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African Journal of Agricultural Research

Full Length Research Paper

Management of the nematode of the nodule of *Meloidogyne incognita* in tomato (*Solanum lycopersicum* L.) with extracts in a biospace condition

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For the management of the nematode of Meloidogyne *incognita* nodule in plants of *Solanum lycopersicum* L., the effectiveness of plant extracts: *Ruta graveolens, Eucalyptus spp., Ocimum basilicum, Acacia farnesiana,* and *Nicotiana tabacum,* and as a control fungus *Paecilomyces lilacinus* 6.5×10^{13} UFC/g were used. For each treatment, 5000 nematodes J2 of *M. incognita*/plant were used. The extracts were applied per intervals of 10 days in three occasions. The assessed variables were: plant height, performance at eight cuts and efficiency of the extracts at 20 weeks after the transplant. The results show there were no significant differences among treatments for the plant height. Regarding the performance with *A. farnesiana,* it obtained the highest performance (18.46 kg m^{-2}), followed by *P. lilacinus* (6.5×10^{13} UFC/g) with 16.46 kg m^{-2}. Both treatments are statistically different from the treatments, control (12.91 kg m^{-2}), *R. graveolens* and *O. basilicum* (13.03 and 13.8 kg m^{-2}), respectively. Regarding the effectiveness for the reduction of the nematode in soil, *A. farnesiana* reduced it by 57% and *P. lilacinum* fungus by 50.5%. So, the use of vegetable extracts for the management of nematodes populations of the *Meloidogyne* gender is an alternative way because they act as repellents and cause the death of nematodes.

Key words: Oils, nematodes, nodules, tomato, extracts, management, tomato, effectiveness.

INTRODUCTION

S. lycopersicum L. tomato is considered the most important vegetable worldwide. Mexico takes the 12th place as a tomato producer, and the 2nd as an exporter. It is the most important product according to the Mexican farming exports (1.43 million ton). The average worldwide consumption per capita has an increasing tendency from 15.4 kg in 2001 to 20.2 kg in 2011. In Mexico, the tendency of the crop in the protected agriculture system SAGARPA (2016) has increased since 2005, by using different levels of crop technologies. In the state of Oaxaca, there is a register of 757.82 ha cultivated with this vegetable. However, 90% of the surface is grown in greenhouse soils of medium and low technology (Martínez-Gutiérrez et al., 2014).

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It has caused several problems both as such in the management of the crop, and in the phytosanitary aspect. Concerning the phytosanitary problems in the tomato crop there are the nematodes, which are rounded microscopic worms present in the root-knots. They form nodules that affect the growing of the plant and cause economic losses of 40-100% in the performance (Quiroga et al*.,* 2007). *Nacobus aberrans* is the principal nematode species that causes damages to the tomato crops from Mexico, and also to other crops like chilli, beans, spinaches, baby squashes, amaranth (Cristóbal et al*.,* 2001). The species of *Meloidogyne incognita, M. javanica* and *M. arenaria,* common in the protected crop system (Arias et al*.,* 2009), are even more important, and are present in several crop zones in Mexico and in the state of Oaxaca (Cid del Prado et al*.,* 2001).

There have been several evaluated control methods for the phytopathogenic nematodes with the use of microorganisms, with good effects of the growing of the tomato plant (Khalil et al*.,* 2012), the same as the use of plant extracts with nematicide effects such as *Azadirachta indica, Tagetes* spp., *Brassica napus, Chrysanthemun* spp, *Calendula* spp, *Ricinus, Raphanus* (Collange et al*.,* 2011), to which there were extracted their metabolites with diverse techniques. Some lilaceae such as *Allium cepa* and *Allium sativum* which contain sulphur were also used. It is hydrolyzed to form a variety of isocyanates with pesticide effects, fungicides, antibiotics, nematicides and toxic effects (Bekhiet et al*.,* 2010), and others such as *Eucalyptus citriodora* Hook (Choi et al., 2007; El-Rokiek and El-Nagdi, 2011).

Chemical pesticides are expensive and not effective, besides having harmful effects for human health, water, soil, and crop products (Brand et al., 2010). Natural products have been considered an alternative solution to environmental problems caused by chemical pesticides and many researchers have tried to identify the most effective natural products to integrate them as control strategies instead of using the traditional solutions (Kim et al., 2005).

The objective of this research was to evaluate wild plants from the study site, such as aqueous extracts of *Ruta graveolens*, *Eucalyptus* spp., *Ocimum basilicum*, *A. fercian* and *Nicotiana tabacum,* to determine the nematicidal effect against *M. incognita* in the culture of *S. lycopersicum* under greenhouse conditions in a biospace.

MATERIALS AND METHODS

Study place

The research was conducted under greenhouse conditions by using a biospace of 300 m^2 surface in the experimental field of the Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional Unidad Oaxaca of the Instituto Politécnico Nacional from Mexico (CIIDIR Unidad Oaxaca IPN). Is geographical coordinates are 17°02' north latitude and 96°44' west longitude, with an altitude of 1,550 m above sea level.

Collection of plants and preparation of the plant extracts

The endemic plants of Ruda (*R. graveolens),* Eucalipto (*Eucalyptus* spp)., Albahaca (*O. basilicum),* Acacia (*A. farnesiana),* and Tabaco de Virginia (*N. tabacum)* were collected in the Central Valleys of Oaxaca, Mexico. The plants were dried in the shade per 10 days. Right away, 200 g of leaves from each plant were individually weighed, and 100 mL of distilled water was included and were blended per 30 s, except *A. farnesiana* where the pre-washed roots were used to remove any dust particles and were manually smashed in a mortar. The mixture of each preparation was put aside for 24 h. After this time, the mixture was filtered by using a multipore filter paper of 0.2 µm, and the concentrate was set in a 1000 mL beaker for its application. The extracts were prepared like the spore suspension of the entomopathogenic fungus *P. lilacinus*. The plants used in the experiments were deposited and identified in the herbarium of the CIIDIR Unidad Oaxaca IPN.

Extraction of the nematodes from infected plants

The extraction of the nematode's eggs and juvenile J2 stage of *M. incognita* of the infected roots was done through the macerate-filtration method (Hooper et al*.,* 2005), by dividing 25 g of roots in pieces of 2-3 cm, which were blended mechanically with 100 mL of distilled water per 30 s. The plant blended material was filtered through a series of sieves of 35, 100, 200 and 400 µm diameter. The particles which retained the sieves of 60 and 100 µm were disposed. The precipitate of the retained eggs in the sieves of 200 and 400 µm was transferred to a beaker by using a pipette. The extracted eggs were hatched in Petri dishes per 9-10 days for the emergence of juvenile J2 stage (Whitehead and Hemming, 1965). Both the eggs and juveniles just hatched eggs were used for the field tests and their application in every treatment.

Experimental design and treatments

The experiment was established with seven treatments: T1: Control treatment (only nematodes); T2: Control treatment *P. lilacinus* fungus at $6.5x10^{13}$ UFC/g, and the extracts T3: *R. graveolens;* T4: *Eucalyptus* spp., T5: *O. basilicum* L.; T6: *A. farnesiana,* and T7: *N. tabacum* at the same doses of 35 mL per plant to each one. There were four repetitions per treatment, under a design per blocks completely aleatorized. There was used a variety of Reserve tomato of undetermined cycle at a planting density of 2 plants$\cdot m^{-2}$, distance among lines and plants of 1.25 m × 0.4 m, guided by a one single stem, and with a common management.

For each treatment, there were applied the amount of 5000 nematode eggs after 15 days of the transplant (ADT) to a depth of 10-15 cm right in the base of each plant. The fungus and the plant extracts were applied with an automated pipette of 1000 mL of capacity in three holes around the stem base of each plant at intervals of 10 days with a total of three applications from the 30 ADT.

The assessed variables were: The plant height, what was performed a destructive test after 20 weeks after the transplant (STD); the performance of the crop kg$\cdot m^{-2}$ considering 8 cuts and an effectiveness percentage of the treatments after 20 (SDT). The effectiveness of the applied treatments (EAT) with plant extracts was calculated as the percentage of reduction of the nematodes in 250 g soil according to the Henderson and Tilton Puntener's formula (Puntener, 1981), as follows:

$$EAT = \frac{(J2\ PTA)(J2\ PCB)}{(J2\ PTB)(J2\ PCA)} * 100$$

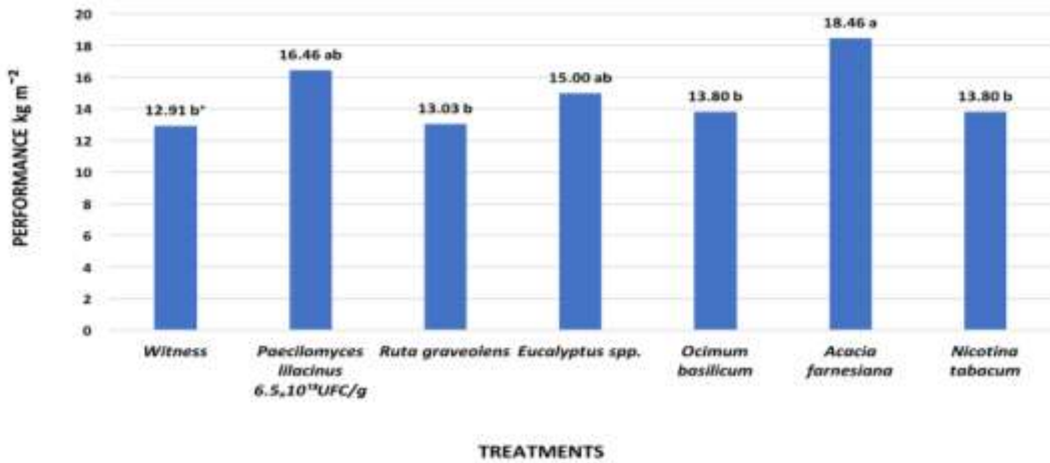

Figure 1. Effect of applications of plant extracts on the performance of *S. lycopersicum* tomato at eight cuts. *Means with same letters are not statistically different (Tukey, 0.05).

Where, *EAT* = Percentage of reduction of the nematodes, in %; *J2 PTA* = Total Population of J2 Nematodes after the application; *J2 PCB* = Total Initial Population of Nematodes of the control treatment, *J2 PTB* = Total Population of J2 Nematodes after the application, and *J2 PCA* = Total Population of Final J2 Nematodes of the control treatment.

Statistical analysis

With the obtained data, variance analysis, and multiple mean comparison tests were done. The efficiency percentage data were transformed by the arcsine function, and later a variance analysis was done to establish the differences among the means of the variables by the Tukey test. All analysis was done using the Statistical Analysis System package (SAS® Institute, 2004).

RESULTS AND DISCUSSION

Effect of plant extracts in the growing of *S. lycopersicum*

The growing of the *S. lycopersicum* plants was homogeneous in all the treatments, which indicates that the presence of nematodes did not affect directly the growing variables until the assessment time. This can be explained based on the Seinhorst's model, which indicates that, in presence of nematodes, the plants can show two effects: one of stimulation, and the other of inhibition or reduction. The plant is able to solve the damage and still to continue with the growing stimulation (Seinhorst, 1965). Niño et al. (2008) evaluated the response of the following population; 100, 200, 500 and 1,000 J2 of *Meloidogyne hapla/*100 cc soil on *Physalis peruviana,* and there were no differences found among treatments during the first samplings at 45 and 245 days. The highest negative effect on height was with 500 nematodes until seven months. Cadete et al. (2005) consider that the nematodes population increases proportionally to the food availability of their hosts, and it is also influenced by the fact that the adult plants with extensive radicular systems provide more food and shelter to the nematodes than the younger plants.

Effect of the plant extracts on the performance of *S. lycopersicum*

Figure 1 shows that the treatment with the application of *A. farnesiana* registered the highest performance with 18.46 kg·m^{-2} which was statistically different from the treatments with *R. graveolens, O. basilicum, N. tabacum* extracts, besides the control. They were overcome by more than 4 kg·m^{-2} of performance. The *P. lilacinus* fungus 6.5×10^{13} UFC/g as a control treatment showed a similar performance with *Eucalyptus* spp., and *A. farnesiana.* They are statistically the same (Figure 1). According to Sikora and Fernández (2005) when any method is used to control the nematodes populations, the performance can be affected until a 41.07% with a presence of 5000 nematodes at the beginning of the crop, and this reduction effect is due to the inhibition of the development of the root-knots which cannot absorb water or nutrients.

Effectiveness of the plant extracts in the reduction of the nematodes population

There were two treatments assessed in this work that showed effectiveness results for the reduction of nematodes in soil higher than 50%, the one with *P. lilacinus* 6.5×10^{13} UFC/g with a 50.5%, and *A. farnesiana*

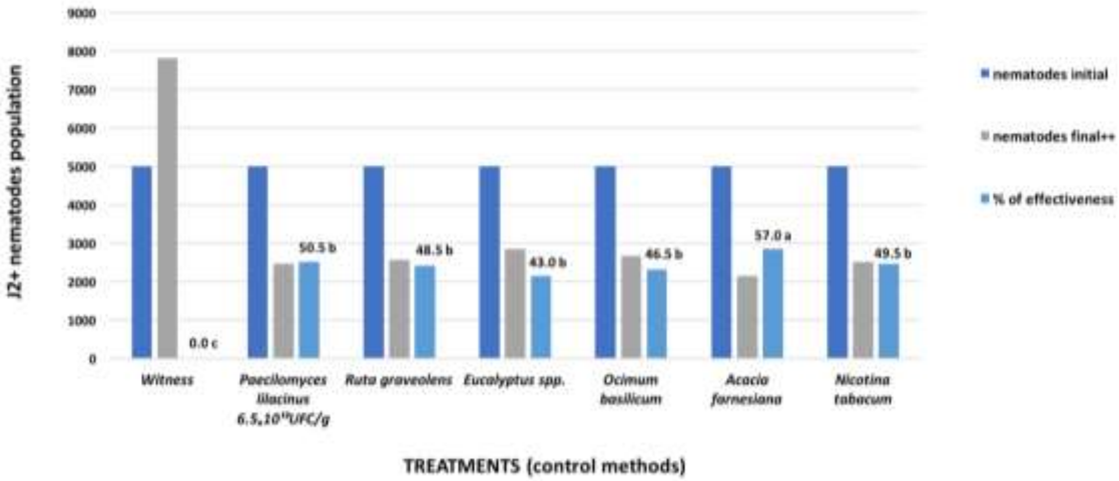

Figure 2. Effectiveness of plant extracts for the reduction of on-soil nematodes populations.

with a 57.0%. This unique one was statistically different from all the treatments. The results of the other assessed treatments had between 40.3-49.5% of effectiveness (Figure 2). It must be mentioned and highlighted that, in the control treatment, the quantity of nematodes increased by 43.28% in the final population of *M. incognita.* The assessment on this study of the treatment with *N. tabacum* presented 49.5% of effectiveness in similar studies with plants having nematicide effects. This is same with the ones done by Wiratno et al. (2009) when they assessed the nematicide activity of extracts from 17 plant species. The results with *N. tabacum* in lab tests obtained a mortality of 94% when testing the extracts from leaves in doses of 5 mg·mL^{-1} over a population of 150 J2 of *M. incognita* exposed for 24 h. Besides, there was registered a mean lethal concentration (LC_{50}) with 3.9 mg·mL^{-1}. The toxic activity of *N. tabacum was rep*orted by Nguyen et al. (2000), who mentioned that it has effects on the inhibition of the acetylcholinesterase just as it is the action of organophosphate and carbamate type of pesticides. Although our results showed that the extract of *A. farnesiana* was the best one compared to the others, it is not recommendable to apply it due to its high toxic activity that affects humans and mammals. Kamal et al. (2009) emphasized the nematicide activity of *Eucalyptus camaldulensis* against young stages of *M. incognita* under assessed in greenhouse conditions.

Hasabo and Noweer (2005) assessed *O. basilicum* for the control of *M. incognita* in *Solanum melongena* eggplant with a mortality percentage of 61% under laboratory conditions assessed at 24 h and of 46.1% in field conditions at 4 months, both to a concentration of 5%. Also, Elbadri et al. (2008) assessed 27 extracts from different plant species to determine their efficiency against juveniles of *M. incognita* in laboratory. As a conclusion, they said that all of them showed a level of toxicity over the nematodes, and specifically with *Acacia nilotica* (the pods extract) there was a percentage of mortality of 94.7%, and for *O. basilicum* 66.5% with the extract of leaves, and 55.5% with the seeds extract assesses after 72 h, both treatments in doses of 500 ppm.

According to the obtained results, the use of the extracts can be useful for the management of the *Meloidogyne* nematodes populations, because they act as growing regulators, in the feeding, repellent inhibitors, distractors, attractors, or to kill them in the *S. lycopersicum* crops. The nematicide effect of the plant extracts could be attributed to its content of certain oxygenated compounds that are characterized by its lipophilic properties, which are capable to dissolve the cytoplasmic membrane from the nematodes cells (Knoblock et al*.,* 1989).

The *P. lilacinus* fungus 6.5×10^{13} UFC/g showed a little higher effectiveness than the extracts (50.0%). The effectiveness of biological organisms, as the one used in this work has been documented on several research, such as Wen-Kun et al*.* (2016). When evaluating *P. lilacinus* in a mixture with *Syncephalastrum rasemosum*, it was found a 70% of ovicidal activity over *M. incognita,* and as a result, the reduction of gills in the roots in cucumber crops, and in tomato crops (Anastasiadis et al*.,* 2008). So this is one of the most effective organisms in its parasitic action over the *M. incognita* eggs in the tomato crop. Oka (2010) suggests its application in more than one occasion during the crop cycle to keep the nematode population under control and to obtain a better effectiveness (Kiewnick and Sikora, 2006; Udo, et al*.,* 2014).

Conclusion

The use of extract of *A. farnesiana* in at least three times during the early developing of the crop can improve the performance of tomato. With the application of the fungus *P. lilacinus* at concentration of 6.5×10^{13} UFC/g, it is possible to obtain good results regarding positive performance and controlling of nematodes on soil nodules.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Mango (*Mangifera indica* L.) production practices and constraints in major production regions of Ethiopia

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Mango (*Mangifera indica* L.) is the second among fruit crops in Ethiopia in its production coverage and economical importance. However, compared to the countries' potential, it is at the infant stage. This study was conducted to identify the main mango cultivars, production practices and constraints in east and western Ethiopia in 2016. Study areas were selected purposively based on their extensive mango production. Thirty-one cultivars of unknown origin were identified based on farmers' characterization criteria. The majority of the farmers were found not to apply fertilizers (63.7%), supplementary irrigation (87.6%), nor prune their mangos (50%). About 50% of growers revealed fruit yield of 100-200 kg/tree and harvest fully ripe. Packaging and transportation of mangos were entirely below the standard. Availability of agricultural inputs such as fertilizers and pesticides, pest, knowledge and skill gap, and availability of improved varieties were the major constraints. Assessment of similarities in terms of farming system, mango production practices, harvest, post-harvest handling, marketing, and their constraints indicated that 76.9% of growers were similar. Therefore, improvement of the pre and post-production practices, utilization and/or conservation of the identified cultivars, and addressing the constraints will be crucial to improving the mango sector in Ethiopia.

Key words: Interview, mango cultivars, tropical fruit, biodiversity.

INTRODUCTION

Mango (Mangifera indica L.) is one of the 73 genera of the family Anacardiaceae and order Sapindales (Ahmed and Mohamed, 2015) which is one of the most versatile and widely grown fruit crops of tropical and subtropical regions (Vasugi et al., 2012). It is believed to have originated from South East Asia and more than 1000 varieties have been identified all over the world (Rymbai et al., 2014). Mango is cultivated approximately on 3.7 million hectares worldwide, occupied the 2nd position among the tropical fruit crops (Jahurul et al., 2015) and

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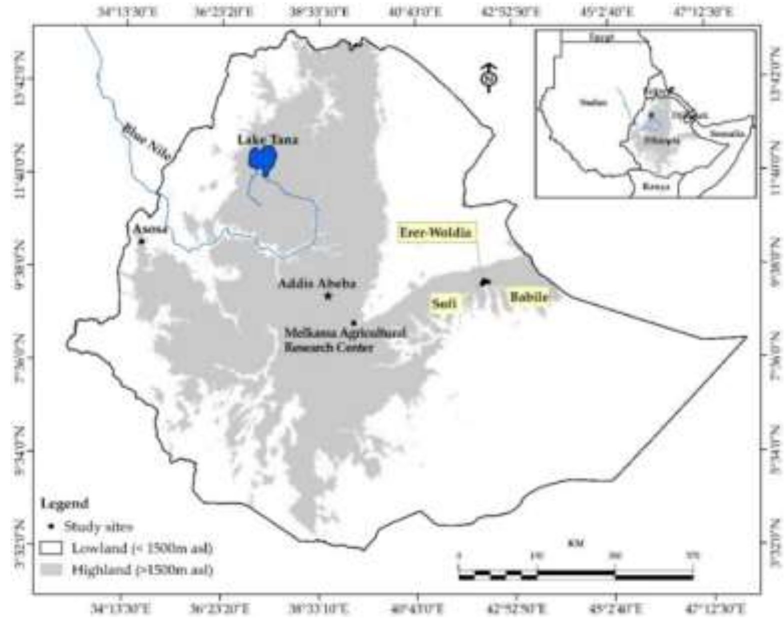

Figure 1. Geographic locations of surveyed districts in the east and western Ethiopia.

5th from fruit crops of the world after citrus, banana, grape, and apple (Shi et al., 2015). Asian countries share the largest (77%) of global production, followed by Americans (13%) and African countries (10%) (Rekhapriyadharshini, 2015). Mango is known as the king of the fruits due to its excellent flavor, delicious taste and high nutritive values (Ullah et al., 2010) that makes the crop valued for both food and nutritional security especially for developing countries like Ethiopia where the realization of food and nutritional security is still a challenge.

Mango is one of the most widely grown among the fruit crops cultivated in Ethiopia preceded only by banana in terms of economic importance (Fita, 2014). A total of 69,743.39 tons of mango is produced from 12,799 ha of land (CSA, 2015). Moreover, within the past 10 years (2003 to 2013), both area coverage and production of mango increased by 208.4 and 247%, respectively (Dessalegn et al., 2014). It is grown in several parts of the country where the western and eastern Ethiopia are among the major producing belt that accounts >50% of the total mango production in Ethiopia (CSA, 2015).

Despite the crop potential to contribute to improved nutritional status and health of the Ethiopian society, the national average production yield is about 7 ton/ha and, in some region like Amhara, it is estimated to be 3.5 ton/ha (Dessalegn et al., 2014). Though the productivity of the crop is governed by various factors like genetic and/or enviromental variables, the productivity in the country is very low compared to the crop potential, about 20-30 ton/ha (Griesbach, 2003; Tiwari and Baghel, 2014). The recently introduced export-oriented horticulture policy of the government is in the process of replacing farmers' indigenous cultivars with the introduction of improved commercial mango varieties. There are few studies which have reported on the practices and constraints of mango production in Ethiopia in the past (Dessalegn et al., 2014; Fita, 2014; Hussein and Yimer, 2013). However, none of them identified the farmers' mango cultivars and the depth of generated information with regard to pre and post production practices and marketing especially in the east and western Ethiopia was not sufficient to alleviate the challenges.

In order to come up with conservation strategies for a crop species at a country level, there is need of good knowledge of the existing diversity within the crop and traditional production system to understand the factors that affect this diversity (Bisht et al., 2007). Other than just for conservation, the locally adapted cultivars usually produce stable yields. Nonetheless, their production is generally lower at optimal conditions than ''improved'' cultivars (Yong'an et al., 2010; Xiahong et al., 2011), suitable for low input requirements, and have low susceptibility to pests and high drought tolerance (Shi et al., 2015) . This study was conducted with the objective of assessing the existing cultivars, production practices and constraints of mango in major production regions of Ethiopia.

MATERIALS AND METHODS

Study areas

The study was conducted in four mango producing districts selected from two geographic regions, viz; Eastern and Western Ethiopia (Figure 1 and Table 1).

Table 1. Details of selected villages and districts.

S/N	Village	Code	Region	District	GPS Coordinate	Altitude (m.a.s.l)
1.	Abdibuch Maru	BA1	Eastern Hararghe Zone, Oromia Regional State	Babile	09°17’59’’N 042° 17’26’’E	1778
2.	Shekhussien Hajisuffe	BA2	Eastern Hararghe Zone, Oromia Regional State	Babile	09°09’59’’N 042°21’11’’E	1571
3.	Sheckhussien-Walqebela	BA3	Eastern Hararghe Zone, Oromia Regional State	Babile	09°10’57’’N 042°21’33’’E	1601
4.	Goromeskida	ER1	Harari People's National Regional State, eastern Ethiopia	Erer-Woldia	09°20’39’’N 042°12’37’’E	1412
5.	Konya	ER2	Harari People's National Regional State, eastern Ethiopia	Erer-Woldia	09°21’34’’N 042°12’50’’E	1457
6.	Ganda Bekere	ER3	Harari People's National Regional State, eastern Ethiopia	Erer-Woldia	09°20’55’’N 042°12’57’’E	1403
7.	Melka Hida	ER4	Harari People's National Regional State, eastern Ethiopia	Erer-Woldia	09°21’22’’N 042°13’16’’E	1446
8.	Nole	HA1	Harari People's National Regional State, eastern Ethiopia	Sofi	09°16’20’’N 042°10’44’’E	1589
9.	Agemboy	HA2	Harari People's National Regional State, eastern Ethiopia	Sofi	09°17’04’’N 042°10’15’’E	1679
10.	Kalu	HA3	Harari People's National Regional State, eastern Ethiopia	Sofi	09°15’45’’N 042°11’20’’E	1491
11.	Bereser	HA4	Harari People's National Regional State, eastern Ethiopia	Sofi	09°15’45’’N 042°10’24’’E	1594
12.	Ura	AS1	Benishangul Gumuz Regional State, western Ethiopia	Asosa	10°08’17.4’’N 034°39’29.8’’E	1485
13.	Amba10	AS2	Benishangul Gumuz Regional State, western Ethiopia	Asosa	10°08’05’’N 034°39’17’’E	1488

Sampling and data collection

Multi-stage purposive sampling technique was employed in the selection of the study sites based on their representativeness of mango production, geographical locations, experiences, and future prospects in consultation with the Regional/Zone agricultural offices. Accordingly, four districts that encompassed 13 villages were purposively selected (Table 1). A total of 113 mango grower households that represented 15% of the identified potential mango growers of each district, were randomly selected. A semi-structured questionnaire was prepared, pre-tested with trained enumerators and remedial action was made accordingly. Data were collected through individual farmer’s interviews using the questionnaire and field observation. It included socio-economics, existing farmers’ cultivars, pre, and post-production practices and overall production constraints.

Data analysis

The collected data were summarized and analyzed using Statistical Package for Social Scientists (SPSS) Statistics for Windows, Version 20.0 (IBM, 2011). *Chi*-square test was computed to find if there was differences in production practices and constraints among the districts where the growers were located. The overall dissimilarity/similarity of growers regarding production practices and constraints were analyzed following the widely used Unweighted Pair-Group Method with Arithmetic Mean (UPGMA) cluster analysis method (Sneath and Sokal, 1973)after the data were standardized using z-score transformation method (Ramette, 2007).

RESULTS AND DISCUSSION

Socio-economics of respondents and farming system

A significant number of respondents’ had an age range of 30-40 years but a total of 58.4% of respondents had >41 years of age. The majority of the respondents did not attend formal education and partly attended up to primary school (Table 2). Aged and illiterate farmers could be among the barriers to adopt improved technologies (Berg, 2013). Positive correlation between education and technology adoption was also noted by Ogada et al. (2014). Similar results were reported in other parts of Ethiopia like east and west Wolega zones of Oromia Regional State (Fita, 2014) and Amhara National Regional State (Dessalegn et al., 2014).

More than half of respondents owned less than 15 mango trees per household and 61.9% of the respondents had more than 15 up to 30 years mango

Table 2. Demographic characteristics of sampled respondents.

Variable	Districts				Total	χ2[a]
	Eastern Ethiopia			Western Ethiopia		
	Erer	Sofi	Babile	Assosa		
Age :						
30-40	11.0	12.0	22.0	2.0	47(41.6%)	40.0***
41-50	8.0	8.0	10.0	7.0	33(29.2%)	
>50	4.0	3.0	4.0	22.0	33(29.2%)	
Mean	43.7	41.4	40.1	55.8	45.3	
Education level:						
No school	16.0	14.0	18.0	9.0	57(50.4%)	17.9***
Primary school	5.0	8.0	18.0	22.0	53(46.9%)	
Secondary school	2.0	1.0	0.0	0.0	3(2.7%)	

Table 3. Number of mango trees and cultivation experience of respondents.

Variable	Districts				Total	χ2[a]
	Eastern Ethiopia			Western Ethiopia		
	Erer	Sofi	Babile	Assosa		
Mango trees per farm:						
<15	10	9	23	16	58(51.3%)	15.4**
15-30	10	8	13	6	37(32.7%)	
>30	3	6	0	9	18(15.9%)	
Mean	20.0	23.1	13.2	32.1	22.1	
Farming experience in years:						
<15	3	3	2	0	8(7.1%)	10.1[ns]
15-30	14	14	26	16	70(61.9%)	
>30	3	6	0	9	18(15.9%)	
Mean	27.5	27.5	25.2	34.2	28.6	
Cultivation knowledge source:						
Ancestors/family	23	19	25	19	86(76.1%)	16.2**
Neighbor's	0	4	11	10	25(22.1%)	
Extension agents	0	0	0	2	2(1.8%)	
Reasons for cultivation:						
Best money making	19	22	29	20	90(79.6%)	11.3*
Tradition	4	1	7	9	21(18.6%)	
No alternatives	0	0	0	2	2(1.8%)	
Planting material:						
Seed	23	23	36	31	113(100%)	-
Cropping system:						
Mixed	23	23	36	31	113(100%)	-

[a]*Chi-square* test, ns = not significant,* and ** Significant at α ≤ 0.05 and α ≤ 0.01, respectively.

cultivation experience. However, the highest proportion of respondents acquired mango farming knowledge from their ancestors of family members and neighbors, whereas very small proportion (1.8%) of them obtained the knowledge from agriculture extension agents (Table 3). Mango production is an income earner for the majority

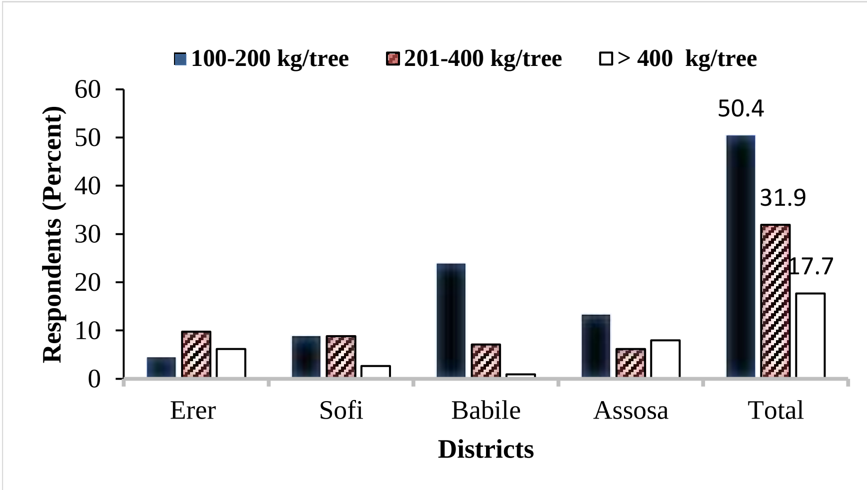

Figure 2. Estimates of mango yield (kg/tree) in the east and western Ethiopia.

of the respondents though some of them (18.6%) grew mango as a tradition. Hence, there is a need for capacity building of the growers by extension agents to improve the farming system (Dessalegn et al., 2014).

Mangos in the study sites were entirely propagated by seed and were under mixed cropping production system (Table 3). Mango can be propagated either by seed or through grafting. However, to guarantee the variety and maximum uniformity, it is essential to using grafting or another asexual method of propagation (Krishna and Singh, 2007). Therefore, the seed propagation might be the reason for the existing variability among the trees in the studied areas (Bally, 2011). The mixed cropping system, that was, growing mango with annual crops like maize, sorghum, beans, groundnut etc., vegetables, and perennial cash crop khat (Catha edulis L.), could be recommended to generate additional income, efficient use, and conservation of resources and diversification of their diet (Tiwari and Baghel, 2014). However, performance and profitability of the existing mango based cropping system should be further studied (Swain, 2014).

Mango cultivars and productivity

Mango cultivars

The cultivars had various local names based on unique features of the fruits (shape, size, color, aroma, taste, and fiber content) and the person introduced in the localities (Table 4). The mango naming in most parts of the world also reflects the grower's culture, languages, origins and spread of the mango tree along with the spread and settlement of communities (Bally, 2011). Due to such diversity in naming, the observed mango trees were mixed and difficult to identify. Consequently, two or more names could exist for the same cultivar. This scenario is similar to Sennhenn et al. (2013) who reported confusion in the identification of Kenyan mango due to local naming.

Seven (22.58%) out of 31 mango cultivars identified in eastern and western Ethiopia were given the name of the person who introduced them to the villages. Since most of the trees were old (more than 50 years), the growers were not sure about the cultivars origin. However, some of the interviewed elders suspected the sources of local mangos in eastern Ethiopia could be from Arab countries introduced by Muslims who used to go to Mecca, and from other countries by traders and missionaries. Whereas the introduction route for western Ethiopia (Asosa) was assumed to be by traders from Sudan.

Mango cultivars productivity

The average yield reported by the respondent farmers was 270 kg per tree where a majority reported 100-200 kg/tree while a few respondents reported more than 400 kg per tree (Figure 2). The reported range of yield was almost comparable with other countries where the productivity of mango ranges from 200 to 300 kg fruits per tree (5.5-33.1 tons/ha) depending on different factors such as variety, tree age, tree size, seasonal conditions, management and previous cropping history (Griesbach, 2003; Tiwariand Baghel, 2014). Therefore, it indicated the presence of high yielding farmers' cultivars in the country that can be considered for future use and/or conservation activities.

Production practices

Agronomic management practices

Planting patterns and fertilizer application: The mango trees in the study sites were planted irregularly (Table 5).

Table 4. Name and distribution of mango cultivars grown in east and western Ethiopia.

Cultivars name	Meaning and basis for naming in the local language	Districts				Total	$\chi 2^a$
		Eastern Ethiopia			Western Ethiopia		
		Erer	Sofi	Babile	Assosa		
Almenga	Meaning mango	0	0	0	31	31(27.4%)	113.0***
AmbaAdi	Fruit color	14	7	17	0	38(33.6%)	26.4***
AmbaAko	Name of introduced person	10	1	3	0	14(12.4%)	26.8**
AmbaArenjata	Texture and taste of fruit	2	0	0	0	2(1.8%)	8.0*
AmbaBere	Name of introduced person	15	7	21	0	43(38.1%)	33.1*
AmbaBishaano	Taste and juiciness of fruit	0	1	0	0	1(0.9%)	4.0^{ns}
Amba Dada	Fruit flush texture when ripe	0	1	0	0	1(0.9%)	4.0^{ns}
AmbaDemma	Taste of fruit	0	1	0	0	1(0.9%)	4.0^{ns}
AmbaDula	Introduced person	0	0	21	0	21(18.6%)	55.2***
AmbaErrero	Origin	0	16	0	0	16(14.2%)	72.9***
AmbaFulla	Shape of the fruit	0	0	1	0	1(0.9%)	2.2^{ns}
AmbaGerjewi	Taste and texture of fruit	1	0	0	0	1(0.9%)	3.9^{ns}
AmbaGuracha	Color of fruit skin when ripe	17	4	14	0	35(31%)	36.8***
AmbaHarewe	Origin	10	0	0	0	10(8.8%)	42.9***
AmbaHudha	Productivity of tree	1	0	3	0	4(3.5%)	4.5^{ns}
Amba Hula	Origin	1	14	0	0	15(13.3%)	57.1***
AmbaKukurfa	Shape of fruit	3	11	0	0	14(12.4%)	36.1***
Amba Lafe	Size of fruit stone	0	3	18	0	21(18.6%)	36.3***
AmbaLibanato	Pulp aroma	0	2	0	0	2(1.8%)	8.0^{ns}
AmbaMaity	Taste of fruit	0	11	0	0	11(9.7%)	47.7***
Amba Mucho	Beak type of the fruit	4	0	0	0	4(3.5%)	16.2***
AmbaNeguse	Fruit size	7	12	26	0	45(39.8%)	38.6***
AmbaSabid	Introduced person	4	0	0	0	4(3.5%)	16.2***
AmbaSabune	Color and texture of fruit	6	0	3	0	9(8%)	15.0***
AmbaSadik	Introduced person	7	0	3	0	10(8.8%)	18.5***
AmbaSeburujena	Origin	0	2	0	0	2(1.8%)	7.9^{ns}
AmbaShimbro	Taste of fruit	1	0	0	0	1(0.9%)	4.0^{ns}
AmbaSibake	Taste of fruit	1	0	0	0	1(0.9%)	4.0^{ns}
AmbaTeyara	Fruit shape	2	0	0	0	2(1.8)	7.9^{ns}
Amba Umar AlishoGuracha	Introduced person	8	0	0	0	8(7.1%)	33.7***
Galbatore	Introduced person	0	0	0	5	5(4.4)	13.8***

[a]*Chi-square* test, ns = not significant,* ,** and *** Significant at $\alpha \le 0.05$, $\alpha \le 0.01$, and $\alpha \le 0.001$, respectively.

Thus, the spacing of the trees was too crowded in some areas and very far apart in other areas. The grower's justifications for irregularity were primarily lack of knowledge and absence of recommended planting spacing. However, regular planting pattern is the most important in realizing good yield and quality of the produce (Verheij, 2006).

Most of the growers did not apply fertilizers to their mangos, though some (36.3%) applied varying amount of organic fertilizers made from compost and manure (Table 5). This is in agreement with Hussen and Yimer (2013) findings who reported 90% of mango growers in northern Ethiopia did not apply fertilizer. The major reasons for excluding inorganic fertilizers were a knowledge gap, cost, and inaccessibility for fertilizers (Table 5). However, proper fertilization program is mandatory in preventing a decline in yield and fruit quality; along with occurrence of imbalance in nutrient status that leads to the biannual bearing phenomenon in mango plant (Shaaban and Shaaban, 2012).

Pruning, bearing behavior of trees and irrigation practices: About half of the growers did not prune their mangos while the few who practiced did it in an irregular and unprofessional manner (Table 6). Consequently, the trees did not have the proper architecture that fit the required pre and post-harvest activities. The observed scenario is in agreement with the mango orchards in

Table 5. Planting pattern and fertilizer application practices of mango grower in the east and western Ethiopia.

Tree management practices	Districts				Total	χ2[a]
	Eastern Ethiopia			Western Ethiopia		
	Erer	Sofi	Babile	Assosa		
Plant spacing:						
Irregular	23	23	36	31	113(100%)	-
Reasons for irregularity:						
Lack of knowledge	20	18	16	25	79(69.9%)	17.8***
No recommended spacing	2	2	9	4	17(15.0%)	
Shortage of land	1	3	11	2	17(15.0%)	
Fertilizer use:						
Organic fertilizer	5	13	23	0	41(36.3%)	35.7***
Do not apply fertilizer	18	10	13	31	72(63.7%)	
Reasons for not applying fertilizer:						
Lack of knowledge	10	10	17	31	68(60.2%)	36.3***
Fertilizers are expensive	13	9	17	0	39(34.5%)	
Inaccessibility of fertilizers	0	4	2	0	6(5.3%)	

[a]*Chi-square* test, ***Significant at α ≤ 0.001.

Table 6. Pruning, trees bearing behavior and irrigation practices of mango growers in east and western Ethiopia.

Tree management practices	Districts				Total	χ2[a]
	Eastern Ethiopia			Western Ethiopia		
	Erer	Sofi	Babile	Assosa		
Pruning:						
Practice irregularly	10	15	26	5	56(49.6%)	23.9***
Not practicing	13	8	10	26	57(50.4%)	
Reasons for not practicing pruning:						
Lack of knowledge	9	6	11	21	47(41.6%)	19.2**
Lack of skill	9	11	10	2	32(28.3%)	
Fear of losing yield	5	6	15	8	34(30.1%)	
Trees' bearing behavior:						
Irregular/alternate	22	23	34	23	102(90.3%)	13.1**
Regular	1	0	2	8	11(9.7%)	
Regulating bearing of trees:						
Yes	0	8	14	5	27(23.9%)	14.2**
No	23	15	22	26	86(76.1%)	
Irrigation practice:						
Yes but irregularly	8	4	2	0	14(12.4%)	17.1**
No	15	19	34	31	99(87.6%)	
Source of irrigation water:						
Rain	15	19	34	31	99(87.6%)	21.1**
Borehole	7	2	2	0	11(9.7%)	
River	1	2	0	0	3(2.7%)	

[a]*Chi-square* test, ** and *** Significant at α ≤ 0.01 and α ≤ 0.001, respectively.

Table 7. Fruit harvesting practices of mango growers in the east and western Ethiopia.

Fruit harvesting practice	Districts				Total	$\chi 2^a$
	Eastern Ethiopia			Western Ethiopia		
	Erer	Sofi	Babile	Assosa		
Harvesting criteria:						
Fruit ripening	23	21	34	31	109(96%)	4.2^{ns}
Market demand	0	2	2	0	4(3.5%)	
Harvesting stage:						
Full ripe	13	7	34	9	63(55.8%)	76.4***
Partially ripe	0	8	2	22	32(28.3%)	
Full and half ripe	10	8	0	0	18(15.9%)	
Harvesting method:						
Hand picking	13	13	36	17	79(69.9%)	22.8***
Using stick	10	10	0	14	34(30.1%)	
Harvesting time:						
Morning	20	14	12	17	63(55.8%)	65.3***
Afternoon	1	8	24	0	33(29.2%)	
Anytime of the day	2	1	0	14	17(15.0%)	

[a]*Chi-square* test, ns = not significant, *** Significant at $\alpha \leq 0.001$.

Northeast Ethiopia (Hussen and Yimer, 2013). The mango tree, however, requires selective pruning of branches to encourage the growth of lateral branches and good tree architecture (Griesbach, 2003). This allows air and sunlight to penetrate, which reduces pests and diseases, and enhances yield and quality of the fruit (Bally, 2011; Nasution, 2013).

The alternate bearing was the common scenario in majority of the respondents' farm. However, most of them did not have any intervention for the alternate bearing, while some growers tried to manage through the application of compost and supplementary irrigation during fruit setting stage of their mangos (Table 6). Alternate bearing is a common challenge for growers in the world that depend on environmental conditions and the genetic makeup of the mango cultivars (Kaur et al., 2014). Moreover, the exhaustion of trees during the period of crop load and vegetative growth at the time of flower differentiation and imbalance in carbon to nitrogen ratio is reported to be among the causes for irregular bearing in mango (Saxena et al., 2014).

Supplementary irrigation was lacking in most farms where the orchards were rainfed (87.6%). However, few growers irrigate their mangos while irrigating their intercrops from their borehole and nearby rivers (Table 6). Proper irrigation is mandatory during critical stages such as flowering, fruiting, and maturity for successful growth and development of mango orchard (Mirjat et al., 2011). Nevertheless, the irrigation amount and frequency is governed by various factors such as the age of the tree, growth stage, climate (humidity, rainfall, and temperature) and soil factors (Mirjat et al., 2011; Sarker and Rahim, 2013)

Harvesting and post-harvest handling practices

Harvesting practices: The harvesting season varies with the location of growers, where it lasts from *March to July* in the west and *May to September* in eastern Ethiopia. Fruit ripening stage was the major criterion for harvesting by most growers, though few consider market demand (Table 7). However, growers did not have scientifically proven fruit maturity standards for harvesting. Thus, most growers harvest fully ripe fruits. While some harvest partially ripe or mixed fruits (Table 7). Mango fruit should be harvested at the right maturity stage; if not, the immature fruit will result in inferior quality while overripe fruits have short postharvest life (Sivakumar et al., 2011; Ahmed and Ahmed, 2014). Therefore, there is a need to determine the appropriate maturity indices of Ethiopian mango based on physical and chemical parameters in order to minimize the quantitative and qualitative losses.

Hand harvesting was the common harvesting method practiced by majorities (Table 7). However, due to lack of proper planting space and canopy management, the trees were too tall and the pickers had to climb on the tree to pick the fruits which were impractical in selecting proper quality fruits to harvest. This poor harvest and handling practices could result in various blemishes on the fruit skin that affect fruit quality and acceptability of

Table 8. Post-harvest and marketing practices of mango growers in the east and western Ethiopia.

Post-harvest and marketing practice	Districts				Total	χ2[a]
	Eastern Ethiopia			Western Ethiopia		
	Erer	Sofi	Babile	Assosa		
Storage type:						
Shade under trees	11	9	28	18	66(58.4%)	10.1**
Storage house	12	14	8	13	47(41.6%)	
Packaging:						
Synthetic fiber sacks	22	23	36	7	88(77.9%)	77.8***
Plastic box (Crates)	0	0	0	9	9(8%)	
Wooden box	1	0	0	3	4(3.5%)	
Do not pack	0	0	0	12	12(10.6%)	
Means of transport:						
Car	12	12	8	24	56(49.6%)	36.0***
Animals (Donkey)	4	2	14	2	22(19.5%)	
Human	1	7	5	5	18(15.9%)	
All of the above	6	2	9	0	17(15%)	
Fruit buyers:						
Retailers	17	21	33	2	73 (64.6%)	69.2***
Wholesalers	6	2	2	19	29(25.7%)	
Processors	0	0	1	10	11(9.7%)	

[a]*Chi-square* test, ** and *** Significant at α ≤ 0.01 and α ≤ 0.001, respectively.

the produce by consumers (Mazhar et al., 2011). There were also differences in harvesting time where more than half of the growers harvest in the morning, some in the afternoon and about 15% of growers did not have a time frame for harvest (Table 7). However, harvesting in the morning is the best time to minimize the sap burn injury to the skin of mango (Amin et al., 2008).

Post-harvest handling and marketing: The harvested fruits were mainly stored under mango trees (58.4%) or storehouse (41.6%) constructed from local materials but did not have control facility to regulate environmental variables such as temperature and relative humidity. The storage of matured mango fruit in open air condition and above or below the optimum temperature requirement of the crop shortens the postharvest life and decline of the fruit quality due to rapid softening of the fruits which make the fruits susceptible to handling damages and postharvest pathogen (Emongor, 2015). Therefore, the development of improved mango storage methods that can maintain the fruit quality and enhance its shelf life is mandatory for the growers.

Standard transport and packaging system for the harvested mangos were lacking in the entire studied areas. Accordingly, some growers used motor vehicles, some used animals (donkey) and human to transport their produce to the market. The synthetic fiber sacks were the most common packaging material used and about 10.6% of the growers did not use packaging materials (Table 8). The improper packaging, transport, and inadequate field handling practices require intervention in Ethiopia since they have significant effect postharvest losses, organoleptic, nutritional and functional quality attributes of the fruits (Sivakumar et al., 2011) and marketing costs (Patel et al., 2013). The growers sell their products mainly to retailers followed by wholesalers (Table 8). However, few growers from the western part of Ethiopia sell to cooperative societies who are engaged in processing and value addition.

Major production constraints

Among several constraints reported by the respondents, accessibility to affordable agricultural inputs mainly fertilizers and pesticides were the major bottlenecks followed by pests and diseases. Moreover, knowledge and skill gap about pre and post production practices, poor marketing system, a limited number of improved varieties, flower and fruit drop and biennial bearing behaviors of the mangoes were also among the prioritized challenges (Table 9). The above-stated challenges are similar to those reported from the mango growers located in the northern (Dessalegn et al., 2014)

Table 9. Major mango production constraints in east and western Ethiopia.

Constraints	Districts				Total	χ2[a]
	Eastern Ethiopia			Western Ethiopia		
	Erer	Sofi	Babile	Assosa		
Input	23	23	24	9	79(69.9%)	44.6***
Pest	23	17	32	3	75(66.4%)	65.1***
Knowledge and skill	17	17	3	20	57(50.4%)	38.1***
Market	15	4	15	21	55(48.7%)	16.8***
Commercial cultivars	12	15	5	14	46(40.7%)	18.0***
Flower and fruit drop	9	1	23	0	33(29.2%)	41.7***
Alternate bearing	11	6	12	0	29(25.7%)	17.7***
Land shortage	4	0	7	1	12(10.6%)	8.6*
Drought	2	2	5	0	9(8.0%)	4.44[ns]
Transportation	2	0	4	0	6(5.3%)	5.96[ns]

[a]*Chi-square* test, ns = not significant,* and *** Significant at α ≤ 0.05 and α ≤ 0.01, respectively.

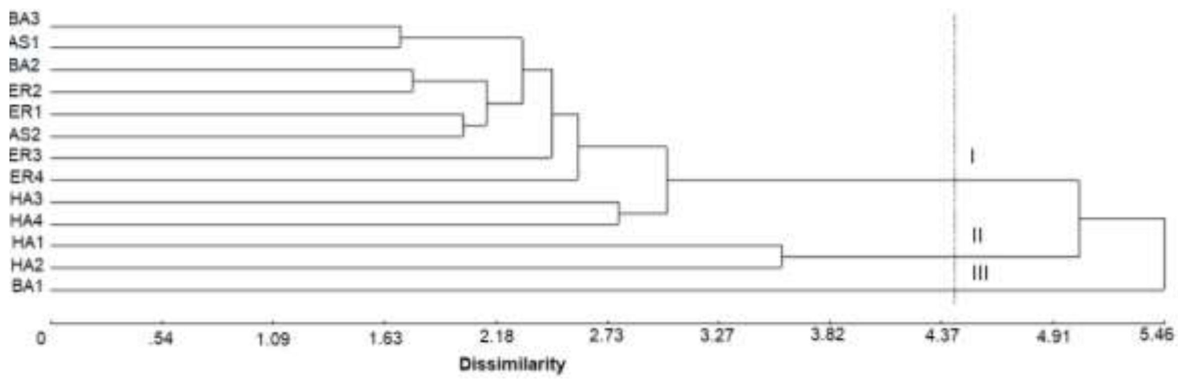

Figure 3. Dendrogram depicting dissimilarity of respondents from east and western Ethiopia.

and North East Ethiopia (Hussen and Yimer, 2013).

Similarity assessment among mango producers

Clustering results revealed respondents in 10 (76.92%) out of 13 villages both from eastern or western parts of the country were grouped under Cluster I. The remaining three villages from eastern Ethiopia were grouped into two clusters of which respondents in AbdibuchMaru (BA1) village from Babile district constructed solitary Cluster III while Nole (HA1) and Agemboy (HA2) from Sofi district constructed Cluster II (Figure 3). This showed that apart from the respondents in three villages, all growers in east and western Ethiopia had similar socioeconomics structure, farming system, mango production experiences and marketing of mangoes. This indicated that there is a possibility to generate packages or strategies on mango production, postharvest and marketing that could be applied in most mango growing regions of the country to enhance the mango sector. It has been suggested that identifying appropriate technologies, preparation of production and postharvest handling packages and providing agriculture extension service for farmers is easier if the farmers have similar socioeconomic situation, production experiences, and problems as compared to diversified situation of producers(Mwangi and Kariuki, 2015; Aremu et al., 2015; Altalb et al., 2015).

CONCLUSION AND RECOMMENDATIONS

The mango sector in Ethiopia is at the infant stage compared to the existing potential. The study revealed that the farmers were practicing mixed cropping system to generate additional income, diversification of their diet, and the majority of them in both east and western part of the country produced mango from the cultivars known by the community traditionally without improved agriculture technologies. It also indicated the existence of high yielding cultivars at farmer’s field that needs to be considered for conservation and improvement strategy. Moreover, unavailability of affordable agricultural inputs, improved varieties, marketing of fruits and low agriculture extension services were the major bottlenecks to the growers in Ethiopia. Therefore, the supply of affordable agricultural inputs and improved varieties, training of growers on technologies of mango production, harvest and postharvest handling is recommended to overcome the production constraints of mango. Safeguarding strategy should be urgently implemented for the identified potential mango cultivars which are on the verge of vanishing. In addition, diversity assessment and characterization of the cultivars is imperative to effectively utilize and/or conserve the genetic resources. However, this study included only the two major production regions (eastern and western Ethiopia) of the country; therefore, it is necessary to extend the similar in-depth research to identify the valuable farmers' mango cultivars, production practices and constraints across the country to alleviate the challenges and move forward the mango sector in Ethiopia.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Growth and yield performance of selected upland and lowland rainfed rice varieties grown in farmers' and researchers' managed fields at Ifakara, Tanzania

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Bridging the yield gaps is of major concern to rice breeders and agronomists under rainfed rice cultivation. The yield performance of lowland and upland rainfed rice varieties was investigated in farmers' and researchers' field conditions at four locations in Ifakara. Selected agronomic practices namely; recommended fertilizer (80 kgN/ha), spacing of 20 cm × 20 cm, weed free fields and high yielding varieties of TXD306, Komboka and Tai for lowland rainfed, and NERICA1, NERICA2 and NERICA4 for upland rainfed rice. Moreover, farmer selected varieties Supa India and WahiPesa were used as the local control in this research. The study revealed that yield performance of lowland rainfed rice varieties and in farmers' fields ranged between 2.9 and 6.9 t ha^{-1}, while in the upland rainfed rice the yield ranged between 2.5 and 5.4 t ha^{-1}. This was similar to yield that was obtained from the researchers' fields which ranged between 2.4 and 8.5 t ha^{-1} in lowland and between 1.8 and 4.8 t ha^{-1} in upland fields. The yield gap analysis revealed that the gap of between 35 and 60% previously reported in lowland rice was narrowed to 0 to 12.1%, while in the upland rice from 24.5 to 28.6% previously reported to 0% and excess yield over the potential yields and yields previously reported by farmers. The performance of all improved rice varieties at farmers and researchers' field were significantly higher compared to the local check varieties Supa India and WahiPesa. It was concluded that, providing farmers with selected good agronomic practices and supervision of farmers in field management activities enhanced rice productivity under farmers' conditions and narrowed or bridged the yield gaps that existed.

Key words: Upland rice, good agronomic practices (GAPs), lowland rice, productivity, yield gaps.

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important cultivated crops in the world. Rice has been reported to be grown on more than 162 million hectares worldwide by 2010 (GRiSP, 2013). In Tanzania, rice is the second

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Table 1. Characteristics of 8 rice varieties, their yield potentials, farmer realised yield and established yield gap.

S/N	Variety (year of release)	Aroma	Agro-ecological system	Days to Maturity	Researcher Potential yield (t/ha)	Farmer realised yield (t/ha)	Yield gap analysed (t/ha)
1	Super India (50s) farmers variety)	Aromatic	Lowland rainfed	120 -135	2.0 - 3.0	0.5 - 1.5	1.5
2	TXD306 (2002)	Semi-aromatic	Lowland rainfed	120 - 125	7.0 - 8.5	4.5 - 5.5	2.5 - 3.0
3	Komboka (2012)	Semi-aromatic	Lowland rainfed	100 - 110	5.0 - 6.5	3.0 - 4.0	2.0 - 2.5
4	Tai (2012)	Non-aromatic	Lowland rainfed	100 - 110	5.5 - 6.8	3.5 - 4.5	20 - 2.3
5	NERICA1 (2009)	Semi-aromatic	Upland rainfed	93 - 101	3.0 - 4.5	2.5 - 3.0	0.5 - 1.5
6	NERICA2 (2009)	Non-aromatic	Upland rainfed	90 - 95	3.0 - 4.0	2.0 - 3.0	1.0
7	NERICA4 (2009)	Non-aromatic	Upland rainfed	93 - 98	4.5 - 6.0	3.5 - 4.5	1.0 - 1.5
8	WahiPesa (farmers variety)	Semi-aromatic	Upland rainfed	110 -120	XX	0.5 - 1.0	XX

XX: Yield potential and gap not known.
Sources: KATRIN (2013); Cholima Agro-Scientific Research Centre's.

important staple cereal crop next to maize in terms of production and consumption (MAFSC, 2009; Mghase et al., 2010; USDA, 2013) and ranks first in Ifakara area, Kilombero district. A total area of 330,000 ha of land is suitable for rice cultivation in the country (MAFSC, 2009). About 72% of the land for rice is under rainfed lowland rice ecosystem, while 20% of it is under upland rainfed rice ecosystem, making a total of about 92% rice production in Tanzania from rainfed ecosystems. Only 8% rice cultivation in Tanzania is under irrigated rice ecosystem. However, rice yield under rainfed ecosystems in Tanzania is always lower due to moisture stress as well as use of low yielding local varieties grown with or without fertilizer application in farmers' fields (GRiSP, 2013).

Despite the release and dissemination of improved rice varieties in the rainfed rice ecosystem such as NERICAs (New Rice for Africa), that is, NERICA1, NERICA2, NERICA4, and NERICA7 with potential yields ranging between 3.0 and 7.0 t/ha in upland ecosystem and TXD306, TXD 88, TXD 85, Tai and Komboka with potential yields ranging between 5.0 and 8.5 t/ha in lowland ecosystem which was released between 2000 and 2012, the farmers have not yet bring their yield close to the yield potentials realized by researchers (Katrin, 2013). The rice yields in farmers' fields have been reported far below the potential yield. For example, a report by GRiSP (2013) which showed yields from farmers fields ranged between 0.8-1.0 and 1.5-2.0 t/ha in the upland and lowland rainfed ecosystems, respectively. These yields are far lower from the potential yields established by researchers (Katrin, 2013).

Another report established by Agricultural research institutes KATRIN and Cholima Agro-Scientific Research centres (Table 1), showed that the yields from farmer fields ranged between 0.5 and 5.5 t/ha in lowland rice depending on the variety used. While in the upland rice ecosystem yield ranged between 0.5 and 4.5 t/ha with use of improved NERICA rice varieties. Crop production capacity can be evaluated by estimating potential yield and water-limited yield levels as benchmarks for crop production under rainfed conditions. The differences between these theoretical yield levels and actual farmers' yields define the yield gaps (Van Ittersum et al., 2013), and particularly explicit knowledge about these yield gaps is essential to guide sustainable agricultural intensification. However, specific constraints reported to dictate the productivity and yield potential of different locations, and therefore location specific management changes and interventions are required to close the observed yield gap (Mueller et al., 2012). In order to boost rice productivity and reduce yield gaps in Ifakara the ecosystem specific analyses of yield gaps were very potential in addressing the yield production constraints of selected rice varieties under rainfed environment.

The study analyzed the upland rainfed and lowland rainfed rice varieties separately to quantify the yield gap (Yg), that is, the difference between water-limited yield potential at researchers' field (Yw) and actual yield (Ya) at farmers' field. The study found a yield gap of between 35 and 60% in lowland rainfed rice ecosystem. While in the upland rainfed rice ecosystem a yield gap of between 24.5 and 28.6% was found between farmers obtained yields and the researchers yield potentials (Katrin, 2013; Merlos et al., 2015). Therefore, intervention plans to boost farmer yield outputs closer to expected yield potentials established by researchers was found essential at the study site in Ifakara.

Previous studies on use of good agronomic practices reported that good plant spacing, use of improved varieties, and use of fertilizers increased the yields under farmers' field conditions in other areas (Zaman et al., 2013; Saito et al., 2010; Meertens et al., 2003). However, the low level of rice production and productivity at Ifakara and Tanzania in general are caused by several reasons including small holder farmers' limited access to rice information (Ronald et al., 2014; Mkanthama, 2013). According to Chapman and Tripp (2003), there are concerns with poor performance of public extension, including its inability to consistently deliver useful information to resource-poor farmers. The good agronomic practices and technologies reported were not very well known to most farmers cultivating rice on small scale in Ifakara. In order to increase their production, access to good agronomic practices (GAPs) such as improved seed varieties, plant spacing, fertilizer and application rate, weeding time and frequency practices were needed.

The resulting growth and yield performances of selected eight rice varieties under farmers and researcher growing condition were analyzed to investigate how (GAPs) is effective on closing or narrowing the previously reported yield gap.

MATERIALS AND METHODS

Description of the study sites

The study was undertaken in Ifakara area, Kilombero district, which lies between 8° 04' to 8° 15' South and 36° 65' to 36° 69' East, at an altitude ranging between 257 and 330 m above sea level. The field experiments were carried out at the following four locations in rainfed conditions. Two farmers managed fields were at Kibaoni (08° 07' S and 36° 68' E) and Michenga (08° 12' S and 36° 66' E). The two researcher managed fields were at the Agriculture Research Institute KATRIN (08° 04' S and 36° 68' E) and Lumemo substation (08° 15' S and 36° 67' E).

In an attempt to bridge the yield gaps between farmers and researchers yields, the farmers and researchers applied the same agronomic practices (GAPs) such as rice varieties, spacing of 20 × 20 cm^2, fertilizer at same rate of 80 kg N/ha, weeding frequency of two time in a season, seeding in line, and thinning to two seedling per hill. The researcher was monitoring all the field management activities accomplished. Ifakara site is considered to have high potential for rice productivity growth; its climate reported to be sub-humid tropical, with an average of 1400 mm per annum and the annual temperature ranged between 28 and 33°C (Katrin, 2012). The area is generally gently sloping with an alluvial sandy loam soils on the flat area and the upper zone is dominated by pale sand of granitic gneiss origin (Katrin, 2012).

Experimental design and crop management

The experiments were carried out under the field condition in a randomized complete block design (RCBD) layout, in plot sizes of 40 m^2 with four replications. Experimental units comprised twenty-rows of 10 m length each, with row-to-row spacing of 20 cm and plant-to-plant spacing of 20 cm. Spacing between blocks and between plots were 1 and 0.5 m, respectively. Five seeds were directly sown per hill. After germination the seedlings were thinned to two plants per hill for both farmers field and researcher field conditions in the upland rice and lowland rice ecosystems.

The yield potential and yield gap previously reported for the varieties used in this study are summarized in Table 1. The soil status of the plots before sowing is shown in Table 2. All plots in farmers managed field and researcher managed fields were fertilized with a standard rate of 80 kg N/ha of urea applied at the effective tillering stage by broadcasting method. Weeding was done twice at vegetative and at maximum tillering stages.

Data collection and sampling techniques

Data were collected on some phenological growth and yield components traits such as days to 50% flowering and 90% maturity, and above ground biomass (SDt), number of tillers, and plant height. Others traits were yield and yield components including number of panicles, total number of spikelets per panicle, number of fertile spikelets per panicle, thousand grain weight and grain yield.

Measurement of yield and yield components

An area of 1 m^2 was sampled for yield and yields components analyses. The total number of panicles, number of fertile and sterile spikelet per panicle was counted from 5 randomly selected panicles in the 1 m^2 plot areas. The 1000 grains were physically counted and weighed to get the 1000 grains weight in (g) at 14% grain moisture content using the procedures described by (Gomez, 1972).

Biomass yield

The total sun-dry weight of the above ground biomass of plants occupying the 1 m^2 area were weighed at maturity, then converted to tons per hectare (tha^{-1}) as described by Fageria (2010), whereby plants in a sampling area were cut at 4 cm above the ground and sun dried for three days and weighed to get the total biomass weights above the ground then threshed to get the grain weight. Then the straws were dried at 80°C until a constant dry weight obtained.

Grain yield

This was taken as the total grain weight per plot in grams after threshing then converted to tons per hectare (tha^{-1}). The grain yields of the selected rice varieties were determined according to (Yoshida, 1981) as follows:

$$GY = (P \times SP \times FS \times 1000GW \times 10^{-5}) \quad (1)$$

where GY is grain yield (tha^{-1}), P is number of panicles (m^{-2}), SP is number of spikelets per panicle, FS is percentage filled spikelets or grain and GW is 1000-grain weight (g).

Grain harvest index (HI)

This was taken as the ratio of grain weight to the total above ground biomass yield computed from an area of 1 m^2. This index was obtained using the relationship established by Fageria (2010) where,

$$HI = \text{Grain weight (g)} / \text{Total weight above ground (Grain + Straw) g} \quad (2)$$

Data analysis

The data obtained in the experimental field trials were subjected to analysis of variance (ANOVA) using (GenStat, 2011) 14th edition and Excel (Microsoft) for graphs and tables. Mean separation was done using Tukey's significance difference test, and the treatments were compared at ($P \leq 0.05$).

Table 2. Agro-ecology and Soil characteristics for the rainfed ecosystems used in the experiment.

Site	Soil texture	Soil pH	EC	OC	Total N	Available (P)	Exchangeable Cations (meq/100 g soil)				CEC
	Class	H_2O	mS/cm	g/kg	g/kg	mg/kg	K	Na	Ca	Mg	Cmol/kg
Katrin (RU)	Sandy loam	6.40	0.10	11.90	0.65	88.46	0.11	0.04	5.45	1.08	10.80
Kibaoni (RU)	Sandy loam	6.10	0.09	5.70	0.60	42.37	0.24	0.08	0.71	0.26	1.52
Lumemo (RL)	Clay loam	5.40	0.18	20.20	1.80	43.40	0.35	0.39	9.04	4.53	21.40
Michenga (RL)	Clay loam	5.40	0.18	20.10	1.80	50.60	0.31	0.36	9.94	4.68	20.80

EC= Electro-conductivity, OC= Organic Carbon, CEC= Cation Exchange Capacity, RU=Rainfed Upland, RL=Rainfed lowland

Table 3. Days to 50% flowering and 90% physical maturity of selected Rainfed rice at Ifakara rainfed ecosystem.

Ecology	Sites	Rice varieties	Days to 50% flowering	Days 90% physical maturity
Lowland rice	Michenga	Komboka	69 ± 0.4	108 ± 0.4
		Tai	71 ± 0.4	110 ± 0.4
		TXD 306	78 ± 0.4	125 ± 0.8
		Supa India	87 ± 0.5	128 ± 0.7
	Lumemo	Komboka	78 ± 0.4	102 ± 0.6
		Tai	80 ± 0.7	104 ± 0.4
		TXD 306	87 ± 0.4	123 ± 1.1
		Supa India	98 ± 0.5	125 ± 0.7
Upland rice	Kibaoni	NERICA1	63 ± 0.9	98 ± 0.4
		NERICA2	60 ± 1.3	95 ± 0.8
		NERICA4	61 ± 1.0	96 ± 0.8
		WahiPesa	68 ± 0.7	117 ± 0.4
	ARI-KATRIN	NERICA1	67 ± 0.8	95 ± 0.4
		NERICA2	64 ± 1.1	92 ± 0.4
		NERICA4	66 ± 1.1	94 ± 0.8
		WahiPesa	72 ± 1.4	114 ± 0.7

Data are means of four replications; ± = Standard error of means.

RESULTS

Phenological and growth characteristics of selected rice varieties

Phenological characteristics

The selected improved rice varieties and two local rice varieties varied over genotype and environment (Table 3). For example, the 50% flowering time in upland and lowland rainfed rice ecosystems, varied among rice genotypes and the site, respectively. The period to 50% flowering was longer in the lowland rainfed rice ecosystem than in the upland rainfed rice ecosystem (Table 3). Flowering for Michenga lowland site was about 69 to 87 days depending on the rice genotypes, and was shorter than that of Lumemo site about 9 to 11 days, while in the Upland rice sites; the days to 50% flowering of all rice genotypes at Kibaoni were shorter by 4 to 5 days compared to that at KATRIN site although such differences were not statistically significant. NERICA 2 had slightly the shortest 50% flowering than all other upland rice genotypes at both Kibaoni and KATRIN sites. The farmers variety (WahiPesa) delayed by 8 to 9 days to reach 50% flowering compared to NERICA2, which was earliest variety at Kibaoni and KATRIN sites (Table 3).

The 90% physical maturity time in both upland and lowland rainfed rice ecosystems varied among rice genotypes and the sites (Table 3). Varieties Komboka and Tai were matured earlier compared to TXD 306

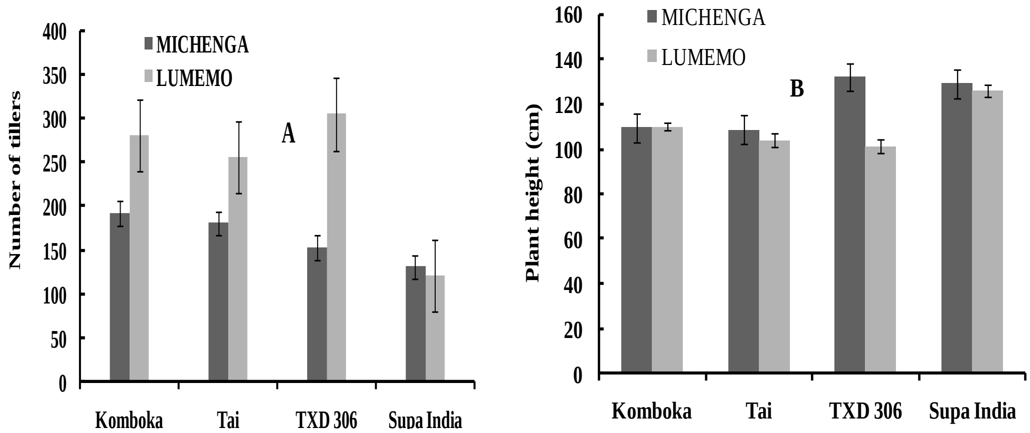

Figure 1. Growth performance of lowland rice at Farmer and researcher fileds (A) number of tillers per m^{-2} of lowland rice at maturity, (B) plant heights of lowland rice at maturity; Bars indicate standar error (SE).

(SARO5) and Supa India by 15 to 18 and 19 to 23 days at Michenga and Lumemo sites, respectively (Table 3). The farmers' variety Supa India matured relatively same as TXD 306 (SARO5) though delayed by 3 to 2 days.

For the Upland rice ecosystem, the 90% physical maturity was relatively the same at Kibaoni and at KATRIN upland rice sites, though delayed by 2 to 3 days longer at Kibaoni. NERICA 2 had the shortest 90% maturity than all other upland rice genotypes both at Kibaoni and KATRIN. The local variety (WahiPesa) delayed by 22 days to reach 90% physical maturity compared to NERICA2, the earlier variety at Kibaoni and KATRIN sites, respectively (Table 3).

Growth characteristics

In the lowland rainfed ecosystem, the number of tillers in the lowland rainfed rice ecosystems was significantly greater at the Lumemo researcher managed site for the improved rice varieties Komboka, Tai and TXD 306 than at Michenga farmer managed site. However, at both sites the local variety Supa India produced significantly lower number of productive tillers compared to other rice varieties tested (Figure 1A). At Michenga farmer managed site, there was no significant difference between Komboka and Tai varieties in the number of tillers per unit area, where a decreasing trend in number of tillers from Komboka, Tai, TXD306 and Supa India was observed (Figure 1A).

Rice plant height under lowland rainfed rice ecosystem were not significantly different regardless of sites for Komboka, Tai and Supa India, while TXD 306 variety showed significant difference among the sites (Figure 1B). At Michenga farmer managed site, TXD 306 was significantly taller than at Lumemo researcher managed site. This characteristic was against the normal plant height behavior for TXD 306. Supa India, the local check variety of the farmers showed the tallest plants regardless of sites (Figure 1B).

In upland rainfed rice ecosystem, the number of tillers varied significantly with varieties both at Kibaoni farmer managed site and at ARI-KATRIN researcher managed site. The local check variety, WahiPesa produced relatively similar small number of tillers both at Kibaoni (farmer managed) and ARI-KATRIN researcher managed sites (Figure 2A).

The plant height in upland rainfed ecosystem significantly differed among the sites (Figure 2B). At Kibaoni all varieties showed no difference in plant heights, while at ARI-KATRIN researcher managed site, WahiPesa local check variety was the tallest than all other upland rainfed rice varieties grown. All NERICA's varieties showed no significant difference in plant heights regardless of sites (Figure 2B).

Yield and yield components

Biomass yield (Dry weights)

The total biomass yield (straw plus grain weights) in the lowland rainfed rice ecosystem was significantly different among sites (Figure 3A). The total biomass yield of all selected lowland rainfed rice plus the local check variety produced significantly larger biomass yield at Lumemo researcher managed site compared to Michenga farmer managed site. However, the farmers' variety Supa India produced the smallest total biomass yield at both Michenga and Lumemo sites. The improved lowland varieties TXD 306, Komboka and Tai produced significantly larger total biomass yield than the local variety Supa India at Lumemo researcher managed site, and Michenga farmer managed sites (Figure 3A).

In the upland rainfed rice ecosystem, the total biomass yield of all selected upland rice varieties including the

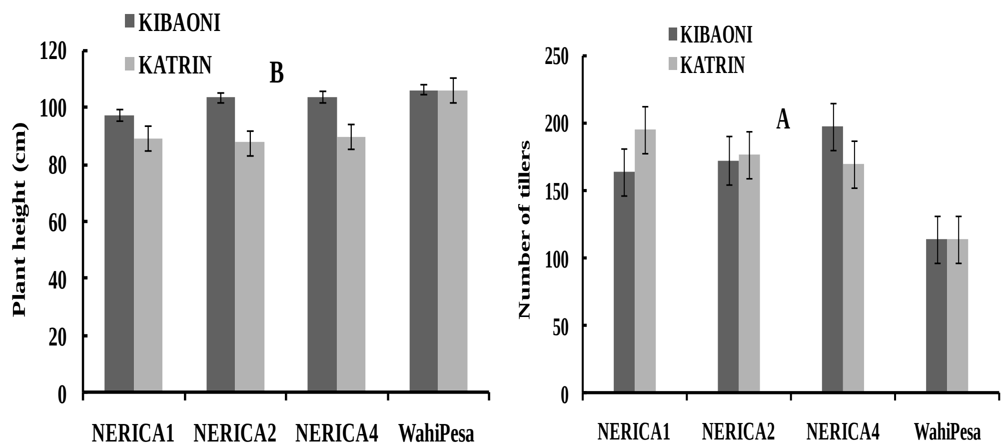

Figure 2. Growth performance of upland rainfed rice (A) number of tillers per m^{-2} of upland rice at maturity, (B) plant height of upland rice at maturity; Bars indicate standar errors (SE).

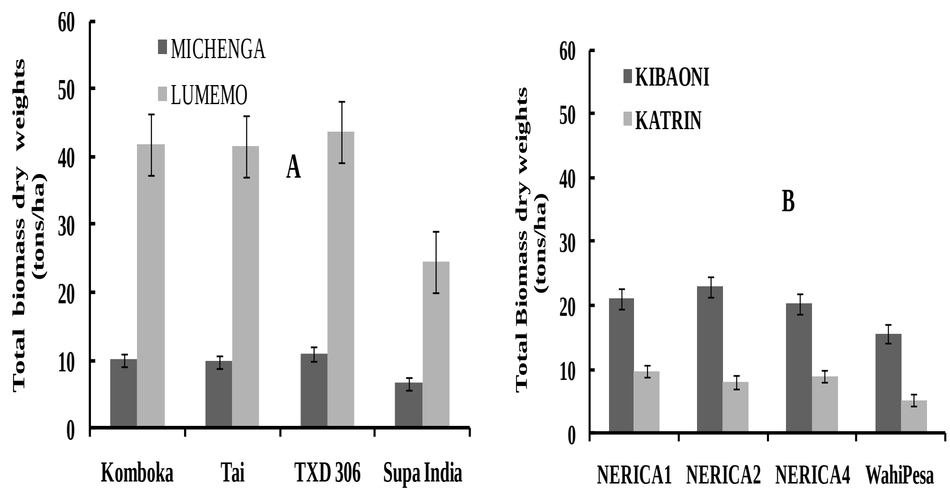

Figure 3. Total biomass yield performance of lowland and upland rainfed rice, (A) total biomass dry weight (tons ha^{-1}) of lowland rice, (B) total biomass dry weight (tons ha^{-1}) of upland rice. Bars indicate standar error (SE).

farmers local check variety, showed significantly higher total biomass yield at Kibaoni farmer managed site than that produced at ARI-KATRIN researcher managed site (Figure 3B). NERICA2 produced the largest total biomass yield at Kibaoni followed by NERICA1 and NERICA4, WahiPesa the farmers' local check variety produced the smallest total biomass yield. NERICA2 had a significantly larger biomass yield compared to that from the farmers' local check variety WahiPesa. The farmers managed upland rainfed rice site at Kibaoni produced significantly higher total biomass yield than the researcher managed upland rainfed rice site at AR-KATRIN (Figure 3B).

Grain yield

In the lowland rainfed rice ecosystem, the grain yields of TXD 306 were significantly higher at Michenga and Lumemo (Table 4). TXD 306 had a yield of 6.86 t/ha at Michenga farmer managed field and 8.45 t/ha at Lumemo researcher managed field. These yields were significantly higher than the grain yields of other lowland rainfed rice investigated, followed by Komboka and Tai which showed relatively similar grain yield performance (Table 4). Supa India variety which was selected by farmers as a local check produced the lowest grain yields 2.88 and 2.43 t/ha at Michenga and Lumemo sites, respectively.

In the upland rainfed rice ecosystem, the results showed that the grain yield of improved rice varieties NERICA1 produced 4.35 and 4.00 t/ha, NERICA2 produced 3.92 and 3.73 t/ha and NERICA4 produced 5.39 and 4.75 t/ha at farmer and researcher fields, respectively (Table 5). These yields were significantly higher than those of the local check WahiPesa rice

Table 4. Grain yield and yield components of four selected rice varieties grown in rainfed lowland ecosystem under Farmer and Researcher field condition.

Site location (S)	Varieties (V)	Grain yield (t ha^{-1})	Harvest index (HI)	Total number of panicle (m^{-2})	Number of Spikelet $panicle^{-1}$	#of Fertile Spikelet $panicle^{-1}$	Fertility (%)	1000grain weight (g)
Michenga	Komboka	5.26[c]	0.52[b]	193 [ab]	171[a]	113[abc]	66.40[ab]	24.51[c]
	Tai	6.00[bc]	0.61[a]	181 [ab]	154[a]	120[ab]	78.16[a]	27.78[b]
	TXD 306	6.86[b]	0.63[a]	154 [b]	171[a]	134[a]	79.66[a]	33.79[a]
	Supa India	2.88[d]	0.44[c]	131 [b]	130[a]	81[c]	62.03[b]	27.56[b]
Lumemo	Komboka	6.08[bc]	0.15[de]	256 [a]	150[a]	98[abc]	65.95[ab]	24.53[c]
	Tai	5.94[bc]	0.16[de]	231[a]	133[a]	91[bc]	68.35[ab]	29.00[b]
	TXD 306	8.45[a]	0.20[d]	255[a]	162[a]	105[abc]	64.16[ab]	33.28[a]
	Supa India	2.43[d]	0.10[e]	122[b]	123[a]	74[c]	60.61[b]	27.29[b]
ANOVA	V	*	*	*	NS	*	*	*
	S	*	*	*	NS	NS	NS	NS
	S × V	*	*	*	NS	*	*	NS

*Indicate Significant at 5% level by ANOVA. NS indicate not Significant. Values followed by the same letter in a column within each treatment are not significantly different at P≤ 0.05. (**Michenga** =Farmers field). (**Lumemo** = Researchers field). S = site effects, V= varieties, (S × V) = Site and varieties interactions.

variety which performed poorly with grain yield of 2.83 and 1.83 t/ha at Kibaoni farmer managed field and at ARI-KATRIN researcher managed field, respectively (Table 5). The interactions in grain yields per unit area were observed to be significant at both lowland and upland rainfed ecosystems, between sites and rice varieties, respectively (Tables 4 and 5).

Yield components

The yield components such as harvest index, number of panicles per unit area, number of spikelets per panicle, fertile spikelets per panicle, fertility percentage ratio and 1000 grain weight varied on genotypes and the sites (Tables 4 and 5).

The harvest index (HI) in the lowland rainfed rice ecosystem, at Michenga farmer managed site were significantly higher than the harvest index at Lumemo reasearcher managed site. At Michenga farmer managed site, TXD 306 and Tai produced the highest harvest index ratio than all other varieties used with ratio of 0.6, followed by Komboka, and Supa India with ratio of 0.4 produced the lowest harvest index (Table 4). At Lumemo researcher managed site, TXD 306 had a significantly higher harvest index than Supa India but was not significantly different from Tai and Komboka (Table 4).

In upland rainfed ecosystem, the havest index at ARI-KATRIN researcher managed site were significantly higher than those at Kibaoni farmer managed site (Table 5). At both sites NERICA4 had a significantly higher harvest index ratio (HI), followed by NERICA2 and NERICA1 which were not statistically significant different in harvest index, and the local check variety WahiPesa indicated significantly lower harvest index at ARI-KATRIN and Kibaoni sites, respectively (Table 5). The interactions in harvest index ratio were observed to be significant at both lowland and upland rainfed ecosystems between sites and rice varieties (Tables 4 and 5).

The number of panicles per unit area in the lowland ecosystem was significantly different between Michenga farmer managed site and Lumemo researcher managed site (Table 4). At Michenga panicles per unit area were not statistically significant different though Komboka and Tai produced relatively higher panicles per unit area followed by TXD 306 and lastly Supa India. At Lumemo site Komboka, TXD 306 and Tai were not significantly different from each other in the number of panicles per unit area, but significantly had higher number of panicles per unit area than Supa India variety (Table 4).

In the upland rainfed ecosystem, the number of panicles per unit area was not significantly different between Kibaoni farmer managed site and ARI-KATRIN researcher managed site. All rice varieties used were statistically similar in the number of panicles per unit area at each site except for NERICA 4 and WahiPesa at Kibaoni which differed significantly (Table 5). The interactions in the number of panicles per unit area were observed to be significant at both lowland and upland rainfed ecosystems between sites and rice varieties (Tables 4 and 5).

The number of spikelets per panicle in the lowland rainfed rice ecosystem was not significantly different between Michenga and Lumemo sites and among varieties (Table 4). In the upland rainfed rice ecosystem,

Table 5. Grain yield and yield components of four selected rice cultivars grown in rainfed upland ecosystem under farmer and researcher field conditions.

Site (S)	Varieties (V)	Grain yield (t ha^{-1})	Harvest index (HI)	Total# Panicle m^{-2}	# Spikelet panicle^{-1}	# Fertile Spikelet panicle^{-1}	Fertility (%)	1000grain weight (g)
Kibaoni	NERICA1	4.35^{ab}	0.21^{ef}	164^{ab}	127^{bc}	88^{bc}	70.04^{a}	30.77^{a}
	NERICA2	3.92^{b}	0.19^{ef}	173^{ab}	114^{c}	78^{c}	69.17^{a}	29.74^{a}
	NERICA4	5.39^{a}	0.27d^{e}	198^{a}	129^{bc}	94^{bc}	72.85^{a}	29.44^{a}
	WahiPesa	2.45^{c}	0.16^{f}	114^{b}	108^{c}	72^{c}	67.12^{a}	30.05^{a}
ARI-KATRIN	NERICA1	4.00^{b}	0.42^{bc}	170^{ab}	141^{abc}	88^{bc}	61.23^{a}	28.40^{a}
	NERICA2	3.73^{b}	0.46^{ab}	151^{ab}	164^{ab}	102^{bc}	62.02^{a}	24.46^{bc}
	NERICA4	4.75^{ab}	0.53^{a}	170^{ab}	173^{a}	113^{a}	65.85^{a}	24.85^{b}
	WahiPesa	1.83^{c}	0.35^{c}d	114^{b}	137^{abc}	74^{c}	54.76^{a}	22.16^{c}
ANOVA	V	*	*	*	*	*	NS	*
	S	NS	*	NS	*	*	NS	*
	S x V	*	*	*	*	*	NS	*

*Indicate Significant at 5% level by ANOVA. NS indicate not Significant. Values followed by the same letter in a column within each treatment are not significantly different at P≤0.05. Kibaoni =Farmer field; ARI-KATRIN = Researcher field; S = site effects; V= varieties; (S × V) = Site and varieties interactions.

there was a significantly higher number of spikelets per panicle at ARI-KATRIN site ranging between 137 and 141 than at Kibaoni site with number of spikelets per panicle ranging between 108 and 129. There was no statistically significant difference among the varieties in the number of spikelets per panicle at Kibaoni and ARI-KATRIN (Table 5). The interactions in the number of spikeletes per panicle were significant in the upland rainfed ecosystem between sites and rice varieties (Table 5).

The fertile spikelets per panicle in the lowland rainfed ecosystem were not statistically different between Michenga farmer managed and Lumemo researcher managed sites (Table 4). However, there was a significant difference among rice varieties in the number of fertile spikelets per panicle at Michenga and Lumemo sites (Table 4).

In the upland rainfed rice ecosystem the number of fertile spikelets per panicle were significantly different between Kibaoni farmer managed and ARI-KATRIN researcher managed sites. At Kibaoni there were no significant differences in the number of fertile spikelets per panicle. While at ARI-KATRIN highly significant differences in the number of fertile spikelets per panicle was observed among the rice varieties (Table 5). NERICA4 had significantly higher number of fertile spikelets per panicle than all other upland rice varieties used, followed by NERICA2 and NERICA1, while WahiPesa was the least (Table 5). The interactions in the number fertile spikelets per panicle were observed to be significant at both lowland and upland rainfed ecosystems, between sites and rice varieties (Tables 4 and 5).

In the lowland rainfed ecosystem, the fertility percentage ratio was not significantly different between Michenga farmer managed site and Lumemo researcher managed site (Table 4). However, there were significant differences in fertility percentage ratio among the rice varieties at Michenga farmer managed site and Lumemo researcher managed site (Table 4). At both sites the local check Supa India indicated significantly lower fertility percentage ratio (Table 4). In the upland rainfed ecosystem, the fertility percentage ratio among improved rice varieties was not significantly different between Kibaoni farmers managed site and ARI-KATRIN researchers managed site (Table 5). The interactions in the fertility percentage ratio between sites and rice varieties were observed to be significant at both lowland and upland rainfed ecosystems (Tabls 4 and 5).

In the lowland rainfed ecosystem, 1000 grain weight was not significant different between Michenga farmers managed site and Lumemo researcher managed site (Table 4). There were varietal significant differences at both Michenga and Lumemo sites respectively (Table 4). TXD 306 variety had significantly the heaviest 1000 grains weights 33.8 and 33.3 g at Michenga and Lumemo sites, respectively. The local check Supa India variety indicated the lightest 1000 grain weight at both sites (Table 4).

In the upland rainfed ecosystem; a 1000 grain weights was significantly heavier at Kibaoni farmer managed site than at ARI-KATRIN researcher managed site (Table 5). At kibaoni, there was no significant differences between the rice varieties tested, while at ARI-KATRIN, NERICA1 had significantly heavy 1000 grain weight (28.4 g) than all other rice varieties, followed by NERICA4 (24.9 g),

Table 6. Correlation coefficients between yield components and yield in selected lowland rice and upland rice varieties at different sites.

Parameter	LUMEMO Grain yields (t/ha)	MICHENGA Grain yields (t/ha)	ARI-KATRIN Grain yields (t/ha)	KIBAONI Grain yields (t/ha)
Grain yields(t/ha)	1	1	1	1
1000 grain weight	0.58*	0.51*	0.64*	-0.27
% grain filled ratio	0.55*	0.91**	0.98**	0.98**
fertile spk/panicle	0.97**	1.00**	0.88**	0.95**
spikelet/panicle	0.91**	0.85**	0.74**	0.92**
Panicles/m^2	0.91**	0.52*	0.97**	0.96**

**Significant at P≤0.01, *significant at P≤0.05.

NERICA2 (24.5 g) and WahiPesa had the lowest 1000 grain weight (22.2 g) (Table 5). The interactions in a 1000 grain weight between sites and rice varieties were significant at the upland rainfed ecosystems (Table 5).

Correlation between yield and yield components of selected rice varieties

A highly positive correlation between yield components and grain yields of selected lowland and upland rainfed rice varieties was observed (Table 6), and the correlation varied significantly with sites location and the yield components. In the lowland rainfed rice ecosystem; the grain yields at Lumemo researcher managed site was highly correlated with the fertile spikelets per panicle, number of spikelet per panicle, and number of panicles per unit area. However, 1000grain weight and grain filled ratio percentage contributed less to the final yield differences between the rice varieties (Table 6). At Michenga farmer managed site, the yield correlated well with the fertile spikelets per panicle, the percentage grain filled ratio, and the number of spikelet per panicle (Table 6). While the number of panicles per unit area and a 1000 grain weights contributed less to the final yield differences among the rice varieties.

In the upland rainfed rice ecosystem, yield at ARI-KATRIN researcher managed site was highly correlated with the percentage grain fertility ratio, number of panicles per unit area, fertile spikelets per panicle and number of spikelet per panicle (Table 6), but a 1000 grain weight contributed less to the final yield differences among the rice varieties. At Kibaoni farmer managed site, the yield correlated well with the percentage grain filled ratio, number of panicles per unit area, fertile spikelets per panicle and number of spikelet per panicle (Table 6), but was negatively correlated to the 1000 grain weight (Table 6).

Yield gap analysis after implementation of selected GAPs in farmers' fields

Yield gap is defined as the difference between maximum attainable yield and actual yield obtained by farmers. Maximum attainable yield refers to the highest yield that could be reached by a crop in a given environment. In the present study analyses of average yield obtained under farmers' field management in comparison to the previous reported yield potentials by research institution and farmers' realised yields (Table 7), which showed that, the yield gap particularly in the lowland rainfed rice ecosystem was reduced and in the upland the analysis showed a closed or excess yield were obtained.

In the lowland rainfed ecosystem the local check Supa India variety produced significantly higher grain yields under farmer field management in excess about 0.38 t/ha from the previous researchers yield potentials reported in ARI-KATRIN and Cholima Agro-Scientific Research Centers (2013), while the varieties Komboka, Tai and TXD 306 indicated reduction in the yield gap from between 2.2 and 2.8 t/ha previously reported gap from 0.2 to 0.9 t/ha in the present study (Table 7). While in the upland rainfed ecosystem, the gap analysis indicated that after application of the selected good agronomic practices the yields was significantly higher in farmers' field. The local check WahiPesa variety produced an excess yield of about 1.65 t/ha from the initial farmers yield reported. All NERICA varieties produced excess yield of between 0.09 and 0.55 t/ha. Implying that the negative gap value meant the yield produced at farmers field were in excess of the potential yields reported by researchers (Table 1), for all the rice varieties investigated in the study (Table 7).

DISCUSSION

Agronomic traits perfomance

In general, the agronomic performance of improved rice varieties both in lowland and upland ecosystem was earlier in terms of 50% flowering and 90% physical maturity than the local check traditional varieties selected by farmers. These finding were in line with those of Heuer et al. (2003), who found better agronomic performance of *Oryza sativa* (IR 64) × *Oryza glaberrima* (TOG5681)

Table 7. Yield gap analysis between potential yield and farmers realised yieldafter using of selected GAPs for the yield performance study in Ifakara.

Varieties analysed	Average initial yield potential (t/ha)	Average Initial farmer yield (t/ha)	Previous yield gap t/ha (%)	Present Farmer yield (t/ha)	Present yield gap (t/ha)
Supa India	2.5	1.0	1.5 (60.0)	2.88	-0.38
Komboka	5.8	3.5	2.3 (39.7)	5.26	0.54 (9.3)
Tai	6.2	4.0	2.2 (35.5)	6.00	0.20 (3.2)
TXD 306	7.8	5.0	2.8 (35.9)	6.86	0.94 (12.1)
NERICA1	3.8	2.8	1.0 (26.3)	4.35	-0.55
NERICA2	3.5	2.5	1.0 (28.6)	3.92	-0.42
NERICA4	5.3	4.0	1.3 (24.5)	5.39	-0.09
WahiPesa	xx-	0.8	xx	2.45	-1.65

Highlighted number in brackets are percentage (**%**) yield gap, and the highlighted negative value is the excess yields in t/ha, referring that the yield gap was closed and excess yield was obtained.

interspecific progenies within Back cross one (BC1) and Back cross two (BC2) populations compared to their *O. sativa* parent in irrigated lowland conditions in the Sahel. However, the upland rice varieties tested in the present study were the earliest in flowering and maturing, therefore are suitable for areas with short growing seasons due to short growth duration compared to the lowland rice varieties investigated by the present study.

Yield and yield components traits

The higher performance in total biomass yield of improved rice varieties (Figure 3A and 3B) in the present study were associated with higher productivity of selected rice varieties, the varieties with the highest accumulated shoot dry weight had the highest grain yields (Tables 4 and 5). Similar findings were reported by Yun et al. (1997), that the superior yield of *Japonica indica* hybrids was associated with the higher capability of reserve formation under the upland condition. Higher total biomass accumulation characteristics in all improved rice varieties investigated in this study were also in line with the results by Katsura et al. (2007), who reported rice yield mainly depends on ability of dry matter production of the variety. Thus low number of tillers was responsible for the reduction in total biomass yield of farmers selected varieties Supa India and WahiPesa varieties under lowland and upland rainfed ecosystem.

In the present study, the grain yield of improved lowland and upland rainfed rice varieties were significantly higher than the local check varieties both at farmers and researchers' fields (Tables 4 and 5). Higher yielding varieties are responsive to fertilizer application, in the present study use of 80 kgN/ha of nitrogen fertilizer applied at the effective tillering stage, increased the yields in farmers' field condition relatively the same as that of researcher managed fields. These findings were in partial agreement with those of Meertens et al. (2003) and Fageria et al. (2006) who reported that use of fertilizer application in fields increased the grain yield of rainfed rice ecosystem. Moreover, broadcasting seeds as the traditionally ways of sowing seeds used by most farmers in rainfed rice ecosystem has been reported to give low plant population and as a misuses of land resources, which leads to low yields (GRiSP, 2013). Therefore, sowing seeds or planting in spacing of 20 cm × 20 cm used in the present study for all rice varieties investigated increased tremendously the yields of farmers field relatively same as that obtained by the researcher fields, making the production in farmers fields attain the yield potentials established by research institution. These results were in partial agreement to those reported by Zaman et al. (2013) who found that the yields of spacing of 30 × 15 cm was higher compared to the grain yield in spacing 30 × 20 cm which had lower plant population per unit area.

The rice performance in both lowland and upland rainfed ecosystems investigated in terms of grain yields and yields components was found to vary considerably with rice genotypes and sites. Yoshida et al. (2006) and Matsunami et al. (2009) reported positive correlations between grain yields and number of spikelets per panicle when evaluating the high yielding varieties in lowland and upland ecosystem. These results are in partial agreement with the findings of the present study, whereby the high yields of improved and local check varieties were highly correlated with the number of spikelet per panicle. Moreover, the number of harvestable tillers is as good as the number of panicles per plant and according to Zou et al. (1991) tillering capacity of varieties is one of the most important characters determining yield potentials. These findings are in partial agreement to the present findings in which the number of panicles per unit area was proportional to the number of effective tillers per plant. Thus, the number of panicles per plant was among the yield parameters responsible in determining yields of the selected rainfed rice varieties in both upland and lowland rainfed rice ecosystem (r = 0.96** and 0.97**) in the upland rice at Kibaoni and ARI-KATRIN respectively, and in the lowland rice (r = 0.52* and 0.91**) at Michenga and Lumemo sites.

Yield gap narrowing or bridging

Understanding the small-scale farm production constraints is essential in designing intervention plans and targeting to boost smallholder farm yield output (Arias et al., 2013). As specific constraints dictate the productivity and yield potential of different regions, region-specific management changes and interventions are required to close the observed yield gap (Mueller et al., 2012). The yield performance analysis of selected rice varieties under lowland and upland ecosystem in the present study showed that after application of the provided good agronomic practices (GAPs) such as improved rice varieties, spacing of 20 cm × 20 cm, sowing seeds in line (or in rows), two weeding times, and 80 kgN/ha urea fertilizer application bridged the yield gaps for some of the rice varieties investigated and reduced in others. The farmers yield increased significantly in both lowland and upland rainfed rice ecosystems relatively same as that of the researchers (Tables 4 and 5). Thus, good field crop management is an important key in rice production and was responsible in bridging the yield gaps between farmers and researchers yields. These observations are in line with those reported by Affholders et al. (2016) who analysed the yield gaps of various crops and found that the share of yield variation due to crop management was greater or equal to the share of yield variation due to the main climatic drivers of crop production, and that variation in soil fertility, weed infestation and agronomic management were factors that explains the yield gaps.

In the lowland rainfed ecosystem application of GAPs increased the yield and narrowed the yield gaps previous reported. For example, the yield gap in TXD 306 variety the gap dropped from 35.9 to 12.1% yield gap remained between farmers' realised yields and the researcher yield potentials. It is therefore that 23.8% gap reduction realized yields in the study. Komboka variety indicated about 30.4% gap reduction, and narrowed the previously yield gap reported from 39.7 to 9.3% yield gap. Tai variety had the highest percent of reduction in yield gap from 35.5% yield gap previously reported in previous study to 3.2% yield gap remained in this study. This is about 32.3% reduction in the yield gap from the previous one. However, the local check variety Supa India in this study produced higher yield than the potential yield reported, and therefore the application of good agronomic practices used found to bridge the gap existed between farmers and researchers yields and gave excess yield of0.38 t/ha (Table 7).

The yield gaps of 24.5 to 28.6% previously reported between farmers realized yield and researchers yield potentials in the upland rainfed rice ecosystem was found to drop to zero and excess yield were observed in all improved NERICA rice. The local check WahiPesa rice variety also produced excess yield about 1.7 t/ha comparing to the reported yields under farmers (Table 7).

Conclusion

The study revealed that the yield performance of lowland rainfed rice varieties was higher than that of the upland rainfed rice varieties at farmers and researcher managed fields. The performance of all improved lowland and upland rice varieties at farmers and researchers managed sites were significantly higher compared to the local check varieties (Supa India and WahiPesa) selected by farmers.

The GAPs applied in the study narrowed the yield gap from 35.5 to 60% in lowland rainfed rice from 3.2 to 12.1% , while in the lowland local check variety Supa India was closed and excess yield of about 15.2% was realized. The GAPs in the upland rainfed rice ecosystem bridged or closed the yield gap and excess yield in all the improved upland varieties was obtained, while the local check WahiPesa yielded 1.7 t/ha in excess of the previous reported yields was obtained.

Thus, it was recommended that, provisioning farmers with GAPs such as improved rice varieties, plant spacing of 20 cm × 20 cm, early weeding and recommended fertilizer application accompanied with farmers supervision in field management, enhanced the high productivity and narrowed the yield gap that existed between farmers realised yields and researchers' yields potentials in rainfed rice ecosystems in Ifakara.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Food Barley Land races Characterization in the Northwestern Highlands of Ethiopia

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Barley is an important crop for the North Gondar highlands of Amhara Region, Ethiopia. To assess the characterization of barley landraces, 180 farmers from six villages in three districts of north Gondar zone were selected and surveyed. With regard to distribution status, most of the recorded landraces of barley were endangered. The main end uses of barley in the study area were *kolo, beso, tela, injera, korefe, kita* and *kinche*. According to farmers, the main criteria for selecting a variety were varietal characteristics mainly in the pre-harvest operation. The main characteristics for doing so are length of the spike, size of the seed, amount of seed per spike, ability to withstand disease, stand of the plant, tillering ability, number of rows, and germination ability. The majority of farmers renew the seed mostly between 1 and 3 years. The main reasons for renewing are production decline, to prevent landraces from elimination and to increase productivity. The majority of the farmers stated that they do not store seeds for long period of time associated with the fact that they hardly produce any surplus that can be stored for longer years. In barley production, women have roles of joint decisions on number and types of varieties to grow, plot allocation, and storage. However, postharvest processing is mainly decided by women. Farmers have proverbs associated with how much women are important in saving and maintaining barley landraces and make ready when the need arises. Hence, barley genetic resources should be conserved before they are lost and farmers' variety selection criteria should be incorporated in the modern breeding of barley. The active involvement of women in the maintenance and improvement of landraces should not be undermined in the modern crop improvement programs.

Key words: Ethiopia, barley, landrace, characterization, traits.

INTRODUCTION

Local knowledge of landraces/farmer's varieties develops over generations of first-hand observation of crucial features, their appearance and performance in a variety of environments, through good and bad rainy seasons (Guarino, 1995). Extended and continuous cultivation as well as maintenance and use of indigenous crop varieties by local farmers have led them to better understand the traits; environmental requirements (soil qualities, rainfall,

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altitude, temperature, etc.), special features of productivity and post harvest processes as well as the special utility values of the varieties have carefully been maintained for years in a very innovative way both as individuals and as members of an interacting community (Asfaw, 1997).

Access to a range of crop genetic variability is critical to the success of breeding programs and consequently to food security and human nutrition (Toledo and Burlingame, 2006). Landraces are considered more locally adapted and genetically variable than modern cultivars (Ceccarelli and Grando, 2000). They contribute to agricultural production around the world, particularly for the rural poor in marginal environments as source of seed for next season planting (Ceccarelli and Grando, 2000). Farmers make crop maintenance decisions based on combinations of factors including adaptability, yield, socio-cultural values and food traditions as well as nutritional values. These decisions affect the genetic diversity of crop populations (Ranjil, 2010). Farmers' maintenance approaches have allowed the continual evolution of landraces diversity in their area of adaptation. This diversity has been the key to food security for generations and an invaluable resource for crop improvement activities around the world.

The value of the evolutionary services delivered by on-farm conservation, while grounded at the community level, is connected to broader social and ecological landscapes where diverse landraces are maintained by different farming communities and interlinked to various degrees through seed systems (Samberg et al., 2013). These landraces are distributed across different types of environments, thus facing diverse selection pressures from environmental factors as well as from human management and preferences.

Smallholder farmers, both men and women, continuously carry out experimentation on the crops grown in their locality based on gastronomic criteria (Oosterhout, 1993) and storability (Teshome et al., 1999) as well as agro-morphological characters. While performing various field activities, farmers carry out evaluation progressively to assess the performance of the crops throughout the growing period (Berg, 1993). Small-scale farmers' choose to grow more than one variety of a given crop simultaneously reflecting their need to address numerous concerns, which no single variety would satisfy (Bellon, 1996). Farmers have multiple concerns that are reflected in multiple criteria for selection and variety ranking. Thus, farmer's management of their varieties and their role in seed selection activities are crucial to agricultural production, conservation and enhancement of the genetic resources. Farmers often noted varieties that had become ''tired'' and needed replacing; they gave their tired seed to farmers in cooler and more fertile areas for multiplication (Almekinders et al., 1994).

The culinary and varietal preferences, generally maintained by women, have a major influence on knowledge, selection, and use of agricultural biodiversity (Howard, 2003). Researchers are now finding that women's contribution is greater than previously perceived. In the literature, few studies investigate specifically the role of women in seed processing, storage, and exchange. Other researchers have focused on specific aspects of women's work in seed management, such as selection (Mulatu and Zelleke, 2002). However, the gender dimensions in the intra household decision-making process were seldom addressed in seed management research.

There are a number of studies that deal with how local farmers manage their seed, select varieties, renew tired seeds and decision making of the varieties in the family. An experiment conducted at Koga of West Gojjam Zone in Ethiopia confirmed diversity among 49 malt barley genotypes (Tilahun and Alemu, 2017). Many studies have shown that farmers in developing countries have intimate knowledge of environmental processes and make rational resource management decisions based on that knowledge (Olango et al., 2014). Although the northern Gondar highlands are potential barley production areas and harbor great diversity of land races, there is no documented study. For this reason, it is important to study and document diversity of barley, farmers' variety selection criteria, management of seeds, renewal of tired seeds, contribution of barley in the livelihood, local seed exchange systems and intra-household decision making systems.

MATERIALS AND METHODS

Description of the study areas

North Gondar zone is selected for the following reasons: (i) barley is one of the first food crops in the zone in terms of area coverage, production and importance, (ii) the zone is one of the micro-center of diversity for barley, and hence ideal sites for studying. In North Gondar, the highland districts of major barley producers are Wogera, Dabat, Debark, Janamora, Lay Armachiho, and Gondar Zuria. Among these six districts three of them namely *Wogera, Dabat and Debark* were selected purposively due to high production potential. Six kebeles, Adisgie Miligebsa and Gomia from Debark, Woken and Talak mesik from Dabat and Daber Lideta and kossoye from Wogera were selected purposively for the purpose of study. In order to assess on farm characterization barley landraces, survey research was undertaken. These were semi-structured interviews (a household survey through structured questionnaire) and focused group discussion.

Research design

The design of the study was non-experimental types based on various data collection methods. With respect to the objectives and nature of the research questions of the study, both qualitative and quantitative data collection methods were employed.

The survey design consisted of three stages. In the first stage, three study districts were purposively selected in consultation with North Gondar Zone Department of Agriculture and Field

Observations. The three representative districts (Debark, Dabat and Wogera) were purposively selected from the potential barley producing districts of the zone in terms of large coverage for barley. In the second stage, two villages were purposively selected from each district in consultation with district agricultural experts with the major criteria being higher importance of barley in terms of area coverage and consumption preference. Finally, respondent households were selected randomly in each kebele in probability proportional to size.

In the third stage, 180 farmers were selected by equal distribution method which means 60 from each districts or 30 household heads were randomly selected from a list of farmers in each selected Kebeles. Women household heads and elders were purposely involved to ensure the representativeness or household diversity in terms of knowledge and seed management.

Both qualitative and quantitative data types were collected in this study. The data used were collected from both primary and secondary sources. Informal and formal surveys were used to collect the primary data. The informal survey was conducted through focus group discussions, interviewing key informants and development agents. The discussions were entirely participatory. The structured and semi-structured questionnaire were pre-tested and used to perform the formal survey. An interval schedule was pre-tested and necessary amendments were made. In the formal survey, farmers were interviewed by the pre-tested questionnaire after interpreted to the local language (Amharic). The survey was conducted from February to March, 2016. Six enumerators who had the local knowledge and language were trained and recruited. The trained enumerators under the supervision of the researcher interviewed those sampled farmers.

At the household level, information were collected on reasons for selecting a variety over the others, when in the seed and varietal selection take place, how seed of barley is renewed and replaced and role of women in barley production. The respondent farmers were also asked to list all the varieties they know, classify and evaluate their varieties based on their name, number of rows, meanings, preferred/non preferred characteristics and uses. Sayings associated with barley were documented. In addition, respondents classified their varieties as popular (abundant), rare, and endangered on the basis of area shared yields of varieties. ‘‘Popular’’ is defined as those varieties grown by many households over large areas. ‘‘Rare’’ types are those grown by few households on very small plots, and ‘‘endangered’’ types are grown either in mixed cultures or by only a few households in neighboring kebeles.

Key-informant interviews were conducted with development agents of the districts. Focus-group discussion was conducted with selected farmer groups, especially elders and female heads to document farmers’ knowledge of the barley varieties and their ranking preference. The issue of women’s role in seed management was addressed not only during the household survey but also in the group discussions.

RESULTS AND DISCUSION

Farmers’ choice of barley varieties

Farmers in the study districts purposely maintain landraces to address various needs. The main traits farmers use to prefer a given variety over the other were maturity, yield potential, suitability for animal feed, grain size, grain color, spike length, tillering capacity, market demand, condition of the soil and product volume. According to Eticha et al. (2008), the selection criteria for landraces of barley reflect adaptations to changing farming conditions, and responses to the socio-economic and cultural factors that shape farmers priorities. With regard to distribution status, most of the recorded landraces of barley were endangered, some are rare and only three varieties are popular (Table 1). This indicates that the need for conservation of the landraces found in the farmers’ hand. Diversity in end-uses is one of the important factors that influence the maintenance and genetic diversity of a particular crop. Different landraces are preferred for specific end-use. The main end uses of barley in the study area were *kolo, beso, tela, injera, korefe, kita* and *kinche*. A study made on enset showed that the biggest uses of landraces are for *kocho*, *bulla*, *amicho*, fiber and medicine (Zerihun et al., 2016). A study made on wheat indicated a wide range of variations among landraces for the traits studied which help farmers with an opportunity to make a choice of genotypes that fit their purpose (Zewdie et al., 2014).

Kolo is roasted grain prepared from dehulled barley. *Beso* is solid food prepared from roasted barley flour and water. *Tela* is alcoholic beverage prepared from *gesho*, malt, roasted grain and *kita*. *Tela* is the most common and preferred local beverage which is made mainly from barley. *Injera* is leaven bread made from raw grain flour with the dough fermented for 2 to 4 days and baked on clay pan. *Korefe* is alcoholic beverage prepared from *gesho*, malt and lightly roasted barley grain and *kita*. The study district inhabitants drink *korefe* early in the morning and it act as a food though it is a beverage. *Kita* is instant bread baked from unfermented dough of raw grain flour. *Kinche* is a dish prepared from cracked raw barley grains. Most of the landraces are suitable for *kolo*, *beso*, *tela*, and *injera*. The preferred landraces for *korefe* are *Derg gebs*, *Weremenie*, *Semeno*, *Andita* and *Nech gebs*. *Abat gebs*, *Tegedie belga* and *Nech gebs* are the preferred landraces for *kita*. The landrace *Tegedie belga* is preferred for *kinche*. *Kinche* is not a common diet for north Gondar highlands.

According to farmers’ response, the choice to select a variety depends on a number of factors including seasonal condition, varietal characteristics, multiple uses, market demand, a combination of the aforementioned factors and other reasons as well. Of these, varietal characteristics (31.7%) play the major role (Table 2).

Farmers may undergo seed and variety selection during different stages of the plant. They stated that, seed and varietal selection occur during pre harvest (45%), post harvest (35.6%) and both pre-harvest and post-harvest (19.4%). During post harvest, seed may be selected before threshing, during threshing, after threshing, during storage and a combination of the above. Almost half (54.5%) of the respondents select seed after threshing (Table 3).

The traits mainly used by farmers to select barley varieties in the field (pre harvest) are length of the spike, size of seed, amount of seed per spike, ability to withstand disease, stand of the plant, tillering ability,

Table 1. Characteristics of major barley varieties in relation to preferred and non preferred traits.

Variety name	Distribution status	Preferred traits	Non preferred traits	End uses
Teklie gebs	Rare	Early maturing; suitable for variety of soil types; palatable straw quality; high-medium grain yield	Attacked by birds; lodging problem	*Kolo, beso*
Derg gebs	Endangered	High-medium grain yield; early maturity; large grain size; palatable straw quality	More straw; low flour; prefers fertile soil	*Korefe, beso, kolo*
Woremene	Rare	Early maturity; high product volume; long spike; drought tolerant; palatable straw quality	Low grain yield; prefers fertile soil; not palatable for injera	*Injera, beso, korefe, kolo*
Semeno	Endangered	Long spike; high tillering capacity; high grain yield; palatable straw quality; early maturing	More awns and less flour; short stature	*Injera, tela, kolo, korefe, beso*
Andeta	Endangered	The product is good both by its quantity and quality; demanded by market; long spike; mature early	Small flour; more awns; straw is not palatable; shattering problem during harvest; attacked by birds	*Korefe, kolo, injera, tela, beso*
Abat gebs	Endangered/Rare	High grain yield; long spike; palatable straw quality; tolerates water logging; mature early	Prefers fertile soil; more awns and less yield	*Kita, tela, injera, kolo*
Nech gebs	Endangered/Rare	Demanded by market specially by its color; not attacked by birds; taller in height; high grain yield	Sensitive to lodging; does not need heavy rain; sensitive to frost and weed; prefers fertile soil	*Beso, kolo, korefe, injera*
Awura gebs	Rare	High grain yield; palatable for food	More awns; small flour	*Injera, beso, kolo*
Shegie gebs	Rare	Demanded by market mainly by the color of its grain; long spike	Low grain yield; lodging problem	*Beso, tela*
Netela belga	Rare/Popular	Early maturity; drought tolerant//drought relief crop/; suitable for double cropping	More awns; low grain yield	*Tela, injera, kolo*
Shewa gebs	Endangered	High yielder; long spike; tolerant to frost; white seed	Small product volume; late maturity; prefers fertile soil	*Injera, tela*
Akiya/senef kolo	Endangered/Rare	High yielder; used mainly for kolo; early maturing; frost tolerant	Single row; prefers fertile soil	*Kolo*

Table 1. Contd.

Tikur gebs	Endangered/Rare	High yielder; tolerate wind and frost; preferred for *tela*	Not preferred by market and is cheap; prefers fertile soil; injera is black; more awns	*Kolo, tela, injera*
Bozie belga	Popular/Rare	Early maturity; tolerate frost and drought	Not preferred by market; more awns	*Tela, beso*
Marwey	Rare	Early maturing; preferred by the market	Prefers fertile land; needs fertilizer	*Tela, injera, animal feed*
Belga	Rare	Grow over large area; high yielder; early maturing	The product is not quality since attacked by weed	*Injera, beverage, animal feed*
Tegedie belga	Popular	Early maturing; withstand frost and heavy rain by bending the spike down; long spike	Low yielder; the injera is hard	*Tela, kolo, injera, kita, kinche, beso*
Dinble nech gebs	Rare	High yielder; early maturing; tolerate to wind, frost, drought	Prefers fertile soil	*Injera, Tela, kita, kolo*

Table 2. Choice to select a variety.

Reason to select and plant a given variety	**N**	**%**
Seasonal condition	22	12.2
Varietal characteristics	57	31.7
Multiple use	30	16.7
Market demand	23	12.8
Seasonal condition and multiple use	6	3.3
Varietal characteristics and multiple use	12	6.7
Other reason	5	2.8
Seasonal condition, varietal characteristics, multiple use and market demand	25	13.9
Total	180	-

number of rows, and germination ability. They also used the traits early maturity, ability to withstand wind, ability to withstand drought, inability to be attacked by birds, color of the seed, and weight of spike into consideration when selecting barley varieties.

The traits mainly used by farmers to select barley varieties after harvest but before threshing are weight of seed, length of the spike, ability to

Table 3. Seed and variety selection.

Stage in the crop for undertaking seed and varietal selection	N	%
Pre- harvest	81	45.0
Post- harvest	64	35.6
Both pre-harvest and post-harvest	35	19.4
Total	180	-
Seed and varietal selection during postharvest		
Before threshing	14	14.1
During threshing	9	9.1
After threshing	54	54.5
During storage	10	10.1
Before threshing, during threshing, after threshing and during storage	10	10.1
During threshing, after threshing and during storage	2	2.1
Total	99	-

Table 4. Renewal of seed.

Renewal/Replacement of seeds	N	%
Yes	165	91.7
No	15	8.3
Total	180	100.0
Frequency of renewal of seeds		
1-3 years	135	81.8
4-6 years	27	16.4
7-10 years	3	1.8
Total	165	-

withstand shattering during harvest, number of rows, not damaged by disease, and having large harvested products per a given area. The traits mainly used by farmers to select barley varieties during threshing are ability of the seed to immediately separate from the husk by using cattle threshing and wind, weight of the seed, quality of the product (without husk), usability of the byproduct for feed, length of the spike, having uniform size and color of the seed.

The traits mainly used by farmers to select barley varieties after threshing are weight of the seed, quality of the seed for various purposes, quality of the floor, size of the seed, uniformity of the seed, purity of the seed, and color of the seed. The traits mainly used by farmers to select barley varieties during storage are inability to be damaged by various means (like pests, diseases), weight of the seed by checking with their hand, ability to store for long period of time without damage, quality of the seed, and amount of the floor during milling.

Although farmers may select barley varieties at different stages of the growth, they give more attention to some traits more than others. The main traits are suitability for food, high yield potential, early maturity, suitability for feed, many end uses, large number of rows (4-6) and tillering ability. In order to differentiate one landrace from another, farmers use a variety of traits. The main traits are maturity, yield, number of rows, suitability for feed, spike length, and seed color.

The majority of farmers (91.7%) renew seed while some (8.3%) do not renew seed. From those that renew seed, seed renewal mostly occurs between 1 and 3 years (Table 4). Farmers stated that the main reasons to renew barley landraces are when the ability to give product decline, in order to prevent landraces from elimination, to

Figure 1. Seed source.

Table 5. Number of years of barley seed is stored and replaced.

Number of years barley seed is stored and replaced	N	%
1-3	122	67.8
4-6	51	28.3
7-10	7	3.9
Total	180	-

increase productivity, purity decline as the time passes by and if not renewed the germination ability declines. Those farmers that renewed barley landraces were asked how they do so. They stated that they renew by sowing in a fertile soil, exchanging with other farmers, sowing the seed by using compost, selecting large sized seeds and multiplying and selecting those plant with good stand and performance in the field.

Barley seed source and replacement

Barley seed source

In each cropping season, each household decides which variety, how much seeds and in which piece of land to grow in their farming area. In most of the cases, farmers in the study area use their own farmer-saved seeds although they may obtain seeds through exchange or purchase. In this study, it was found that 89.4% of the respondent farmers retain their produce and depend on their own seeds while 5 and 4.4% buy away from homestead and in their neighbor village, respectively. Limited number of respondents (0.6%) exchange either in their village or away from homestead. This showed those farmers nowadays purchase their seed directly rather than the old days exchange of seeds by other seeds (Figure 1).

Farmers in the study area store their seeds through container made of mud (*gotera*), sack, material made from animal skin (*akimada*), big material made of clay soil (*insera*), and also by sowing a small seed in their piece of land.

Barley seed replacement

Seeds of cereal crops can be stored for a certain periods and replaced. Farmers stated that barley seed can be stored from 1-3, 4-6 and 7-10 years with the proportion of 67.8, 28.3 and 3.9%, respectively and replaced afterwards (Table 5). The majority of the farmers stating that they do not store seeds for long period of time are associated with the fact that they hardly produce any surplus that can be stored for longer years.

Role of woman in barley production

Women play key roles in barley varietal selection and management of seed. Intra-household decision making data collected from 180 respondents related to number

Table 6. Intra household decision making (%) on barley production activities.

Intra household decision making	Number of varieties	Type of varieties	Plot allocation	Storage	Postharvest processing
Women	1.1	1.7	2.8	41.1	49.3
Men	12.8	20.0	29.4	4.4	3.4
Both	86.1	78.3	67.8	54.5	47.3

and type of varieties to grow, plot allocation, storage and postharvest processing is presented in Table 6.

The decisions on number of varieties to grow (86.1%), types of varieties to grow (78.3%), plot allocation (67.8%), and storage (54.5%) were mostly decided jointly (Table 6). However, postharvest processing is largely decided by women (49.3%). This result is mainly in agreement with Fetien et al. (2008) who stated that number of varieties to grow and plot allocation were mainly decided by both while post harvest processing is decided mainly by women. This result showed that though farming is mainly believed to be mainly the work of men; most decisions are made jointly by husband and wife. Though the type of variety to sow is decided jointly, in the focus group discussion they stressed that where to sow the different varieties varies between the two groups. Women usually want early maturing varieties to be sown near their home so that they will use it for hunger relief. They also consider whether they have program in the coming season or not and base their variety choice to sow. On the other hand, men give priority to sow their barley plot of land with no weed infestation, accessible for keeping away from birds attack and animal damage, and an area where there is another barley crop in the vicinity. Men believe that if there is another crop in the vicinity, damage caused by birds will be minimized and they will have common threshing ground.

From our focus group discussion, the role of women in seed management and sayings associated with them are discussed as follows. “If there is no woman, there is no barley.” This is to show that women play a role in conservation of barley. “The beauty of barley relies on woman.” This is to show that women make barley ready for various purposes. “Intelligent women say to her husband that there is no barley to eat in order to keep secretly for sowing purpose.” This is to show that women keep seed for sowing purpose rather than using the whole product for food or sale for market. “The owner of barley is woman.” This is to show that women make barley whatever she wants. “If summer is not coming all are houses, if May is not coming all are wives.” This is to show that an intelligent wife is the one who keep seed and deliver to her husband for sowing purpose. “The use of barley and wife is clearly shown in the kitchen.” This is to show that barley is used for so many things prepared in the kitchen and at the same time wife in the kitchen covers everything. “Good wife is icon for her husband.” This is because the wife saves seed and delivers when the need arrives. It will not cause the husband to suffer when the need for barley arises during the sowing time. All the aforementioned sayings show how much women are important in saving and maintaining barley and make ready when the need arises.

CONCLUSION AND RECOMMENDATION

Farmers purposely maintain landraces to address various needs. The main traits farmers use to prefer a given variety over the other were maturity, yield potential, suitability for animal feed, grain size, grain color, spike length, tillering capacity, market demand, condition of the soil and product volume. Most of the recorded landraces of barley were endangered indicating the need for conservation of the landraces. The main end uses of barley in the study area were *kolo, beso, tela, injera, korefe, kita* and *kinche*.

The main factor that farmers consider to select a given variety over the others was varietal characteristics. The main varietal characteristics traits were length of the spike, size of seed, amount of seed per spike, ability to withstand disease, stand of the plant, tillering ability, number of rows, and germination ability.

The majority of farmers renew barley landraces mostly between 1 and 3 years. The main reasons were to prevent decline in product, to prevent landraces elimination, and to increase productivity, since a reduction in the purity of product over time and its nonrenewal causes decline in germination ability. Farmers renew landraces by sowing in a fertile soil, exchanging with other farmers, sowing the seed by using compost, selecting large sized seeds and multiplying and selecting those plants with good stand and performance in the field.

In each cropping season, each household decides which variety, how much seeds and in which piece of land to sow in their farming area. Both men and women pass decisions jointly in agricultural activities. Based on this, number of varieties to grow, types of varieties to grow, plot allocation, and storage were mostly decided jointly. Postharvest processing was largely decided by women. This result showed that though farming is believed to be mainly the occupation of men; husband and wife make most decisions jointly.

From this study it is recommended that: breeding should be participatory by including traits farmers are interested to be incorporated in their varieties, endangered barley landraces should be collected and conserved for future improvement and the role of women should not be undermined in the conservation, selection and improvement of barley. Besides, this indigenous knowledge of the farmers should be incorporated in modern breeding.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Organic amendments applied to a degraded soil: Short term effects on soil quality indicators

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Low agricultural productivity is a threat to achieving global food security. Improving productivity of degraded soils is key to achieving sustainable food production. This study investigated the effects of four organic amendments (OAs) (Mushroom Compost, MC; PAS-100 compost, PAS; Anaerobic Digestate Solid Waste, AD_SW; and Poultry Manure, PM), applied at 10 t ha^{-1} and 30 t ha^{-1} on the physical, chemical and biological Soil Quality Indicators (SQIs) of a degraded sandy loam soil. The OAs had about 76 and 49.1% ($p < 0.05$) increase in the Olsen P and soil organic matter compared to control (un-amended) treatment respectively. There were significant percent increases in the microbial biomass C, total organic C and available K associated with the OAs treatments relative to the control treatment. Applying MC, PAS, AD_SW and PM at 30 t ha^{-1} best improved the soil physical, chemical and biological SQIs. Long term field study is recommended to further evaluate the effects of these OAs on the overall soil health.

Key words: Soil quality indicators, microbial biomass, organic matter, degraded soil.

INTRODUCTION

Soil is a finite resource that is crucial to human wellbeing (Lal, 2015). However, agricultural lands are currently under threats of soil degradation. Soil degradation is characterised by declining soil organic matter, nutrient depletion and loss of soil fertility (Lal, 2015). Soil degradation has been identified as a major cause of low agricultural productivity in many developing countries (Hüttil and Frielinghaus, 1994). Loss of soil organic matter specifically affects soil biological, chemical and physical properties. Changes in soil properties due to loss of organic matter have negative impact on soil biodiversity, soil buffering capacity, cation exchange capacity, nutrient availability and water infiltration, and can also lead to increased soil compaction and erosion (Karami et al., 2012).

Annually, 3 gigatonnes (Gt) of grain crops residues are produced globally. However, these residues are often removed from the farms for alternate uses such as fuel, hay and other uses (Lal, 2004). In sub-Saharan Africa, nutrient depletion caused by low-input and extractive farming was estimated to be 40 kg of NPK ha^{-1} on cultivated land (Lal, 2004). Low crop production due to increasingly degraded agricultural soils is a threat to achieving global food security. Therefore, to satisfy the food demand of the current world population (7.3 billion and rising) and cope with the future food demand there is need to adopt techniques that maximise food production from our agricultural soils whilst improving soil quality,

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using available organic amendments. Currently, there are major agricultural developments in Africa South of the Sahara to increase crop productivity and eradicate hunger. However, such transformation can only be sustainable through improvements in soil quality rather than simply increasing the use of new crop varieties and inorganic chemical fertilizers (Sanchez, 2015). Periodic application of fresh organic matter either as litter or crop residue is an effective way of rehabilitating degraded soils (Abiven et al., 2009).

Soil organic matter is an important regulator of many environmental processes that affect crop productivity (Tejada et al., 2008) through its beneficial effects at improving soil physical properties, increasing plant growth and crop yields (Karami et al., 2012). Application of organic amendments in terms of the quantity and quality applied is critical to improve fertility of degraded soils (Abiven et al., 2009). This is because soil biological processes are influenced by the soil physical and chemical characteristics, plant communities and agricultural practices which can negatively or positively affect soil fertility. Hence, soil organic matter management through the use of organic amendments is key to alleviating soil degradation by maintaining soil organic matter, thus reclaiming degraded soils and supplying plant nutrients (Tejada et al., 2008; Unagwu et al., 2013). Also, organic matter has been reported to improve soil water retention, nutrient retention ability, soil pH, and increase soil aggregation; consequently preventing and even reversing soil degradation (Karami et al., 2012). It is therefore suggested that improving the biological, chemical, and physical soil quality indicators (SQIs) can be critical to overcoming the global soil degradation challenge. Studies on the effect of organic amendments with or without inorganic fertilizer to improve soil productivity suggest that soil management practices improve SOM, increase crop productivity and have positive effects on the soil physical, chemical, biological properties (Unagwu et al., 2013; Nwite and Okolo, 2016; Mbah et al., 2017).

The degraded soil used in this study was characterised by poor soil structure, inadequate levels of NPK, low soil organic carbon and low microbial biomass. Unless the relevant SQIs are improved (Arthur et al., 2011) such low SQIs will affect its potential use for agricultural purposes. Hence, this study investigated the effects of Mushroom Compost, MC; PAS-100 compost, PAS; Anaerobic Digestate Solid Waste, AD_SW; and Poultry Manure, PM; applied at 10 and 30 t ha^{-1} on selected physical, chemical and biological SQIs.

METHODOLOGY

Soil sampling

The experiment was set up in a glasshouse at Cranfield University, UK, following a completely randomized design with four replications. Soils were sampled from a 0-150 cm depth of a non-agricultural field. The soil was sandy loam, it had a pH of 8.2, associated with low levels of total oxides of nitrogen, 0.45 (mg kg^{-1}); Olsen-P (32.9 mg kg^{-1}) and available-K (82.7 mg kg^{-1}) (Table 1). Prior to organic amendment application, a baseline soil samples (6 composite samples) were collected from the bulk test soil for physicochemical and biological analyses (Table 1). Postharvest, soil samples were collected for physicochemical and biological analyses. An intact soil cores (5.0cm depth x 5 0cm internal diameter) were collected from each experimental replicate for determination of bulk density. Further, a 400g 3-point composite soil sample was taken from the top 10 cm of each of the experimental treatment replicates. A portion (250 g) of the soil sample was air-dried and ground to <2.00mm for chemical analysis. The remaining portion (150 g) of each sample was stored at 4^{0}C prior to determination of microbial biomass carbon (MBc).

Experimental procedure

The treatments used in the study were four types of organic amendments namely: Mushroom Compost, MC; PAS-100 compost (compost produced based on UK standard composting regulations), PAS; Anaerobic Digestate Solid Waste, AD_SW; and Poultry Manure, PM. Prior to application, the organic amendments were air dried, ground and then to pass through a 2 mm mesh for the determination of chemical, while the fresh samples were sieved with a 4 mm mesh for the determination of biological properties. The physico-chemical and biological properties of the organic amendments are presented in Table 2. Each organic amendment was applied at two different rates 235 and 705 g pot^{-1} which is equivalent to 10 and 30 t ha^{-1} respectively. Thereafter, a 10 kg air-dried soil sample was weighed into polythene bags containing a pre-weighed amount of each of the organic amendments. Subsequently, the treatments were thoroughly mixed in the polythene bag and then transferred into 10 litre plastic pots and incubated at a moisture content of 35% for two weeks prior to sowing of the maize crop.

Laboratory analyses

Soil bulk density was calculated from the volume of soil cores (5.0 cm depth × 50 cm internal diameter) and oven-dry mass of soil cores (ISO 11272:1998).

$$\text{Bulk Density} = \text{Oven\_dry soil [g]} \Big/ \text{volume (cm}^3\text{)}$$

The particle size distribution was determined using the sieving and sedimentation method (ISO 112777:1998). Soil organic matter (SOM) was determined following loss on ignition by dehydrating the soil at 105°C and then ashing it at 450°C in a Carbolite furnace (British Standard BS EN 13039:2000). Soil pH was measured in a water extract at soil:distilled water = 1:5 (w/v); using pH meter (ISO 10390:2005) method. Also the EC was measured in water extract at soil:distilled water = 1:5 (w/v) using a pH and conductivity meter (ISO 11265:1994) method. Soil total organic carbon (TOC) was determined following ISO 10694:1995 method. Total nitrogen (Total_N) was determined using the British Standard method (BS EN 1364-2:2001). The ammonium-N (NH_4-N) and total oxides of nitrogen (TON) analysis were determined following the potassium chloride extraction method (MAFF reference book 427:1986). In addition, the available K (Av. K) was determined following British Standard method (BS 3882:1994) with soil microbial mass carbon

Table 1. Baseline characteristics of the test soil prior to application of the organic amendments.

Parameter	Values
Total sand (%w/w)	77 (± 1.24)
Coarse sand (%w/w)	8 (± 1.56)
Medium sand (%w/w)	46 (± 2.11)
Fine sand (%w/w)	23 (± 1.15)
Silt (%w/w)	17 (± 0.9)
Clay (%w/w)	6 (± 0.88)
Texture	Sandy loam
pH	8.2 (± 0.03)
EC (µS cm^{-1})	130 (± 0.003)
Olsen-P (mg kg^{-1})	32.9 (± 0.6)
TON (mg k g^{-1})	0.45 (±0.08)
NH_4-N (mg kg^{-1})	4.17 (± 0.33)
Available K (mg kg^{-1})	87.3 (± 1.96)
Soil organic matter (%)	2.33 (± 0.08)
Total N (%)	2.27 (± 0.093)
C:N	0.11 (± 0.03)
Total organic C (%)	0.25 (± 0.011)
Microbial biomass C (mg kg^{-1})	17.6 (± 0.06)

Values in parentheses represent +/- 1 standard error of the mean.EC = Electrical conductivity, SOM = soil organic matter; TON = Total oxides of nitrogen.

Table 2. Baseline compositions of the organic amendments.

Parameter	Amendments			
	MC	AD_SW	PAS	PM
pH	7.3^{a}	10.3^{d}	8.7^{c}	8.0^{b}
Olsen-P (mg kg^{-1})	380^{a}	1190^{b}	260^{a}	2420^{c}
TON (mg k g^{-1})	96.2^{b}	0.20^{a}	0.45^{a}	0.18^{a}
NH_4-N (mg kg^{-1})	120^{b}	700^{c}	96.7^{a}	900^{c}
Available K (mg kg^{-1})	1370^{a}	1500^{a}	4600^{b}	9140^{c}
Organic matter (%)	61.8^{c}	85.8^{a}	37.4^{b}	83.8^{a}
Total N (%)	1.90^{a}	1.99^{a}	0.98^{b}	3.14^{c}
Total organic C (%)	25.7^{b}	37.0^{c}	15.4^{a}	39.0^{d}
C:N	14.1^{ab}	19.7^{d}	15.6^{b}	12.8^{a}
Microbial biomass C (mg kg^{-1})	1358^{d}	20972^{a}	1929^{c}	23943^{a}

MC = Mushroom compost; AD_SW = Anaerobic digestate solid waste, PAS = PAS 100:2005 Quality Protocol compliant compost; PM = Poultry manure. TON = Total oxides of nitrogen. Within each column values followed by a different letter denote statistical differences ($p \leq 0.05$) following One-way ANOVA and a post-hoc Fisher LSD analysis.

(MBc) determined following the fumigation-extraction method (ISO 14240-2:1997).

Statistical analysis

Data were subjected to Analysis of Variance (ANOVA) using Statistica 12 software version 12.1. The differences between the means were tested using Duncan's multiple range test at $p < 0.05$.

RESULTS AND DISCUSSION

The soil is sandy loam and somewhat gritty texture and belongs to Tectonic series. The baseline soil

Table 3. Effect of organic amendment treatments on selected SQIs.

Treatments	pH	SOM (%)	Olsen-P (mg kg^{-1})	Av. K (mg kg^{-1})	TN (mg kg^{-1})	TOC (mg kg^{-1})	MBc (mg kg^{-1})	BD (mg cm^{-3})
Control	8.10^{a}	1.97^{b}	28.8^{a}	86^{a}	374^{a}	830^{a}	22^{a}	1.86^{c}
PM	8.14^{a}	3.74^{a}	121^{e}	188^{b}	1597^{c}	8220^{b}	371^{c}	1.36^{ab}
PAS	8.29^{b}	3.22^{c}	47.3^{b}	215^{b}	963^{b}	7480^{b}	150^{b}	1.40^{ab}
AD_SW	8.10^{a}	3.64^{a}	85.0^{d}	475^{d}	1161^{b}	9320^{c}	432^{c}	1.26^{a}
MC	8.10^{a}	3.39^{ac}	59.4^{c}	365^{c}	1136^{b}	9890^{c}	141^{b}	1.56^{b}
Rates	NS	*	*	*	*	*	*	NS
T x R	*	*	*	*	*	*	*	*

PM = Poultry manure, PAS = PAS 100:2005 compliant compost; AD_SW = Anaerobic digested solid, waste; MC = Mushroom compost; SOM = soil organic matter; Av. K = available K; TN = total N; Rates = treatment applications rates (10 t ha^{-1} and 30 t ha^{-1}); T x R = Treatment xApplication rate-interaction MBc= Microbial biomass C, BD = bulk density. Within each column values followed by a different letter denote statistical differences ($p \leq 0.05$) following Two-way ANOVA and post-hoc Fisher LSD analysis. NS = not significant; * = significant at ($P<0.05$).

characteristics are shown in Table 1. The soil is alkaline with a pH of 8.2 and has low levels of TON, Olsen-P and Av. K, TOC and MBc.

Soil response-changes in chemical SQIs

pH

Fourteen weeks after the amendments were added to the soil, no significant difference ($p < 0.05$) in the soil pH was observed between the amended treatments and the un-amended control except for the PAS treatment which had a significantly higher ($p < 0.05$) pH as compared with all other treatments (Table 3). Similarly, treatment application rates were not associated with significant difference ($p < 0.05$) in the soil pH. There was a significant interaction effect ($p < 0.05$) between amendment type and application rate on soil pH, because the soil pH is associated with the PAS treatment. The non-significant difference in the pH observed for the treatments except the PAS treatment may be due to the buffering capacity of the soil which resisted change in the soil pH. Bedada et al. (2014) found no significant difference in the soil pH with the application of compost manure. However, Arthur et al. (2011) reported a significantly higher pH of 0.5 pH unit with the long term application of 30 m^3 ha^{-1} of composts as compared with the un-amended acid soil. The long term compost application in addition to the high compost application rates and acidic soil (pH of 5.5) may account for the observed significant increase in soil pH reported by Arthur et al. (2011).

Soil organic matter (SOM) and total organic carbon (TOC)

Across both application rates, PM, PAS, AD_SW and MC treatments had significantly ($p < 0.05$) higher SOM than the Control treatment (Table 3). The PM treatment, across both application rates, recorded the highest (3.74%); although that was not significantly higher ($p < 0.05$) as compared with the AD_SW and MC treatments. The PM, PAS, AD_SW and MC treatments, across application rates, had 47.3, 38.8, 46 and 42% higher ($p < 0.05$) SOM as compared with the Control treatment respectively. The significantly higher SOM values recorded for the organic amendment treatments were due to the high organic matter levels associated with the amendments applied (Tables 1 and 2). This result is similar to the findings of Hati et al. (2006) who reported 41% increase in organic carbon content after three years application of 10 t ha^{-1} farmyard manure. Compared with an untreated plot, Guo et al. (2016) reported that the SOM in cattle manure compost fertilized plots increased significantly ($p < 0.05$) by more than 28% at 0-20 cm soil depth.

Furthermore, across both application rates, the organic amendments significantly increased ($p < 0.05$) soil TOC. The Control treatment recorded a significantly lower ($p < 0.05$) TOC content as compared with all amended treatments. The result indicated that TOC content was in the order: MC = AD_SW > PM = PAS > Control (Table 3).

The high TOC associated with these amended treatments can be attributed to the high OM content associated with the organic amendments (Table 2). Hati et al. (2007) reported similar findings following long time (28 years) application of farm yard manure at 15 Mg ha-1, with or without inorganic fertilizer. Lal (2015) suggested that restoring the soil organic carbon (SOC) pool to a threshold level of about 11 to 15 g kg−1 (1.1-1.5% by weight) within the root zone was critical to reducing soil degradation and protecting the environment from potential degradation risks. Guo et al. (2016) found that the 5-year application of cattle manure compost resulted in a 28% increase in TOC as compared with the control. Studies have reported higher TOC with organic fertilizer application as compared with the un- amended control treatment (Hati et al., 2007; Ding et al., 2012; Guo

Table 4. Correlation between selected SQIs.

	MBc	TN	TOC	C:N	Olsen-P	AvailableK	NH_4-N	TON
SOM	0.78*	0.86*	0.95*	0.78*	0.80*	0.67*	0.43*	0.57*
MBc		0.73*	0.73*	0.57*	0.77*	0.62*	0.23^{ns}	0.63*
TN			0.85*	0.56*	0.86*	0.54*	0.38*	0.71*
TOC				0.85*	0.70*	0.77*	0.36*	0.51*
C:N					0.45*	0.69*	0.23^{ns}	0.24^{ns}
Olsen-P						0.46*	0.42*	0.79*
AvailableK							0.19^{ns}	0.40*
NH_4-N								0.04^{ns}

* = significant ($p < 0.05$); ns = No significant difference; MBc = Microbial biomass C; TN = Total nitrogen, TOC = Total organic carbon, C:N= Carbon to nitrogen ratio, NH_4-N = Ammonium-N, TON = Total oxides of nitrogen, SOM = Soil organic matter.

et al., 2016). Furthermore, the results indicated that treatment application rates significantly affected the TOC due to a greater supply of carbon by the organic amendments at higher application rates. This is evident by the significantly strong and positive ($p < 0.05$) correlation (r = 0.95) between TOC and SOM (Table 4). Our result clearly shows that organic amendment application has positive impacts on soil organic matter and soil organic carbon.

Olsen-P

Similarly, the organic amended treatments showed significantly higher ($p < 0.05$) soil Olsen-P as compared to the Control treatment across both treatment type and application rate (Table 3). The PM treatment recorded the highest soil Olsen-P value (120.6 mg kg^{-1}) which was significantly higher than all other treatments. Olsen-P values were subsequently in the order: PAS > AD_SW > MC > PAS > Control. The high Olsen-P associated with the PM treatment is largely due to the significantly higher Olsen-P in the PM amendment (Table 2). These findings corroborate those of Bedada et al. (2014) and Unagwu (2014) who reported significantly higher soil Olsen-P values following organic treatments application. The present result demonstrates the potentials of organic amendments in improving the Olsen-P content of a degraded soil.

Available-K

The organic amended treatments, across both application rates, resulted in significantly higher Available-K as compared with the Control treatment. The AD_SW treatment recorded the highest (475 mg kg^{-1}) Available-K value as compared with the Control treatment and all other treatments (Table 3). No doubt, the high residual Available-K observed for the organic amended treatments was due to the high level of Available-K associated with the organic amendments as compared with the baseline soil values (Table 1). In addition, since soil organic matter is associated with exchange sites to bind available cations in the soil exchange complex, it is likely that the high Available-K recorded for the organic amended treatments is due to the high organic matter associated with the organic treatments. The significantly strong positive ($p < 0.05$) correlation between SOM and Available-K (r = 0.67; $p < 0.05$) thus confirmed that the organic matter contributed to the observed higher Available-K associated with the amended treatments (Table 4).

Soil total nitrogen (TN) content

Compared with the un-amended control treatment, the organic amended treatments across both application rates had significantly higher ($p < 0.05$) total nitrogen (TN). The PM treatment recorded the highest TN content (~ 1600 mg kg^{-1}; $p < 0.05$) as compared with all other treatments as well the as un-amended treatment. Soil TN content in the control treatment was more than 60% lower as compared with all the organic amended treatments. The soil TN was in the order: PM > AD_SW = MC = PAS > Control. The significantly higher TN recorded for the amended treatments were linked to the higher SOM associated with the applied organic amendments. This is evident by a significant and positive correlation (r = 0.86; $p < 0.05$) between the SOM and the TN content (Table 4). This relationship explains why the organic amended treatments were associated with higher soil TN than the Control treatment. Furthermore, treatment application rates had a significant effect on the soil TN. This was no doubt due to the higher supply of N with increasing rates of organic amendment applied. This result is similar to the findings of Guo et al. (2016) who reported significant increases in soil TN with cattle manure compost application.

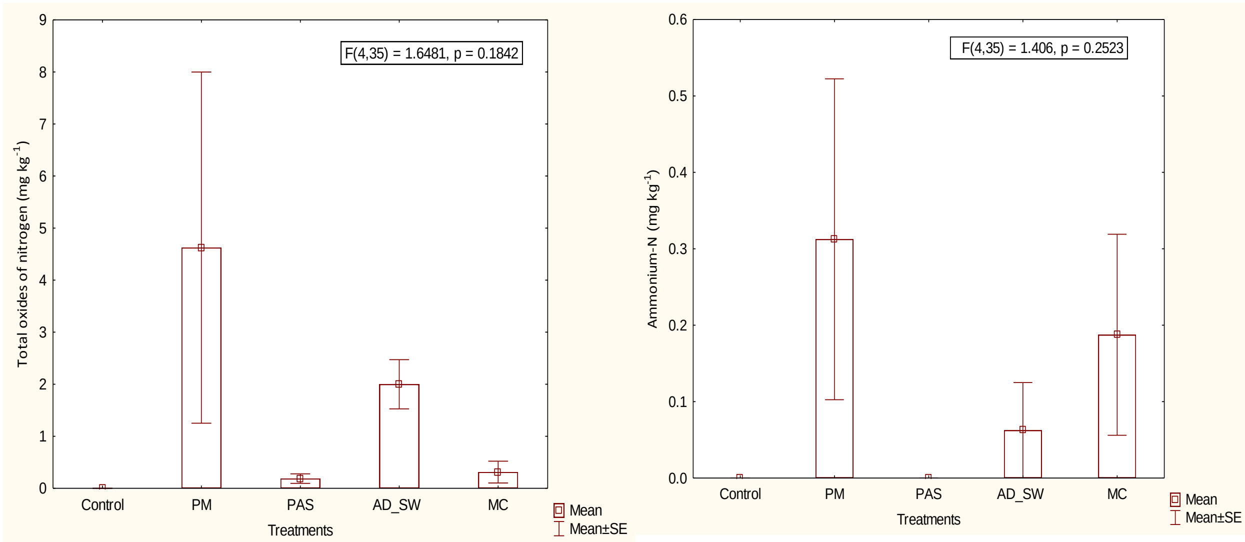

Figure 1. Effect of treatments on Total oxides of nitrogen and Ammonium-N across treatment application rates.

Total oxides of nitrogen (TON) and Ammonium-N (NH_4-N)

Across both treatment application rates, no significant difference in soil TON values was observed between treatments (Figure 1). Since N is a critical and important nutrient for maize growth, it is likely that the post-harvest non-significant difference in TON between the organic amended treatments and the control was due to plant N uptake. Further, a similar trend was observed for ammonium-N (NH_4-N). The PM, AD_SW, PAS and MC treatments across treatment were not significantly different as compared with the Control treatment. The non-significant difference in the NH_4-N between treatments and control could be due to either direct uptake by the maize plant or due to indirect uptake of NH_4-N because of microbial conversion of NH_4-N to nitrite and nitrate. More so, the wide variability in the TON and NH_4-N mean values could account for the non-significance observed between the amended treatments.

Soil response-changes in biological SQI

Microbial biomass C (MBc)

The microbial biomass carbon (MBc) in the organic amended treatments was significantly higher ($p < 0.05$) than that observed in the Control treatment ($p < 0.05$). This could be attributed to the significantly higher OM associated with the applied organic amendments which enriched the soil microbes with organic C (the energy source of soil microbes). The SOC pool is a critical component of soil quality (Lal, 2015). Microbial biomass (population) is affected by several factors such as temperature, nutrient source, water content and the type of organic matter applied. Hence, the type of OM applied could have a significant effect on the MBc depending on C-availability. Labile OM is a readily available energy source which is more easily degraded by the soil microbes than the less labile or non-labile (recalcitrant) OM. The supply of readily metabolizable C from organic amendments was suggested to be the most influential factor contributing to increases in biomass-C. This was because the soil microbial biomass responds rapidly to readily available C (Tejada et al., 2006). Also, the significantly higher MBc observed for the PM and AD_SW treatments as compared with the PAS and MC treatments could suggest the comparative availability of metabolizable C. Furthermore, the significant ($p < 0.05$) positive correlation ($r = 0.73$) observed between TOC and MBc confirmed that the higher MBc (Table 4) recorded for the organic amended treatments was attributable to their higher TOC which provided easily degradable carbon that stimulated the autochthonous microbial activities (Tejada et al. 2006). A similar result was reported by Tejada et al. (2008) who observed a progressive increase in soil MBc with higher application of organic matter.

Soil response-changes in soil physical SQIs

Bulk density

Across both application rates, the bulk density recorded for the organic amended treatments were significantly lower ($p < 0.05$) as compared with the Control treatment

(Table 3). The AD_SW treatment had lowest soil bulk density (1.26 g cm-3) followed by the PM treatment (1.36 g cm-3) though both treatments were not significantly different. Organic materials are associated with low bulk density (0.8 g cm-3). Hence mixing organic materials (less dense materials) with soil (a denser material) reduced the soil bulk density. Guo et al. (2016) reported that soil bulk density was significantly and inversely related to rates of cattle manure compost applied. The significantly lower bulk density associated with the organic amended treatments could partly be due to the effect of the plant roots. Hati et al. (2006) and Guo et al. (2016) found significant reductions in the bulk density with NPK application which they attributed to increased root growth.

In addition, treatment application rates had significant effects on the soil bulk density. This could suggest that the quantity of organic amendment applied to soil had significant effects on the soil bulk density probably due to the effect of higher organic matter content. Celik et al. (2004) reported a similar result. They observed that the soil bulk density decreased with increasing application of compost and manure treatments due to increased soil organic matter concentrations. Also, a significantly lower soil bulk density following application of cattle compost and manure at 25 t ha-1 in a long term study was reported (Celik et al., 2010). However, in the present study, the bulk density did not strongly correlate with SOM (r = 0.24). This could probably be due to the short duration of the study. D'Hose et al. (2014) had a similar result with application of farm compost. They found a weak correlation between bulk density and SOC (R2 = 0.25) which they attributed to the limited range of SOCs (1.07-1.25%) in their experiment.

Conclusion

The study observes the effectiveness of the OAs in improving soil physical, chemical and biological SQIs. The results obtained indicate that the OA types have varied significant effects on the SQIs. This suggests that the type of OAs applied plays a crucial role in improving the soil properties of a degraded soil. The application of PM, PAS, AD_SW and MC at 30 t ha^{-1} best improved the soil physical, chemical and biological SQIs, which are crucial to increasing crop yield production. This study advocates for further field study to evaluate the potency of these OAs to improve the SQIs of a degraded soil.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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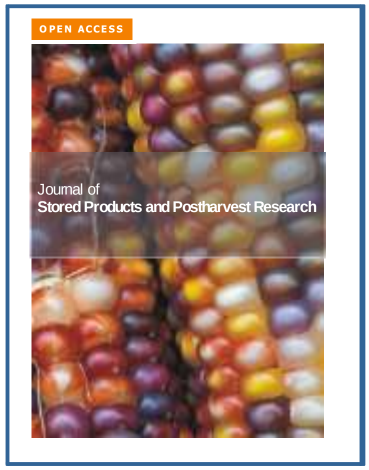

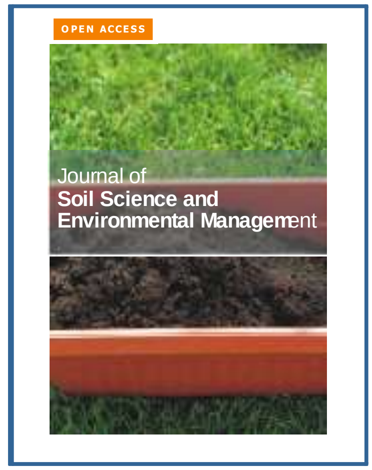

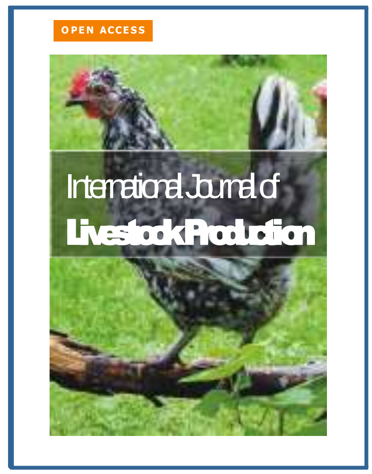

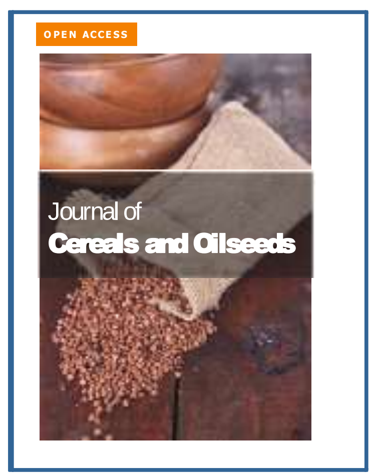

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