the soil (Bordin et al., 2003; Cazetta et al., 2008; Muraoka et al., 2002; Pöttker and Roman, 1994; Scivittaro et al., 2005, 2008; Reis et al., 2008; Silva et al., 2006, 2010).

Therefore, the use of GM in combination with N fertilizers can be an important complementary strategy to reduce cost of production and to improve upland rice yield. The fate of green manure N as affected by N fertilizer in dryland soils and vice versa is poorly understood (Aulakh et al., 2000; Li et al., 2015). The use of ^{15}N tracer technique is important to evaluate the fate of N derived from N fertilizer, GM and their combination.

The objectives of this work were to evaluate (i) N use efficiency (NUE) by the rice plant derived from GMs sunn hemp (*Crotalaria juncea* L.), millet (*Pennisetum glaucum* L.) and urea (labeled with ^{15}N); (ii) the effect of N sources on rice yield; (iii) the contribution of N derived from the roots and above ground parts of GMs to rice; (iv) and to quantify the N in rice as affected by urea application time (at seeding and topdressing).

MATERIALS AND METHODS

The experiment was carried out in the greenhouse at the Center for Nuclear Energy in Agriculture (Cena/USP), state of Sao Paulo, Brazil, at 22°42'30"S, 47°38'0"W, 554 m altitude. The study was carried out with clay texture soil (440 g kg^{-1} of clay), collected from the top 20 cm depth of a Rhodic Hapludox according to United States (2006), classified as the Brazilian soil Dystroferric Red Latosol, loamy, cerrado (savannah) phase by Embrapa (2013). The soil chemical analyses were performed according to the methods described by Raij et al. (2001), with the following characteristics: pH ($CaCl_2$): 4.8; total N: 1.0 g kg^{-1}; soil organic matter: 12.7 g dm^{-3}; P (resin-extractable): 11.7 $mgdm^{-3}$; S: 7.5 $mgdm^{-3}$; K^+: 2.0 $mmol_c dm^{-3}$; Ca^{2+}: 20.0 $mmol_c$ dm^{-3}; Mg^{2+}: 10.0 $mmol_c$ dm^{-3}; H+Al: 26.0 $mmol_c$ dm^{-3}; base sum: 32.0 $mmol_c$ dm^{-3}; cation exchange capacity: 58.0 $mmol_c$ dm^{-3}; base saturation: 55.0%.

The study was conducted in two phases. The first phase was focused on the production of sunn hemp and millet, with and without the addition of labeled ^{15}N fertilizer. In the second trial phase, rice plants were grown with combined application of GM residues unlabeled and ^{15}N-urea labeled or GM residues isotopically^{15}N-labeled combined with urea without ^{15}N. These two phases were performed in order to distinguish the origin of N in rice plants from different sources (urea, sunn hemp or millet).

In the first phase, plastic pots lined with polyethene bags, containing 5 kg soil, were used to produce the biomass of GMs. Twenty five pots received 12 seeds each of sunn hemp (*C. juncea*, cv. IAC KR1) or millet (*P. glaucum*, cv. ADR-500) and, five days after emergence (DAE), seedlings were thinned to five plants per pot. The isotopic labeling of the GMs was performed with a rate of 300 mg N per pot as $(NH_4)_2SO_4$ enriched with 10% of atoms of ^{15}N, split into three applications of 100 mg N per pot vessel at 15, 33 and 45 DAE. Plant shoots and roots were harvested at 63 DAE, rinsed with deionized water, oven-dried at 70°C, weighed, and fragmented into pieces of approximately 0.02 cm. A representative sub sample of each GM was ground to 0.149 mm in a Wiley mill, for chemical analyses. After digestion with H_2SO_4, total N was determined by the Kjeldahl method as described in Malavolta et al. (1997). Total C was analyzed by dry combustion at 1.400°C in an elemental analyzer Leco CN 2000 (Nelson and Sommers, 1982). Then, the C/N ratio was determined. The abundance of ^{15}N was analyzed in mass spectrometry (Barrie and Prosser, 1996).

In the second phase, rice plants were grown in pots with 4 kg of air dried soil each, by combining with or without N fertilizer as urea and GM residues labeled with ^{15}N. The residues were applied in proportion of 4:1, being 20 g of shoots and 5 g of root for both GMs, which were mixed to the soil 12 days before sowing the rice. The soil was watered using deionized water (0.6 μS cm^{-1}), and soil water content was kept at approximately 60% of the retention capacity.

In rice plants (cultivar IAC 202) cultivation, a completely randomized design with 12 treatments was used, in a 3x4 factorial arrangement, with three replicates. The treatments were the combination of two GMs (sunn hemp or millet) and no organic source of N (soil without GM) with four N rates as urea (0, 28.6, 57.2 and 85.8 mg N kg^{-1}).

At sowing, 15 seeds of rice were sown per pot and thinning was carried out eight DAE, keeping four seedlings. All pots received a sowing fertilization with 25.51 mg P kg^{-1} as single superphosphate, 24.94 mg K kg^{-1} as potassium chloride. At 10 DAE, basic nitrogen fertilization (20% of total N rate) was done, except in the control treatments (no added urea-N), and 43 DAE (maximum tillering), 80% of the rest was applied in topdressing.

Rice plant shoots were harvested at 120 DAE, after grain physiologic maturation, by cutting the plants at 1 cm above the soil surface, then, the shoots were separated into straw and grain part. Straw and grain were oven-dried at 60°C, for 72 h, weighed, and ground at 0.42 mm in a Wiley mill. The rice grain yield data were adjusted to 13% moisture. Total N was determined by Kjeldahl method, after digestion with H_2SO_4 according to the methods described by Malavolta et al. (1997). Also, total N and the abundance of ^{15}N were determined in the mass spectrometer (Isotope Ratio Mass Spectrometry, IRMS), elemental analyzer interfaced with N, Stable Isotope Laboratory in the Cena/USP (Barrie and Prosser, 1996).

The calculations of the total N accumulated, percentage (NPDFGM) and quantity (QNPDFGM) of N in rice plant derived from green manures and derived from urea (NPDFF and QNPDFF) and the N utilization efficiency (NUE) from green manure and urea by rice plants were performed according to IAEA (2001).

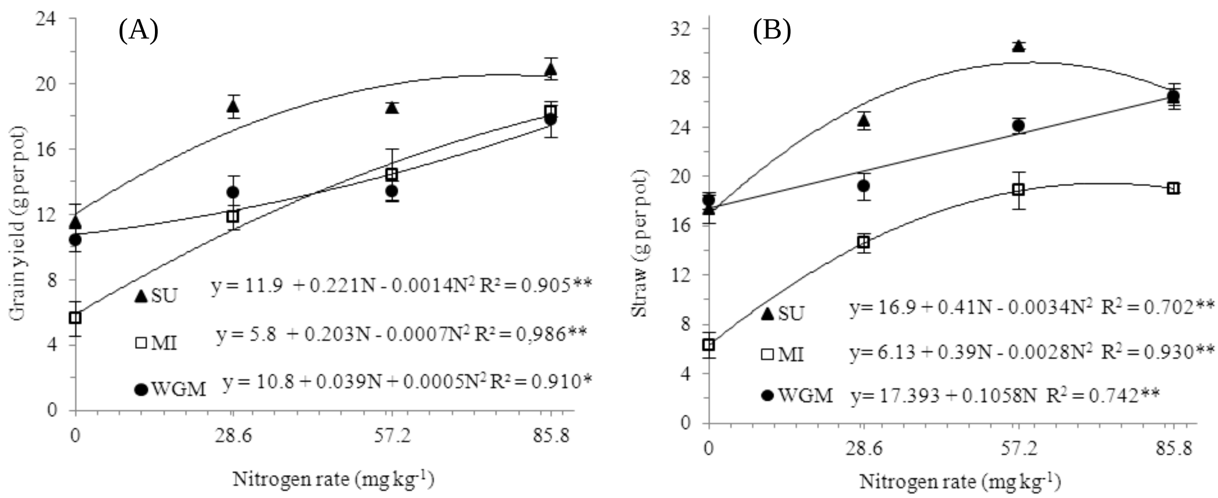

Figure 1. Rice grain yield (A) and straw biomass (B) as affected by N fertilizer rate and without application of green manure (WGM) and application of sunn hemp (SU) or millet (MI). ** and * significant by the F test at 1 and 5%, respectively.

The data obtained were subjected to analysis of variance and, when significant effects were detected at 5% probability, Tukey test at the 0.05 probability was used to compare the means. The factors were adjusted to regression equations for N rates. Linear and quadratic components were tested, and the model with larger significant degree was chosen. The statistical analyses were performed using SAS package (SAS Institute, 2001).

RESULTS AND DISCUSSION

Carbon (C) and nitrogen content in green manures

Shoot C and N content of sunn hemp were 429.6 and 24.0 g kg^{-1}, respectively; in roots, the C and N content were 339.8 and 19.2 g kg^{-1}, respectively. Similarly for millet, the C and N contents of shoot were 419.4 and 10.7 g kg^{-1}, respectively, and in the roots were 320.0 and 10.0 g kg^{-1}, respectively. The greater N content in both shoot and root of sunn hemp as compared to millet may be due to biological N fixation by sunn hemp (Muraoka et al., 2002; Scivittaro et al., 2003; Singh et al., 2004).

Upland rice grain yield and straw biomass

Both upland rice grain yield and straw biomass were significantly influenced by N-urea application rate and GM application. Grain yield increased significantly in a quadratic model with increasing N-urea rate, both with and without the application of sun hemp or millet (Figure 1A). As compared to the millet treatments or without any GM application, the use of sunn hemp showed greater grain yield and maximum grain yield (20.5 g per pot) was obtained with N fertilizer application rate of 77.0 mg kg^{-1}. Therefore, it is suggested that the application of suun hemp supplied more N for rice plants, which resulted in higher grain yield with less N fertilizer. Previous studies with GM also showed higher rice grain yield with the application of N fertilizer in combination with GM when compared with the supply of individual N sources (Muraoka et al., 2002; Bordin et al., 2003; Scivittaro et al., 2003; Fageria and Santos, 2007). Biological N fixation by leguminous green manures can reduce the need for inorganic N fertilizers for the succeeding crop (Singh et al., 2004).

Without N fertilizer input (control treatment with no N fertilizer), the application of sunn hemp increased grain yields by 51 and 12%, respectively, as compared to millet and without application of GM treatments (Figure 1A). Furthermore, the application of only sunn hemp was equivalent to N-urea rate from 24.6 mg kg^{-1}. Muraoka et al. (2002) observed that the application of sunn hemp showed rice grain yield equivalent to N fertilizer rate of 40 kg ha^{-1}. In another study with maize, Silva et al. (2006) observed that the application of sunn hemp resulted in an effect equivalent to N-urea rate of 60 to 90 kg ha^{-1}. This observation suggests that other nutrients were probably released from GM simultaneously with N during the decomposition of sunn hemp residues.

On the other hand, the use of millet affected negatively upland rice yield. In the control treatment (no N fertilizer), rice grain yield was reduced by 44% as compared to without application of GM treatment and it was also lower up to N fertilizer rate of 43 mg kg^{-1} (Figure 1A). This negative effect is related to the high C/N ratio of the GM that resulted in temporary N immobilization as also shown by Amado et al. (2002) and Silva et al. (2006).

For treatments with GM application, rice straw biomass increased significantly and quadratically with increased N application rates. The maximum straw biomass (29.2 and

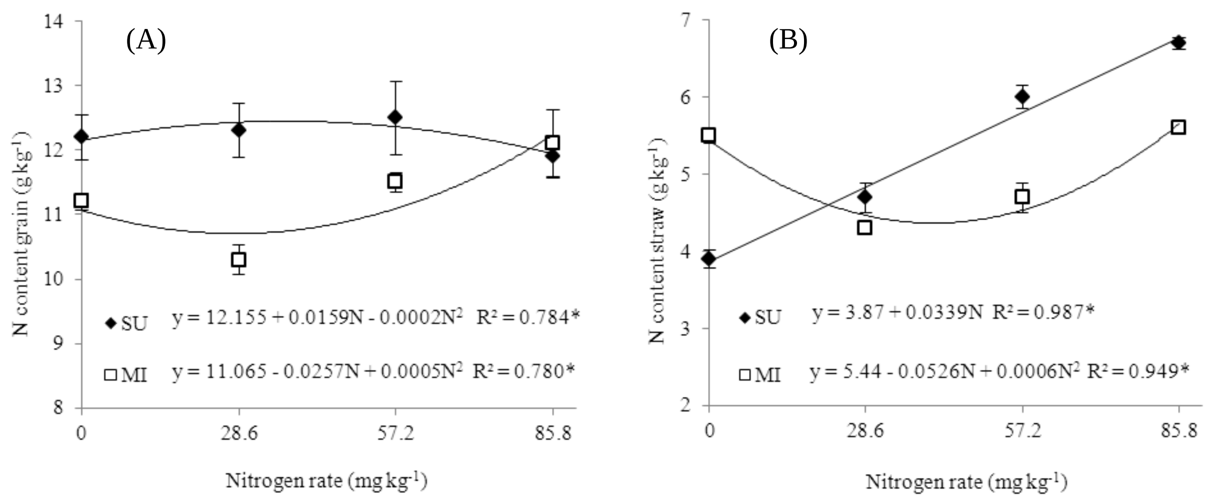

Figure 2. Nitrogen concentration in rice grain (A) and straw biomass (B) as affected by N fertilizer rate and application of green manure sunn hemp (SU) or millet (MI). * significan by the F test at 5%.

19.4 g per pot for sunn hemp and millet, respectively) were obtained with N fertilizer rates of 59.7 and 72.7 mg kg^{-1} for sunn hemp and millet, respectively (Figure 1B). The maximum rice straw biomass for treatment with application of suun hemp was 33.6% higher as compared to millet. Therefore, to achieve the same maximum rice straw biomass obtained in treatment with application of suun hemp, it would be necessary to increase N fertilizer rate to about 20% in the treatment with millet (Figure 1B). Thus, these results suggest that the application of millet increase N immobilization in soil as also shown by Amado et al. (2002) and Silva et al. (2006).

Nitrogen uptake by upland rice as affected by green manures

Nitrogen concentration in rice grain was greater than that in straw (Figure 2) and showed that grain is an important sink for N. There was a significant quadratic relationship between N concentration in rice grain and N fertilizer rate both with sunn hemp and millet application (Figure 2A). For sunn hemp, the maximum N concentration in grain was 12.5 g kg^{-1} for the N rate of 37.9 mg kg^{-1}. In treatment with application of millet, the maximum N concentration of 12.0 g kg^{-1} was obtained with N fertilizer application rate of 85.8 mg kg^{-1}.

Nitrogen concentration in rice straw increased significantly with the application of sunn hemp and linearly with increasing N rate, ranging from 3.9 to 6.8 g kg^{-1} (Figure 2B). With the application of millet, N concentration in straw had significant quadratic relation with N-urea rate and ranging from 4.4 to 5.6 g kg^{-1}. Under millet, N concentration in straw (ranging from 4.4 to 5.6 g kg^{-1}) showed significant quadratic association with N fertilizer application rate and decreased up to N fertilizer rate of 41.1 mg kg^{-1} probably because of N immobilization at low rates of N fertilizer.

Nitrogen accumulation in rice straw has significant quadratic association with N fertilizer rate under both sunn hemp and millet (Figure 3A). The application of sunn hemp showed maximum N accumulation of 182.7 mg per pot and it was equivalent to the application of 83.7 mg kg^{-1} as N fertilizer. While the N fertilizer required for maximum N accumulation was 83.7 mg kg^{-1} under sunn hemp, the N accumulation in rice straw was 42.4% lower when similar amount was applied with N fertilizer and millet.

Percentage of N in rice straw biomass derived from green manure (NPDFGM) decreased with increase in N fertilizer rate under both sunn hemp and millet (Figure 3B). The minimum NPDFGM (5.56%) in straw was obtained with application of millet and at N fertilizer rate of 65 mg kg^{-1} mineral. In the control treatment with no N fertilizer application, the NPDFGM in straw was 22% greater in sunn hemp than that under millet.

The amount of N in rice straw biomass derived from green manure (QNPDFGM) was significantly ($P \leq 0.01$) and quadratically increased with increasing N fertilizer rates under both sunn hemp and millet (Figure 3C). The QNPDFGM (Figure 3C) and NUE from GM in straw were lower with the application of millet as compared to sunn hemp at all N fertilizer rates which may be due the lower N content and higher C/N ratio of millet (Figure 3D). NUE of rice straw under millet was low and ranged from 2.2 to 2.8% of the N contained in the GM (Figure 3D). With application of sunn hemp, the maximum NUE was 8.1% and it was obtained at N fertilizer of 65 mg kg^{-1}. The N fertilizer rate significantly increased N accumulation in rice grain and is in a quadratic association with application of sunn hemp (Figure 4A). The maximum N accumulation was 248.7 mg per pot for sunn hemp at N

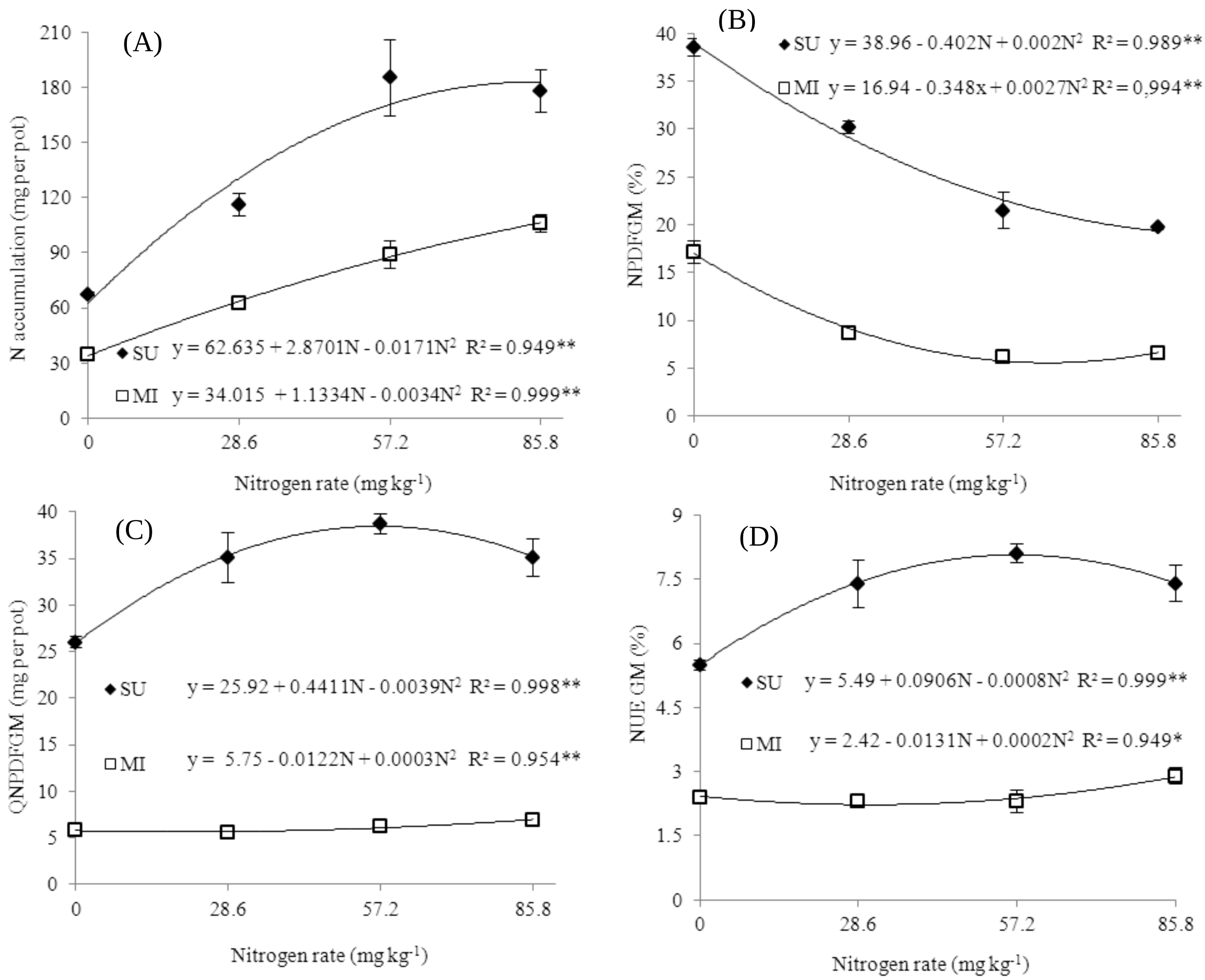

Figure 3. Nitrogen accumulation in rice straw (A), percent (NPPGM) (B) and quantity (QNPPGM) of N in rice straw from green manure (C) and N utilization efficiency (NUE) from sunn hemp (SU) and millet (MI) by straw rice (D), as affected by N fertilizer rate. ** and * significant by the F test at 1 and 5%, respectively.

fertilizer rate of 69.3 mg kg^{-1}. With the application of millet, N accumulation in grain increased linearly with increasing N fertilizer rate and ranged from 64.52 to 221.18 mg per pot (Figure 4A). The percentage of N in rice grain derived from green manure (NPDFGM) decreased significantly and quadratically with increasing N fertilizer rates to both sunn hemp and millet (Figure 4B). The percentage of NPDFGM with application of sunn hemp was higher as compared to millet at all N fertilizer rates. With no N fertilizer input, the application of sunn hemp was equivalent to N fertilizer rate of 23 mg kg^{-1} as compared to same treatment with millet.

The QNPDFGM both for sunn hemp and millet (Figure 4C) and the NUE from these two GMs by rice grains (Figure 4D) were not significantly influenced by N fertilizer application rates. The average of QNPDFGM sunn hemp was 56.4 mg pot^{-1} and it was equivalent to 11.8% of N applied as residue (476.77 mg per pot). With application of millet, the QNPDFGM was on average 12.7 mg per pot, equivalent to a recovery of 5.3% of N applied as GM (239.26 mg per pot). Muraoka et al. (2002), using legumes sunn hemp (*Crotalaria juncea*) and velvet bean (*Mucuna aterrima*) as green manure, reported an effect equivalent to the fertilization of 40 kg ha^{-1} of urea, indicating that these legumes are an important alternative source of N and other plant nutrients. Scivittaro et al. (2004) conducted an experiment to determine the temporal pattern of N release from velvet bean (*Mucuna aterrima*) and studied the dynamics of N contained in green manure in soil-plant system, and found that the incorporation of GM promoted increased dry matter yield and N uptake by rice plants.

As compared to millet, sunn hemp showed greater N accumulation (NA), percentage (NPDFGM) and amount (QPDFGM) of N in rice derived from green manure, NUE from green manure by upland rice (Table 1). Therefore,

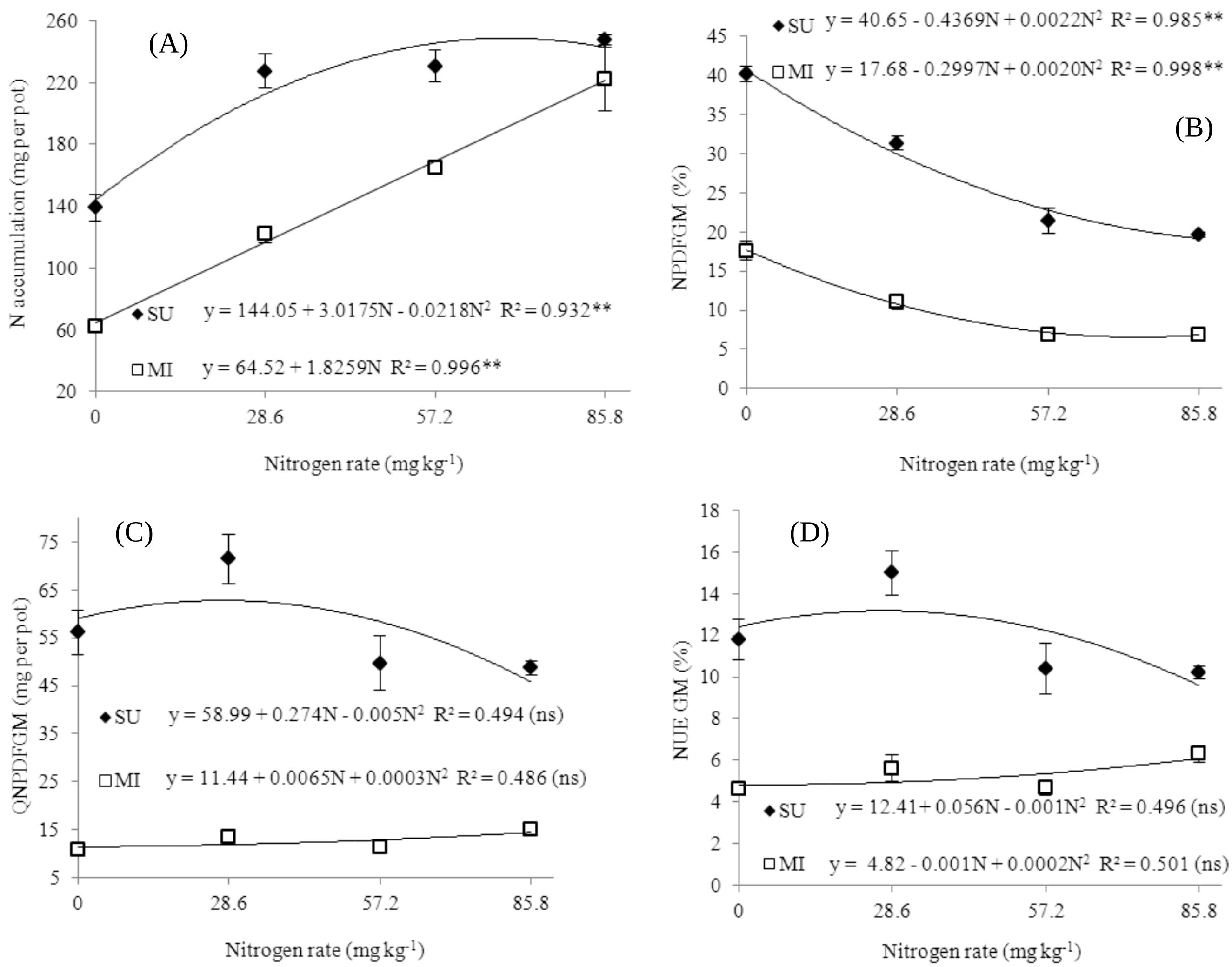

Figure 4. Nitrogen accumulation in rice grain (A), percent (NPDFGM) (B) and quantity (QNPDFGM) of nitrogen in rice grain derived from sunn hemp (SU) and millet (MI) (C) and N utilization efficiency (NUE) from green manures by the rice grain (D), as affected by N fertilizer rate. ns and ** not significant and significant by the F test at 1%, respectively.

the amount of N in rice derived from sunn hemp and the NUE from this GM were approximately five and two times greater than those with millet. This effect was observed probably due mainly to higher C/N ratio of millet as compared to sunn hemp that resulted in lower mineralization rate of the residue and probably immobilization of N under millet (Silva et al., 2006, 2010; Carvalho et al., 2011). Other studies have obtained values of NUE from sunn hemp to be between 10 and 37% for rice crop (Muraoka et al., 2002) and 8% for wheat (Araújo et al., 2005). Studies with other legumes (*Sesbania aculeata*) in rice grown area reported NUE of 19.3% (Azam, 1990) and of 19.7% for sorghum (Kurdali et al., 2007). Using GMs as N source, studies obtained values of NUE from GMs to be between 3 and 8% for rice (Muraoka et al., 2002), and 12% for corn crop (Scivittaro et al., 2003; Silva et al., 2010). In studies with three legumes, Odhiambo (2010) showed that sunn hemp tend to release N at a faster rate, followed by lablab and velvet bean. The application of sunn hemp also showed potential to increase maize yield in smallholder farms (Odhiambo, 2011).

The low NUE from green manure observed in this study indicates that a majority of N from GM remained in the soil, probably as organic form (Azam et al., 1995, Amado et al., 2002; Muraoka et al., 2002; Ambrosano et al., 2003; Scivittaro et al., 2003). Studies reported that less than 50% of the N incorporated into soil as organic form is transformed into inorganic N by mineralization and the other part has been found to be in association with the soil microbial biomass (Mengel, 1996; Scivittaro et al., 2004).

Traditionally, both legume and non-legumes have been used as GM to develop sustainable agricultural systems

Table 1. Nitrogen accumulation (NA), quantity (QNPDFGM) and percentage (NPDFGM) of N in upland rice (straw + grain) derived from green manure and N utilization efficiency (NUE) from green manure by upland rice (straw + grain), as affected by green manure specie (sunn hemp and millet).

Green manure	NA	QNPDFGM	NPDFGM	NUE
	mg per pot		%	
Sunn hemp	347.9[a]*	90.2[a]	27.5[a]	18.9[a]
Millet	215.8[b]	18.6[b]	10.0[b]	7.8[b]
CV (%)	9.99	15.54	10.21	14.18

Values followed by different letters, in the same columns, do not differ by the Tukey test at 5%.

Table 2. Percentage (NPDFGM) and quantity (QNPDFGM) of N in upland rice (straw + grain) derived from root or shoot green manure and N utilization efficiency (NUE) of green manure by rice plant (straw + grain), as affected by green manure specie (sunn hemp and millet).

Green manure		Straw			Grain		
		NPDFGM	QNPDFGM	NUE	NPDFGM	NPDFGM	NUE
		%	mg per pot	%	%	mg per pot	%
Sunn hemp	Shoot	21.7[a]	38.3[a]	9.6[a]	23.3[a]	50.2[a]	12.5[a]
	Root	3.1[b]	4.8[b]	6.3[ab]	3.0[b]	7.5[b]	9.8[ab]
Millet	Shoot	5.2[b]	8.3[b]	4.6[b]	5.8[b]	12.2[b]	6.8[b]
	Root	2.0[b]	3.2[b]	5.3[b]	2.0[b]	4.1[b]	6.8[b]

Values followed by different letters, in the same columns, do not differ by the Tukey test at 5%.

due their numerous benefits which is related to improving soil fertility, water retention and reducing soil erosion (Fageria et al., 2005; Fageria, 2007). However, leguminous GMs are considered superior because substantial amount of biologically fixed N can be subsequently transferred to non-legume cereal crop under subsequent rotations (Fageria, 2007).

Nitrogen in upland rice derived from shoot and root of green manures

The highest percentage and amount of NPDFGM, both in upland rice grain or straw, was observed with application of sunn hemp shoot as compared to others treatments (Table 2). NUE of shoot and root of sunn hemp by rice (grain and straw) were similar, but NUE of sunn hemp shoot was higher as compared to the application of both shoot and root of millet.

The NUE from root (5.3%) and shoot (4.6%) of millet by rice straw was lower than N from sunn hemp shoot (9.6%) (Table 2), possibly due to slower mineralization of the millet residues with higher C/N ratio. Also, reimmobilization of millet residues mineralized N (Silva et al., 2006; Carvalho et al., 2011) may have occurred. Although, usually only the N content in shoot of GMs is considered, the roots is another important N and other nutrients source for succeeding crops (Araújo et al., 2004; Scivittaro et al., 2004; Silva et al., 2008).

The NUE from sunn hemp shoot by rice (grain or straw) did not differ significantly from root of this legume (Table 2), and it was higher than the N recovery from millet root and shoots. The overall average NUE from GMs root by upland rice plants was 14.1%, whereas it was 16.8% for shoot.

Nitrogen use efficiency by upland rice derived from N fertilizer (urea)

Nitrogen use efficiency in rice plants (grain + straw) was not influenced by N fertilizer application rates under with or without GMs and it was on average, 53.7% (Figure 5A). Bronson et al. (2000) reported lower NUE of urea by rice crop (44%). Therefore, the NUE from urea in rice grain (34.8% on average) was not affected either by N fertilizer rate or application of different GMs (Figure 5B).
The NUE from urea in rice straw (18.9% on average) was significantly influenced by the application of GM. The application of millet reduced NUE from urea as compared to treatment without GM and with sunn hemp application (Figure 5C), probably due to N immobilization as shown by Corak et al. (1992). However, NUE did not differ significantly between treatments with application of sunn hemp and without addition of GM. The NUE from N fertilizer in rice straw was not influenced by N-urea rates.

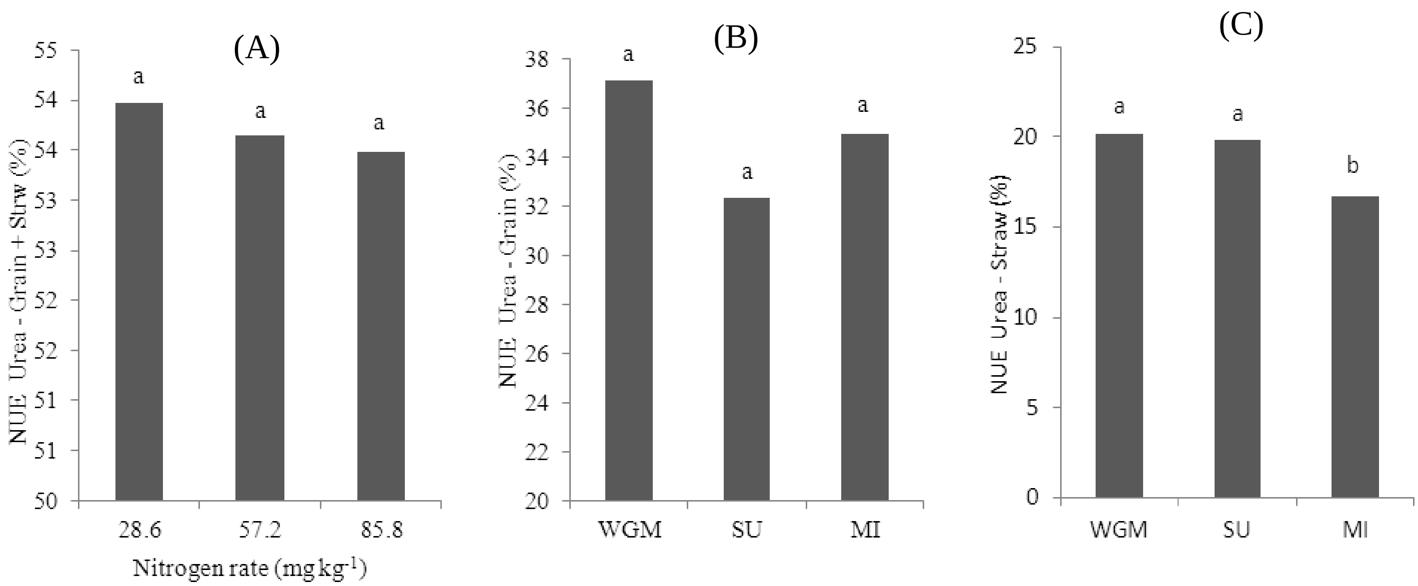

Figure 5. Nitrogen utilization efficiency (NUE) from fertilizer (urea) by upland rice: grain yield + straw biomass (A), grain yield (B) and straw biomass (C), as affected by N fertilizer rate and application of sunn hemp (SU), millet (MI) and without green manure addition (WGM). Bars followed by the same letter do not differ significantly according to Tukey test at 5%.

Table 3. Nitrogen in upland rice (straw + grain) derived from fertilizer urea (NPDFF) and N utilization efficiency (NUE) as affected by N fertilizer application time, at seeding or topdressing, grown in the absence and presence of green manure (sunn hemp or millet).

Green manure	NPDFF %		NPDFF mg per pot		NUE %	
	Seeding	Topdressing	Seeding	Topdressing	Seeding	Topdressing
Without GM	7.6^{Bab}	29.0^{Ab}	28.9^{Ba}	124.1^{Aa}	63.3^{Aa}	67.8^{Aa}
Sunn hemp	6.2^{Bb}	21.6^{Ac}	28.1^{Ba}	107.7^{Aa}	61.7^{Aa}	47.1^{Bb}
Millet	8.3^{Ba}	38.4^{Aa}	24.0^{Ba}	107.3^{Aa}	52.7^{Ab}	58.6^{Aa}
CV (%)	9.9	9.4	9.7	7.2	9.6	7.6
Average	7.4	29.7	27.0	113.0	59.2	57.8

Values followed by the same letters, for the same variable (lower case letter in columns and capital letter in row), do not differ by the Tukey test at 5%.

Nitrogen use efficiency as affected by time of N application (seeding and topdressing)

Percentage and amount of N in rice derived from fertilizer (NPDFF) were greater when N fertilizer was applied at topdressing as compared to seeding (Table 3). In contrast, the percentage of N in rice derived from green manure (Table 1), the percentage of NPDFF in upland rice (straw + grain) were greater in treatments with application of millet as compared to the sunn hemp (Table 3).

Nitrogen use efficiency of urea was not affected significantly by supply of N fertilizer at seeding or topdressing, in treatments without GM or with application of millet (Table 3). However, with application of sunn hemp, the NUE of urea was greater when N fertilizer was applied at seeding (61.7%) as compared to topdressing (47.1%).

In this study, N recovery in rice root was not evaluated, thus the NUE of GM or urea by whole upland rice plant (root + shoot) were underestimated. Previous studies have been reported in literature that high amount of N fertilizer is present in plant roots under these production systems (Azam et al., 1995; Silva et al., 2006, 2008).

Results of this study showed that the application of GM, mainly sunn hemp, in combination with N fertilizer may be a fertilizer management practice to increase upland rice yield, improve N fertilizer efficiency and reduce inorganic N fertilizer inputs. As some of these GM are legumes, they have the potential to grow as rotational vegetation with crops such as rice, maize and other cereal crops.

Conclusion

The introduction of sunn hemp to soils before rice crops showed greater upland rice grain yield and straw biomass as compared to millet and without application of green manure. As a legume, sunn hemp fixes atmospheric N and transfer part of this N to soil. Some of this N can be subsequently mineralized and made available to rice crops and subsequently increase yield. The NUE from sunn hemp by rice grain was higher than the NUE by the straw. The sunn hemp NUE by the rice plants was two times higher than that from the millet. The N-urea rates, with or without green manures, did not affect the NUE of fertilizer by rice plants. The NUE from shoot and root of GM by the rice plants were similar. With application of sunn hemp, the NUE from urea was observed when N fertilizer was applied at seeding as compared to topdressing. However, this effect was not observed with application of millet and without addition of GM. The study showed that the introduction of green manures, particularly legume green manures may help meet some of the N requirements of subsequent cereal crops such rice. Further field studies are important to assess the role of legume green manures in supplying N to subsequent crops.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors thank Coordination for the Improvement of Higher Education Personnel (CAPES) for the research scholarship granted to the first author; International Atomic Energy Agency (IAEA) for the financial support and National Council for Scientific and Technological Development (CNPq) for the research fellowship to the others authors.

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academicJournals

Vol. 11(13), pp. 1181-1186, 31 March, 2016
DOI: 10.5897/AJAR2015.10345
Article Number: 432ED5E57853
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Management of soy supply (*Glycine max*) and its exploitation in farming crambe (*Crambe abyssinica*)

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Received 25 August, 2015; Accepted 29 October, 2015

The experiment was conducted in the 2013/14 season, in an experimental area of the C-Valle, in Palotina Municipal District, Parana State, Brazil. The cultivar used was Monsoy 6210 IPRO. The experimental design was a randomized block with four replications. The treatments consisted of basic fertilization (AB) in soybean sowing, AB + 20% AB + 40% AB + coverage with potassium, AB + 20% + coverage with potassium and AB + 40% + coverage with potassium. The variables evaluated for agronomic performance of soybeans were: Plant height, first pod height, number of pods per plant, yield and mass of one hundred seeds. Could not find significant differences in the variables analyzed. We conclude that the fertilization treatments were not effective for the increase of soybean grown in clay soil parameters. The crambe culture can be considered a culture that recycles nutrients and has good potential for the use of residual fertilizer from previous crops.

Key words: Residual fertilizer, base fertilizer, nutritional requirements.

INTRODUCTION

Soybean (*Glycine max*) belongs to Fabaceae family having as diversification of central Asia and was domesticated to grain production oriented human consumption (Mundstock and Thomas, 2005). Soybean crop is due for two main reasons: High oil content and protein. Other features involved are the plants uniformity allied production technologies coming increasingly expanding the cultivated area and yield (Lazzarotto and Hirakuri, 2010). According to FAO (2015), soybean production in the 2012/2013 harvest was approximately 241 million tons while in Brazil, soy production in the 2014/2015 crop, was around 95 million tons (Conab,

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2015). According to SEAB (2013), the average production of Paraná State in the 2011/2012 harvest was approximately 11 million tons.

For soybean cultivation, the optimal thermal conditions necessary are around 20 to 30°C (Embrapa, 2009, 2011). In relation to the maturity groups, soybean Parana, can be divided into: early (up to 115 days), semi-early (116-125 days), medium (126-137 days) and semi late (138-145 days) (Embrapa, 2003).

With these characteristics from the surrounding environmental conditions of temperature and aging groups, this species is very demanding in all macronutrients. These nutrients are required and must be made available so that the plant can perform their production cycle (Sfredo, 2008). The potassium demand begins in the vegetative growth stage at which the maximum absorption rate of the nutrient is about 30 days before flowering (Tanaka et al., 1993). The phosphorus is a major factor limiting the soybean yield. This nutrient is a constituent of carbohydrates, co-enzymes, nucleic acids, among others (Bingham, 1966). To supply N, soybean uses the symbiosis with nitrogen-fixing bacteria of the genus Bradyrhizobium that associate in plant roots, forming structures called nodules, which occur in such a setting. These bacteria reduce N_2 to ammonia (NH_3) and then utilize the hydrogen ions that are incorporated into the ammonia production occurring ammonium ion (NH_4^+) that will be used by plants (Hungria et al., 2001).

The crambe (*Crambe abyssinica* Hochst) belongs to the Brassicaceae family Brassicae tribe, which is similar to other species such as canola and mustard (Desai, 2004). According Pitol (2008) the crambe is very tolerant to cold and not resisting frost at critical stages of growth such as the flowering, where abortion flowers occurs.

Even in agricultural development as culture, crambe presents a good performance in the search fields, low cost of production, drought resistance, hardiness, able to adapt to low productivity of soils (Neves et al., 2007). According to these characteristics, this culture can be grown in the winter as an option even crop rotation providing less risk of crop frustration (Möllers et al., 1999).

According Pitol (2008), the crambe yield in Brazil is estimated to 1000 to 1500 kg ha^{-1}, however in some cases productivity reached 2300 kg ha^{-1} (Mai Neto, 2009; Silva et al., 2012).

To obtain good productivity, nutrient supply is essential (Malavolta et al., 1997). In the successive cultivation systems, when the above species are fertilized, the residual effect of the fertilizers can be noticed in a significant way (Silva et al., 2001). In experiment checking the residual effect of nitrogen applied to corn for the subsequent cultivation of oats, Fernandes et al. (2008) conducted experiments in sandy clay Latossol nitrogen for concluding that there was little waste, characterized in leaching losses of a crop to another. However Silva et al. (2001) evaluated the effect of residual fertilizer potato on the production of bean-to-pod in continuous cultivation in Oxisol sandy texture, observed that increasing doses of mineral potato fertilization also increased phosphorus, exchangeable potassium and calcium in the soil without changing the pH. The production and other components of the analyzed production showed a positive increase in function of this residual effect. Found that it is feasible the production of the bean-to-pod just with the residue of potato fertilization.

According Pitol (2008), crambe culture can be considered a culture that recycles nutrients and has good potential for the use of residual fertilizer from previous crops. In view of these evidences are important studies of fertilization needs and the possible increase of fertilization on preceding crop to increases in yield crambe crop.

The aim of this study was to evaluate the effect of residual fertilization of soybeans on the development of crambe crop.

MATERIALS AND METHODS

The experiments were conducted in the 2013/14 season, in an experimental area of Agroindustrial Cooperativa C-Vale, located in the city of Palotina, located in the State of Paraná West Region, with the following coordinates 24°20'26" S and 53°51'31" O, with elevation of 355 m.

Soil was classified as oxisol tipic clayey (Embrapa, 2006). Was carried out chemical analysis and physical soil before the experiment, the depth from 0.0 to 0.20 m. This showed the following results: pH ($CaCl_2$) = 5.2; C = 8.12 g dm^{-3}; MO = 13.97 mg dm^{-3}; P (Mehlich) = 8.31 mg dm^{-3}; V = 59.70%; 0.0, 3.97, 0.20, 4.79, 0.89, 9.85 $cmol_c$ dm^{-3} Al, Al H +, K, Ca, Mg, CTC, respectively.The climate that the region has It is the CFA with well defined seasons and well distributed rains during the year, according to the Köppen classification.

It was used to cultivate soy Monsoy 6210 IPRO, which was chosen for presenting great acceptability and seeding in the region. The same was sown on 09.22.2013. The plots consisted of four rows of five meters in length (between lines spacing of 0.45 m). For evaluations, we used floor area of 3.6 m^2, which were considered only the two central rows, discarding 0.5 m from each end of the rows (borders).

The experimental design was a randomized block with four replications. The treatments are shown in Table 1 were made using the formulation of N, P_2O_5, K_2O 02-20-18 respectively. The application of potassium chloride was given coverage in the stadium V4 to V5 soybeans.

The other cultural installation practices and phytosanitary management followed the requirements of Embrapa (2011). The experimental areas were kept free of the presence of weeds, pests and diseases throughout its development.

The variables evaluated for agronomic performance of soybeans were: plant height, first pod height, number of pods per plant, yield and mass of one hundred seeds.

To determine the height of the plants were assessed 10 plants chosen at random from the floor area of the portions, performing measurements with the aid of a millimeter ruler, and the results are expressed in centimeters. Number of pods per plant was evaluated at the time of full maturity (R8 stage), by manually counting the number of gifts pods, also in ten plants.

The plants were harvested by hand at the R8 stage, that is, when 95% of the pods had the typical color of ripe pods (Fehr et al.,

Table 1. Arrangement of fertilization treatments in soybean in clay soil, in Palotina – PR, Brazil.

Treatments	Fertilizer (kg ha^{-1})	Nutrient (kg ha^{-1})		
		N	P	K
Basic fertilization (BF)	269	5.38	53.80	48.42
BF + 20% of BF	323	6.46	64.60	58.14
BF + 40% of BF	376	7.52	75.20	67.68
BF + K top dressing (K)	269 + 60	5.38	53.80	108.42
BF + 20% + K of BF	323 + 60	6.46	64.60	118.14
BF + 40% + K of BF	376 + 60	7.52	75.20	127.68

Table 2. Plant height, first pod insertion height and number of soybean pods, depending on the management fertilization.

Treatments	Plant height (cm)	Pod insertion height (cm)	Pods number
Basic fertilization (BF)	94.6	14.6	38.6
BF + 20% of BF	93.5	15.0	42.6
BF + 40% of BF	94.5	15.0	44.7
BF + K top dressing (K)	94.5	15.7	40.7
BF + 20% + K of BF	98.1	14.5	43.3
BF + 40% + K of BF	96.0	15.5	39.1
CV %	6.1	6.9	12.1
F test	n.s.	n.s.	n.s.

n.s. = not significant; CV = Coefficient of variation.

1971). Then the pods were threshed on threshing for experiments, cleaned with the aid of screens and packed in paper bags.

Starting from the grain yield in the plots, productivity in kg ha^{-1} was estimated, for each treatment and repetition. Thereafter, the thousand grain weight was determined through weighing of eight replicates for each field repetition. For the calculation of income and thousand grain weight, moisture content was adjusted to 13% wet basis.

For evaluation of the residual fertilizer use, crambe plots were installed in exactly the same place as the previous crop (soybeans). Sowing was held on 04.10.2014 with the help of a tractor and seeder plots. Cultivar used was developed by Bright FMS MS Foundation. Seeds were sown at a depth of 0.03 m, spacing 0.17 l, used seeding rate was established at 1,000,000 plants per hectare. The experimental areas were kept free of the presence of weeds, pests and diseases throughout its development.

The experimental design was a randomized block design with four replications and seven treatments. The plots consisted of six lines of crambe five meters. For evaluations, floor area of 2.72 m^2 was used; only the four central rows were considered, discarding 0.5 m from each end of the rows (borders). The treatments consisted of residual fertilization of soybeans (Table 1), with one more treatment with a fertilization of 269 kg ha^{-1} formulation 02, 20 and 18 respectively of N, P_2O_5 and K_2O.

The variables evaluated for agronomic performance of crambe were: Final population of plants, oil content, the 1000 seeds and yield.

To determine the final population, stand counts was performed in the two central rows in 2 m portion, totaling 0.34 m^2, and these extrapolated values or plants per hectare. The oil content was determined from the chemical extraction thereof by method described by Silva et al. (2015).

Yield for determining the productivity plants were harvested by hand, thereafter the siliques were threshed on threshing for experiments, cleaned with the aid of screens and packed in paper bags. Starting from the grain yield in the plots, productivity was estimated in kg ha^{-1} for each treatment and repetition. The thousand grain weight was then determined through weighing of eight replicates for each field repetition. For the calculation of income and thousand grain weight, moisture content was adjusted to 13% wet basis.

Both data were submitted to analysis of variance and the media submitted to Tukey test ($p<0.05$).

RESULTS AND DISCUSSION

Analyzing plant height data, insertion height of the first pod and number of pods (Table 2) revealed no significant difference between the different managements of fertilization. Through soil analysis, it is possible to interpret that the P and K nutrients were high and middle levels, respectively, and may have led to non significant results of fertilization managements once the soil has good chemical characteristics.

For the thousand grain weight and productivity (Table 3), there was also no significant difference between the managements of fertilization. According to Conab (2015), Brazilian average yield in soybean crop from 2013 to 2014 was approximately 2.858 kg ha^{-1} and according to Table 3, there was an increase of 84.3% on average in

Table 3. Thousand grain weight and soybean yield, depending on the management of fertilizer in sowing and coverage.

Treatments	1,000 grains weight (g)	Yield (kg ha^{-1})
Basic fertilization (BF)	157.6	5.134
BF + 20% of BF	159.2	5.133
BF + 40% of BF	164.5	5.397
BF + K top dressing (K)	164.2	5.234
BF + 20% + K of BF	160.5	5.223
BF + 40% + K of BF	162.0	5.481
CV %	5.2	8.0
F test	n.s.	n.s.

n.s. = not significant; CV = Coefficient of variation.

Table 4. Final plant population and crambe oil content, according to residual fertilization of soybean cultivation.

Treatments	Final plant population (1,000 plants ha^{-1})	Oil content (%)
Soybean residual (SR)	1,088.23	31.0
SR + 20% of SR	1,070.58	30.7
SR+ 40% of SR	1,105.88	30.6
SR + K	1,085.29	30.9
SR + 20% of SR + K	1,094.11	30.8
SR + 40% of SR + K	1,063.25	30.3
SR + crambe fertilization	1,102.94	31.1
CV (%)	3.7	1.9
F test	n.s.	n.s.

CV = Coefficient of variation. n.s. = Not significant at 5% probability of error.

productivity of treatments. This increase reflects the good climate and soil conditions of edafo chemical conditions in favor of the production potential offered by variety.

Due to the amount of basic fertilizer supplied and the application of K coverage, it may be noted that the use of nutrients occurred in all treatments. According to Raij et al. (1997), K is a nutrient that has low adsorption on soil colloids and the installment of K_2O aims at optimizing the K use available for the plants by reducing their losses by leaching and salt effect on seeds of time sowing with greater caution in sandy soils with characteristics (Alvarez et al., 1999; Raij et al., 1997).

For P use, Gonçalves et al. (1985) points out that the presence of organic matter in no-till soils ensures the absorption of this nutrient by the plant. Organic matter acts in interaction with Al and Fe oxides reducing phosphorus fixation sites in the soil and promoting better use by the P plant from the phosphate fertilizer (Fontes et al., 1992; Afif et al., 1995; Andrade et al., 2003). As the content displayed on the chemical analysis of the soil 13.97 g dm^{-3} of organic matter, it can be stated that there is phosphorus utilization by all treatments. Extinguishing ability of some treatment has significant result of varying the presence and amount of potassium coverage.

In assessing the final population of crambe culture, a significant difference was not found between treatments as the seeder was well measured (Table 4). For the oil content, there were no significant differences between the treatments of residual fertilization and fertilization in crambe. This shows that the crambe culture has the ability to recycle and take advantage of the residual nutrients from the preceding crop, thus agreeing with the statement of Pitol (2008).

There was also no significantly different oil content in Lunelli et al. (2014) experiment, who observed the application of N, P and K in crambe culture, but in numerical terms noted that treatment containing NPK nutrients associated possible increased value compared to other nutrients. Like all treatments that contained NPK whether residual or fertilization in culture, the oil content was not altered significantly.

For the 1,000 seeds (Table 5) there was no significant difference between treatments. However, for productivity (Table 5) a significant difference was found in which, RS + 40% + K treatment differed significantly greater than the treatments: Residual soybean (RS) RS and RS + K fertilization in crambe. This significant difference is probably linked to the increased number of grains per

Table 5. Mass 1,000 grains (g) and yield (kg ha^{-1}) crambe, depending on the residual fertilizer of soybean cultivation.

Treatments	Mass 1,000 grains (g)	Yield (kg ha^{-1})
Soybean residual (SR)	5.83[a]	1.774[b]
SR + 20% of SR	5.80[a]	1.844[ab]
SR+ 40% of SR	5.70[a]	1.842[ab]
SR + K	5.93[a]	1.764[b]
SR + 20% of SR + K	6.02[a]	1.892[ab]
SR + 40% of SR + K	5.97[a]	1.949[a]
SR + crambe fertilization	5.99[a]	1.741[b]
CV (%)	3.9	3.8
F test	n.s.	*

CV = Coefficient of variation. n.s. and * = not significant and significant at 5% error probability, respectively.

plant, since there was no difference in plant population per hectare which presented denser grain seen by the mass of 1,000 grains.

The results for higher productivity in the treatment crambe RS + 40% + K can be explained by the greater presence of nutrients in the waste form, that is, not used by the previous soybean. For this treatment in soybeans, it received the highest nutrient loading in view of the data in Table 1.

Conclusion

There were no significant associations between variables in terms of increased fertilizer and potassium fertilizer to increase coverage. On the other hand, it showed good soil chemical conditions, and the high clay content and the presence of organic matter, requiring further study of these treatments on other soil types in different conditions. The crambe crop is effective in taking advantage of the residual fertilization of soybeans, when it is held in large quantities, under the conditions in which the experiment was conducted.

Conflict of Interests

The authors have not declared any conflict of interests.

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academicJournals

Vol. 11(13), pp. 1187-1193, 31 March, 2016
DOI: 10.5897/AJAR2015.10078
Article Number: A4624BD57856
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Comparative analysis of three different spacing on the performance and yield of late maize cultivation in Etche local government area of Rivers State, Nigeria

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Received 27 June, 2015; Accepted 17 February, 2016

This study was carried out to compare and analyze how spacing influenced the performance and yield of late maize in Egwi, Etche Local Government Area (LGA) of Rivers State, Nigeria between September-December in 2013 and 2014. The study adopted experimental research design. The experiment was laid out in a randomized complete block design (RCBD) with three replicates. One maize variety was evaluated under three spacing for performance data such as plant heights, stem girths, number of leaves, number of nodes and leaf area and for the yield, data were collected on cob length, cob weight, cob + husk weight, cob diameter and 1000-grain weight (yield). The results obtained 56 days after planting (DAP) in the two years of study showed significant differences (p < 0.05) in plant height, stem girth and leaf area. The 70 x 30 and 60 x 40 cm spacing gave higher values of the morphological parameters than 80 x 20 cm. With regard to yield, 80 x 20 cm gave the highest average cob weight of 0.74 kg and 1000-grain weight (yield) of 0.27t/ha. Based on the findings of the study, the 80 x 20 cm spacing was recommended for local farmers in Etche for maximum yield and economic returns.

Key words: Etche Local Government Area (LGA), maize plant, Nigeria, Rivers State, spacing.

INTRODUCTION

Maize (*Zea mays*) is a member of the grass family Graminae. It originated from South and Central America. It was introduced to West Africa by the Portuguese in the 10th century. It arrived Nigeria in the 16th century (FAO, 2012). It is one of the most important grains in Nigeria, not only on the basis of the number of farmers that are engaged in its cultivation, but also in its economic value (Adeniyan, 2014; Olaniyi and Adewale, 2012). Maize has been in the diet of Nigerians for centuries. It started as a subsistence crop and has gradually become an important commercial crop on which many agro-based industries depend on for raw material (Ike and Amusa, 2004). In Nigeria, maize is prepared and used for different types of foods and it also has some medicinal values.

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Khawar et al. (2007) described maize as one of the most valuable cereal grains because of its high net energy content. Due to the important uses of maize, the effort towards increasing its production has grown and the study of the agronomic practices that will enable farmers adapt to the effective early and late production is important for increased productivity in West Africa (Drechsel et al., 2004). Studies have shown that maize farm of 1.2 ha can overcome hunger in the household and the aggregate effect can double food production in Africa (Ogunsumi et al., 2005). According to Ogunsumi et al. (2005), about 561397.24 ha of Nigerian lands are planted with maize yearly. This constitutes about 61% of total cultivable land in Nigeria. Maize cultivation in Nigeria, unlike temperate regions, is mainly done in intercropping system. Intercropping has long been recognized as a common practice among subsistence farmers in the traditional semi-intensive system of agriculture due to the flexibility of labor used (Ighalo and Alabi, 2005). One of the cultural practices in a sustainable maize cultivation is irrigation (Anyadike and Obeta, 2013). Irrigation in Nigeria has become an issue of vital importance considering present population growth rate. Virk et al. (2004) noted that Asia's food security depended largely on irrigated rice fields. In the United Kingdom and America, there have been well articulated institutional frameworks for irrigation and water supply since the past 150 years or thereabout (Anyadike and Obeta, 2013). Enujeke (2013) stated that the decline in maize production over the years were based on the following:

1. Rapid reduction in soil fertility
2. Failure to identify and plant high yielding maize varieties
3. Use of inappropriate plant spacing which determine the plant population and the final yield.

Hence, Mureithi et al. (2005) asserted that raising the yield per unit area of individual crops was the way forward. Yield potentials have usually been represented in parts under the most favorable combination of soils, climate and crop management in certain places without considering spacing which is a major factor in increased yield potential of maize. With the statistics and records available on maize production in Nigeria, there is no doubt it is one of the three most useful crops in the nation. Exploiting all avenues to increase its production under any condition to meet the demands of the teeming population would not be out of order, thus the need for a good choice of spacing. Reports of inconsistent yield effects of plant spacing uniformity could be the consequence of plant density difference and the method through which plant spacing variability was measured (Fowler 2012; Thompson, 2013). Yield increases are dependent on many factors ranging from water availability and distribution, nutrient supply as well as spacing which is a major determinant of yield addition or subtraction (TLC, 2009). Increasing population density remains the most effective way to increase whole-plant yield in short-season corn with 13% advantage. Narrow row spacing was found not to have a negative effect on whole-plant yield and nutritive value (Baron et al., 2006; Boloyi, 2014). Wider spacing encourages growth of weed and thus more labor and increase in cost of production. Sharifi et al. (2009) concluded that plant population density influenced maize dry matter yield. Moderate densities were seen as good, and significant reduction occurred only at very high densities. Grains (maize) seem to respond to population densities and spacing. Boloyi (2014), therefore showed 75 x 25 cm as the best spacing for mechanized farming. Tri (2009) observed that the best spacing was 20 to 25 cm along rows and 70 to 80 cm between rows, but the popular spacing was 75 x 25 cm at one plant per stand and 75 x 50 cm at two plants per stand. Anyanwu (2013) was of the opinion that maize should be sown at 90 x 45 cm spacing on ridges and 90 x 30 cm when staggered, and that maize spacing should actually be determined by the soil fertility of an area. Rui et al. (2011) recommended a spacing distance of 30 cm along the row and 90 cm between rows, while Leebass (2012) recommended 90 x 60 cm along and between rows at two seeds per hole. Futlless et al. (2010) compared four spacing (75 x 25, 75 x 20, 75 x 15 and 75 x 10 cm) in Mubi, Nigeria and found out that maize planted at 75 x 25 cm gave the highest grain yield of 1900 kg/ha. They therefore recommended that farmers in Mubi should adopt the spacing of 75 x 25 cm for maximum productivity. Zamir et al. (2011) recommended 60 x 20 cm for farmers in Faisalabad in Pakistan as it gave the highest average yield of 7.6 kg/ha. They observed further that the yield was determined by the agro-climatic condition of the area after comparing the spacing of 60 x 20 cm, 60 x 25 and 60 x 30 cm. Boloyi (2014) recommended a spacing of 90 x 25 cm for farmers in Ibadan, Nigeria since it gave the highest average yield of 232.3 kg/ha in comparison with the other spacing of 75 x 50 and 75 x 25 cm that produced lower yields.

However, in Etche, farmers plant maize indiscriminately without due consideration of appropriate spacing, thus, the need for this study on comparative analysis of three different spacing (80 x 20, 70 x 30 and 60 x 40 cm) on the performance and yield of late maize cultivation in Etche.

MATERIALS AND METHODS

The experiment was conducted in Etche in Rivers State of Nigeria, during the late planting seasons of 2013 and 2014 between September and December. Etche lies between longitude 6°45' and 7°18'E and latitude 4°45' and 5°15'N and 169 m above sea level. It is located in the ecological zone of Southern Nigeria with mangrove vegetation and an average annual rainfall of 2000 mm, relative humidity above 80% and a mean temperature of 28.14°C.

Etche land is chosen for this research because its soil is very good for agriculture, there is also favorable weather condition to

Table 1. Physio-chemical properties of experimental site particle size distribution in percentage.

Soil property	Value interpretation
Coarse sand	34%
Fine sand	41%
Silt	11%
Clay	14%
Texture	Sandy loam
pH H_20	6.6 Acidic
Cacl	5.9 acidic
Organic carbon g kg-1	0.93
Organic matter g kg^{-1}	0.2 very low
Total Nitrogen g kg^{-1}	0.125 low
Available phosphorus (ppm)	28.3
Exchangeable bases	
Na^+	0.58 moderate
K^+	1.2 low
Ca^{2+}	3.1 low
Mg^{2+}	1.1 low
Cation exchange capacity	5.32
Exchangeable acidity	**(cmol kg^{-1})**
Al^{3+}	Trace
H^+	1.6
Effective Exchangeable Capacity (cmol kg^{-1})	6.2

support agricultural practice at any time of the year but the people have been found to practice maize cultivation indiscriminately without due consideration of spacing. The maize variety used for the study was yellow flint TZSR-Y maize.

The experiment was done on a land area of 4 x 6 m (24 m^2). Soil samples were collected from different portions of the land and aggregated into composite sample for laboratory analyses of the soil physical and chemical properties. The physio-chemical properties of the experimental site are shown in Table 1. The result showed that sand was predominant in the study area, and that it gradually decreased down the soil profile. The texture of the experimental site is classified as sandy loam. The soil is acidic with a pH of 6.6 in H_2O and 5.9 in $CaCl_2$. The organic matter content and total nitrogen were low with values of 1.43 and 0.125 g kg^{-1}. The available phosphorus was high with a value of 28.3 mg kg^{-1}. The exchangeable cation (Ca, Mg, Na and K) were also low in status with values of 3.1 cmol kg^{-1} for Na^+, 0.58 cmol kg^{-1} for $Ca^{2+,}$ 1.2 cmol kg^{-1} for k and 1.1 cmol kg^{-1} for Mg. The exchangeable acidity was only trace Al^{3+} with features low for H^+ and a value of 1.6 cmol kg^{-1}. The layout of the experiment was in a randomized complete block design with three replications. Three seeds were planted per hole at a depth of 3 cm on the side of the ridges and later thinned down to two plants per stand soon after emergence. The different spacing used were 80 x 20 cm with plant population size of 62500 plants/ha, 70 x 30 cm with population size of 45524 plants/ha and 60 x 40 cm with population size of 41667 plants/ha. Germination was first observed five days after planning (DAP) and 100% emergence recorded seven days after planting (DAP). Regular routine check was carried on in the farm. Two weeks after planting (WAP), ring application of chemical N.P.K (15:15:15) fertilizer (at the rate of 300 kg/ha) was carried out 15 cm away from the plants to avoid injuries to the roots. Weeding and earthening up was also done on the thirty-fifth day to further inhibit the growth of weeds and avoid lodging of the plants.

Morphological data collection

Forthnighly, random sampling of six plants from each of the three blocks (replicates) was done for data collection on plant height, stem girth, leaf area, number of leaves per plant and number of nodes per plant.

The height of each plant was measured in centimeters from the ground level to the tip of the topmost leaf. The measurement was later expressed as a mean of the selected plants. Stem diameters of the randomly selected six plants were taken using a pair of Venier calipers. The measurement was taken 10 cm from the ground level and converted to girth with the following formula:

Stem girth (SG) = stem diameter (D) x π (*pi*)

Where π = 22/7 (constant)

Data collected were later expressed as a mean of the six selected stands. The leaf area was measured with centimeter tape. This was achieved by measuring the widest part of each leaf per plant and the leaf length and multiplying by 0.75 according to Ndubuaku et al. (2006). The formula used was as follows:

Leaf area = leaf length x leaf breadth x 0.75 (constant). The leaf area per block was calculated by multiplying the leaf area per plant by total number of maize stands per block. Number of leaves and nodes were counted forthrightly until the maize tasseled and the measurements were also expressed as means of the selected plants. Average values of the measurements for the morphological parameters for 2013 and 2014 were recorded.

Table 2. Summary of field performance analysis of mean plant height (cm) of the maize plants 56 days after planting (DAP).

Spacing	14 DAP	28 DAP	42 DAP	56 DAP
80 x 20 cm	18.50	55.33	109.50	122.33
70 x 30 cm	18.83	59.00	124.83	168.83
60 x 40 cm	22.50	59.88	113.50	150.50
Mean	19.61	56.07	115.94	147.22
$LSD_{0.05}$	NS	NS	NS	4.26

Values represent means of 2013 and 2014 planting seasons' data.

Table 3. Summary of field performance analysis of mean stem girth (cm) of the maize plants 56 days after planting (DAP).

Spacing	14 DAP	28 DAP	42 DAP	56 DAP
80 cm x 20 cm	0.96	3.43	6.60	7.00
70 cm x 30 cm	1.50	4.41	7.11	7.71
60 cm x 40 cm	2.41	4.88	7.18	8.10
Mean	1.63	4.18	6.96	7.63
$LSD_{0.05}$	NS	NS	NS	NS

Values represent means of 2013 and 2014 planting seasons' data.

Table 4. Summary of field performance analysis of mean number of leaves of the maize plants 56 days after planting (DAP).

Spacing	14 DAP	28 DAP	42 DAP	56 DAP
80 cm x 20 cm	4	9	13	15
70 cm x 30 cm	5	10	14	17
60 cm x 40 cm	5	12	14	16
Mean	4.67	10.33	13.67	16.00
$LSD_{0.05}$	NS	NS	NS	NS

Values represent means of 2013 and 2014 planting seasons' data.

Yield data collection

Six plants were also randomly selected from each of the treatment blocks, and their cobs were left to dry on the field. They were later harvested dry, weighed and dehusked and the cob length and diameter measured using a measuring tape. The cob length and diameter of the undehusked and dehusked cobs were measured using a centimeter tape. The cob length was measured as the length between the two tips while the diameter was taken as the mean of the diameter of the two distal ends at the broadest portion of the cob. Values were taken and expressed as the means of the six selected cobs. Dry weights of cob + husk and cob alone were taken. The values were later expressed as a mean of the six selected cobs. The cobs were then shelled and 1000-grains from each of the treatments were oven-dried to a constant weight and moisture content of about 13%. The yield was measured in tons per hectare. However, the farmers were more interested in the harvest of dry weights than the oven-dry weights.

Method of data analysis

The data obtained were further subjected to statistical analysis using analysis of variance (ANOVA). The significant means were separated using Fishers least significant difference (FLSD) at 5% probability.

RESULTS

Results obtained from the study on comparative analysis of the three different spacing (80 x 20, 70 x 30 and 60 x 40 cm) and the effects on the morphological parameters of the maize plants in 2013 and 2014 are presented in Tables 2 to 6. The 70 x 30 cm spacing gave the highest values of plant height, number of leaves and number of nodes at 56 days after planting (Tables 2, 4 and 5). The 60 x 40 cm gave the highest values of the stem girth and leaf area at 56 DAP (Tables 3 and 6). There was a significant difference ($p < 0.05$) in the plant height among the different spacing at 56 DAP. The other morphological parameters considered showed no significant differences ($p > 0.05$) in the different spacing throughout the period of the study except the leaf area.

Table 7 shows the yield components of the maize plants at harvest. The 80 x 20 cm gave the highest 1000-grain weight (yield) (0.27 ton/ha) at harvest followed by 60 x 40 cm spacing (0.24 ton/kg) and 70 x 30 cm (0.21 ton/kg), respectively. The 80 x 20 cm also gave the highest cob weight (0.74 kg). The 60 x 40 cm gave the highest cob length and cob + husk weight. The mean cob length decreased with increased row spacing between plant from 14.01 to 16.15 and the lowest plant spacing (60 x 40 cm) gave the highest cob length, The different spacing showed no significant differences ($p > 0.05$) in the yield components.

Tables 8 and 9 show the summary of the analysis of variance (ANOVA) used. The analysis of result obtained for cob weight using f- ratio shows a calculated value of 1.3 and critical value of 5.14 at 5% level of significant. That obtained for 1000–grain weight using f- ratio gave a calculated value of 0.5 and a critical value of 5.14 at 5% level of significance.

DISCUSSION

Plant height determines the growth attained during the growing season. Plant height increased with the lower spacing densities on the field showing observable differences. The highest mean plant height of 168.83 cm and the lowest mean plant height of 122.33 cm at 56 DAP showed that spacing affected plant height significantly. It was observed that as the number of plants increased in a given area, the competition among the plants for nutrients and sunlight interception also increased (Reid, 2015; Sangarakka et al., 2004). Boomsma et al. (2009) found out that plant height declined with increase in plant population while Sangoi (2000) and Sangoi et al. (2001) observed that reducing plant space increased crop yield and performance and

Table 5. Summary of field performance analysis of mean number of nodes of the maize plants 56 days after planting (DAP).

Spacing	14 DAP	28 DAP	42 DAP	56 DAP
80 cm x 20 cm	3	8	13	14
70 cm x 30 cm	4	9	13	16
60 cm x 40 cm	4	11	13	15
Mean	3.67	9.33	13.00	15.00
$LSD_{0.05}$	NS	NS	NS	NS

Values represent means of 2013 and 2014 planting seasons' data.

Table 6. Summary of field performance analysis of mean leaf area (cm^2) of the maize plants 56 days after planting (DAP).

Spacing	14 DAP	28 DAP	42 DAP	56 DAP
80 cm x 20 cm	21.54	172.62	505.20	697.76
70 cm x 30 cm	19.65	227.25	628.44	793.95
60 cm x 40 cm	32.12	259.68	640.14	918.94
Mean	24.43	219.85	591.26	803.55
$LSD_{0.05}$	2.24	7.14	8.68	10.02

Values represent means of 2013 and 2014 planting seasons' data.

Table 7. Summary of total comparative yield analysis of maize at harvest.

Spacing	Cob length (cm)	Cob diameter (cm)	Cob + husk weight (kg)	Cob weight(kg)	1000-grain(t/ha)
80 x 20 cm	15.00	13.01	0.86	0.74	0.27
70 x 30 cm	14.01	13.48	0.78	0.57	0.21
60 x 40 cm	16.15	13.21	0.92	0.69	0.24
Mean	9.05	13.23	0.65	0.67	0.24
$LSD_{0.05}$	NS	NS	NS	NS	NS

Values represent means of 2013 and 2014 planting seasons' data.

Table 8. The analysis of variance (ANOVA) summary table for the comparative analysis of the mean of cob weight of maize.

Source of variance	Sum of square (ss)	Degree of freedoms (df)	Mean of square (ms)	f-ratio	f-critical
Between groups	5088.9	2	2544.45	1.3	5.14
Within group	13466.7	6	2244.45		
Total	18555.6	8			

such output was dependent on the interactions between management and environment. Stem girth determines the dimensional attainment of a plant during the growing period. Stem girth increased with lower plant densities as the average stem girths from the highest to the lowest dimensions were 8.1, 7.71 and 7.0 cm at 56 DAP. This coincides with the opinion of Maqboola et al. (2006) that wider spacing encouraged highest vegetative growth as seen with treatment 60 x 40 cm. Plant leaf area was affected significantly as observed between the highest and lowest populations. The highest leaf area of 918.94 cm^2 was produced by treatment 60 x 40 cm while treatment 80 x 20 cm produced the lowest leaf area of 697.76 cm^2. The leaf area reduced with closer plant density which confirmed that stand architecture alters growth and development patterns of maize (Baron et al., 2006; Raemaker, 2011). Unfortunately the treatment 60 x 40 cm with the highest leaf area as indicated in result,

Table 9. The analysis of variance (ANOVA) summary table for the comparative analysis of the mean of of 1000-grain weight (yield) of maize.

Sources of variance	Sum of square (ss)	Degree of freedoms (df)	Mean of square (ms)	f-ratio	f-critical
Between groups	0.0006	2	0.0003	0.5	5.14
Within group	0.004	6	0.0006		
Total	0.0046	8			

could not convert its vegetative mass to optimum grain yield. The number of leaves and nodes on the plant coincided with the increase in the plant height. The number of nodes in every plant represents the total number of leaves produced by an undecapped plant at any given time of growth as observed by Ikenganyia et al. (2015) who also noted that leaf number and leaf area were good measures of the photosynthetic capacity in cucumber (*Cucumis sativus*).

The mean cob length decreased with increased row spacing between plants from 16.15 to 14.01 as the lowest plant spacing (60 x 40cm) gave the highest cob length, showing that cob length decreased with increased plant population. This is in agreement with the findings of Enujeke (2013) that spacing has significant effect on cob length, also confirming the findings of Baloyi (2014) who indicated that maize planted on ridges have longer cobs than those planted on ordinary ground. There was a positive effect of spacing at harvest on the cob + husk weight The treatment 70 x 30 cm could not translate its plant height and number of leaves advantage to yield of production and this may not have been unconnected with the findings of Maqboola et al. (2006), Adeniyan (2014) and Anyanwu et al. (2003) that excessive growth during early stages of growth may result in severe competition for water between plants later in life, thereby, making the plant unable to produce at very critical stage. There was no significant difference among the weights obtained for the various treatments. Even though 80 x 20 cm seemed to have the least field performances as seen from the results, it stands significant in terms of the cob weight. Perhaps, this is due to the number of grains on each cob measured. The above observation is a confirmation of the studies carried out by Sharifi et al. (2009) which showed that plant population density increased maize dry matter yield and thus, maize grain responded to population density and spacing. The 1000-grain yield weight did not show mean significant difference in weights between the treatments.

Conclusion

Spacing significantly affected the performance of late maize production in Etche in terms of yield components. The 80 x 20 cm seemed to present a much viable agricultural and economic future for local farmers in Etche. However, further comparative analysis study on spacing of late maize cultivation in Etche is hereby suggested.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors acknowledge the contributions of the Head of Department of Vocational Teachers Education and all the technical staff of the department for their useful contributions towards the success of this work.

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African Journal of Agricultural Research

Volume 11 Number 13 31 March 2016
ISSN 1991-637X