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Full Length Research Paper

Adapting Nyando smallholder farming systems to climate change and variability through modeling

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This study was done in Nyando, Kenya to model maize production under different climate scenarios and project the yields up to 2030 and 2050 using Decision Support System for Agrotechnology Transfer (DSSAT) under rain fed conditions. Three maize varieties were used; Katumani Comp B as early maturing variety, Hybrid 511 as a medium maturing variety and Hybrid 614 as a late maturing variety. Global coupled model Hadley Centre Global Environment Model version 2 (HadGEM2-ES) under representative concentration pathways (RCP) 4.5 and 8.5 was used to downscale Nyando's climate data for the years 2030 and 2050. Past climate data for 53 years and current data was obtained from Kisumu Meteorological station while crop growth and farm management data was obtained from 70 farmers in Nyando. Results showed a decrease in yields across the years from 2015, 2030 and 2050 under both RCP 4.5 and 8.5. Average simulated yields for 2015 were 2519 kg ha⁻¹ while projected yields under RCP 4.5 were 2212 and 2081 kg ha⁻¹ in 2030 and 2050 respectively. Average yield projections under RCP 8.5 were 2184 and 1806 kg ha⁻¹ for the years 2030 and 2050 consecutively. The study found out that temperatures will increase and rainfall duration will reduce. In addition, Katumani Comp B maize variety was not very much affected by these changes in temperatures and rainfall compared to H511 and H614.

Key words: Climate change, Decision Support System for Agrotechnology Transfer (DSSAT), global coupled models, maize yield.

INTRODUCTION

Global sectors in agriculture faces a significant need to increase production in order to provide enough food for a population projected to rise to nine billion by mid-21st century while ensuring there's environmental protection and a sustainable functioning ecosystem (Rosenzweig et

al., 2012). Households that were engaged in farming in East Africa and other parts of the world faced challenges and changes in the first decade of 21st century in addition to increase in population that resulted into increased food prices, reduced fertility of soil and crop yields, poor

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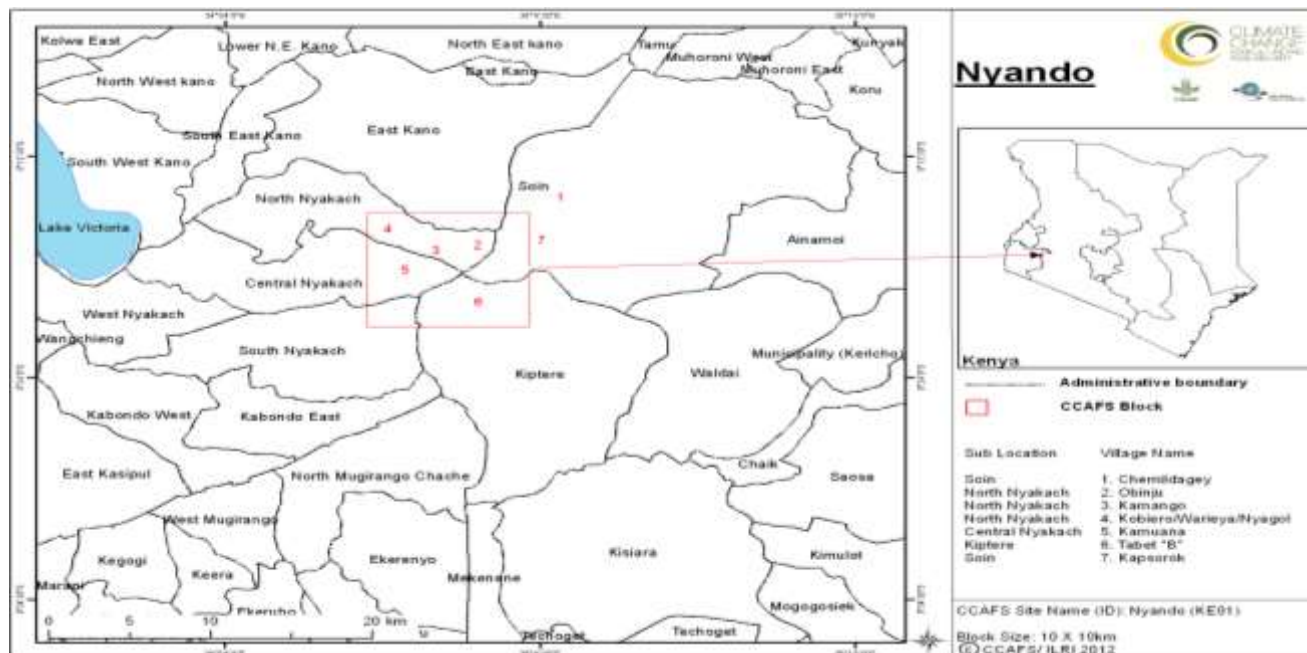


Figure 1. Location of the study area. Source: Climate Change Agriculture and Food Security Site Atlas, Nyando/KatukuOdeyo, Kenya, Sijmons et al. (2013).

access to markets, constrained access to land, and high inflation (Nelson et al., 2010). Despite these challenges, there is an expectation that up to 70% more food will have to be produced by 2050 to feed the growing populations especially in third world countries (Nuerfeldt et al., 2011). Furthermore, Nuerfeldt et al. (2011) explained that climate change will cause rise in temperature and change in precipitation patterns and the resultant weather extremes will negatively reduce global production of food.

Climate change and variability is evident in Nyando Basin in western Kenya. There is an increase in droughts, floods and unpredictable rainfall which affect agriculture and food security (Macoloo et al., 2013). In the villages of Nyando, 81% of the families experiences up to two months of hunger where they do not have enough food for consumption, while 17% of the families experience three to four months of hunger (Kinyangi et al., 2015). The primary source of income and food in Nyando is farming (mixed crop-livestock system), but the farmers have not diversified and show a few agricultural innovations (Macoloo et al., 2013). A household baseline survey carried out in Nyando by Mango et al. (2011) observed that households that had not introduced any new crop were 37%, only one or two new crop varieties had been introduced by 32% and those households that had incorporated three or more new varieties of crops into their farming systems were 32%.

Just like many Kenyan communities, Nyando communities have high preference for maize consumption. The survey report by Mango et al. (2011)

showed that the number of households that cited maize as one of their most important crop was 99%, those that cited sorghum were 73% and beans were 35%. Based on this data, it was necessary to carry out a study on maize production in the area which is the most preferred crop amongst farmers and the most likely to be affected by climate change. In this study, model was used because according to Gettinby et al. (2010), modelling has played a very important role in improving efficiency of agricultural production systems in the last 30 years. Therefore using Decision Support System for Agrotechnology Transfer (DSSAT) crop model, maize yields were simulated under the existing climate scenario and the future potential yields of maize were projected up to 2050 under different climate scenarios. The model will help in giving an overview of impacts of climate changes on maize yields to enable coming up with coping and adaptation strategies for Nyando farmers.

MATERIALS AND METHODS

The Lower Nyando block where the study was carried out is located in the lake plain of Lake Victoria in Nyando and Kericho sub-counties (Figure 1). It is within a 10 km by 10 km block known as the Lower Nyando Block (Between $0^{\circ}13'30''S$ - $0^{\circ}24'0''S$, $34^{\circ}54'0''E$ - $35^{\circ}4'30''E$).

This study used purpose sampling technique in selecting subjects for study according to Marshall (1996). Soil sampling was carried in five farms before sowing. The soil samples were taken by driving soil auger into the soils and samples were taken at different soil depths (0-5, 5-15, 15-20, 20-25 and 25-30) and placed into sampling bags. The samples were air dried, ground and sieved

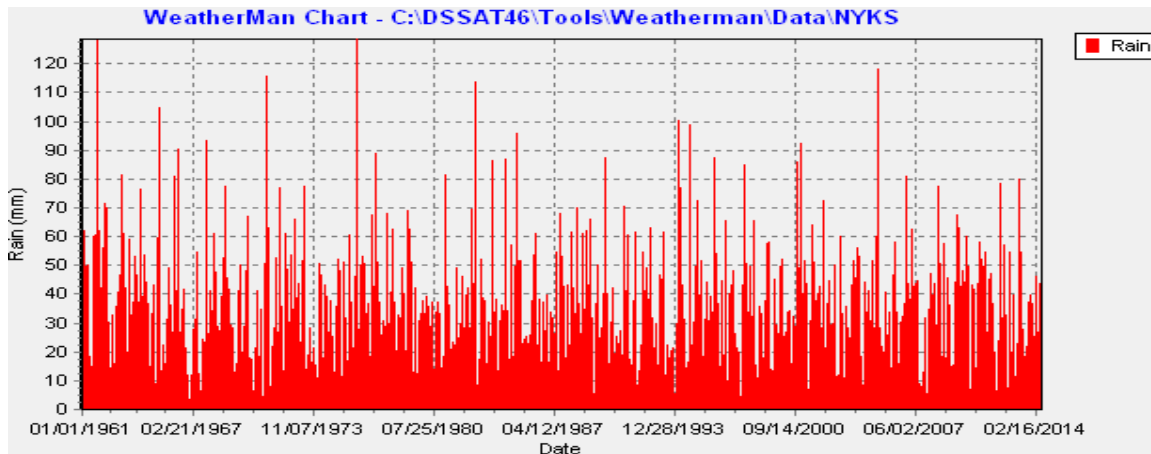


Figure 2. Trends of rainfall in Nyando

through a 2-mm sieve. They were kept in polythene bags for future physical and chemical analysis. The physical soil analysis included particle size distribution and soil bulk density using methods of Okalebo et al. (1993). Volumetric moisture content was also determined. Chemical soil analysis included soil organic carbon determined by Walkley and Black procedure, total N by Kjeldahl method, available P by Olsen method, exchangeable cations and soil pH by methods described in Okalebo et al. (1993). Descriptive data were also used and include: Slope, drainage, runoff and relative humidity. Soil data tool (SBuild) under the tools section in DSSAT v 4.6 was used to create the soil database which was used for the general simulation purposes. Name of the country, name of study site, site coordinates, soil series and classification were among the data entered in this utility. Percent clay, silt and gravel entered in the SBuild utility was used to calculate hydraulic conductivity, saturated upper limit and drained upper limit.

Weather data was obtained from Kisumu meteorological station comprising of rainfall, maximum temperature, minimum temperature and solar radiation. Past climate data was also obtained from Kisumu meteorological station. To assess the impact of climate change under different climate scenarios on maize production; climate data was generated from MarkSim DSSAT weather file generator, a MarkSim web version for IPCC AR5 data in the Coupled Model Intercomparison Project Phase 5 (CMIP5). This data was downscaled using HadGEM2-ES under Representative Concentration Pathways 4.5 and 8.5 for the years 2030 and 2050. Representative Concentration Pathways (RCPs) are greenhouse gas concentration trajectories adopted by international panel on climate change. Under RCP 8.5, there is no future policy change to reduce emissions. This future is characterized by today's CO₂ emission will be three times by 2100, methane emissions will rapidly increase, use of cropland and grassland will increase driven by increase in population, 12 billion world populations by 2100, technological development will be low, increased reliance on fossil fuels, high energy intensity and there is no implementation of climate policies. RCP 4.5 was developed in the United States by the Pacific Northwest National Laboratory. Under this RCP, radiative forcing is stabilized shortly after 2100, consistent with a future with relatively ambitious emissions reductions (Bjones, 2012). This future is characterized by energy intensity that is lower, reforestation programs that are strong, yield increases and dietary changes resulting into decreased use of croplands, climate policies that are stringent, methane emissions that are stable and emissions of CO₂ that increases slightly before decline commences around 2040. The Weatherman utility in DSSAT was used to create the

weather file that was used by the CERES-Maize model. Data used to create the weather file include station information: Name of weather station, latitude, longitude and altitude. Daily maximum and minimum temperature, daily solar radiation and daily rainfall for a period of fifty three years (1961-2014) were imported into the DSSAT model. Their units of measurements were converted into those used by the DSSAT. The data was then edited and exported to DSSAT format and was ready for use by the CERES-Maize model. Agronomic data was collected through administration of questionnaires to 70 farmers and measurements. The data collected through questionnaires and measurements include planting dates, spacing, tillage, plant height at physiological maturity (maturity was determined when the silk appeared to be dried and the eye of the grain appeared dark), number of days to 50% silking, number of days to 50% tasseling, plant height at harvest measured from the base of the plant to the flag leaf and yields harvested. This data was fed into XBUILD utility of DSSAT v 4.6.

RESULTS AND DISCUSSION

Rainfall

The annual rainfall in Nyando showed high temporal variability with a coefficient of variation of 25% as shown in Figure 2.

The year 2014 recorded the lowest annual rainfall with a total of 345 mm compared to 2013 and 2012 which recorded 549.3 and 524.4 mm respectively. Generally, since the year 2000, the lowest amount of rainfall received was recorded in 2014; with a range value of 412.3 mm from the maximum amount of 757.3 mm. The destruction of water catchment areas at the upper Nyakach and reduced forest cover were identified as the main causes of reduced amount of rainfall in Nyando.

Temperature

The analysis indicated that the average annual

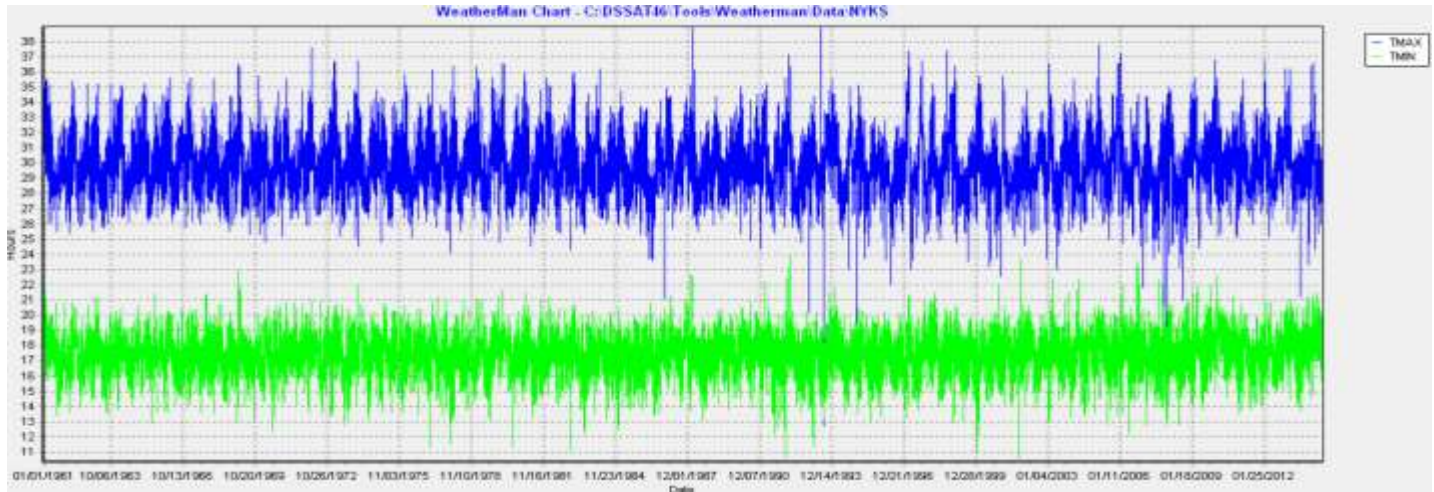


Figure 3. Historical variation in minimum and maximum temperatures in Nyando.

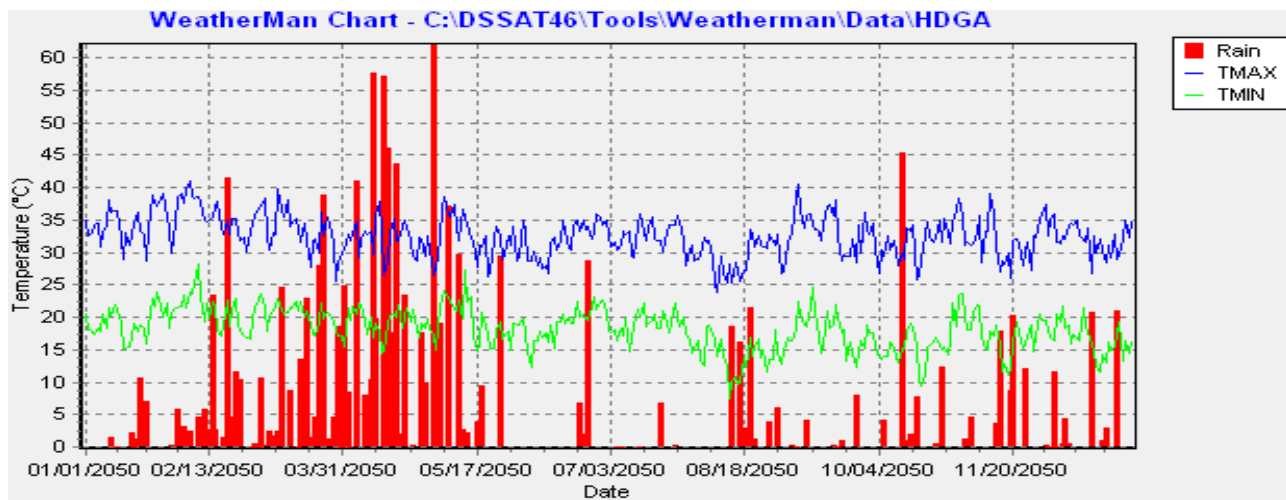


Figure 4. Projected climate in Nyando for 2050.

temperatures were increasing at the rate of 0.011°C every year (Figure 3). Minimum temperatures were getting warmer by 0.005°C every year while the annual increase in maximum temperatures was 0.007°C .

When analyzed for decadal wise increase, the average annual temperature in Nyando during the period 2001-2010 was 0.067°C higher compared to the period 1981 to 1990, an indicator of rise in temperatures therefore change in climate; most farmers' clear vegetation from their land to pave way for cultivation. In addition, the rates of agroforestry and afforestation practices are low in Nyando. This increases the impacts of high temperatures on maize production. This study was carried out in 2015 which had an average of 29.91°C maximum temperature and 18.2°C minimum temperatures.

Projected climatic conditions for the year 2030 and 2050 in Nyando

The model projected maximum temperatures of over 40°C both in 2030 and 2050 as shown in the Figures 4 and 5. The lowest projected minimum temperatures in 2030 are 6 and 8°C for the year 2050.

The increase in projected maximum and minimum temperatures by 2030 and 2050 is due to expected rapid growth in industrialization in Kenya which will result in emission of greenhouse gasses into the atmosphere. In Figures 3 and 4, the long rain periods are also expected to reduce with high concentration of rainfall occurring between March up to mid-May. The shortened rainfall period will be as a result of further encroachment of forest areas and water catchment areas along Lake Victoria

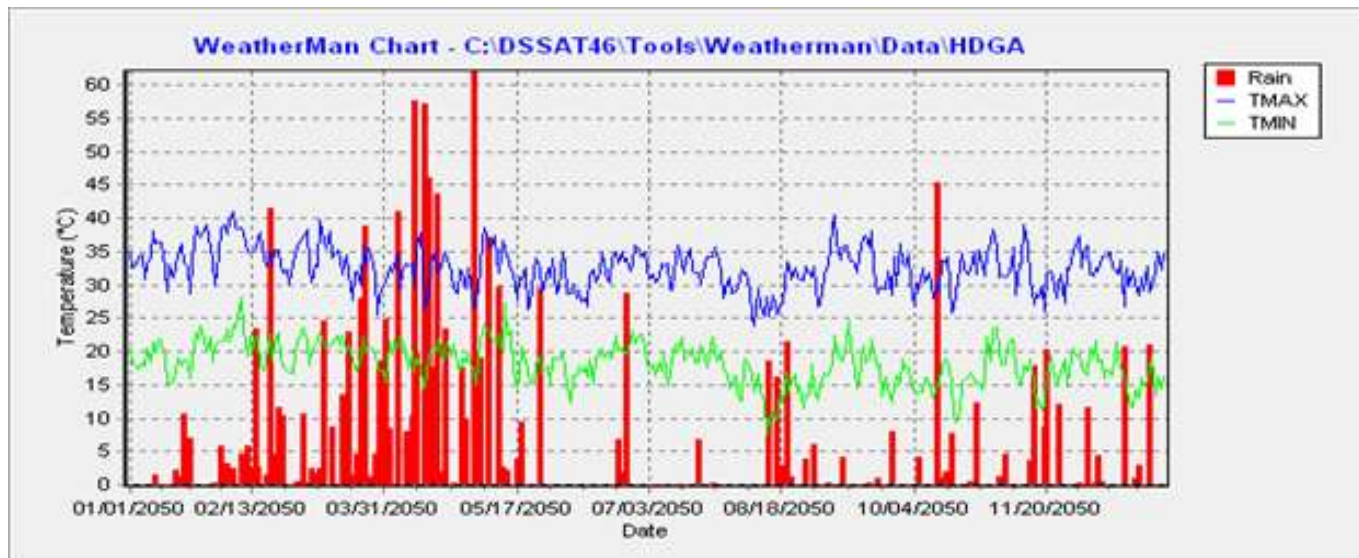


Figure 5. Projected climate in Nyando for 2050

Table 1. Summary of soil parameters.

Soil depth (cm)	Lower limit (cm ³ /cm ³)	Upper limit (cm ³ /cm ³)	SAT SW (cm ³ /cm ³)	EXTR SW (cm ³ /cm ³)	INIT SW (cm ³ /cm ³)	Root distance (cm ³ /cm ³)	BULK density (g/cm ³)	pH	NO ₃ (ugN/g)	NH ₄ (ugN/g)	ORG C (%)
0 - 5	0.280	0.349	0.530	0.069	0.349	1.00	1.25	6.30	0.00	0.00	1.00
5 - 15	0.282	0.328	0.530	0.046	0.328	0.95	1.33	6.30	0.00	0.00	0.81
15 - 20	0.280	0.311	0.530	0.031	0.311	0.10	1.40	6.30	0.00	0.00	0.62
20 - 25	0.182	0.273	0.338	0.091	0.273	0.64	1.40	6.30	0.00	0.00	0.49
25 - 30	0.174	0.264	0.338	0.090	0.264	0.58	1.40	6.30	0.00	0.00	0.49

SAT SW, Saturated water content; INIT SW, Initial soil water; ORG C, Soil organic carbon.

watershed and clearing of more vegetation in highlands of Upper Nyakach areas.

Soil parameters

The 0 to 5 cm depth which is the main rooting depth for the maize fibrous roots had a bulk density of 1.25 g cm⁻³ and from 15 to 30 had 1.4 g cm⁻³. The same top layer, 0 to 5 cm deep also had 1.00% organic carbon with saturated water content of 0.53 cm³/cm³ (Table 1).

Crop parameters

Katamani comp B (Table 2) is a fast growing maize variety that takes 60 to 65 days to flowering and maturing within 90 to 120 days. This variety performs well within an altitude range of 500 - 1000 m above sea level and is suitable in marginal areas where there is a rainfall range

of 250 to 500 mm.

The harvesting of Katamani maize variety started in late June and ended early July 2015. This maize variety showed no stress in phosphorus which was applied during the planting. However, nitrogen and water stress was observed at 75% silking stage but farmers applied top dressing nitrogen fertilizer to mitigate the impacts of the stress on grain filling. Poor rainfall in the area was the result of water stress. H511 maize variety is commonly grown in coffee growing belts. It takes 4 to 5 months to mature under a favorable rainfall of between 750 and 1000 mm (Table 3).

This variety took 125 days from planting to harvest. It did not show any stress to plant phosphorus apart from water and nitrogen. The water and nitrogen stress occurred at 75% silking stage, 82 days from planting date. Nitrogen stress was because there was no secondary application of nitrogen fertilizer (top dressing). Water stress was basically due to reduced rainfall and no irrigation which would have acted as a secondary source

Table 2. Crop and soil fertility status at main development stages for Katumani Comp B in Nyando.

Date	Crop growth		Biomass (kg/ha)	LAI	LEAF NUM	Crop N		Stress				
	Age	Stage				kg/ha	%	H ₂ O	Nitr	Phos1	Phos2	RSTG
14 MAR	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
14 MAR	0	Start Sim	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
15 MAR	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
19 MAR	5	Emergence	29	0.00	1.8	1	4.4	0.00	0.01	0.00	0.00	1
2 APR	19	End Juveni	48	0.10	5.6	2	3.5	0.03	0.00	0.00	0.00	2
7 APR	24	Floral Ini	92	0.20	6.7	3	3.6	0.00	0.00	0.00	0.00	3
24 MAY	71	75% Silkin	2149	0.72	14.3	18	0.8	0.15	0.36	0.00	0.00	4
4 JUN	82	Beg Gr Fil	2221	0.46	14.3	18	0.8	0.69	0.67	0.00	0.00	5
3 JUL	111	End Gr Fil	2675	0.16	14.3	19	0.7	0.60	0.59	0.00	0.00	6
5 JUL	113	Maturity	2675	0.16	14.3	19	0.7	1.00	0.51	0.00	0.00	10
5 JUL	113	Harvest	2675	0.16	14.3	19	0.7	0.00	0.00	0.00	0.00	10

LAI, Leaf area index; LEAF NUM, Leaf number; CROP N, Crop nitrogen, Phos, Phosphorus.

Table 3. Crop and soil fertility status at main development stages for H511 in Nyando.

Date	Crop growth		Biomass (kg/ha)	LAI	LEAF NUM	Crop N		Stress				
	Age	Stage				kg/ha	%	H ₂ O	Nitr	Phos1	Phos2	RSTG
14 MAR	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
14 MAR	0	Start Sim	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
15 MAR	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
19 MAR	5	Emergence	29	0.00	1.8	1	4.4	0.00	0.01	0.00	0.00	1
7 APR	24	End Juveni	86	0.19	6.7	3	3.7	0.02	0.00	0.00	0.00	2
12 APR	29	Floral Ini	152	0.31	7.8	5	3.6	0.00	0.00	0.00	0.00	3
4 JUN	82	75% Silkin	2198	0.54	16.6	18	0.8	0.28	0.49	0.00	0.00	4
15 JUN	93	Beg Gr Fil	2437	0.37	16.6	19	0.8	0.15	0.70	0.00	0.00	5
6 JUL	114	End Gr Fil	2583	0.15	16.6	19	0.7	0.91	0.55	0.00	0.00	6
8 JUL	116	Maturity	2583	0.15	16.6	19	0.7	1.00	0.39	0.00	0.00	10
17 JUL	125	Harvest	2583	0.15	16.6	19	0.7	0.00	0.00	0.00	0.00	10

LAI, Leaf area index; LEAF NUM, leaf number; CROP N, Crop nitrogen, Phos, phosphorus.

of water. This negatively impacted on the grain filling on the cob. Hybrid 614 maize varieties are suitable in medium to high altitudes of 1500 to 2100 m with a rainfall requirement of 800 to 1500 mm (Table 3). The day temperatures should not exceed 28°C and night temperatures can drop as low as 8°C.

In Nyando the harvest for H614 started late August to early September 2015 (Table 4). Crop nitrogen was seen as early as the emergence stages. This implied low use of nitrogen fertilizer by farmers and high rate of volatilization due to high daytime temperatures of 29.91°C (Table 4). Water stress set in at 75% silking stage because at this time in the year (July), rainfall had reduced in Nyando. Therefore, the soil moisture available at the crop root zone was low, and evaporation also was high. This resulted into slowed grain filling on the maize cobs.

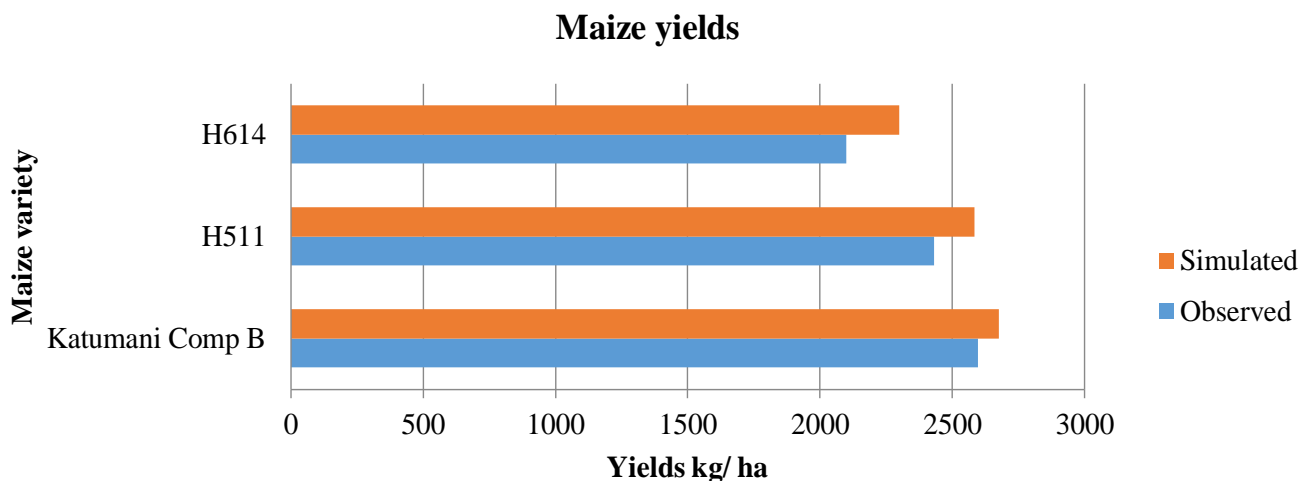
Comparison between 2015 observed and simulated yields in Nyando

In the baseline year 2015, Katumani comp B gave the highest observed yields of 2597 kg ha⁻¹ as shown in Figure 6, compared to H511 and H614. This variety gave the highest yields because it was able to mature fast and therefore escaped the negative the impacts of low rainfall (KSC, 2010). H514 and H614 observed yields were lower than Katumani comp B because of the climatic challenges. The low rainfalls of 420 mm in 2015 were not sufficient in providing sufficient moisture for these varieties which requires between 750 and 1000 mm for H511 and 800 to 1500 mm for H614. In addition, the high temperatures of 29.91°C in Nyando in 2015 exacerbated the impacts of climate change on available soil moisture necessary for the maize growth. This water stress was

Table 4. Crop and soil fertility status at main development stages for H614.

Date	Crop growth		Biomass (kg/ha)	LAI	LEAF NUM	Crop N		Stress				
	Age	Stage				kg/ha	%	H ₂ O	Nitr	Phos1	Phos2	RSTG
14 MAR	0	Sowing	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
14 MAR	0	Start Sim	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	8
15 MAR	1	Germinate	0	0.00	0.0	0	0.0	0.00	0.00	0.00	0.00	9
19 MAR	5	Emergence	29	0.00	1.8	1	4.4	0.00	0.01	0.00	0.00	1
7 MAY	49	End Juveni	143	0.30	7.8	5	3.7	0.02	0.00	0.00	0.00	2
27 MAY	74	Floral Ini	244	0.47	8.9	9	3.6	0.00	0.00	0.00	0.00	3
28 JUL	135	75% Silkin	2343	0.51	18.8	19	0.8	0.29	0.55	0.00	0.00	4
2 AUG	140	Beg Gr Fil	2276	0.32	18.8	19	0.8	0.86	0.72	0.00	0.00	5
5 SEP	174	End Gr Fil	2299	0.20	18.8	19	0.8	0.98	0.56	0.00	0.00	6
7 SEP	176	Maturity	2299	0.20	18.8	19	0.8	1.00	0.07	0.00	0.00	10
15 SEP	184	Harvest	2299	0.20	18.8	19	0.8	0.00	0.00	0.00	0.00	10

LAI, Leaf area index; LEAF NUM, Leaf number; CROP N, Crop nitrogen, Phos, Phosphorus.

**Figure 6.** Yield comparison between observed and simulated yields in DSSAT-CERES for the year 2015.

evident especially at 75% silking stage of these maize varieties.

Projected maize yields for the years 2030 and 2050 in Nyando using DSSAT-CERES model

Projected maize yields for the year 2030

The projected yields under both RCP 4.5 and 8.5 in Figures 7 and 8 showed that Katumani Comp B gave the highest yields of 2369 and 2325 kg ha⁻¹ respectively compared to H511 and H614.

Katumani composite B did well because it will be able to maximally utilize the projected rainfall which shall take approximately three months only. This maize variety has an advantage of fast growth by flowering within 90 days

(KSC, 2010). The difference in the projected yields for the three maize varieties is also associated with the difference in days to completion of the life cycle and the genetic make-up of these maize varieties (Benedicta et al., 2012). Furthermore, Benedicta et al. (2012) explains that this difference in maize yields under the different climate scenarios is attributed to the amount and distribution of rainfall.

Projected maize yields for the year 2050

The 2050 yield projections are lower compared to 2030 for all the three maize varieties. However Katumani comp B still showed higher yields in 2050 compared to H511 and H614 (Figures 9 and 10).

The reduction in yields is associated with climate

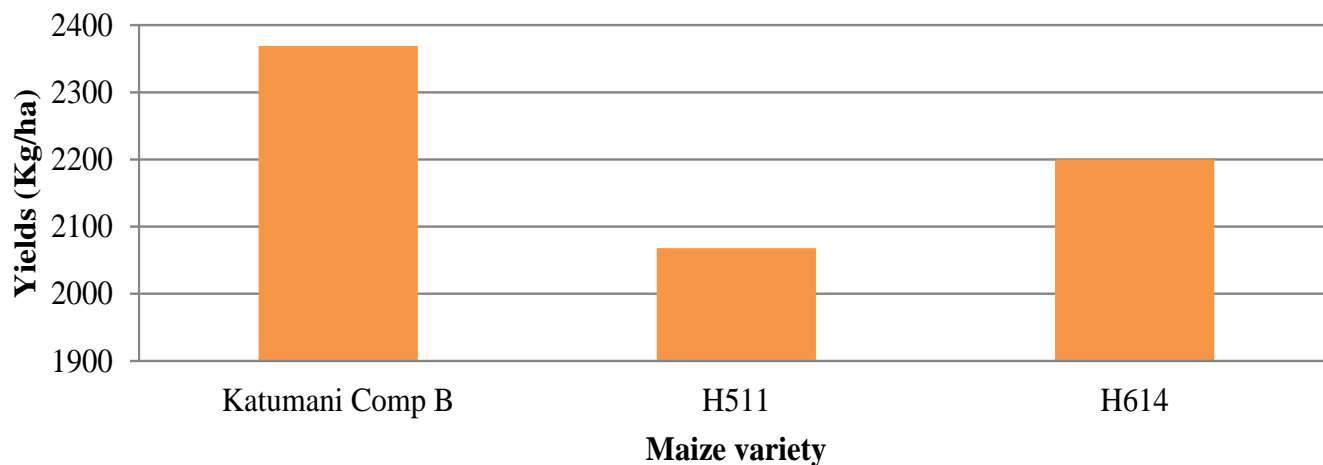


Figure 7. CERES-Maize projected yields for 2030 under representative concentration pathway

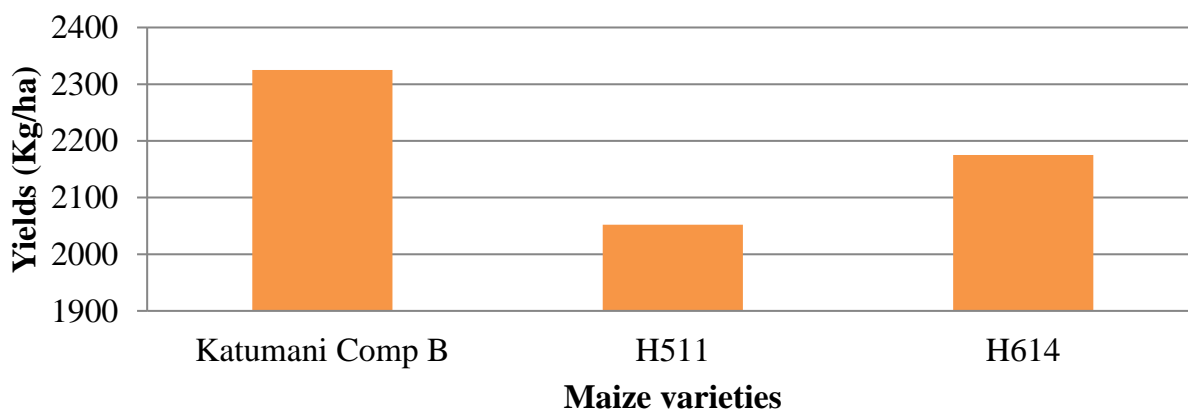


Figure 8. CERES-maize projected yields for 2030 under representative concentration pathway

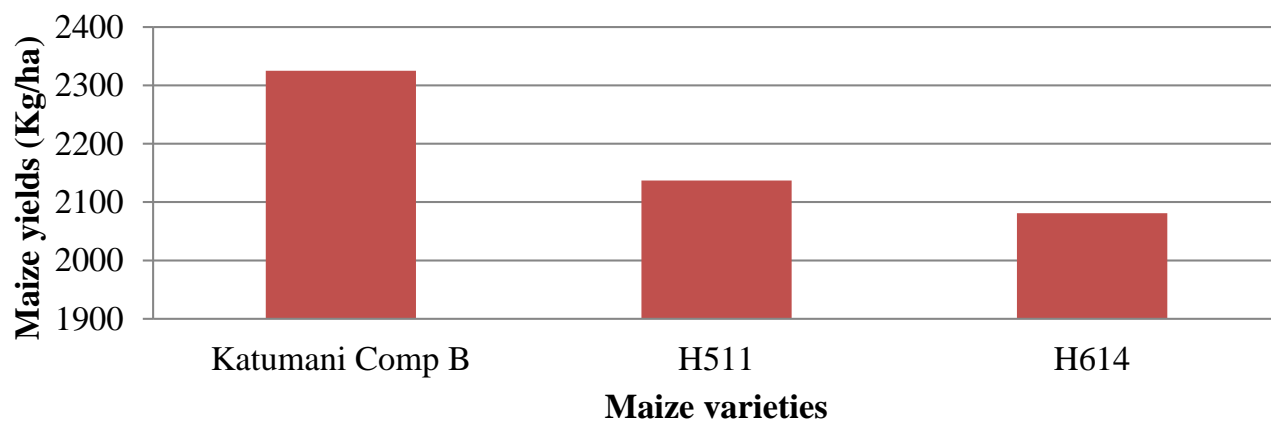


Figure 9. CERES-maize projected yields for 2050 under representative concentration pathway.

changes where maximum day temperatures are expected to rise above 40°C with minimum night temperatures going up to 8°C. The changes in temperatures with

reduced rainfall period of only three months negatively impacts H511 and H614 maize varieties which requires up to 125 and 190 days to maturity. This implies that

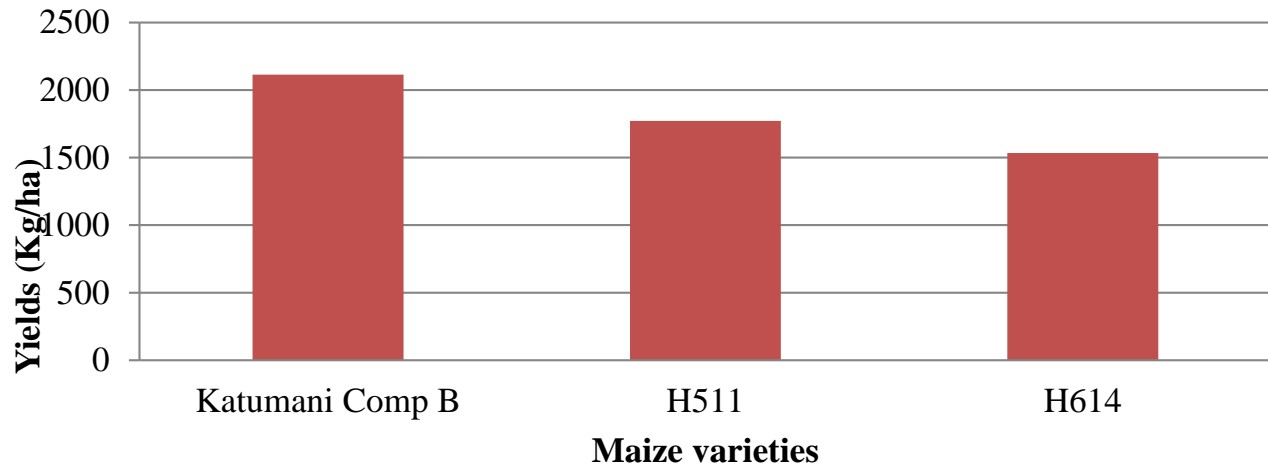


Figure 10. CERES-maize projected yields for 2050 under representative concentration pathway.

H511 and H614 will face a lot of stress during their growth.

Herrero et al. (2010) studied the impacts of climate change on maize crop production in Kenya up to 2050 and found out that the projected impacts of climate change to 2050 results in lower rain fed maize yields for Kenya in 4 out of 6 scenarios. Lobell et al. (2011) associated this reduction in maize yields to increasing maximum (day) temperatures that have a greater negative impact on yields than the minimum (night) temperatures. This increase in day temperatures/ warming exacerbates evaporation and crop water deficits while the rainfall is declining (USAID, 2010 In Bulgaria, Alexandrov and Hoogenboom (2000) investigated the effects of climate change on maize and found out that maize yields could be reduced by between 5 and 10% by 2050. This author deduced that the reason for reduction in yields is due to reduced growing period.

Conclusion

From this study, it is evident that Climate Change in Nyando, Kenya is real and will continue to change in the future. DSSAT-CERES projections for 2030 and 2050 showed that maize yields will reduce by the year 2050 according to the existing climatic projections for this area. On the other hand, Katumani Comp B maize variety will still remain the most suitable to be grown in Nyando up to the year 2050 compared to H511 and H614 under the existing and projected climatic conditions. The projections also indicate that there will be an increase in soil moisture stress due to high evaporation as a result of increase in daytime temperatures. This will require farmers to select more resilient and fast maturing maize varieties like Katumani Comp B. Empowering farmers in the issues of climate change and its effects on the production of maize and other staple crops will also let them understand the

interventions that are required to shield themselves against the inevitable impacts of these changes.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Resistance to *Phytophthora infestans* in tomato wild relatives

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Late blight of tomato (*Solanum lycopersicum* L.) caused by the heterothallic oomycete *Phytophthora infestans* (Mont.) de Bary, is one of the most destructive and serious diseases of tomato in cool and wet environments. Tomato breeders have developed late blight-resistant tomato lines and cultivars based on *Ph* resistance genes derived from *S. pimpinellifolium*, but resistance can be short-lived because *P. infestans* is highly diverse and can readily develop virulence towards the *Ph* resistance genes. Studies were carried out to assess the resistance level of four tomato genotypes and 48 wild relatives of cultivated tomato to *P. infestans*. The highest late blight resistance was detected in *S. habrochaites* accessions LA1777, LA1352, LA2855, LA1347, LA1718 and LA1295, with disease severities ranging from 4.5 to 13.5%. Interestingly, tomato genotypes containing *Ph-2* and *Ph-3* had significantly lower disease severity indices compared with the susceptible control 'Super Strain B' when inoculated with a highly virulent isolate. However, when a different isolate was used in 2014, the *Ph-2* and *Ph-3* containing tomato genotypes were as susceptible as 'Super Strain B'. The overall results demonstrate that LA1777, as previously reported, had a high level of resistance against all isolates of *P. infestans* and is a useful genetic resource for future tomato breeding programs.

Key words: Tomato, late blight, *Phytophthora infestans*, disease resistance, *Ph*-genes, *Solanum habrochaites*.

INTRODUCTION

Economically, tomato (*Solanum lycopersicum* L.) is the fourth most important crop in the world after rice, wheat, and soybean (Nowicki et al., 2013), with global production

of 162 million tons and a net value of more than \$62 billion in 2014 (FAO, 2017). In Egypt, the tomato crop production value was estimated at \$1.7 billion in 2014

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(FAO, 2017). Diseases caused by different organisms including fungi, bacteria, virus, and nematodes can limit tomato production. Late blight, caused by the hemibiotrophic oomycete *Phytophthora infestans* (Mont.) de Bary, is considered a major threat to tomato production in tropical and subtropical regions (Lima et al., 2009; Elsayed et al., 2012). The pathogen attacks all above-ground parts of the plant including leaves, petioles, stems and fruit at any growth stage, causing blights, necrosis, blotches and rots that reduce yield and fruit quality (Lievens et al., 2004). The disease can spread and kill plants rapidly when favorable environmental conditions of high humidity and low temperature (18°C) prevail (Haq et al., 2008; Stroud et al., 2016).

P. infestans is a highly diverse pathogen that can reproduce sexually and asexually. During asexual reproduction *P. infestans* produces lemon-shaped sporangia, while sexual reproduction results in the production of large, thick-walled oospores capable of surviving for several years in soil or plant debris (Smart and Fry, 2001). The widespread potential of sexual reproduction may increase the risk of host resistance breakdown, due to the development of new aggressive races and genotypes (McDonald and Linde, 2002). Recently, the genetic diversity in *P. infestans* is most often characterized using simple sequence repeat (SSRs) markers (Cooke and Lees, 2004; Lees et al., 2006; Li et al., 2010, 2013). The data is used to assign genotypes to isolates, for example in Europe Cooke et al. (2012) uses a system where 2 to 25 alleles per locus were detected in many European isolates using 11 SSR markers. These genotypes, however, do not reflect information regarding the specific race of the pathogen, with the same SSR genotype containing different races (Li et al., 2012)

Late blight management strategies include the use of several fungicides. Apart from the economic impact of their use, fungicides have been shown to reduce efficacy and resistance problems, particularly formulations containing metalaxyl (mefenoxam) (Randall et al., 2014; Saville et al., 2015; Montes et al., 2016). It can be difficult to detect *P. infestans* in the field during the initial stages of infection, from where it can rapidly develop into severe epidemics due to the pathogen's short life cycle. Most fungicides are ineffective once the pathogen had been established in the field. Host resistance has the potential for being a key component in managing late blight of tomato; it would reduce fungicide use and provide cost-effective, environmentally safe management strategies against the pathogen.

A few resistant varieties of tomato have been developed through the introgression of resistance genes obtained from wild tomato species (Panthee and Gardner, 2010). To date, five late blight resistance genes have been identified. *Ph-1*, a single dominant allele located on chromosome 7, confers resistance to *P. infestans* race 0 but it has been overcome by new races of the pathogen.

The second gene, *Ph-2*, a partially dominant allele located on chromosome 10, confers partial resistance to some *P. infestans* isolates and often fails in the presence of aggressive isolates. *Ph-3*, a single dominant allele located on chromosome 9, provides increased resistance against some aggressive isolates like Pi-16 from Taiwan that can overcome *Ph-1* and *Ph-2* (Irzhansky and Cohen, 2006). However, *Ph-3* can also be overcome by some isolates (Kim and Mutschler, 2006; Chen et al., 2008; de Miranda et al., 2010). A new resistant gene, *Ph-5*, has been identified recently on chromosome 1 and 10, and confers strong resistance to several *P. infestans* isolates including those overcoming the aforementioned four resistance genes (Foolad et al., 2008). Currently, the *Ph-2* and *Ph-3* genes are available in tomato breeding lines (e.g. 'NC1 CELBR', 'NC2 CELBR') and hybrid cultivars (Gardner and Panthee, 2010; Zhang et al., 2014). The continuous cycle of resistance being overcome by new *P. infestans* races warrants continuous efforts to identify additional sources of resistance from commercial cultivars, or other wild relatives of tomato in order to improve future breeding programs. The objectives of this study were to (i) investigate the level of resistance to *P. infestans* in wild relatives *S. habrochaites*, *S. pennellii*, *S. pimpinellifolium* and *S. peruvianum* and (ii) determine whether tomato accessions containing late blight resistance genes (*Ph-1*, *Ph-2* and *Ph-3*) could provide acceptable resistance to *P. infestans* isolates present in Egypt.

MATERIALS AND METHODS

Plant material and growth condition

Forty-eight wild tomato accessions were evaluated, including 24 accessions of *S. pimpinellifolium*, 12 accessions of *S. habrochaites*, eight accessions of *S. pennellii*, and four accessions of *S. peruvianum*, along with four accessions of *S. lycopersicum* containing *Ph* resistance genes. Seed was obtained from the C. M. Rick Tomato Genetics Resource Center (TGRC), University of California, Davis (LA numbers). Tomato variety 'Super Strain B', received from the Horticulture Research Institute, Agricultural Research Center (ARC), Egypt, which is known to be susceptible to late blight, was included as a control. In the greenhouse (25±2 °C, 16/8 h day/night), seeds of all accessions and the susceptible control were sown in 209-cell seedling trays containing 40 ml of peat moss-vermiculite mixture (1:1 volume) per cell plug. Plants were watered daily and fertilized weekly with N: P: K 15-15-15. Five weeks after sowing, seedlings of accession and control plants were transplanted into 20 cm pots containing potting soil, which were used for whole plant assays in 2013 and 2014. Seven-week-old plants were moved from the greenhouse to a growth room (20 ± 2°C, 90% relative humidity (RH), 16/8 h day/night) at the Plant Pathology Research Institute at ARC for inoculation assays.

Isolate selection and maintenance

Fourteen *P. infestans* isolates were collected from naturally infected tomato plants from 2013 to 2014 epidemics occurring in Beheira,

Table 1. Geographic locations where *Phytophthora infestans* isolates were collected in Egypt, which were evaluated for virulence.

<i>P. infestans</i> isolates	County	District	Genotype	Year	Mean disease severity (%)
EG_1	Kafr El Sheikh	Baltem	23_A1_10	2013	45.0±2.9 ^c
EG_1.1	Kafr El Sheikh	Baltem	23_A1_10	2013	44.7±2.6 ^c
EG_2	Kafr El Sheikh	Sidi Ghazy	23_A1_10	2013	22.7±1.5 ^e
EG_3	Kafr El Sheikh	Sakha	23_A1_10	2013	44.7±2.6 ^c
EG_4	Qalubiya	Qaliub	23_A1_12	2013	30.0±2.9 ^{de}
EG_5	Ismailia	Kasasen	Unknown	2013	75.0±2.9 ^b
EG_6	Beheira	Nubaria	Unknown	2013	37.3±1.5 ^{cd}
EG_6.1	Beheira	Nubaria	Unknown	2013	41.7±5.8 ^{cd}
EG_7	Kafr El Sheikh	Sakha	23_A1_12	2013	99.0±0.6 ^a
EG_8	Kafr El Sheikh	Sidi Ghazy	23_A1_10	2013	80.0±1.7 ^b
EG_9	Beheira	Badr	Unknown	2014	96.7±3.3 ^a
EG_10	Beheira	Badr	Unknown	2014	78.3±9.3 ^a
EG_11	Kafr El Sheikh	Sakha	Unknown	2014	100.0±0.0 ^a
EG_12	Beheira	Kom Hamada	Unknown	2014	100.0±0.0 ^a

Means disease severity rating followed by ± standard error. Means followed by different letters are significantly ($P = 0.05$) different, whereas means followed by the same letter are not significantly different.

Kafr El Sheikh, Qalubiya, and Ismailia counties in Egypt (Table 1). The susceptible 'Super strain B' control was artificially inoculated with the 10 *P. infestans* isolates collected in 2013, as described for the germplasm testing, in order to select the most virulent isolate for late blight screening. Among the 10 evaluated isolates, EG_7 was the most virulent (Table 1). Isolate EG_7 was identified as genotype 23_A1_12 and mating type A1 based on identification carried out by the laboratory of Dr. David E. L. Cooke at the James Hutton Institute, Dundee, UK. This isolate was chosen as the inoculum source in the first round of germplasm tests conducted in 2013 and 2014. In 2014, another four *P. infestans* isolates were collected from naturally infected tomato plants (Table 1). These isolates were used to re-test germplasm from the first round of testing, due to the severe epidemics they caused in tomato fields in 2014.

Inoculum production

Sporangia and zoospores were produced as described by Chen et al. (2008). Tomato leaves collected from 6-week-old plants of the susceptible 'Super strain B' genotype were placed on moist filter paper in 140 mm sterilized Petri plates. The abaxial surface of the leaves were injured at the center using a sterile 10 µl micropipette tip and inoculated with 30 µl of a sporangial suspension obtained from 20-day-old rye agar plates. Leaflets were incubated for 48 h at 18°C in darkness, followed by incubation at 18°C for 10 days with a 12-h photoperiod. Subsequently, tomato leaflets were placed in a glass beaker containing 500 mL sterilized distilled water and gently shaken using a vortex to dislodge sporangia from the leaflets. The suspension was filtered through four layers of sterile muslin cloth. The concentration of the sporangia was determined using a haemocytometer, and was adjusted to 15×10^4 sporangia/ml. The suspension was chilled at 4°C for 2 to 4 h prior to inoculation to encourage zoospore release from the sporangia.

Disease assessment using *P. infestans* isolate EG_7

Eight-week-old plants of 48 wild accessions along with four tomato

genotypes containing *Ph* genes and a susceptible control were inoculated with *P. infestans* isolate EG_7 using whole plant assays. Plants were sprayed with a suspension of *P. infestans* zoospores using a hand sprayer until complete leaf coverage and excess runoff was observed. The inoculated plants were covered with a plastic tunnel to increase humidity and kept at 16 to 18°C in the dark in a growth chamber for 24 h under 100% RH. The inoculated plants were then grown at 18 to 20°C and 90% RH with a 12 h photoperiod for 7 to 12 days. Plants were arranged following a completely randomized design with five replicate plants per accession.

The experiment was conducted twice from November to January in 2013 and 2014. Plants were evaluated individually at 10 days post-inoculation (dpi) by visually scoring the disease severity using a scale of 0 to 6 as described by Chen et al. (2014), where 0 indicates no symptoms (immune); 1 indicates <5% leaf area affected and small lesions (highly resistant); 2 indicates 6 to 15% leaf area affected and restricted lesions (resistant); 3 indicates 16 to 30% leaf area affected and/or water-soaked flecks on stems (moderate resistant); 4 indicates 31 to 60% leaf area affected and/or a few stem lesions (moderate susceptible); 5 indicates 61 to 90% leaf area affected and expanding stem lesions (susceptible); 6 indicates 91 to 100% of leaf area affected, extensive stem damage, or a dead plant (highly susceptible).

Reassessment of disease resistance using *P. infestans* isolates EG_9, EG_10, EG_11 and EG_12

The four *P. infestans* isolates collected in 2014 were used to confirm the resistance identified in *S. habrochaites* accession LA1777, and to re-access the response of the five tomato accessions containing *Ph* resistance genes against different *P. infestans* isolates. The susceptible control 'Super Strain B' was also included in the re-testing. Preparation of isolates and disease assessments were carried out as described previously. The experiment was repeated twice only with LA1777 along with the susceptible control 'Super Strain B' inoculated with isolate EG_11.

Statistical analysis

Statistical procedures were performed using the statistical software SAS (version 9.1; SAS Institute, Cary, NC). The percentage of late blight severity was transformed using Arcsine square root transformation. Back-transformed data are presented in tables. All data were subjected to one-way analysis of variance (ANOVA). Mean separations were determined using the Tukey-Kramer honestly significant difference (HSD) test ($P = 0.05$).

RESULTS

Isolate selection

To identify the most virulent isolate, 10 *P. infestans* isolates collected from tomato fields in 2013, were artificially inoculated on the susceptible control 'Super Strain B' under controlled greenhouse conditions. All *P. infestans* isolates infected the susceptible control, with disease severity ranging from 99% for the most aggressive isolate EG_7 to 22.7% for the least aggressive isolate EG_2 (Table 1). In addition to isolate EG_7, isolates EG_5 and EG_8 also exhibited high virulence causing disease severities of 75 and 80%, respectively. Based on these results, *P. infestans* isolate EG_7 was selected and used to further screen late blight resistance in 48 tomato wild tomato relatives along with tomato genotypes containing the *Ph* genes and the susceptible control.

Disease assessment using *P. infestans* isolate EG_7

Late blight severity on the 48 wild accessions, four tomato genotypes containing *Ph* genes, and the susceptible control 'Super Strain B', was evaluated using a whole plant assay under controlled greenhouse conditions (Table 2). The ANOVA revealed highly significant differences among treatments ($P < 0.0001$). Results from our two experiments conducted in 2013 and 2014 were similar. No genotype was immune to *P. infestans* EG_7 and all susceptible control plants had a 100% blight severity (dead). Mean disease ratings of all tested accessions eight weeks after sowing ranged from 4.5 to 100% (Table 2). Lower disease severities were identified for *S. habrochaites* accessions LA1777, LA1352, LA2855, LA1347, LA1718 and LA1295, with disease severities ranging from 4.5 to 13.5%. *S. lycopersicum* accessions containing *Ph-2* and *Ph-3* genes had significantly lower disease severity values, whereas LA3152 (*Ph-2*), LA3151 (*Ph-2*) and LA4286 (*Ph-3*) were moderately resistant. Conversely, all *S. peruvianum* and *S. pennellii* accessions were susceptible or highly susceptible to isolate EG_7. The majority of the evaluated *S. pimpinellifolium* accessions were either susceptible or highly susceptible to EG_7, whereas LA

1269 and LA1578 were moderately resistant with disease severity 22 and 23%, respectively. No correlation was seen between the geographic origin of tomato genotypes and their resistance to *P. infestans*. For example, all resistant accessions in this study originated from Peru and Ecuador, but many susceptible accessions also came from these regions.

Reassessment of disease resistance using *P. infestans* isolates EG_9, EG_10, EG_11 and EG_12

The late blight resistance identified in the 2013 and 2014 experiments in *S. habrochaites* accession LA1777 and the *S. lycopersicum* genotypes containing *Ph* genes was verified using a new set of *P. infestans* isolates including EG_9, EG_10, EG_11 and EG_12, which were collected from tomato epidemics in 2014 (Table 3). Responses to individual isolates varied. Genotypes inoculated with the aggressive isolate EG_12 had 13.3 to 100% disease ratings, while genotypes inoculated with EG_10, the least aggressive isolate, had disease severities of 0 to 78.3% (Table 3). LA1777 was the most resistant genotype, exhibiting the lowest disease severity values against all selected isolates of *P. infestans* compared to other genotypes containing *Ph* genes and the susceptible control, with disease severity means ranging from 0 to 13.3%. The susceptible control had a significantly higher disease severity compared to LA1777 and tomato genotypes containing *Ph* genes when inoculated with isolates EG_10 and EG_11. Interestingly, all *S. lycopersicum* accessions containing *Ph-2* and *Ph-3* genes were found to be moderately resistant or resistant to isolates EG_9 and EG_10, but were susceptible to isolates EG_11 and EG_12 with mean severity ratings > 68.3%.

DISCUSSION

Late blight is one of the most devastating diseases of tomato, especially in cool and moist environments. In Egypt, it is almost impossible for grower's to produce tomatoes from November to February, when cool and moist weather predominate and favour *P. infestans* epidemics. Knowledge on the effectiveness of resistance genes in existing cultivars can help growers in Egypt to manage late blight. Efforts must thus continue to assess the stability of resistance and whether such cultivars are adaptable to all tomato-growing regions.

Resistance to *P. infestans* has been discovered in numerous wild tomato species, including *S. pimpinellifolium*, *S. habrochaites* and *S. pennellii* (Conver and Walter, 1953; Turkensteen, 1973; Moreau et al., 1998; Chunwongse et al., 2002; Smart et al., 2007; Li et al., 2011). To the best of our knowledge, cultivars

Table 2. Mean late blight disease severity ratings for 48 wild tomato accessions and controls inoculated with *P. infestans* isolate EG_7.

Taxa accession	and Origin	Mean disease severity (%) ^z			Disease response ^y
		2013	2014	Mean combined	
<i>S. habrochaites</i> [#]		45.2±5.0	43.9±4.8	44.5±1.7	
LA1777	Peru	2.0±1.2 ^l	7.0±1.2 ^{hi}	4.5±0.9 ^j	HR
LA1352	Peru	9.0±1.8 ^k	5.0±2.2 ⁱ	7.0±1.8 ^{hi}	R
LA2855	Ecuador	9.0±3.3 ^k	6.0±3.7 ⁱ	7.5±3.3 ^{hi}	R
LA1347	Peru	10.0±2.2 ^k	7.0±2.0 ^{hi}	8.5±1.3 ^{ghi}	R
LA1718	Peru	12.0±1.2 ^{jk}	9.0±1.9 ^{hi}	10.5±1.2 ^{gh}	R
LA1295	Peru	14.0±1.9 ^{jk}	13.0±2.0 ^{gh}	13.5±1.7 ^g	R
LA2196	Peru	40.0±1.6 ^{gh}	65.0±2.2 ^{cde}	52.5±1.6 ^{de}	MS
LA1252	Ecuador	76.0±1.9 ^{cde}	84.0±2.5 ^{abcd}	80.0±2.1 ^{bc}	S
LA1772	Peru	90.0±2.7 ^{abcd}	77.0±2.0 ^{abcde}	83.5±1.7 ^{abc}	S
LA1223	Ecuador	90.0±2.2 ^{abcd}	82.0±2.0 ^{abcd}	86.0±1.9 ^{ab}	S
LA1378	Peru	95.0±2.2 ^{abc}	85.0±2.3 ^{abcd}	90.0±1.4 ^{ab}	S
LA0094	Peru	95.0±0.0 ^{abc}	87.0±2.0 ^{abcd}	91.0±1.0 ^{ab}	HS
<i>S. pennellii</i> [#]		87.6±2.6	83.9±2.0	85.7±1.6	
LA1367	Peru	54.0±2.5 ^{fg}	68.0±3.7 ^{bcd}	61.0±1.9 ^{de}	S
LA1340	Peru	72.0±2.6 ^{def}	63.0±2.0 ^{de}	67.5±2.1 ^{cd}	S
LA0716	Peru	85.0±2.7 ^{abcd}	84.0±2.5 ^{abcd}	84.5±2.4 ^{ab}	S
LA1674	Peru	91.0±4.0 ^{abcd}	89.0±5.1 ^{abc}	90.0±3.6 ^{ab}	S
LA1303	Peru	100.0±0.0 ^a	88.0±1.2 ^{abcd}	94.0±0.6 ^{ab}	HS
LA1302	Peru	100.0±0.0 ^a	89.0±1.0 ^{abc}	94.5±0.5 ^{ab}	HS
LA0751	Peru	99.0±1.0 ^{ab}	91.0±2.5 ^{ab}	95.0±0.8 ^{ab}	HS
LA1649	Peru	100.0±0.0 ^a	99.0±1.0 ^{ab}	99.5±0.5 ^a	HS
<i>S. pimpinellifolium</i> [#]		88.7±2.0	89.4±1.9	89.0±1.2	
LA1269	Peru	20.0±2.7 ^{ij}	24.0±2.9 ^{fg}	22.0±2.3 ^f	MR
LA1578	Peru	19.0±2.5 ^{ij}	27.0±2.0 ^f	23.0±1.2 ^f	MR
LA1478	Peru	77.0±2.0 ^{bcd}	82.0±2.6 ^{abcd}	79.5±1.8 ^{bc}	S
LA1594	Peru	86.0±2.9 ^{abcd}	90.0±2.7 ^{abc}	88.0±1.5 ^{ab}	S
LA2646	Peru	85.0±1.6 ^{abcd}	92.0±2.6 ^{ab}	88.5±1.3 ^{ab}	S
LA0443	Ecuador	95.0±0.0 ^{abc}	88.0±1.2 ^{abcd}	91.5±0.6 ^{ab}	HS
LA1586	Peru	91.0±3.3 ^{abcd}	92.0±3.4 ^{ab}	91.5±3.2 ^{ab}	HS
LA1561	Peru	94.0±2.9 ^{abc}	90.0±2.7 ^{abc}	92.0±1.7 ^{ab}	HS
LA0413	Ecuador	91.0±2.9 ^{abcd}	93.0±3.7 ^{ab}	92.0±2.9 ^{ab}	HS
LA2147	Peru	95.0±1.6 ^{abc}	91.0±2.5 ^{ab}	93.0±1.7 ^{ab}	HS
LA1579	Peru	93.0±2.0 ^{abcd}	96.0±2.4 ^a	94.5±2.0 ^{ab}	HS
LA1617	Peru	97.0±2.0 ^{abc}	93.0±4.3 ^{ab}	95.0±2.3 ^{ab}	HS
LA1633	Peru	95.0±1.5 ^{abc}	96.0±2.4 ^a	95.5±1.4 ^{ab}	HS
LA2391	Peru	98.0±1.2 ^{abc}	96.0±1.9 ^a	97.0±0.9 ^{ab}	HS
LA3123	Ecuador	98.0±2.0 ^{abc}	96.0±2.5 ^a	97.0±1.2 ^{ab}	HS
LA3161	Mexico	98.0±2.0 ^{abc}	99.0±1.0 ^a	98.5±1.5 ^a	HS
LA1246	Ecuador	98.0±1.2 ^{abc}	100.0±0.0 ^a	99.0±0.6 ^a	HS
LA0375	Peru	99.0±1.0 ^{ab}	100.0±0.0 ^a	99.5±0.5 ^a	HS
LA0114	Peru	99.0±1.0 ^{ab}	100.0±0.0 ^a	99.5±0.5 ^a	HS
LA1237	Ecuador	100.0±0.0 ^a	100.0±0.0 ^a	100.0±0.0 ^a	HS
LA1469	Peru	100.0±0.0 ^a	100.0±0.0 ^a	100.0±0.0 ^a	HS
LA1256	Ecuador	100.0±0.0 ^a	100.0±0.0 ^a	100.0±0.0 ^a	HS
LA1242	Ecuador	100.0±0.0 ^a	100.0±0.0 ^a	100.0±0.0 ^a	HS
LA1343	Peru	100.0±0.0 ^a	100.0±0.0 ^a	100.0±0.0 ^a	HS
<i>S. peruvianum</i> [#]		97.3±1.2	96.8±1.2	97.0±1.3	

Table 2. Contd.

LA1935	Peru	92.0±3.4 ^{abcd}	93.0±3.7 ^{ab}	92.5±2.9 ^{ab}	HS
LA0446	Peru	97.0±2.0 ^{abc}	97.0±2.0 ^a	97.0±1.2 ^{ab}	HS
LA2581	Chile	97.0±2.0 ^a	97.0±2.0 ^a	98.5±1.0 ^a	HS
LA1333	Peru	100.0±0.0 ^a	100.0±0.0 ^a	100.0±0.0 ^a	HS
<i>S. lycopersicum</i> [#]		47.8±3.1	48.2±3.5	48.0±2.3	
LA3152 (<i>Ph-2</i>)		27.0±3.0 ^{hi}	24.0±2.9 ^{fg}	25.5±1.5 ^f	MR
LA3151 (<i>Ph-2</i>)		26.0±4.3 ⁱ	26.0±5.6 ^{fg}	26.0±3.2 ^f	MR
LA4286 (<i>Ph-3</i>)		28.0±2.5 ^{hi}	33.0±3.5 ^f	30.5±2.7 ^f	MR
Table 2. continued					
LA2009 (<i>Ph-1</i>)		58.0±5.6 ^{ef}	58.0±5.6 ^e	58.0±4.1 ^{de}	MS
Super Strain B		100.0±0.0 ^a	100.0±0.0 ^a	100.0±0.0 ^a	HS

²Means of visually disease severity ratings throughout 2013 and 2014 experiments followed by ± standard error (± SE; n=5). Means followed by different letters are significantly ($P = 0.05$) different. ³Disease response: HS = highly susceptible, S = susceptible, MS = moderately susceptible, MR = moderately resistant, R = resistant, and HR = highly resistant.

Table 3. Mean late blight disease severity ratings for *Solanum habrochaites* accession LA1777 compared to controls inoculated with four different *P. infestans* isolates (EG_9, EG_10, EG_11 and EG_12).

Accession code	Resistance gene	<i>P. infestans</i> isolates			
		EG_9	EG_10	EG_11	EG_12
L A2009	<i>Ph-1</i>	98.3±1.7 ^a	41.7±4.4 ^{ab}	96.7±3.3 ^{ab}	85.0±2.9 ^a
LA3151	<i>Ph-2</i>	36.7±3.3 ^{bc}	31.7±8.3 ^{cb}	86.7±3.3 ^{bc}	80.0±15.3 ^a
LA3152	<i>Ph-2</i>	21.7±1.7 ^c	0.0±0.0 ^e	95.0±2.9 ^{ab}	83.3±12.0 ^a
LA1269	<i>Ph-3</i>	40.0±5.8 ^{bc}	11.7±1.7 ^d	68.3±7.3 ^c	81.7±11.7 ^a
LA4286	<i>Ph-3</i>	53.3±3.3 ^b	21.7±6.0 ^{cd}	83.3±6.7 ^c	78.3±9.3 ^a
LA1777	Unknown	1.7±1.7 ^d	1.7±1.7 ^e	6.7±1.7 ^d	13.3±3.3 ^b
Super Strain B	None	96.7±3.3 ^a	78.3±9.3 ^a	100.0±0.0 ^a	100.0±0.0 ^a

Means of visually disease severity rating followed by ± standard error (± SE; n=5). Means followed by different letters are significantly ($P = 0.05$) different.

commonly grown or introduced in Egypt have not been assessed for their resistance to local populations of *P. infestans*. Therefore, a large number of accessions and genotypes were screened for their resistance to late blight using a highly virulent isolate EG_7 under controlled greenhouse conditions. Our results showed that *S. habrochaites* accessions LA 1777, LA1352, LA2855, LA 1347, LA1718 and LA1295 exhibited high levels of resistance to late blight, with LA1777 being the most resistant. Similar results have been reported in *S. habrochaites* accessions by Abreu et al. (2008) in BGH6902, Brouwer et al. (2004) in LA2099, and Li et al. (2011) in LA1777.

Although the resistance mechanism is unknown, these accessions have high densities of glandular trichomes type IV and VI (Muigai et al., 2003; Momotaz et al., 2010; Bergau et al., 2015), which are often able to secrete exudates with antifungal activities as has been shown in a wild potato species (*S. berthaultii*) that are resistant to

P. infestans (Lai et al., 2000). Additional resistance mechanisms in LA1777 could be the secretion of a wide range of proteins that have been shown in other plants to play a role in the degradation of microbial cell walls, and in blocking pathogen-released elicitors (Ferreira et al., 2007). The resistance present in LA 1777 will, however, be difficult to confer to tomato since *S. habrochaites* is a distant relative of cultivated tomato and challenges such as self-incompatibility, segregation distortion, and linkage drag complicate the transfer of useful genes into tomato (Covey et al., 2010; Elizondo and Oyanedel, 2010; Labate and Robertson, 2012; Haggard et al., 2013). The sequencing of the tomato genome will be helpful in this regard since it has resulted in the availability of thousands of molecular markers that can facilitate the mapping and introgression of beneficial genes from wild species into cultivated tomato.

Tomato genotypes containing *Ph-2* and *Ph-3* genes, LA3152, LA3151 and LA4286, demonstrated acceptable

levels of resistance when inoculated with *P. infestans* EG_7. These genes have thus far been used in commercial cultivars and may directly benefit farmers by reducing their dependence on fungicides to control *P. infestans*, thus lowering their production cost. These results support previous reports indicating that *Ph-2* and *Ph-3* confers resistance to *P. infestans*. *Ph-2* is a completely dominant gene that confers partial resistance to *P. infestans* and in this case isolate EG_7, and *Ph-3* is a partial dominant allele that confers stronger resistance to *P. infestans* when it is homozygous. Notably, resistance to *P. infestans* EG_9, and EG_10 isolates exhibited by accession LA3152 (containing *Ph-2*) was significantly higher than the resistant accessions LA3151, LA1269 and LA4286 containing *Ph-2* or *Ph-3*, suggesting the presence of unknown resistance gene(s) potentially involved in resistance to late blight in accession LA3152. Further, *P. infestans* is a highly diverse pathogen that can develop virulence toward the *Ph* resistance genes (Goodwin et al., 1995; Bradshaw et al., 2006; Chen et al., 2014). The fluctuation of *P. infestans* populations may be due to sexual recombination and transposable elements (Vetukuri et al., 2012). Based on the results of this study, tomato accessions possessing *Ph-2* and *Ph-3* resistance genes were susceptible to *P. infestans* isolates EG_12 and EG_11, whereas LA1777 had a high level of resistance against all five evaluated *P. infestans* isolates. In addition, the tomato accession possessing the resistance gene *Ph-1* was also susceptible to all five *P. infestans* isolates EG_7, EG_9, EG_10, EG_11, and EG_12.

The differences in the effect of *Ph* genes against different *P. infestans* isolates could be due to isolates used in this study probably having different race compositions. For example, isolates EG_2 and EG_7 were collected from the same county, but differed in their virulence to the host plant. Differences between these isolates have significant implications for local tomato breeding programs against *P. infestans* in Egypt, where the diversity of pathogen populations, the existence of different physiological races within *P. infestans*, and polygenic inheritance can hamper breeding efforts (Singh and Singh, 2006; Zhang and Kim, 2007; Harbaoui et al., 2011; Pule et al., 2013; Tian et al., 2016). Further studies are required to characterize *P. infestans* populations, define races that infect tomato, and determine their spatial structure in order to deploy tomato breeding programs effectively in Egypt.

Only two accessions of *S. pimpinellifolium*, LA1269 and LA1578, were found to be moderately resistant. These red-fruited accessions are closely related to tomato and therefore fewer backcrosses may be required to introgress late blight resistance into tomato compared to the green-fruited species *S. pennellii* and *S. habrochaites* (Rick, 1971; Peralta et al., 2008). LA1269, also known in the literature as L3708, was described as being resistant

to multiple strains of *P. infestans* (Chunwongse et al., 2002). Such resistance has been linked to the *Ph-3* gene and *qPh2.1* QTL, which confers resistance to isolate Pi733 in Taiwan (Black et al., 1996; Chen et al., 2014). Although breeders might be interested in attaining high levels of resistance, the use of partially resistant cultivars can be useful and can help to reduce the number of fungicide applications (Stevenson et al., 2007).

Interestingly, some accessions found to be resistant in other studies were moderate or susceptible in this study. For example, *S. pennellii* LA716 was reported as highly resistant by Eshed and Zamir (1994) and Smart et al. (2007), but was found to be susceptible in this study with a mean rating of 5.0. Conversely, the most resistant *S. habrochaites* accession LA1352 identified in this study was highly susceptible to aggressive *P. infestans* isolate T1, 2, 3, 4 in Taiwan, with a mean rating 6. Differences in resistance in different studies could be due to the use of different experimental designs or more likely differences in *P. infestans* races. Simple sequence repeat was recently conducted (Li et al., 2013) genotyping 40 isolates of *P. infestans* collected from different regions in Egypt from 2012 to 2014, which revealed genetic variability among *P. infestans* isolates (Arafa et al., unpublished data). This could have implications for resistance screening. However, since SSR genotypes cannot be linked to race composition, race typing will also have to be conducted to determine the extent of variation in races in Egypt and their relevance in resistance screenings.

The results of the study show that resistance in *S. habrochaites* accession LA1777 was higher than the resistance conferred by *Ph-2* and *Ph-3* genes, indicating that the LA1777 genome contains a different source of late blight resistance. This is in agreement with the study of Li et al. (2011), who also found that LA1777 has a good level of resistance to several isolates of *P. infestans*. Li et al. (2011) has identified five loci derived from LA1777 (*Rlbq4a*, *Rlbq4b*, *Rlbq7*, *Rlbq8* and *Rlbq12*) associated with lesion size, which were co-localized with previously described QTLs from *S. habrochaites* LA2099 except QTL *Rlbq4b* (Brouwer et al., 2004). Pyramiding resistance alleles from LA1777 and available late blight resistance genes such as *Ph-2* and *Ph-3* in cultivated tomato could enhance the durability of resistance to late blight.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest

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Full Length Research Paper

Optimizing degraded steep upland paddy field under no tillage practice using leaf mulching and earth-worms

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A field experiment project was conducted in Karawang District, Indonesia from April to October, 2016 in the search of efforts to optimize degraded steep upland paddy field and paddy yield. The experiment was designed under no tillage practices and statistical randomized block were applied with two factors, that is, banana leaf mulch, and worms where each factor is varied into four levels of treatments with three times-replication, respectively. Results showed that both banana leaf mulch and worms significantly improved the soil physic properties of degraded land such as reduced soil bulk density by 28%; increased soil water capacity by 144%; increased total porosity by 24.5% ; and soil permeability from 1.12 to 29.34 cm/h. While, the regression/corelation of this improvement to the paddy (dry-land paddy rice) tiller and yield is strong at $R^2 = 0.54$ and $R^2 = 0.72$, respectively.

Key words: Banana leaf, mulching, degraded upland paddy field, earth-worms, paddy.

INTRODUCTION

Degraded land may occur due to erosion exerted by raindrop and/or surface run-off and become critical problem in a marginal land. The loss of soil from land surfaces by erosion is widespread and reduces the productivity of all natural ecosystems as well as agricultural, forest and pasture ecosystems (Troeh et al., 2004). Top soil loss due to run-off is more intensive in sloping land. Despite its poor condition for retaining water, the land practice for long has served as a field for cultivating crops with so-called upland paddy rice field which relies on rainfall for its growth. Moreover, the land may be critical for agriculture if managed not in compliance with the standard procedures of soil

conservation.

In general, sloping dry lands in Indonesia are critical since it lost their fertile top soil owing to erosion. Damages left by erosion are mostly disturbances either in biological, chemical and/or physical properties of the soil such as the loss or even the absence of nutrients and organic substances (Cruse et al., 2010) and the increase in soil compaction (Horn and Peth, 2011) and reduced water holding capacity (Berndes, 2008). These undermined properties will in turn reduce the soil's benefit for agriculture (Blum and Nortcliff, 2013). Organic matter, phosphorous, nitrogen, clay, dust, field capacity, wilting point and available water capacity were higher in

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afforested areas which was 15 years than un-afforested areas, while it was opposite for pH, sand, lime and volume weight values (Yazici and Turan, 2016).

In light of the phenomenon described above, land exploitation for agriculture should refer to proper land conservation techniques in order to be continuous. This implies some proper and accountable planning as well as management for farms are necessary to prevent them from being possibly degraded. Sloping dry lands where the upland paddy is commonly cultivated should be made as rainwater catchment areas to control flood and prevent surface erosion. When well-managed, sloping dry lands can keep ecological stability, maintain bio-diversity and absorb greenhouse gases. The paddy mostly relying on rainfall for growth often cultivated in such condition. Unfortunately, it has never been massively cultivated, as compared to wet land paddy, so far owing to its low productivity.

Proper and proportional fertilizing is one effort to improve the soil's fertility. Other efforts such as the implementation of organic fertilizers to replace inorganic, are now being exercised. Organic fertilizers that have been used to improve soil quality and productivity are manure and compost. However, farmers reluctant use the latter owing to its relative amount in every hectare of land cultivated, that is, 10 to 20 tons, in order to meet a specified need of soil nutrition. Large tonnages of compost are difficult to provide fertile soils typically containing 100 tons of organic matter per hectare (4 to 5% of total topsoil weight) (Pimentel et al., 2005; Sundquist, 2010). Many vehicles are needed to transport them to the sites, and fertilization process is laborious. Due to this, production cost of an agriculture program becomes high owing to high cost of fertilization process using compost. In fact, Indonesia has still a great number of natural resources other than compost to be beneficially exploited in relatively short time.

Agriculture results have wasted other materials besides grain. Leave waste of the banana leaf is abundant as being adaptive to any environment. However, not much effort is applied to scientifically observe it or adopt it as something useful. The use of banana leaf as mulching will give a good prospect because the farmers can reduce the use of the relatively expensive and harmful inorganic fertilizer. This type of leaf mulching can supply chain-food to the population growth of earthworm species.

The importance of macro-organisms (e.g., earthworms and termites) for restoring soil quality has been widely recognized for centuries (Darwin, 1881). Earthworms in soil enriches the availability of nutritive elements of nitrogen (N), phosphorus (P) and potassium (K) and soil structure changes (Castellanos-Navarrete et al., 2012). Observation on barren lands used to be mining areas in Ohio, USA, shows that *Lumbricus rubellus* is able to increase the availability of potassium and phosphorus in

soil as much as 19 and 16.5%, successively (Curry and Good, 1992). Earthworm not only fertilize soil, but leave as well in them tracks in the form of burrows or holes, serves as aeration and drainage paths that make the soil become more friable. It assists also the transportation of organic substances-bearing layers and changed soil structure. The presence of burrows in soil enhances infiltration and percolation so as to reduce the surface runoff.

Muys and Granval (1997) showed that worms consumes organic substances, such as leaves, in an equivalent weight to its body in 24 h. It can decompose organic waste 2 to 3 times faster than the decomposing microorganism, and the organic waste that has been decomposed by earth-worms generally loses its weight to 40 to 60%. Moreover, it can live as long as 1 to 10 years and serves much improvement in the soil's physical properties.

Based on the facts described above, observation in search for the benefit as well as role of the bio-agents of bananas leaf and earthworm in optimizing of soil physic of the degraded lands and their effect to the paddy yield is necessary.

MATERIALS AND METHODS

A field observation was done from April to November 2016 in a steep and degraded upland paddy field in Karawang District, Indonesia. Duo bio-agents such as banana leaf mulch (code M) (with-out; 0.5; 1.0; and 1.5 kg/m² land) and earth-worms (code W) (0, 36, 72, and 108 worms population per meter square of land) were applied aiming to optimize its potential energy. Statistical methods were designed by randomized complete block design and repeated three times.

Analysis of variance followed by the F test with 5% level of significance is used to test the overall data. The Duncan's multiple range test 5% and correlation-regression analysis was also obtained following the analysis of variance.

Response variables to observe in this research are as follows: (1). The soil physic, that is, bulk density, soil water content, soil total porosity and permeability. A *core ring sampler* technique as an undisturbed soil was tested in Soil Laboratory of Faculty of Agriculture, University of Singaperbangsa; and; Upland paddy tiller and yield.

RESULTS AND DISCUSSION

The improvement of soil physical properties of degraded land

The absence of difference between physical properties of degraded land in Table 1 proves that there is an improvement in soil's physical properties due to the collaboration of mulching and worms used in the land.

Worms with 108 populations gave the best bulk density and reduced by 28%. It plays an important role in improving physical properties of degraded land by

Table 1. Improvement of bulk density of degraded paddy field upland by mulch and earthworms.

Treatment	Bulk density (gr/cm ³)
Worms	
W ₀ = none	1.27 ^d
W ₁ = 36 worms/m ²	1.17 ^c
W ₂ = 72 worms/m ²	1.10 ^b
W ₃ = 108 worms/m ²	0.99 ^a
Mulch	
M ₀ = none	1.18 ^b
M ₀ = 0.5 kg/m ²	1.15 ^a
M ₀ = 1.0 kg/m ²	1.13 ^a
M ₀ = 1.5 kg/m ²	1.0 ^{8a}

Means in the same rows followed by same letters are not significantly different at p<0.05.

Table 2. Improvement of soil water capacity of degraded paddy field upland by mulch and earthworms.

Interaction	Water content (%)			
	M ₀	M ₁	M ₂	M ₃
W ₀	19.20 ^{Aa}	28.02 ^{Ba}	32.36 ^{Ca}	33.56 ^{Ca}
W ₁	35.00 ^{Ab}	36.82 ^{Bb}	39.39 ^{Cb}	41.05 ^{Db}
W ₂	42.43 ^{Ac}	43.65 ^{Ac}	43.99 ^{Ac}	43.75 ^{Ab}
W ₃	44.76 ^{Ac}	45.62 ^{Ac}	45.11 ^{Ac}	46.91 ^{Ac}

Means in the same rows followed by same small letters are not significantly different at p<0.05; Means in the same column followed by same capital letters are not significantly different at p<0.05.

Table 3. Improvement of soil total porosity of degraded land due to interaction of mulch and earthworms.

Interaction	Total porosity (%)			
	W ₀	W ₁	W ₂	W ₃
M ₀	50.76 ^{Aa}	52.08 ^{Aa}	52.27 ^{Aa}	54.53 ^{Ba}
M ₁	55.09 ^{Ab}	55.66 ^{Ab}	56.23 ^{Ab}	56.61 ^{Ab}
M ₂	58.12 ^{Ac}	59.44 ^{Ac}	59.24 ^{Ac}	58.49 ^{Ab}
M ₃	58.11 ^{Ac}	58.68 ^{Ac}	61.89 ^{Bd}	63.20 ^{Bc}

Means in the same rows followed by same small letters are not significantly different at p<0.05; means in the same column followed by same capital letters are not significantly different at p<0.05.

decomposing organic materials and mix them with soil so as to form soil aggregates, and restore land structure.

The improvement of soil's physical properties of the degraded land is sharply marked by the soil's total pore space. The absence of difference between soil's water capacity in Table 2 proves that the both agents are able to increase the number the pore spaces in degraded land as shown in Table 3. Also, soil permeability as shown in

Table 4. Worms improves aeration system in earth due to the development of cavities and improvement of soil porosity following the restoration of land structure (Spurgeon et al., 2013). The movement of worms is very aggressive and random depending on temperature of its living environment and the need for food such as mulch. Owing to its aggressive movement, the soil became more porous. Once the soil temperatures increases, it moves

Table 4. Improvement of soil permeability of degraded paddy field upland by mulch and earth-worms.

Interaction	Permeability (cm/hour)			
	W ₀	W ₁	W ₂	W ₃
M ₀	1.12 ^{Aa}	1.15 ^{Aa}	1.51 ^{Aa}	1.65 ^{Aa}
M ₁	2.18 ^{Aa}	2.82 ^{Aa}	3.35 ^{Aa}	3.87 ^{Ab}
M ₂	4.92 ^{Ab}	7.59 ^{Bb}	10.80 ^{Cb}	13.39 ^{Dc}
M ₃	15.28 ^{Ac}	18.10 ^{Bc}	20.05 ^{Bc}	29.34 ^{CD}

Means in the same rows followed by same small letters are not significantly different at $p < 0.05$; means in the same column followed by same capital letters are not significantly different at $p < 0.05$.

to underground places of better aeration to recover oxygen from free air for breathing through skin. Worms are fond of organic materials derived from dung and plant remains. That is why they are referred to as decomposing agent that are able to service the soil function and ecosystem (Blouin, 2013) due to its ability to change organic materials into compost (Muys and Granval, 1997).

Relationship between soil physical improvement to the paddy's tiller and yield

The influence of the improved soil's physical properties on the productive tillers is shown by the following regression-correlation equation:

$$Y = 2.52 + 4.55_{BD} + 0.54_{TP} + 0.01_{PER} + 0.60_{WC} \quad (r = 0.73 \text{ and } R^2 = 0.54)$$

This statistics shows that the improved soil's physical properties have significantly influenced the tiller production in the degraded land. The tiller production is due to the significant increase in proportion of the needed soil's components such as water, air, minerals and organic materials.

The improvement of soil's physical properties by reclaiming the degraded land using bio-agents of banana leaf such as mulch and earth-worms leads to an increase of paddy yield as depicted by the following equation:

$$Y = 27.79 + 1.20_{BD} + 0.20_{TP} - 0.04_{PER} + 0.03_{WC} \quad (r = 0.85 \text{ and } R^2 = 0.72)$$

Earth-worms make burrows or cavities in the earth by pushing earth masses or eating them (Abbot, 1989). The burrows or cavities developed are used not only to nullify earth pressure on its body during motion, but to store food and digest it as well (Edwards and Bater, 1992). Viert (1989) showed that burrow in soil of 0.80 cm in diameter developed by *Lumbricus* can join the A and subsoil horizons. Having been digested, foods are partly

secreted as solid waste. Edwards and Bater (1992) showed that most of the minerals digested by *Lumbricus* are returned into the soil as useful waste with high nutrients. Production of solid waste depends much on species and monsoon. Healthy population of earth-worms can produce 100 tons/ha/year. Edwards and Bater (1992) cited that *Lumbricus* can perforate soil body vertically downward and upward as deep as one meter so as to allow water to permeate in greater volume, reduce the velocity of surface runoff and in turn prevent surface erosion. *Lumbricus* improves aeration system in earth due to the development of cavities and improvement of soil porosity following the restoration of land structure (Alaoui et al., 2011). Earth-worms can present a better aeration system for the growth of crops roots, particularly when soil moisture is high enough. Total earthworm density and biomass were strongly correlated with each other and positively associated with soil moisture (Crusmey et al., 2014). In the presence of high moisture, the absorption of nutrients by parts of the plants will run easily. The optimal moisture for *Lumbricus* to grow well is 15 to 30%. Earth-worms will die when exposed directly to sun light or living in a hot environment (Mele and Carter, 1999). When its living environment gets hot, it always moves to moister environment in order to survive. Sawdust is so far of great use to maintain the optimal moisture of the soil, intensify the action of earth-worms in improving physical properties of the soil, restore the fertility of soil and maintain the presence of the groundwater (Beven and Germann, 2013). Sawdust can be served as well as food resource for earth-worms.

Lee (1985) showed that *Lumbricus* has an ability of perforating the soil body to a depth of 1 m to make water permeate easily in greater volume, reduce the velocity of surface runoff, lessen the possibility of land erosion and increase underground water content. The sowing of 0.5 g of live *L. terrestris* and *L. rubellus* on 1 kg soil significantly increase 25% dry weight of crops and harvest.

Conclusion

Banana leaf mulching and earth-worms restore the

degraded land by improving some of its physical properties such as bulk density, total porosity, permeability and water capacity. The improvement of soil's physical properties by the two bio-agents has significantly improved both tiller and yield of the degraded paddy field.

Having healthy soil fauna populations is beneficial to the soil. Developing a restoration project requires analysis of the resource to determine the level of degradation and amounts of site preparation necessary for reclamation. The literature examined did not have extensive information on pre-degradation site conditions, including the species of invertebrates present and ground cover. Having this information could give planners an indication of abundance and diversity of species adjacent to the site. These species have the potential of dispersing the site.

Restoration projects require follow up evaluations to determine the success of colonization. Documentation of successes and failures can help future restoration projects succeed.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Irregular migration and smallholder farmers' crop production: A case of Kasulu District, Tanzania

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Despite the fact that irregular migrants (IRMs) have often been facing a lot of challenges in sustaining their livelihood in Kasulu District, in recent years, there has been an increase of IRMs from within and outside Kasulu District in search of casual labour in the local communities. The study therefore was undertaken in four villages in Kasulu, Kitanga, Kagera-Nkanda, Mvugwe and Nyachenda to determine the contribution of IRMs to the growth and prosperity of smallholder farmers. Specifically, the study aimed to; compare agricultural productivity among farming households employing IRMs and those not, identify smallholder farmers' reasons for employing or not employing IRMs and identify problems/issues in relation to smallholder farmers and IRMs interaction. A cross-sectional research design was adopted for the study in which simple random sampling, purposive and snowball sampling techniques were employed to select a sample size of 120 respondents. Data were collected using a variety of methods, that is, a questionnaire, key informant interviews, focus group discussions and direct observations. Quantitative data were analysed using statistical package for social science (SPSS) whereby descriptive statistics were determined. In addition, gross margin analysis was done to determine farmers' maize and beans production profitability. Qualitative data were analysed using content analysis. Generally, results show that households employing IRMs recorded a higher productivity both for maize and beans: The households also recorded significantly higher gross margins for both crops. Nonetheless, the results also show existence of a general negative attitude to IRMs by farmers in the study area. It can therefore be concluded that employment of IRMs is benefiting the households involved. However, based on the negative attitude by most of the surveyed households, there is need for the relevant authorities to ensure the well-being of both the recipient communities and that the IRMs are maintained. In addition, there is a general need for education for both the recipient communities and the IRMs with regard to the right procedures to be followed by migrants under the international law.

Key words: Irregular migration, agricultural production, smallholder farmers.

INTRODUCTION

Irregular migration is common all over the world. Available literature on irregular migrants (IRMs) describes irregular migration as a common and necessary feature

of modern life which is universally acknowledged and has extensively contributed to the development of different societies worldwide in the form of farm cheap labour

(Mattsson, 2008). However, studies on irregular migration are constrained by inaccurate data (Mouaatamid, 2010). According to literature (UN DESA, 2013) as cited by UNHCR (2015) there are an estimated 232 million international migrants in the world. However, due to difficulties of accurately estimating the number of Irregular migrants (IRMs) (IOM, 2015) the most recent global estimate of irregular migration suggests that in 2010 there were at least 50 million irregular migrants worldwide most of whom were a result of smuggling services.

According to the UNHCR (2016) as cited by UNHCR (2017) at the end of 2015 the world was hosting 21.3 million refugees, 16.1 million of whom were under UNHCR's mandate and 5.2 Palestinian refugees under the United Nations Relief and Works Agency (UNRWA). Generally, literature on IRMs shows that strict barriers on legal entry of irregular migration have been placed by many states worldwide. Despite the above, a large number of irregular migrants in different countries are used as cheap labourers (Aggarwal et al., Undated). According to Triandafyllidou and Maroukis (2012: 8), the research and international organization expert circles when talking of "irregular migration" prefer to denote a form of migration that is "not regular", "unlawful" or not according to the rules (without necessarily being "illegal", "illicit" or "criminal" in the legal sense). Therefore an "irregular migrant" is a migrant who, at some point in his migration, has contravened the rules of entry or residence.

Tanzania has a long porous border with eight surrounding states. All of these neighbouring states have at one point or the other experienced conflicts which have produced refugees. As a consequence of the aforementioned conflicts many IRMs fled and decided to reside in Tanzania. Generally, the easy entrance in to Tanzania by the IRMs has mainly been due to as mentioned earlier the porous nature of the country's border and the high degree of cultural affinity within 'The Great Lakes Region'. All the above have made irregular migration within the region an easy prospect (URT, 2010). Due to the above and Tanzania economic conditions it has been extremely difficult for the country to effectively control activities happening outside the formal entry points. As a consequence, the country is extremely vulnerable to irregular migration from the neighbouring countries of Burundi, Rwanda and the Democratic Republic of Congo (IOM, 2010; Mouaatamid, 2010).

Since 1972, following the civil war in Burundi about 300,000 Burundians were estimated to have spontaneously settled in Tanzanian villages along the border between Tanzania and Burundi. These are the

refugees who either lived/live in the local villages or get out of the refugee camps irregularly for several years, very often without formalising their stay, working and movement status (Jennifer, 2007; Johnson, 2008). Existing literature (URT, 2010) explicitly shows that, irregular migration in Tanzania is not simply a concern for only those who come into the country, but also those who exit from the refugee camps and for those who refuse to leave the country. It has also been stated that, some of these IRMs have established their own homes, are owning or renting land and are involved in farming as casual labourers, livestock keepers, rendering human labour to farmers in the rural areas, and others are married to Tanzanians without legal documents that allow them to engage in the mentioned activities (URT, 2010). Furthermore, discussions on irregular migration in Tanzania have become fundamentally tied to the management and control of IRMs, as the country's migration laws do not allow these IRMs to engage in paid or unpaid employment or staying in the country without legal documents from the relevant authorities (Johnson, 2008).

From the economic perspective literature shows that, irregular migration is actually quite useful in many states of destination as liberalisation of economies does in one way or another lead to demand of various forms of skilled and semi-skilled labourers, from which irregular migration becomes a potential source (Ruark, 2010; Wheaton et al., 2010). However, IRMs have often faced a lot of challenges in their livelihood activities in Kasulu District; these include provision of hard labour in agricultural related activities, being subjected to deportation, harsh treatment and receiving poor remuneration in return (Mouaatamid, 2010; URT, 2010).

Despite the existence of the aforementioned challenges on irregular migration, Kasulu District has been experiencing an increase of IRMs from within and outside the district searching for casual employment in the local communities (URT, 2010; Mouaatamid, 2010). Nonetheless, existing literature on irregular migration in Tanzania has limited information on IRMs, as it does not explicitly provide empirical evidence on the IRMs' contribution of labour to the agricultural production of smallholder farmers. This inadequacy is a prime constraint to a better understanding of IRMs interaction with local smallholder farmers in the study area. Therefore, the study on which the paper is based aimed at determining the contribution of IRMs to agricultural production of smallholder producers in Kasulu District, Kigoma region. Specifically, the study aimed to; compare agricultural productivity among farming households employing IRMs and those not, identify smallholder

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farmers' reasons for employing or not employing IRMs and identify problems/issues in relation to smallholder farmers and IRMs interaction. The main driving questions for the paper are, what benefits if any do smallholder farmers get by using irregular migrants compared to those not using them? And how are irregular migrants and smallholder farmers affected in relation to their interaction? To answer the above questions the paper use maize and beans production as illustrations.

RESEARCH METHODOLOGY

Description of the study area

Kasulu District is one of the four districts of Kigoma Region; it comprises seven divisions with 30 wards divided into 92 villages and covers approximately 9,324 km². The district borders Burundi to the West for about 150 km of porous land border, a large game reserve (Moyowosi) to the East. To the North-East it shares borders with Kibondo District and Kigoma District is to the South. The study was carried out in five wards namely Kitanga, Nyamidaho, Kagerankanda, Nyachenda and Kitagata. Kasulu District was selected because it hosts both irregular migrants (IRMs) who are estimated to be over 15 000 (URT, 2010). In addition, the district has been home to refugees since 1972, most often these refugees have been moving and working from one village to another without legal documents allowing them to travel, stay or work while in Kasulu. The district has also been hosting the 1993 cohort of refugees who are still living in refugee camps and unwilling to repatriate voluntarily to Burundi. These refugees have also been observed moving out of their camps to nearby villages in search of employment as casual labourers despite their status not allowing the same in accordance to the international law governing refugees.

Kasulu District's main economic activity is agriculture (that is, crop and livestock production). These activities are in most cases conducted in typical rural areas where the majority of its inhabitants, the Ha people make their living from small-scale farming. However, they do also engage in hunting, fishing, petty trade, honey gathering and pit lumbering. Although not all households have domestic animals, about 90% of the population is engaged in shifting cultivation. Most households grow maize, cassava, beans, millet, sorghum and sweet potatoes for food; and ground nuts, oil palm and tobacco as cash crops. All these crops are grown in the lowlands along with bananas and coffee in the highlands (KDC, 2010). Kasulu District has an estimated 12,000 km² of land out of which 6,606 km² or 70.8% of the total area is arable. Out of the arable land, only 30% is actually utilised which means there is a wide room for agricultural expansion. In addition, the district has 10,150 ha of irrigated land of which only 5% is currently being utilised. However, adoption of modern farming practices in the District is still low resulting into low agricultural productivity per unit of land area (that is, kg/ha) (KDC, 2010).

According to the 2012 Population and Housing Census (URT, 2013), Kasulu District had a total population of 425 794 (20% of Kigoma region's population). Out of this, 207,794 were males and 218,373 were females. The population growth rate was estimated to be 2.4 annually. The main ethnic group in Kasulu District is the Ha people who are the native in the area. The population is largely influenced by long term IRMs estimated to be over 12,000 (URT, 2010). The rest of the population in the District are the registered and unregistered refugees from the DRC and Burundi. The district has in recent years experienced the scaling down of refugees and refugee camps. Currently, only the Nyarugusu refugee camp is operational out of the three that were there initially, the camp has a total of 60,345 refugees. However, some of these refugees are

returning voluntarily to their countries, nonetheless others have become IRMs offering cheap labour within Kasulu District (URT, 2010).

Research design, sampling and sample size

The study adopted a cross-sectional research design; the design was the most appropriate for the study on which the current paper is based. Generally, the design is less costly and allows one to collect the required data in a relatively short period of time. According to Bryman (2012), the design is useful for descriptive purposes as well as for determination of relationship between and among variables and it allows a researcher to collect data at one point in time. The study's population included all IRMs (non-citizens) employed by smallholder farmers in the studied villages (Kitanga, Nyamidaho, Kagerankanda, Nyachenda and Kitagata), smallholder farmers who employ the IRMs and those who did not.

According to Bryman (2012), the minimum sample or sub sample for a research generally depends on a number of factors such as time and cost and need for precision increasing as one increases the sample size e.g. from 50, 100, 150 and onwards. Based on the above, the study used 120 respondents from four villages. To obtain the above sample, a combination of three different sampling techniques, was adopted, that is, purposive sampling, simple random sampling and snowball sampling. Purposive sampling was used in selecting two divisions out of the available seven, four wards out of thirty and four villages out of ninety, all the above have a high number of IRMs. Key informants and participants to focus group discussions were selected purposively. Simple random sampling was used to get the respondents from the households employing IRMs in agricultural production and those not. Snowball sampling was used to get prominent IRMs who were living and employed by smallholder farmers as cheap labourers but who were hard to find through purposive and simple random sampling as they did not stick with one farmer in one place.

Data collection

Data were collected using a pre-structured questionnaire with open and close ended questions. Generally, before the actual household survey a pilot study to pre-test the questionnaire was undertaken in three villages after getting the required clearance from Sokoine University of Agriculture, the District Commissioner's Office and from the Village governments'. The pilot aimed at testing the reliability and validity of the data collections tools in terms of precision, objectivity and relevancy. Based on the findings, some revisions were made to remove ambiguous questions and add new ones which were relevant for the study. In addition, the questionnaire and key informant interview checklist were translated from English into Kiswahili to allow easy communication. Generally, the research adhered to ethical considerations whereby participation was on a voluntary basis and respondents were assured of their anonymity in relation to the information shared. In addition to the above, data collected through the questionnaire were complemented by information collected through direct observations, in-depth interviews with key informants and the focus group discussions (FGDs). All these aimed at allowing triangulation of the study findings. Overall, five FGDs were conducted; these normally involved eight participants each and 16 in-depth interviews were conducted, four for each village. The key informants for the in-depth interviews included village leaders, extension officers, teachers, land officers, forest officers, immigration officers, refugees' officers, auxiliary police, militia personnel, and IRMs.

Data collected were used to determine descriptive statistics, determination of gross margins in relation to maize and beans production and to test for differences between smallholder farmers

employing IRMs and those not. In addition, data collected through the questionnaire were complemented with information collected through direct observations, in-depth interviews with key informants and FGDs. All the facts were linked to smallholder farmers maize and bean production, IRMs and their interactions with the host communities.

Data analysis

The study's unit of analysis was the household. Descriptive and gross margin analysis was employed to analyse quantitative data. Generally, quantitative data from the questionnaire were collected, edited, summarised, coded and thereafter analysed by using the statistical package for social science (SPSS). SPSS was used to determine descriptive statistics, that is, frequencies, percentages, standard deviation and means, minimum, maximum, cross tabulation. In addition, the Likert scale was used to determine the smallholder farmers' attitude towards IRMs. A t-test was employed for specific objective number one to determine whether there was a significant difference between the means for cost of production, yield (kg/ha), gross revenue (GR) and gross margin (GM) between smallholder farmers employing IRMs and those not.

The gross margin analysis

Gross margin (GM) analysis as a tool for quantitative data analysis was used to address objective number one. The GM analysis aimed at determining differences in the profitability of smallholder farmers using irregular migrants and those who were not using them.

$$GM = \sum Tri - \sum TVC$$

Where: GM = Gross Margin (gross profit) of crop production in Tsh/kg; $\sum Tri$ = Sum total revenue from sale of crop production in Tsh/kg; $\sum TVCi$ = Sum total variable cost spent on crop production in Tsh/kg.

Analysis of qualitative data

The qualitative data were analysed using content analysis the qualitative information collected through the key informant interviews and FGDs was into meaningful themes. Generally, the qualitative information has been used in this paper to complement what was collected through the questionnaire.

RESULTS

Socio-economic and demographic characteristics of the respondents

Demographic characteristics of respondents are essential for the interpretation of findings and understanding of the results of this study. This sub-section provides socio-economic and demographic characteristics of the respondents contacted as shown in Table 1. These include respondents' sex, age distribution, marital status and household size, household heads main occupation and education level. Results in Table 1 show that the majority of all the three groups, that is, households employing IRMs, those not using IRMs and IRMs were

headed by males the remaining proportion were headed by females. Results in Table 1 further show that less than a quarter, and over a third of the smallholder farmers who employed IRM, those not hiring IRM, and the IRMs respectively were living as singles: The majority of those employing IRMs were married. Results in Table 1 further show that the majority of households employing IRMs had a household size of four members and above.

Profitability of maize and bean production between smallholder farmers

To compare profitability among farming households employing IRMs and those not gross margin (GM) analysis for maize and beans production was done. The purpose of the gross margin analysis was to determine the value in relation to cost incurred. Generally, the margin on sales represents a key factor behind many of the most fundamental business consideration, including budgets and forecasts. Table 2 shows that smallholder farmers employing IRMs got a relatively higher GM for both maize and beans. For maize, the GM was 926 925 Tsh (Tanzanian shillings) and 289 200 Tsh for smallholder farmers employing and those not employing IRMs respectively. As regards beans production, the GM was 924 375 and 223 170 Tsh for the two groups respectively. Table 2 also shows smallholder households employing IRMs also recorded higher total revenues than those not.

In order to test whether a statistically significant difference existed in relation to the productivity (kg/ha) and profitability (gross margins) for maize and beans between farming households employing and those not employing IRMs a t-test was run. The t-test results Table 3 show that both productivity (that is, for maize and beans) and gross profit margin significantly ($p = 0.000$) differed between farming households employing IRMs in their farming operations and those not.

Reasons for employing irregular migrants

Smallholder farming households provided a variety of reasons for employing IRMs as shown in Table 4. The major reasons as reported by 20% and above were IRMs are easily found, IRMs are diligent workers and they are cheap to hire compared to local labourers. The above is further supported by what was pointed out during the FGDs and key informant interviews that; the majority of IRMs are paid cheaply compared to local labourers who were reluctant to take low pay hence demanding higher wages.

Reasons for not employing irregular migrants

Smallholder farmers not employing IRMs had several

Table 1. Respondents demographic characteristics (n=120).

Characteristic		Smallholder farmers employing IRMs (n _E = 40)	Smallholder farmers not employing IRMs (n _{NE} = 40)	Irregular migrants (n _{IRM} = 40)
Respondent's sex	Male	35 (87.5)	31 (77.5)	34 (85.0)
	Female	5 (12.5)	9 (22.5)	6 (15.0)
Age categories	15- 25	3 (7.5)	1 (2.5)	5 (12.5)
	26 -36	10 (25.0)	9 (22.5)	17 (42.5)
	37- 47	16 (40.0)	17 (42.5)	11 (27.5)
	>47	11 (27.5)	13 (32.5)	7 (17.5)
	Not married	9 (22.5)	28 (70.0)	28 (70.0)
Marital status	Married	29 (72.5)	11 (27.5)	11 (27.5)
	Divorced	2 (5.0)	1 (2.5)	1 (2.5)
Household size	1-3	5 (12.5)	10 (25.0)	25 (62.5)
	4- 7	17 (42.5)	14 (35.0)	10 (25.0)
	8 and above	18 (45.0)	16 (40.0)	5 (12.5)
	Minimum	2	2	1
	Maximum	13	12	8
	Average	7.15	6.65	3.25
	Main economic activity	Farming	31 (87.5)	34 (85)
Charcoal making		1 (2.5)	1 (2.5)	2 (5)
Logging		4 (2.5)	1 (2.5)	5 (12.5)
Farming		31 (87.5)	34 (85)	32 (80)
Charcoal making		1 (2.5)	1 (2.5)	2 (5)
Education level	No formal education	8 (20)	7 (17.5)	33 (82.5)
	Primary education	26 (65)	28 (70)	6 (15)
	Secondary education	6 (15)	5 (12.5)	1 (2.5)

n_E: Number of smallholder farmers employing IRMs, n_{NE}: number of smallholder farmers not employing IRMs; n_{IRM} = number of IRMs and numbers in brackets indicate percentage.

Table 2. Profitability of household's crop production based on employment or non-employment of IRMs (n=80).

Crop		Smallholder farmers employing IRMs (n _E = 40)		Smallholder farmers not employing IRMs (n _{NE} = 40)	
		Mean	Range	Mean	Range
Maize	Yield (Kg/ha)	3,238.50	1,000 - 5500	1,266.75	600-2,100
	Total cost (Tsh)	383,975	30,000 - 700,000	217,000	120,000 - 350,000
	Total revenue (Tsh)	1,310,900	400,000 - 2,200,000	506,200	240,000 - 840,000
	Gross margin (Tsh)	926,925	166,000 - 157,5000	289,200	40,000 - 610,000
Beans	Yield (Kg/ha)	1,937.5	600 - 4,000	636.75	100 - 1,200
	Total cost (Tsh)	238,125	100,000 - 520,000	158,700	20,000 - 290,000
	Total revenue (Tsh)	1,162,500	360,000 - 2,400,000	381,870	60,000 -720,000
	Gross margin (Tsh)	924,375	240,000 - 2,010,000	223,170	20,000 -500,000

reasons, the major ones (that is, those pointed out by 20% and above) included, fear of being arrested and detained for employing IRMs, scarce and limited resources at household level (that is, lack of cash), and the criminal acts committed by IRMs other details are as presented in Table 5. In support of the above, FGD

participants argued that there was a lack of concrete evidence of the effect of irregular migration on agricultural production among the smallholder farmers employing them. In addition, others claimed that life hardship among smallholder farmers' specifically scarce and limited resources at household level for example money for their

Table 3. t-Test results for productivity (kg/ha) and profitability (gross margins) for maize and beans between farming households employing and those not employing IRMs.

Variable		Average	t-test value (df = 78)	P value
Maize productivity (kg/ha)	Farming households employing IRMs	3,238.5	11.833	0.000
	Farming households not employing IRMs	1,266.75		
Bean productivity (kg/ha)	Farming households employing IRMs	1,937.5	4.387	0.000
	Farming households not employing IRMs	636.75		
Gross margin profit (Tsh) for maize	Farming households employing IRMs	926,925	6.54	0.000
	Farming households not employing IRMs	289,200		
Gross margin profit (Tsh) for beans	Farming households employing IRMs	924,375	9.942	0.000

Table 4. Reasons for employing irregular migrants (n=40).

Influence for employing IRMs (n _E = 40)	Frequency	Percentage
Irregular migrants are cheaper (lowly paid)	10	25
Reluctance of locals' labourers to take low paid jobs	4	10
Irregular migrants are easily found	8	20
Irregular migrants are diligent workers	10	25
Irregular migrants are ready to reside anywhere	7	17.5
Missing value	1	2.5

Table 5. Factors for not using irregular migrants (n=40).

Reason for not using IRMs (n _{NE} = 40)	Frequency	Percentage
There is no sustainability on agricultural productions	4	10
Scarce and limited resources at household level	11	27.5
Criminal conducts done by irregular migrants	10	25
Avoid arrest and detention.	8	20
No production difference noticed for farmers employing IRMs	7	17.5

wages funds and food to feed them. In addition, some argued that they did not have the necessary capital for extension of their farming land hence; there was no justification for employment of IRMs. Further to the above-mentioned, during the FGDs it was also revealed that the natural resource destruction and the rise of criminal acts such as theft, banditry, carjacking, poaching and rape restrained smallholder farmers from employing IRMs. FGD participants also claimed that, their hesitation to employ IRMs was to avoiding pressure and disturbances that had been experienced in the past in relation to engagement with IRMs.

Kind of irregular migrants employed by smallholder farmers in Kasulu District

Study results (Figure 1) show that farming households in Kasulu district employed both long and temporary IRMs

with the majority (62.5%) of those employed working on a temporary basis.

Time spent in Kasulu for employed irregular migrants

The findings in Figure 2 show that more than three quarters of the IRMs interviewed and who were employed as cheap labourers had stayed in Kasulu for not more than five years while a fifth had spent six to ten years working as cheap labourers and a negligible proportion of the respondents were those termed as long term IRMs.

Issues of concern on smallholder farmers' interaction with IRMs

The third objective of the study was to identify both smallholder farmers and IRMs concerns due to their

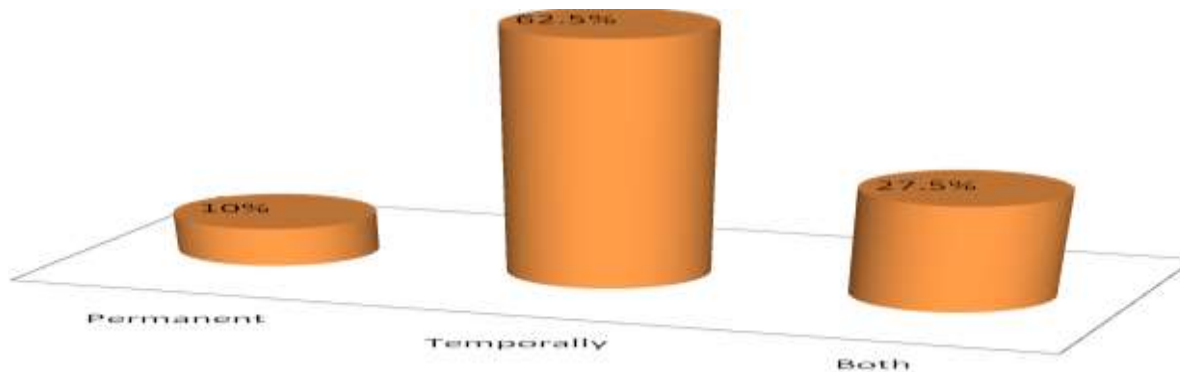


Figure 1. Category of irregular migrants' employed by smallholder farmers.

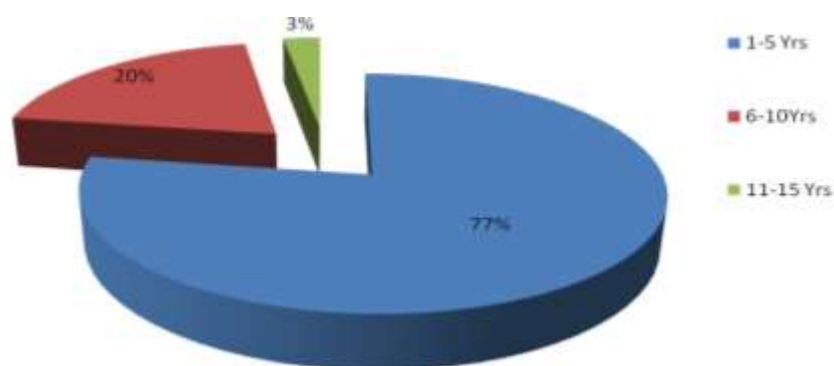


Figure 2. Time spent by irregular migrants in Tanzania.

Table 6. Issues around Kasulu smallholder farmers interaction with IRMs (n= 40).

Issue around IRMs and smallholder farmers interaction	Frequency	Percentage
Lack of technical assistance.	26	65.0
lack of permanent residence for irregular migrants	28	70.0
Theft and robbery	31	77.5
Conflict on land ownership	18	45.0
Arrested and detained in prison	14	35.0
Reduce labour market	18	45.0
Farmers become lazier	29	72.5
Lack of grants	28	70.0

interaction. Various issues of concern in relation to the smallholder farmers' interaction are presented in Table 6. Generally, about two thirds of the respondents said that they have no access to various programs related to agriculture specifically, on technical assistance. The results also show that most of the respondents reported lack of permanent residence for IRMs as another setback in their agricultural activities. The lack of permanent residence was also a major concern of the FGD participants who argued that this makes it hard for them

to trace the IRMs especially when they do not accomplish the task agreed upon.

In addition to the above, more than three quarters of the surveyed respondents argued that theft and robbery committed by IRMs was among the problems constraining their interaction with IRMs. According to the results, conflict on land ownership between smallholder farmers and IRMs was another concern reported to affect IRMs' interaction with smallholder farmers in Kasulu District, this was pointed out by under a half of the

respondents. Other reasons include fear of being arrested for breaking the law hence possibility of imprisonment, reduced labour market for the locals, and smallholder farmers have becoming lazier (Table 6). The above-mentioned concerns conform to what the FGD participants pointed out therefore suggesting a commonality of issues around smallholder farmers' interaction with IRMs.

DISCUSSION

Socio-economic and demographic characteristics of the respondents

Household headship

In Tanzania, currently female household-s account for 24.5 (MoHCDGEC et al., 2016). According to the results presented in Table 1, most of the respondents were in the productive age category thus suggesting they were economically active in pursuit of their households well-being. According to URT (2014) those aged 15 to 64 years are seen as economically active: an individual's age influences his/her productivity and the same can explain the level of production and efficiency. Generally, children and the old tend to be less active in economic activities than those in the middle ages who are more active, aggressive and motivated by the needs of their families.

Marital status

The observation that most of the surveyed households were married (Table 1) is in line with what has been reported by URT (2014) that 53% of Tanzania's rural population are in marriage union. However, when the number of individuals living together (co-habiting) is added then the above rises to 60%. Generally, through marriage households are able to get children: at times such households live with relatives from both sides who may either be requiring or offering assistance and this could lead to having a large household. As a consequence of the above, such households may need to employ cheap labour in form of IRMs so as to increase production for the increased requirements in terms of food and other necessities.

Household size

The observation that the majority of households employing IRMs had a household size of four members and above is not surprising. According to NBS (2013), Tanzania mainland's average household size is 5. Nonetheless, the fact that 45% of this group had a

household size of 8 and above may explain why such households needed the IRMs. Generally, with more mouths to feed one needs to increase production and more so if a household relies on own food production. In addition, households will need to raise their overall production to allow for their own consumption and surplus to be marketed to raise income to cover other household needs. According to URT (2013), the size of the household can be a burden particularly when it is composed of many dependants compared to working individuals. This sometimes leads to need for more funds to meet the household's needs with regard to purchasing of food, and other basic social needs thus, the need for more cheap IRM labour. Overall, average household sizes for households employing IRMs and those not were higher than that of the IRMs.

Households' main occupation

Agriculture was the main economic activity of the surveyed respondents: This was the main livelihood strategy for more than four fifths (Table 1). Apart from farming activities, both categories of smallholder farmers were engaged in non farm activities as an additional income source. The study's observation is consistent with the KDC (2010) profile which estimates that about 90% of the local communities are engaged in agricultural activities for their livelihood. Further to the above, farming activities were also a major livelihood strategy for the majority of IRMs; these were engaged mostly as casual labourers. Generally, the IRMs situation could be due to the fact that they neither have capital nor other alternatives to legally earn a living with their current status. This observation is in line with Finnwatch (2016) who pointed out that the majority of IRM workers rely on their employers for their continuing stay in an alien country.

Education level

Literacy level is very useful for smallholder farmers and IRMs. Those with better education may easily be able to grasp and implement whatever skills that are provided to them such as using modern technology in agriculture and employment in general. Contrary to the study's prior expectation that illiteracy rate was very high in rural areas study results (Table 1) show that most of the respondents were literate both those employing and those not employing IRMs. Nonetheless, those with secondary school education were relatively fewer. As regards the IRMs, the majority lacked formal education which suggests a general lack of employable skills which could enable them to be absorbed in the formal job market; only one had secondary school education. Smallholder Farmers' Agricultural Production based on employment

or non-employment of IRMs.

Profitability of maize and beans production between smallholder farmers

Based on study findings (Table 2), it can be said that in addition to the IRMs contribution to Tanzania's economy farm households employing them are also enjoying relatively higher gross margins in both their maize and beans production. A similar observation has been reported in literature (Ruark, 2010; Wheaton et al., 2010) that due to the need for firms and employers to maximize profits there has been a tendency to rely on immigrants as the source of the least expensive labour. Generally, in Kasulu smallholder farmers' use of cheap IRMs labour enables them to reduce production costs allowing them to expand their farms, create food surpluses, increased incomes from crop sales, hence general improvement of their households living conditions. In addition, during the FGDs, participants pointed out that employment of IRMs in their area has increased both production in addition to creating new local markets and trade links between smallholder farmers and IRMs. As a result of the above facilitates and motivates more labour mobility to Kasulu. According to Whitaker (2002) increase in production and the size of the local common markets does boost business and trade activities conducted by both hosts and IRMs in the areas used to host refugees.

Reasons for employing irregular migrants

Smallholder farming households had a variant of reasons for employing IRMs as shown in Table 4. Of major interest is IRMs are cheap to hire compared to local labourers. The above finding is in line with Ruark (2011) who argues that under normal market economy conditions most producers will not go for labourers demanding higher wages when cheap ones are available. Generally, based on their legal status IRMs have very limited choice hence their proneness to exploitation making them part of the millions of vulnerable workers employed in the informal economy worldwide. The above is further supported by what was pointed out during the FGDs and key informant interviews that; the majority of IRMs are paid cheaply compared to local labourers who were reluctant to take low pay demanding higher wages. Moreover, most disliked being employed in boring and tedious jobs such as farming compared to the IRMs therefore, providing room for IRMs to secure jobs easily. Additionally, IRMs are regarded as diligent workers who accomplish their assigned task on time. Furthermore, IRMs are generally ready and willing to live alone, in a family or with fellow IRMs within or near the farms regardless of distance from where their employer lives. The above is particularly important as smallholder

farmers in Kasulu still practice shifting cultivation and at times the farms are located far from the main villages.

During the FGDs, it was also observed that, employment of IRMs was being done by most villagers and that, some of those who do not employ IRMs were jealous over the success made by those employing IRMs; hence, indirectly being forced to employ IRMs. In addition, IRMs take the kind of jobs that native-born citizens could not. According to the FGDs it was revealed that the kind of verbal contracts (normally verbal) entered between smallholder farmers and IRMs encouraged the former to employ the latter. Generally, two kinds of oral contract were identified. First, was the short term contracts whereby IRMs have to participate in preparing part of the farm, for example bush clearing, planting and weeding, after which they were paid and off they went. The second, was that which required the IRMs to prepare the farm from the beginning of the season until harvesting and sale of crops; after this, they were paid and departed or could decide to renew the contract for another season. According to the study's observation, the latter has been the preference of many smallholder farmers since it does not need a lot of capital. Generally, payment was not based on acreage rather IRMs were required to remain on the farm the whole season. In addition, no limit of farming land was given but a fixed payment ranging between 250,000 and 450,000 Tsh per season. Smallholder farmers were only required to have enough land for cultivation, food to feed them and a stipend to last up to the harvest season and not necessarily housing; most of the IRMs lived in grass thatched houses/huts built near the farms.

Through the FGDs and face to face interviews, it was observed that the study area had long term IRMs who fled to Kasulu for various reasons since the 1970s. And because of this and their continued connection with their kinship and social networks ties in Burundi more IRMs have been attracted from Burundi to Kasulu in search of employment. It was also reported by FGD participants that the employment acquired by IRMs as cheap labourers has contributed to the economy of their households both within Kasulu and for their fellow Burundians outside Kasulu District. The money earned from working as cheap agricultural labourers has further encouraged new IRMs to cross the border in search of casual work. In connection to the above, during the field study a maize milling machine bought by an IRM was observed suggesting that some IRMs may be doing quite fine income wise despite the low wages they get. Ownership of such property by IRMs attracts other IRMs from Burundi in search of similar jobs and success. It was also highlighted during key informant interviews that lack of comprehensive farmer support services by the government and NGOs working in the district, such as, effective extension services, use of modern farming technologies such as tractors, inappropriate and often inefficient planning were also identified as reasons for

employing IRMs hoping that by employing IRMs smallholder farmers can expand both the size of the farms therefore more production and hence, profit.

Reasons for not employing irregular migrants

Smallholder farmers not employing IRMs had several reasons as shown in Table 5 are generally in line with what has been reported elsewhere. For example, Sunpuwan and Niyomsilpa (2015) have reported that in Thailand, refugees and migrants from neighbouring Myanmar have been negatively perceived and blamed for deforestation due to being hired as loggers and also due to competition for collective resources such as bamboo shoots, mushrooms and firewood. In support to the concerns raised in Table 5 FGD participants argued that there was a lack of concrete evidence of the effect of irregular migration on agricultural production among the smallholder farmers employing IRMs. In addition, others claimed that life hardships among smallholder farmers' specifically scarce and limited resources at the household level for example money for their wages and food to feed them were the main reasons for not employing IRMs. In addition, some argued that they did not have the necessary capital for extension of their farming land hence, no justification for employment of IRMs.

Further to the aforementioned, during the FGDs it was also revealed that the natural resource destruction and the rise of criminal acts such as theft, banditry, carjacking, poaching and rape restrained smallholder farmers from employing IRMs. FGD participants also claimed that, their hesitation to employ IRMs was to avoid pressure and disturbances that had been experienced in the past in relation to engagement with IRMs. The study's findings are in conformity with Sunpuwan and Niyomsilpa (2015) who have reported that Thai citizens have pointed out that migrants or refugees posed a threat to their physical and economic well-being, life and property, and human safety. In particular non-registered migrants were seen as the biggest threat.

Kind of irregular migrants employed by smallholder farmers in Kasulu District

The study's findings (Figure 1) generally show that most smallholder farmers employed IRMs on a temporary basis; however a few were employed on a more permanent basis. The above was mainly due to the fact that long term IRMs residing in particular villages dislike being employed as cheap labourers hence, the employment of temporary IRMs. In addition, an exercise for closing refugee camps (mass deportation of irregular migrants which took place under "Operation Kimbunga" in 2013 (IOM, Undated) and ongoing repatriation of Burundians refugees made those refugees who did not

want to be repatriated to Burundi to flee the camps and integrate into the local communities. According to Gambagambi (2015) the long and porous nature of Tanzania's border makes it very challenging to manage mixed migration hence, large flows of persons, including irregular and "mixed flows," moving across regions and national borders. The above makes it easy for smallholder farmers to hire more IRMs to fill the gap left by permanent IRMs. Further, FGD participants had mixed opinions whereby they argued that though they were employing temporary IRMs, permanent/long term IRMs were better as they were more trustworthy and could easily be traced. The above suggests that after being in contact with IRMs for a long period some social bonding normally takes place making it easy for a win-win situation for both the employer and the IRM.

Time spent in Kasulu by employed irregular migrants

The findings presented in previously show that more than three quarters of the employed IRMs had stayed in Kasulu for not more than five years and a few had been in the area for six to all working as cheap labourers. From the study's findings it is easy for one to conclude that most of those who are employed as cheap labourers in Kasulu are temporary IRMs who come on irregular basis either directly from Burundi or from the refugee camps. Responding on how they managed to reach Kasulu, IRM FGD participants pointed out that some of them were quite familiar with Kasulu and that this was based on their initial experience as refugees in the designated camps making it easy for them to enter the communities. Others, especially those coming directly from Burundi said they normally get assistance from some Tanzanians who go to their areas of origin in search of cheap labourers; their hosts then teach them on how to evade security checks along the borders due to their lack of valid international travel documents. Further to the above, the FGD participants also pointed out that some IRMs are brought by their fellow Burundians who are familiar with Kasulu.

Issues of concern on smallholder farmers' interaction with IRMs

Generally, the observation that theft and robbery committed by IRMs was among the problems constraining their interaction with IRMs is in conformity to claims made elsewhere as per literature. For example, issues of competition for resources (in particular land) have been cited as one of the things concerning host communities when it comes to migrants (Crush and Ramachandran, 2010). Other reasons include fear of being arrested for breaking the law hence possibility of imprisonment, reduced labour market for the locals, and

smallholder farmers becoming lazy (Table 7). The aforementioned concerns conform to what the FGD participants pointed out; therefore, suggesting a commonality of issues around smallholder farmers' interaction with IRMs. In addition to the above concerns, FGD participants thought there was need for the government or NGOs to provide education to the communities around immigration laws to enable them understand the requisite procedures thus, enabling them to abide to the same and avoid unnecessary encounters with law enforcement organs or even imprisonment. Discussants further claimed that, they need agricultural training on proper use technologies as this may enable them to increase productivity without necessarily expanding their farm land. Moreover, the knowledge gained could equip smallholder farmers with a better understanding of their surroundings and how to raise productivity without having to depend on IRMs.

Generally, the in-depth interviews with key informants revealed that smallholder farmers lack of title deeds for their land was a major problem and this has created a loophole for IRMs to own land illegally: IRMs ownership of land and other valuable assets was another cause for some of the bad feelings held by local communities towards this group perhaps just due to sheer jealousy. The above was supported by the FGD participants who pointed out that IRMs acquire land either for free or sometimes they buy it from their hosts and due to a lack of official contracts during these transactions, such land has at times been repossessed forcefully leading to hostility between the IRMs and local communities. In addition, ownership of cattle by the IRMs was also reported to be a cause of conflicts; some of the IRMs migrated with their cattle herds to Kasulu and at times these feed on smallholder farmers' crops thus leading to conflicts. Other factors fuelling the hostility were; presumed wealth accumulation through illegal means such as logging, and charcoal making. Berry (2008) reported that some villagers have experienced IRMs coming to their villages and once employed in their farms; they steal their crops or get involved in unlawful activities such as logging and poaching purposes hence affecting the environment and ecosystem in general.

According to literature (Crush and Ramachandran, 2010), hostility between migrants and their host communities can arise due to a number of reasons. These include depriving citizens of scarce resource (Crush and Ramachandran, 2010), exaggeration of migrant numbers hence making host communities feel like their national territory is under siege from the outside (Crush and Ramachandran, 2010). Other reasons include xenophobic discourses which portray migrants as a threat to the economic, social and cultural rights and entitlements of citizens. Based on the above, migrants get bad labels as 'people who 'flood' and 'swamp' local communities and job markets. In addition, they are stereotyped as bringers of disease, crime and a variety of

other social ills, and as people who steal jobs and compete unfairly with citizens for resources, shelter and public services (Crush and Ramachandran, 2010:216). Based on the above, both legal and illegal migrants in South Africa were targeted by some locals whereby innocent lives were lost and property destroyed due to xenophobia (Everatt, 2011; Associated Press in Johannesburg, 2015; Brand South Africa, 2015; Patel, 2016; SAHO, 2016; Huffingtonpost, 2017; Quartz Africa, 2017; Thisday 2017).

Observations from the in-depth interviews revealed that the kind of contracts entered between smallholder farmers and IRMs were not formal but just verbal and because of this and the illegal status of the IRMs some smallholder farmers declined to pay the IRMs their dues particularly, when harvests are not good due to natural calamities e.g. shortage of rainfall. Therefore, under such circumstances the IRMs had no choice but, either to extend their contract to the following season or terminate the same without payment. Nonetheless, it was observed that extension of the previous contract generally leads to dissatisfaction, anger and denial of rightfully earned payments all of which affect the IRMs well-being. As a consequence, some IRMs ask for bus fare to enable them return home, while others avenge by stealing or destroying the hosts crops and leave unpaid.

During the FGDs it was further revealed that some of the local communities thought that the presence of IRMs has increased unemployment to locals though it has also indirectly led to economic growth among the smallholder farmers employing them. However, it was also noted that smallholder farmers employing IRMs have become lazy; they work less following the arrival of IRMs as their cheap labourers. The observations are consistent with those given by key informants during the in-depth interviews whereby it was reported that with the IRMs working in the farms smallholder farmers and their families stay at home idle or doing light work on their home gardens. In addition, due to having lots of surplus time they frequently visit the local market for local brew or to refresh themselves. FGD participants further claimed that household heads (employers of IRMs) rarely go to inspect their farms. One of the reasons for the above was most of the farming lands are far (sometimes over fifty kilometres) away. One FGD participant said:

"Because of not being actively involved in farming, children of these IRM employers dislike farming, they drop from school, and become social misfits, drug abusers; robbers and some opt for prostitution" (A 49 years old woman, Nyachenda Village)

The study's findings imply that the future generation of the IRM host communities are in danger as economic downturn might be inevitable in case the law and regulations on irregular migration will strictly be upheld by the relevant authorities. It will be difficult in the future for

local communities to realise the national goals in agricultural production under the slogan “Agriculture first” initiative (“*Kilimo Kwanza*” in Swahili). The observation provides a snapshot of the impact of IRMs to Kasulu and this may not only be confined to Kasulu but may in the long run spread to the other regions of Tanzania as irregular migration seems to persist.

Observations from the FGDs also show that most farmland is far away from the main villages hence, both smallholder farmers and IRMs travel long distances in order to reach the same. Respondents claimed that, the exercise costs them a lot, in terms of money, energy and time. This is one of the reasons which forces IRMs to build temporary houses near the farms whereby in the long run they strive to have their own farmland and permanent residence; ultimately they start establishing unauthorized permanent hamlets along the farm areas as it was observed during physical survey. FGD participants further pointed out that suburbs built close to the border are facilitating underground movement of IRMs back and forth from Burundi and sometimes they house all kinds of IRMs including criminals. On the other hand, most of the key informants interviewed said that, currently, land is not a problem for local people in Kasulu and that is why they even dare to practice shifting cultivation as shown in the quote as follows:

“There is abundant uncultivated land in Kasulu District that is why it is easy for IRMs to access land undisturbed” (A 48 years old man, Mvugwe Village).

The findings from the study further show that, smallholder farmers were at other points in time the cause of conflict during their interaction with IRMs. This mainly occurred when there was a delay in paying IRMs their wages. According to the respondents, this oversight was rooted partially due to various reasons including natural calamities such as drought and floods. Another reason was lack of agricultural skills such as the use of fertilizers for their crops as a result smallholder farmers fail to meet their targeted harvests hence less income consequently leading to their failure to pay the IRMs as agreed. The above oftentimes creates conflicts between IRMs and smallholder farmers, whereby the latter deliberately decide to report the former to either the police or immigration officers leading to their arrest, prosecution, and later deportation. According to Leerkes et al. (2012) IRMs may find themselves in situations where they cannot decide or control what happens. Some may be involved in crimes, such as theft, property crimes, burglary or violence and drug dealing in response to their marginal social position or to meet various social standards that they could not.

The study further observed that there was no special program about civic education to both smallholder farmers and IRMs on national laws governing immigration law and those of natural resources management which,

among other things, include security matters, land and forest management. However, the study observed that victims of irregular migration according to immigration laws were both smallholder farmers and IRMs. Therefore, understanding the laws which govern entry and residence could make them comply with the laid down laws and of their country of origin and that of the host country. The study’s finding somehow conforms to the argument by (Craig, 2015) that since some migrants including the irregular ones (IRMs) may not be interested in permits and or integration into host communities as some are just there for economic reasons. Further to the above, another possibility is that IRMs may be afraid that if their application for residence or asylum is not granted then they may be subjected to deportation hence, opting to simply continue their stay as illegal migrants.

CONCLUSION AND RECOMMENDATIONS

A number of conclusions are hereby drawn from the major findings of this study: While results presented show a general negative attitude towards IRMs those employing them generally record higher gross margins for both maize and bean production. Nonetheless, due to the negative attitude by most of the surveyed households, there is need for the relevant authorities to ensure the well-being of both the recipient communities and of the IRMs. It can also be concluded that most of IRMs employed as cheap labourers in Kasulu are the temporary ones, that is, those coming on an irregular basis either directly from Burundi or from the refugee camps. It is therefore recommended that Tanzania needs to fortify her border control in order to address not only the human tragedy and the sufferings to which the IRMs exposed to but also the threat they may pose to the recipient communities.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Organic carbon dynamics and changes in some physical properties of soil and their effect on grain yield of maize under conservative tillage practices in Abakaliki, Nigeria

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In Nigeria and other Sub-Saharan Countries of Africa, erosion is pervasive and major source for loss of soil and productivity. This has necessitated continued search for appropriate soil management technologies to ensure sustained and profitable crop production. An experiment was carried out using maize (*Zea mays* L.) to evaluate organic carbon dynamics and changes in some physical properties of soil and grain yield of maize under conservative tillage practices on an ultisol in Southeastern Nigeria. The study consisted of three conservative tillage practices which were laid out in the field using randomized complete block design replicated seven times. Data were analyzed using statistical analysis for agricultural science. Results showed that tillage reduced seedlings emergence by 5 days compared to zero tillage. Highest grain yield of maize, significantly higher by 4 and 20% was obtained in deep tilled plot when compared to yields in shallow and zero tilled plots. Deep tilled plot had 2-9% significantly lower bulk density and 20-36, 1-8 and 27-55% higher total porosity, gravimetric moisture content and saturated hydraulic conductivity when compared to shallow tilled and zero tilled plots. Deep tilled plot had 15 and 55% significantly organic carbon when compared to their counterparts in shallow and zero tilled plots. Conservative tillage practices are recommended for sustainable and profitable production of maize crop in Nigeria.

Key words: Edaphic, grain yield, organic carbon, soil properties, tillage practices.

INTRODUCTION

Abakaliki of Southeastern Nigeria is predominantly agrarian. The farmers in the area grow intensively staple

food crops which range from cereals to tubers. Maize (*Zea mays* L.), rice (*Orzyae sativa*), yam (*Dioscorea* spp),

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cassava (*Manihot* spp), cocoyam (*Colocasia esculenta*) and potato (*Impomea batata*) are most commonly grown. These crops have adapted to the ecological and edaphic conditions prevailing in the area. Of all these, maize crop constitute about 30% of annual production (NPAFS, 2010). The agroecological conditions which facilitate crop production in Abakaliki include adequate sunlight and moisture regime, favourable temperature, soil nutrient storage and rooting depth (Anikwe, 2006; NPAFS, 2010).

Tillage is an important agronomic practice which has direct influence on soil condition. It is the physical manipulation of soil carried out to create conditions suitable for seeds germination, seedling emergence, poor growth and reduce weeds (Ibudialo et al., 2015). Mostly affected are temperature regime, porosity, compaction, moisture content and root proliferation (Anikwe et al., 2007). Furthermore, tillage practices improve soil properties, crops growth and development and promote their resilience to drought and other adverse environmental conditions (Atkinson et al., 2007). Tillage practices also create favourable edaptic and ecological environment for seedling emergence (Anikwe et al., 2007). Conservation tillage minimizes soil disturbances, protects the soil against degradation and improves sustainability (Melero et al., 2009).

In addition, soil condition is critical to nutrient dynamics. Since soils in southeastern part of Nigeria is sandy and deficit in organic carbon (Ohiri and Ano, 2012), there is need to intensify studies into acceptable management practices to stabilize and improve condition of the soil, their fertility and productivity (Mbah and Nneji, 2010) especially as management strategies have many effect on organic carbon content of soil (Ojeniyi and Ighomrore, 2004). In this part of the country, farmers engage in conventional tillage practices; which involves raised heaps as means of preparation of their soil for crop production.

This management strategy may be associated with physical degradation and nutrient losses. Certainly, there is need to avoid these problems (Mbah and Nneji, 2010) through adoption of proper soil management techniques. In their separate studies, Ibudialo et al. (2015) and Omoju and Ojeniyi (2012) corroborated that tillage increased cocoyam and sweet potato yields in Akure, Nigeria. Agbede and Adekiya (2011) studied no tillage and conventional tillage and reported that conventional tillage improved yield of potatoes as well as physical properties of soil. Evolving sustainable tillage practices for sustenance of soil fertility and productivity is important for planning of future farming operation and developing appropriate soil management system for higher productivity. Although, there had been studies on tillage research in the area, these experiments are not exhaustive as such researches often bothered on raised heaps, beds or ridges. Besides, information on conservation tillage practices on soil physical properties,

organic carbon dynamics and maize yield is completely lacking or non-existence in the ecology. This necessitated the research aimed to study organic carbon dynamics and changes in some physical properties of soil and grain yield of maize (*Z. mays* L.) under different conservative tillage practices.

MATERIALS AND METHODS

The study was carried out in 2013 planting season at Teaching and Research Farm of Faculty of Agriculture and Natural Resources Management, Ebonyi State University, Abakaliki (Figure 1). The experimental site is located by latitude 06° 4 N and longitude 08° 65 E in the derived Savannah Zone of the Southeastern agroecological area of Nigeria. The area experiences a bimodal pattern of rainfall which is spread from April to July and September to November with a break in August known as "August break". The total annual rainfall within the area ranges from 1500 to 2000 mm with an average of 1800 mm. At the beginning of rainy season, it is normally characterized by torrential rainfall, often violent and accompanied with heavy lightning and thundering. The rain sometimes lasts for few hours. Daily mean temperatures range from 27 to 31°C for minimum and maximum throughout the year. Minimum daily temperature occurs during cold harmattan periods between December to January while maximum temperature is experienced during the hottest periods of the year which is between February to April. Relative humidity is normally high (80%) during rainy season but declines to 60% or even less in dry season. The soil of the area is derived from sedimentary rocks from successive marine deposits of the cretaceous and tertiary periods. Abakaliki agricultural Zone is reported to lie within "ASU river group" in the geology of soil formation in the area and consists of Olive brown sandy shales, fine grained sandstones and mudstones (FDALR, 1985). The soil is shallow often with clay pan concretion with unconsolidated parent materials (Shale residuum) within 1m depth and belongs to the order ultisol which is classified as Typic Haplustult (FDALR, 1985).

Field methods

A land area that measured 30 m x 30 m approximately 0.09 ha was used for the study. The site was cleared of existing vegetation with machet and debris removed without burning. The field was laid out using Randomized Complete Block Design. The plots measured 10 m x 10 m and were separated by 0.5 m spaces while the seven replicates were each set apart by 1 m alley. There were three treatments which consisted of Zero tillage (ZT), shallow tillage (ST) and deep tillage (DT). These tillage practices were replicated seven times to give a total of twenty one plots. Zero tilled plot was cleared of vegetation and debris removed without any kind of tillage carried out on it. Whereas in shallow tilled plot, hand held hoe was used to till the soil flat to a depth of 10 cm and in deep tilled plot, the soil was tilled flat with hoe to a depth of 15 cm. The soil in each case was not upturned.

Planting and other agronomic practices

Maize seed (Suwan-1-SR-hybrid) variety which was sourced from FADAMA office Onuebonyi Izzi, Abakaliki, Ebonyi State of Nigeria was used as a test crop. The maize variety is resistant to stem borer attack, does not lodge and high yielding. Two maize seeds were planted per hole at a depth of 5 cm and planting distances of



Figure 1. Map of Abakaliki, Ebonyi State.

50 cm x 50 cm for both intra and inter row spacings. After two weeks of seedling emergence, those that failed to germinate including weak ones were all replaced by replanting to achieve optimum plant population. There were 40,000 maize plants per hectare. Fertilizer NPK 20:10:10 was applied at 400 kg ha^{-1} to all the plots two weeks after germination. The fertilizer was drilled and 5 cm away from the maize plants. Weeds were removed with hand at three weekly intervals till harvest.

Soil sampling

Soil samples were collected randomly with steel auger at 0-20 cm depth at twenty different points after clearing the site. The samples were composited and bulked for pre-planting soil analysis. Five undisturbed cores and auger each of soil samples were further collected at 0-20 cm depth from each plot at maize tasselling for determination of some post-harvest physical properties and organic carbon. The soil core samplers used were 6 cm in height and open faced, analyzed separately and average results used for evaluation, whereas the auger samples were mixed and composited for laboratory analysis.

Agronomic data collection

Maize seedling emergence was taken after five days of planting (DAP) since a viable seed is supposed to emerge between 5-10 days. Percentage germination count was calculated using the formula:

$$\text{Germination Count \%} = \frac{\text{Number of germinated maize seeds per plot}}{\text{Total number of planted maize seeds per plot}} \times 100 \quad (1)$$

For grain yield of maize twenty (20) plants representing 50% of total plant population per plot were selected and tagged from the net plot and sampled. The maize cobs were harvested when the husks had turned brown and dry. The cobs were dehusked, shelled, grains dried to constant weight and grain yield determined at 14% moisture content.

Laboratory methods

Composite soil samples collected from twenty points in the

experimental site before the initiation of study were used for pre-planting analysis. Auger soil samples collected from each plot were dried, passed through 2 mm sieve and used for determination of organic carbon. Core samples were used for measurement of some physical properties of soil. Particle size distribution was determined by hydrometer method of Gee and Or (2002). Dry bulk density was calculated using the formula:

$$\text{Dry bulk density} = \frac{\text{Oven dry weight of soil (g)}}{\text{Bulk volume of soil (cm}^3\text{)}} \quad (2)$$

Bulk volume of soil approximated volume of core as $\pi r^2 h$.

Where $\pi = 22/7$, r of Core = 2.5 cm and height of core = 6 cm. Total porosity value was estimated from bulk density data as follows:

$$\text{TP} = \left(\frac{1 - \text{Bd}}{\text{pd}} \right) \times \frac{100}{1} \quad (3)$$

Where

TP = Total porosity

Bd = Bulk density

Pd = Average particle density of soil was assumed at 2.65 Mgm $^{-3}$. Gravimetric moisture content (GMC) was determined using Obi (2000) procedure. The procedure is

$$\text{GMC\%} = \frac{\text{WWS} - \text{DWS}}{\text{DWS}} \times \frac{100}{1} \quad (4)$$

Where

WWS = Wet Weight of soil sample (g)

DWS = Dry Weight of soil sample (g)

Saturated hydraulic conductivity was determined by constant head method of Obi (2000). The value was calculated using the formula:

$$K_s = \frac{Q}{A_t} \times \frac{DH}{L} \quad (5)$$

Where

$$K_s = \frac{\text{Mean volume of water conducted}}{\text{Cross sectional area of Core} \times \text{Time}} \times \frac{\text{Hydraulic head change}}{\text{Soil sample length}} \quad (6)$$

Total N was determined by the macro-Kjedahl method (Bremmer, 1982). Available phosphorus and organic carbon determinations were done using Bray-2 method and Walkley and Black procedure as reported in Page et al. (1982) respectively. Soil pH in KCl was determined by the glass electrode pH meter (McLean, 1982). The exchange cations and cation exchange capacity were extracted using the method described by Mba (2004). Base saturation was determined with formula:

$$\%BS = \frac{\text{TEB}}{\text{CEC}} \times \frac{100}{1} \quad (7)$$

Where:

%BS = percent base saturation

TEB = Total exchangeable bases

CEC = Cation exchange capacity.

Data analysis

The data obtained from the study were analyzed using analysis of variance (ANOVA) test based on RCBD using F-LSD at $P < 0.05$ according to Statistical Analysis for Agricultural science (SAS, 1985). Significance was accepted at 5% probability level.

RESULTS AND DISCUSSION

Soil properties at initiation of study

Results (Table 1) show properties of soil at initiation of study. Sand was predominantly higher than other fractions giving sandy loam texture. Soil pH in KCl was 5.0. Organic carbon, organic matter and nitrogen had respective values of 0.68, 1.17 and 0.10%. Available phosphorus had a value of 24.00 mgkg^{-1} . Exchangeable cations were 5.10, 2.41, 0.24 and 0.12 cmolkg^{-1} respectively for calcium, magnesium, potassium and sodium. Cation exchange capacity was 8.08 cmolkg^{-1} while base saturation recorded a value of 78.0%.

The preliminary investigation showed that the soil was strongly acidic (Schoeneberger et al., 2002). The organic carbon, organic matter, nitrogen and available phosphorus were very low (FMARD, 2002) bench mark for tropical soils. The exchangeable cations except calcium and cation exchange capacity were of low values (Anikwe, 2006) but base saturation was moderate. The results depict a soil that is poor, degraded and of low fertility status.

Influence of tillage practices on maize seedling emergence

Maize seedling emergence count started on 5 days after planting (DAP). Results (Table 2) showed that there was neither significant ($p < 0.05$) treatment effect of tillage practices on seedling emergence for both 5 and at 10 DAP nor significant differences on the seedling emergence among tillage practices. Nevertheless, deep tilled (DT) plot had higher percent maize seedling emergence (50%) compared to those of shallow tilled (ST) and zero tilled (ZT) (48-38%) plots respectively after 5 DAP. At 10 DAP, both shallow tilled and deep tilled plots had maize seedling emergence of 100% whereas zero tilled plot had 98%.

The result show that at 5 DAP, deep tilled plot had the highest rate of maize seedling emergence, followed by shallow tilled plot and zero tilled plot had lowest. Whereas, both shallow and deep tilled plots had optimum maize seedling emergence at 10DAP compared to zero tilled plot. These findings imply that shallow and deep tillage more than zero tillage enhanced number of days required to obtain optimum maize seedling emergence by 5days in both 5 and 10 DAP. The results further indicate

Table 1. Soil properties at initiation of study.

Soil properties	Values
Sand (gkg^{-1})	650
Silt (gkg^{-1})	190
Clay (gkg^{-1})	160
Textural Class	Sandy loam
pH in KCl	5.0
Organic carbon (%)	0.68
Organic matter (%)	1.17
Nitrogen (%)	0.10
Available phosphorus (mgkg^{-1})	24.00
Calcium (cmolkg^{-1})	5.10
Magnesium (cmolkg^{-1})	2.41
Potassium (cmolkg^{-1})	0.24
Sodium (cmolkg^{-1})	0.12
Cation exchange capacity (cmolkg^{-1})	8.08
Base saturation (%)	78.00

Table 2. Influence of conservative tillage practices on percent maize seedling emergence at 5 and 10 DAP.

Tillage practices	Days after planting	
	5	10
Zero tillage	38	98
Shallow tillage	48	100
Deep tillage	50	100
Mean	42.7	99.3
FLSD ($p < 0.05$)	NS	NS

that deep tilled plot had more improved soil tilth and moisture content (Table 3). This suggests that good soil tilth, improved soil warmth, aeration and higher moisture content in deep tilled plot have positive influence on maize seedling emergence more than adverse effect of mechanical impedance although there was no significant differences in seedling emergence among tillage practices. Anikwe et al. (2007) reported that higher moisture content facilitated seedling emergence in tilled plots compared to untilled plot. This observation was supported by Gajiri et al. (2002) that seed germination and crop emergence were affected by seed zone soil water potential, oxygen diffusion rate and mechanical impedance. Seedling emergence is affected by soil physical properties in the order of soil temperature > soil matric potential > soil aggregate size distribution. It is instructive that depth of planting and seed soil contact (Obi, 2000; Anikwe et al., 2007) influenced seed germination and seedling emergence. It could be inferred from the results that soil tilth more than soil warmth, air, moisture content and depth of tillage influenced maize

Table 3. Effect of conservative tillage practices on grain yield of maize.

Tillage Practices	Yield (tha ⁻¹)
Zero tillage	1.83
Shallow tillage	2.20
Deep tillage	2.30
FLSD (p<0.05)	0.04

seedling emergence in deep and shallow tilled plots than in zero tilled plot. The effect of mechanical impedance and edaphic environment did not have much influence because even in zero tilled plot, seed holes were opened for planting of maize seeds and this reduced soil compaction to of little or no effect. This finding contradicts earlier report of Anikwe et al. (2007) which noted that both increased temperature and moisture content influenced corm emergence more than mechanical impedance.

Grain yield of maize as influenced by conservative tillage practices

Highest grain yield of maize was obtained in deep tilled plot (2.30 tha⁻¹) (Table 3). This was significantly (p<0.05) higher than yields obtained in shallow and zero tilled plots by 4 and 20%. The grain yield of maize in shallow tilled plot was significantly higher by 17% when compared to yield recorded in zero tilled plot. There were significant differences in grain yields of maize among the different tillage practices.

These results show that tillage practices influenced grain yields of maize. For instance, the high percent of grain yield of maize advantage obtained in deep tilled plot relative to their respective yields in shallow and zero tilled plots could be due to differences in soil tilth and edaphic conditions of soil as a result of impact of tillage. Tillage improved soil physical conditions, reduced seedling emergence time, weed competition, diseases and pests incidence and these resulted in better grain yields of maize. Furthermore, comparing grain yields of maize between deep and shallow tilled plots, results showed a total grain yield difference of 0.10 tha⁻¹ for deep tilled plot. This difference is made possible because of deeper tillage. The hoe penetrated deeper thereby loosening soil aggregates and creating channels for water transmission into the crop root rhizosphere. Anikwe (2007) as corroborated by Agbede and Kiya (2011) noted that zero tilled plot had lower yield than tilled plots. Similarly, tillage provided favourable soil edaphic conditions for organic carbon decomposition and mineralization (Anikwe et al., 2007) which made more nutrients available in tilled plots. The grain yield of maize was 26 and 20% lower in zero tilled plot than the respective yields in deep and shallow

tilled plots. These differences in grain yields of maize may be because of the techniques employed in tillage.

Generally, zero tilled plot had the least grain yield of maize and this could be attributed to least suitable edaphic conditions provided for the maize crop. Zero tilled plot had highest bulk density, least total porosity and moisture content as well as water transmission. These imply root restriction, poor aeration and impeded drainage which could have affected microbial activities and hampered nutrients release. The result is the low grain yield of maize obtained in zero tilled plot when compared to yields in other tilled plots.

Changes in some physical properties of soil under conservative tillage practices

Results of changes in some physical properties of soil under conservative tillage practices are shown in Table 4. There were significantly (p<0.05) higher changes in studied soil physical properties among different tillage practices. Results show significant treatment effect on bulk density value of 1.30 mgm⁻³ in zero tilled plot with their counterparts in shallow and deep tilled plots (1.20 and 1.18 mgm⁻³). Shallow tilled plot had significant bulk density of 1.20 Mgm⁻³ which was higher than the value obtained in deep tilled plot (1.18 mgm⁻³). The result of total porosity showed a reciprocal trend of corresponding values of bulk densities recorded under different tillage practices. Total porosities obtained in shallow and deep tilled plots (55.00 and 55.50%) were significantly higher than its corresponding value in zero tilled plot (51.00%). There was no significant difference in total porosity between shallow tilled and deep tilled plots. The gravimetric moisture content (GMC) in deep tilled plot was significantly higher (25.00%) than their counterparts in shallow and zero tilled plots (20.00 and 16.00%). The value of GMC in shallow tilled plot was significantly (20.00%) higher than the one recorded in zero tilled plot (16.00%). Result further shows that deep tilled plot had significantly higher saturated hydraulic conductivity (11.00 cmh⁻¹) than their corresponding values in shallow and zero tilled plots (5.00 and 8.00 cmh⁻¹). There was significantly lower saturated hydraulic conductivity (8.00cmhr⁻¹) in shallow tilled plot when compared to value obtained in zero tilled plot (5.00 cmh⁻¹). Generally, in deep tilled plot, bulk density was 8 and 10% lower than in shallow and zero tilled plots whereas GMC, total porosity and saturated hydraulic conductivity were 20-36, 1-8 and 27-55% higher in deep tilled plot compared to values obtained in shallow and zero tilled plots.

Tillage significantly reduced bulk density from 1.30 mgm⁻³ in zero tilled plot to 0.10 and 0.12 mgm⁻³ in shallow and deep tilled plots, respectively. The change in soil bulk density due to tillage was more glaring in deep tillage. This positive impact on soil bulk density by tillage is

Table 4. Changes in some physical properties of soil due to conservative tillage practices.

Tillage practices	BD (Mgm ⁻³)	TP (%)	GMC (%)	K _s (cmh ⁻¹)
Zero tillage	1.30	51.00	16.00	5.00
Shallow tillage	1.20	55.00	20.00	8.00
Deep tillage	1.18	55.50	25.00	11.00
FLSD(p<0.05)	0.02	1.20	0.03	0.23

BD – Bulk density, GMC – Gravimetric moisture content, TP – Total porosity, K_s – Saturated hydraulic conductivity.

expected since hand hoe was used than tractor in effecting tillage practices (Omoju and Ojeniyi, 2012). The soil was loosened rather than compacted and this increased the bulk volume of soil which reduced soil compaction. This finding contradicts the observations of Anikwe et al. (2003, 2007) that soil bulk density was increased after tillage as a result of trafficking after field operations. Anikwe et al. (2007) noted that effect of tillage in increasing bulk density dissipates with time but the use of hand hoe reduced impact of trafficking which could have resulted to decreased soil volume and increase in bulk density. Low bulk density is a positive indicator for assessing soil productivity (Obi, 2000; Anikwe, 2006) as it enhances nutrient retention and supply, moisture retention and resilience to degradative forces. High bulk density in zero tilled plot could be attributed to forces of crusting, sedimentation or sealing which reduced soil volume. This finding is supported by Obi (2000) who reported that crusting and sealing propensity caused soil compaction and increased its bulk density. Tillage caused significant change from lowest total pore volume in zero tilled plot to higher total pore volume which was highest under deep tillage. Bulk density and total porosity has reciprocal relationships and so the values of total porosity under different tillage practices followed the trend of their corresponding values of bulk density. According to Anikwe et al. (2007), soil compaction increased bulk density and decreased pore volume (Agbede and Adekiya, 2011; Ojeniyi et al., 2012). The general trend in increase in soil total porosity due to tillage practices is deep tillage > shallow tillage > zero tillage.

There was significant positive change in gravimetric moisture content as influenced by tillage practices. Retention of water in soil due to tillage practices followed the trend of bulk density and total porosity. Tillage practices created fine soil particles and or soil tilth which increased moisture retention as opposed to zero tillage. This finding is intandem with the observation of Anikwe et al. (2007) and Omoju and Ojeniyi (2012) that tillage created favourable edaphic environment which reduced evaporation losses and conserved moisture. On the other hand, the result is in support of the report that compaction increased proportion of soil pores filled with

water as average pore size decreased (Anikwe et al., 2007). Low proportion of pores could lead to aeration stress. This suggests that zero tillage cannot only cause soil compaction and reduction in total pores but also “moisture stress” which is detrimental to productivity.

Result (Table 3) further indicated that tillage practices had significantly higher change in saturated hydraulic conductivity when values obtained in deep and shallow tilled plots are compared to the zero tilled plot. This change is highly pronounced under deep tillage. The trend in saturated hydraulic conductivity as influenced by tillage practices is deep tillage > shallow tillage > zero tillage. Higher saturated hydraulic conductivity obtained in deep and shallow tilled plots could be attributed to low bulk density and high total porosity as well as gravimetric moisture content in those plots (Ibudialo et al., 2015).

The highest saturated hydraulic conductivity obtained in deep tilled plot is attributable to corresponding lowest bulk density and highest total porosity and gravimetric moisture content in the plot. However, beyond this observation, it is believed that hand hoe caused “bulb tire” elliptical impact (Obi, 2000) on the soft soil that created “micro, meso and macro pores” which facilitated higher water transmission on the soil. High water conductivity or transmission is a soil productivity indicator as it could lead to free drainage of water, increased aeration and microbial activities as well as reduce denitrification process. If water conductivity becomes slow or too slow, it will cause water logging or even ponding and that could constitute limitation to soil productivity due to negative associated impacts that it could initiate.

Effect of conservative tillage practices on changes in particle size distribution

Table 5 shows that conservative tillage practices did not cause pronounced change in distribution of particle of soil. Nevertheless, sand fraction was dominant in different tillage practices which ranged from 740 – 780 gkg⁻¹ for the tillage practices. Clay fractions were higher (120, 150 and 180 gkg⁻¹) in deep tilled plot than silt

Table 5. Effect of conservative tillage practices on changes in particle size distribution.

Tillage practices	Soil particle sizes (Gkg ⁻¹)			
	Sand	Silt	Clay	Texture
Zero tillage	780	100	120	Sandy loam
Shallow tillage	760	90	150	Sandy loam
Deep tillage	740	80	180	Sandy loam

Table 6. Influence of conservative tillage practices on organic carbon dynamics.

Tillage practices	Organic carbon (%)
Zero tillage	0.90
Shallow tillage	1.70
Deep tillage	2.00
FLSD (p<0.05)	0.07

fractions (100, 90 and 80 gkg⁻¹) for the zero, shallow and deep tilled plots for the different tillage practices.

Tillage caused higher concentration of sand fraction through podzolization and eluviations of finer particles from upper to lower depth since sampling depth was 0-20 cm. This finding was corroborated by Akamigbo (2010) that pedoturbation caused elluviation of finer particles of soil which led to concentration of sand fraction and silica on upper soil layer. The higher clay fraction could be attributed to effect of illuviation through channels created by hand hoe. On the other hand, high clay fraction in deep and shallow tilled plots could be due to higher total porosity and water transmission in those plots which influenced its movement downward. There was no obvious change in texture due to tillage practices. This is expected because according to Obi (2000) short term cultural practices do not modify the texture. From practical point of view, tillage practices had the same effect on soil particle size distribution probably because the data on particle size distribution were not statistically analyzed. Texture is a factor of soil productivity indicator (Anikwe, 2006) and it has good relationship with nutrient storage, water retention, compatibility and compressibility (Smith et al., 1998) all of which affect inherent productivity of soil. Sandy loam is associated with high nutrient storage and supply, water retention, aeration, friability and aggregation which are positive indicators of soil productivity.

Influence of conservative tillage practices on organic carbon dynamics

Results (Table 6) shows that there were significant

(p<0.05) differences in organic carbon dynamics among different tillage practices. Deep tilled plot had significantly (p<0.05) higher organic carbon (2.00%) compared to corresponding values obtained in shallow and zero tilled plots (1.70–0.90%). Tillage practices increased organic carbon from 0.9% in zero tilled plot to 2.00 and 1.70% in deep and shallow tilled plots. These represent 55 and 47% increments in organic carbon in deep and shallow tilled plots compared to value obtained in zero tilled plot. Generally, the trend in organic carbon dynamics from highest to lowest values is in the order of deep tilled plot < shallow tilled plot > zero tilled plot.

From these results, deep tilled plot had higher organic carbon when compared to their counterparts in shallow and zero tilled plots. This indicates that tillage impacted on organic carbon content of soil positively. Tillage as inferred improved soil heat content, decomposition, mineralization and microbial activity which influenced organic carbon content soil more than in zero tillage (Omoju and Ojeniyi, 2012). Organic carbon content of different tillage practices except that of deep tillage ranged from very low to low values (FMARD, 2002) benchmark for tropical soils. Asadu (1990) reported low organic carbon content of soils in the tropics due to high temperatures which caused high mineralization. Low organic carbon content in zero tilled plot could be as a result of low mineralization and negative effects of untilled soil. Poor physical properties of soil such as low water transmission which can possibly cause denitrification and leaching of organic carbon content from soil. Although, organic carbon content in zero tilled plot is low compared to shallow and deep tilled plots but not limiting to soil productivity (FMARD, 2002).

Conclusion

The results of this study have shown that tillage practices could affect organic carbon content and changes in some physical properties of soil as well as grain yield of maize. Tillage could influence maize seedling emergence, organic carbon dynamics, bulk density, total porosity, soil moisture content and transmission and grain yields of maize. Deep tilled plot had the highest grain yield of maize of 2.30 tha⁻¹ while shallow tilled grain and zero tilled plots had 2.20 and 1.83 tha⁻¹ of grain yield of maize respectively. This suggests that deep tilled plot provided better edaphic conditions for higher yield of maize crop than other tillage practices. Conservative tillage practices are important soil management approach for sustainable productivity as it could be used to manipulate soil environment and increase organic carbon content and improve bulk density, porosity, moisture content and transmission for profitable production of maize in tropical environment. Although, the difference between shallow and deep tilled plots in organic carbon dynamics and

grain yield of maize is significant, however, both are recommended as conservative practices to enhanced soil sustainable productivity and increased grain yield of maize. Improved physical properties and organic carbon content should be enhanced as they are crucial for sustainable and profitable maize crop production under tropical environment.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Near infrared spectroscopy (NIRS) technology applied in millet feature extraction and variety identification

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Near infrared spectroscopy (NIRS) technology is widely used on agricultural products for quality detection, classification and variety identification due to its rapid speed and high-efficiency. NIRS experiments were conducted to identify varieties of DUN millet, JIN 21 millet and 5 other types of millet. The NIRS characteristic curves and data of millet samples were collected. The spectroscopic data on different types of millet were analyzed by discriminant analysis, principal component analysis and neural network technology. The calibration set correct classification was 98.9%. A BP neural network prediction model for millet was also built. It was found that the forecast results of original wave spectrum prediction model were best, with its correlation coefficient of validation (R_v) at 0.9999, the standard error of prediction (SEP) was 0.0191 and the root mean square error of prediction (RMSEP) was 0.0189. Moreover, the R_v of first derivative spectra was 0.9976, the SEP and RMSEP were 0.1043 and 0.1437, respectively, and the R_v , SEP and RMSEP of second derivative spectra were 0.9835, 0.28735 and 0.2720 respectively. This study laid the foundation for identification of millet varieties by NIRS.

Key words: Millet, near infrared spectroscopy (NIRS), principal component analysis, neural network prediction, variety identification.

INTRODUCTION

A large amount of millets are grown in Northern China (Lu et al., 2005). They are very popular miscellaneous grain crops and are commonly used as a food source (Liu et al., 2012). Millet is an important food because of the variety of rare nutrients it provides, and is widely respected as a healthy food (Yang et al., 2012). Therefore, millet planting and related industries in recent years have developed substantially (Yang et al., 2009). Many of the characteristics of millet varieties have been

used in production, but some of these millets in the market have been exaggerated with regard to their compositions and effectiveness (Hua, 2010). Therefore, it has practical significance to identify the quality of millet varieties. Applying NIRS on agricultural materials is beneficial because this approach is nondestructive and it has been widely used in many agricultural application areas such as classifying agricultural products (Qiu et al., 2009; Jia et al., 2014), conducting quality inspection

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(Burks et al., 2000), agricultural soil (Zheng et al., 2008), quantifying crop nutrition (Liao et al., 2015) and identifying species (Tolleson et al., 2005; Liu et al., 2014). Lidia EsteveAgelet analyzed the damage of soybean and maize kernel by NIRS (Lidia et al., 2012); Zhu (2012) and Zhu et al. (2015) reported on the application of NIRS for the detection of seed quality, and the application of NIRS is used to identify soybean, cassia seed, bitter beans and three other kinds of hard seeds with an identification rate of 95%; Liang et al. (2009) showed that the identification of rice varieties and authenticity by NIRS, and showed that feature wave band optimization model is effective. Zheng et al. (2015) performed detection and analysis of the quality of peanut seeds by using NIRS technology, and showed that the average correct recognition rate of 3 peanut varieties was 95%. The above research provides a useful reference, and suggests a variety of uses for NIRS on agricultural products. In this paper, near infrared spectroscopy techniques were used to measure the spectral characteristics of 7 different varieties of millet, such as DUN millet, JIN 21 millet, ZHANG 2 miscellaneous cereals, ZHANG 3 miscellaneous cereals, Zhang 5 miscellaneous cereals, ZHANG 9 miscellaneous cereals, and ZHANG 10 miscellaneous cereals. Then the near infrared spectroscopy characteristic curves are analyzed; principal component analysis and neural network identification model (Zheng et al., 2008; Yuan et al., 2003; Ghamari et al., 2010) are established, and the verification is carried out.

METHODOLOGY

Material

Test samples were taken from the millet varieties cultivated and popularized in recent years in Shanxi Agricultural University, including DUN millet, JIN 21 millet, ZHANG 2 miscellaneous cereals, ZHANG 3 miscellaneous cereals, Zhang 5 miscellaneous cereals, ZHANG 9 miscellaneous cereals, ZHANG 10 miscellaneous cereals. 7 varieties, 36 samples for each species, a total of 252 samples were used.

Instrument and parameters

Experiments were conducted in order to test the spectrum for each millet variety. A FieldSpex 3 spectrometer was used and its transmission accessory was produced by an American company, ASD (Analytical Spectral Device). Its sampling spectrum interval (Wide Frequency) is 1.5 nm. The range of testing was 350 to 2500 nm, and the scanning time is 30 times, and the resolution is 3.5 nm.

Model

MATLAB scripting language was used to write and construct a variety of functions for network design, training routines and typical neural network activation function. In multiple linear regression analysis, principal component regression can be used to diagnose the co-linearity between the independent variables, and give the

final regression prediction equation.

RESULTS

The procedure for collecting and analyzing spectrum data

The spectrum data test on millet was collected by a spectrometer. Its original results were exported by software ASD View Spec Pro. Then the first and second derivatives were found. The original, first and second derivative spectra were exported to EXCEL in the form of ASCII. Then a spectral image was created in MATLAB to find the characteristic wave with the most obvious change in permeability from these three spectrograms. The reflectivities from different levels of millet corresponding to the characteristic wavelengths were listed in EXCEL. Finally, the qualitative discriminations based on the principle components neural network were computed using MATLAB.

The extraction of spectral features and near infrared spectroscopy

Original visible and near infrared spectrum average were collected from the 7 different varieties of millet as shown in Figure 1. It can be seen from the Figure that, 7 different millet varieties (DUN millet, Zhang 5 miscellaneous cereals, Zhang 2 miscellaneous cereals, Jin Gu 21, Zhang 3 miscellaneous cereals Zhang 9 miscellaneous cereals, Zhang 10 miscellaneous cereals) are consistent with the visible near infrared spectral curve trend, and have a relatively strong spectral absorption peak at 500-600 and 1400-1900 nm band; in 600- 1900 nm the wavelength range shows differences in permeability. The spectroscopic data in combination with chemical measurement methods for each type of millet were calibrated in order to establish the discriminate model of millet varieties, and understand the differences between varieties. Figure 2 is a derivative of the corresponding visible / near infrared spectra of averages; Figure 3 is the second order differential of the corresponding average visible / near infrared spectra.

The extraction of spectral features

From Figures 1 to 3, the initial part and the terminal part of the spectra curve have higher noise. In order to mitigate the influence of the noise, the spectra from 400 to 2400 nm bands were selected. The peaks and troughs of the wavelength curve's relative error is almost zero, so the original curve, the first derivative, and the second derivative were calculated, and showed 20 changes in the apparent wavelength as the characteristic wave. Principal component analysis was used to analyze the

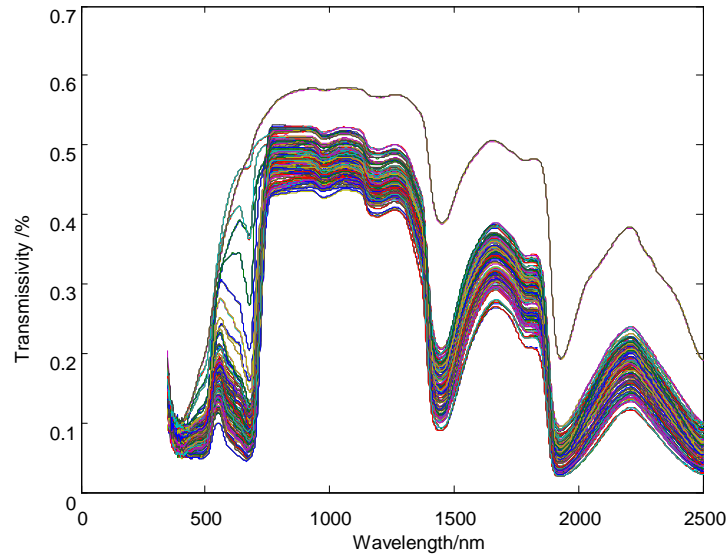


Figure 1. The original spectrum curve of millet

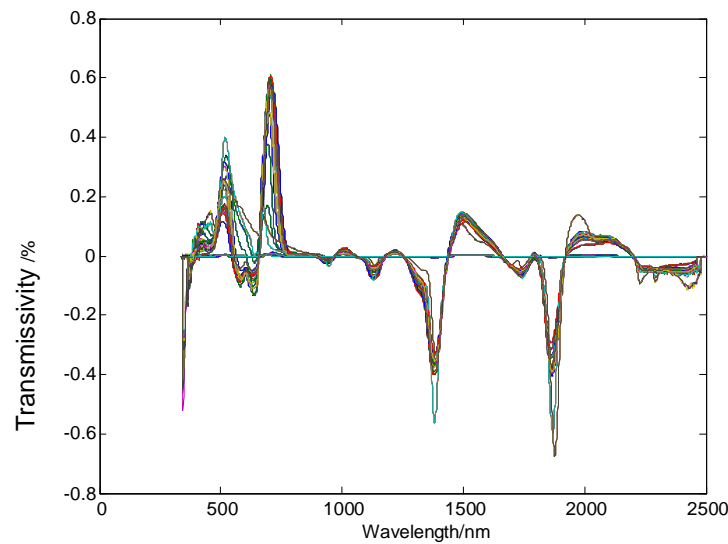


Figure 2. The first derivative spectra curve of millet

neural network. The original spectral characteristics were selected at 400, 440, 548, 585, 630, 655, 688, 752, 879, 924, 981, 1071, 1195, 1269, 1457, 1670, 1765, 1805, 1929 and 2204 nm. The first order derivative spectral characteristic wave was found at 450, 538, 591, 643, 717, 955, 1022, 1139, 1232, 1506, 1755, 1806, 1877, 2012, 2256nm and so on. Second order spectral characteristic waves were also found at 429, 465, 514, 571, 693, 760, 951, 1107, 1176, 1354, 1435, 1775, 1849, 1929, 2230 nm and so on. In order to reduce the error, 2 data are extended around each data as characteristic waves.

Since differences were found among the spectra of different millet varieties in order to find the best spectrum to distinguish different varieties of millet, the original spectrum, first derivative spectra, and second derivative spectra of 7 different varieties were used in the principal component analysis. The input of the neural network is used as the main component of the neural network, 1, 2, 3, 4, 5, 6, 7 respectively, as the output of the neural network, said the different varieties (1-DUN millet, 2 - Zhang 5 miscellaneous cereals, 3 - Zhang 2 miscellaneous cereals, 4 - JIN 21 millet, 5 - Zhang 3 miscellaneous cereals, 6 - Zhang 10 miscellaneous

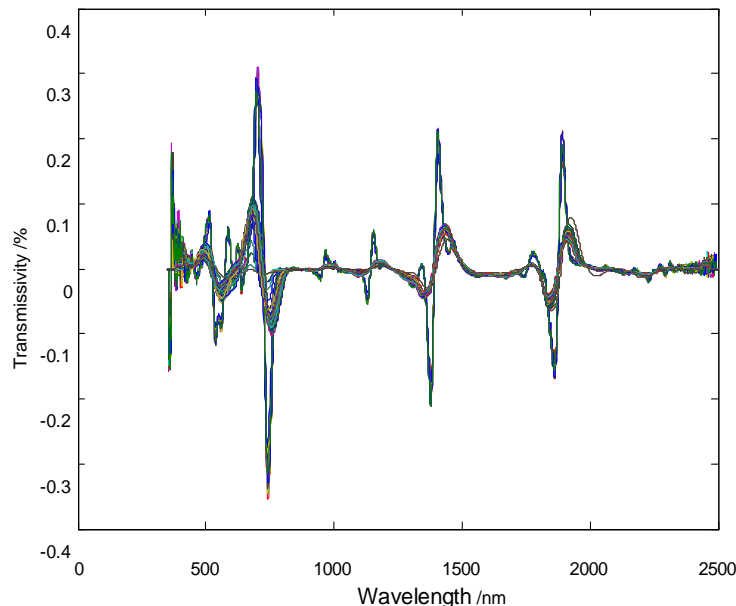


Figure 3. The second derivative spectra curve of millet

Table 1. Identification results of checking samples for millet samples.

Types of spectra	Accurate number	Total number	Accurate rate (%)
The original wave spectrum	84	84	100
The first derivative spectra	79	84	94.1
The second derivative spectra	60	84	71.4

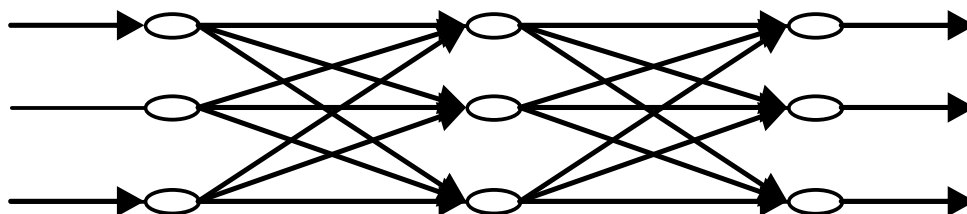


Figure 4. BP neural network structure chart.

cereals, 7 - Zhang 9 miscellaneous cereals), establishing the corresponding neural network model. Table 1 shows the identification results of using principal component neural network to correctly identify the samples.

DISCUSSION

Neural network has a nonlinear adaptive information processing ability (Ghamari et al., 2010), and BP network is a kind of multilayer feed forward neural network (Shao

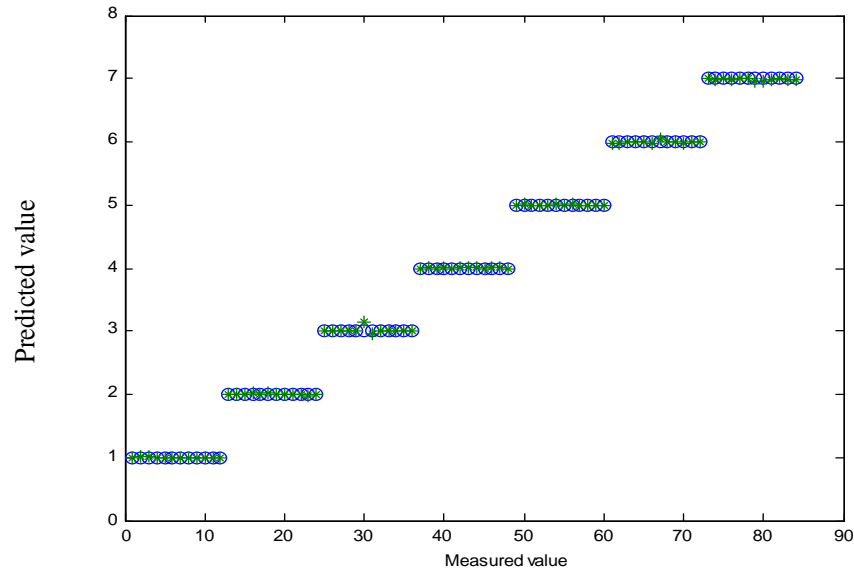
et al., 2007), which transfer function is S function and output is continuous between 0 and 1. It can achieve any nonlinear mapping from input to output (Huang et al., 2011). In recent years, it has proven to be very useful in the simulation of nonlinear functions. The general structure is shown in Figure 4.

Input layer hidden layer output

In this paper, Levenberg-Marquardt (LM) was used to

Table 2: Evaluation parameter of the prediction model

Evaluation parameter	The original wave	The first derivative spectra	The second derivative spectra
RMSEP	0.0189	0.1037	0.272
SEP	0.0191	0.1043	0.2735
Rv	0.9999	0.9976	0.9835

**Figure 5.** The comparing chart of predicted value and standard value

optimize the neural network algorithm (Lera et al., 2002). This method helps make the convergence process smooth, and completes the iterative process of the network in a relatively short time. The input curve tangent S activation function by function layer (tansig), and the output layer uses a linear activation function (purelin). The entire program can be written in the M file of MATLAB and the artificial neural network toolbox is used for debugging and simulation.

In the selected feature wave, 30 groups were trained at each level and 20 groups were predicted. The maximum number of training was 5. The training accuracy is 10^{-4} , transfer function (tansig), the training function is (trainlm).

The prediction model on the original spectrum

The original spectrum from BP network and the evaluation parameters of the prediction model (Qi et al., 2003) are shown in Table 2, prediction results are shown in Figure 5, the correction standard error is shown in Figure 6.

The prediction model on the first derivative spectra

The evaluation parameters of the correction and

prediction model on the first derivative spectra are shown in Table 2, prediction results are shown in Figure 7, the correction standard errors are shown in Figure 8.

The prediction model on the second derivative spectra

The evaluation parameters of the correction and prediction model on the second derivative spectra are shown in Table 2, prediction results are shown in Figure 9, the correction standard errors are shown in Figure 10.

Comparison between the prediction and model

The evaluation parameters adopted in the model include standard error of prediction (SEP), root mean error of prediction (RMSEP), and correlation coefficient of validation (Rv).

It can be concluded from the comparison that among these three prediction models the prediction models based on the BP neural network achieve the highest accuracy. The forecast results for the original spectrum model were the best, with a correlation coefficient of validation (Rv) at 0.9999, the standard error of prediction (SEP) at 0.0191 and the root mean square error of

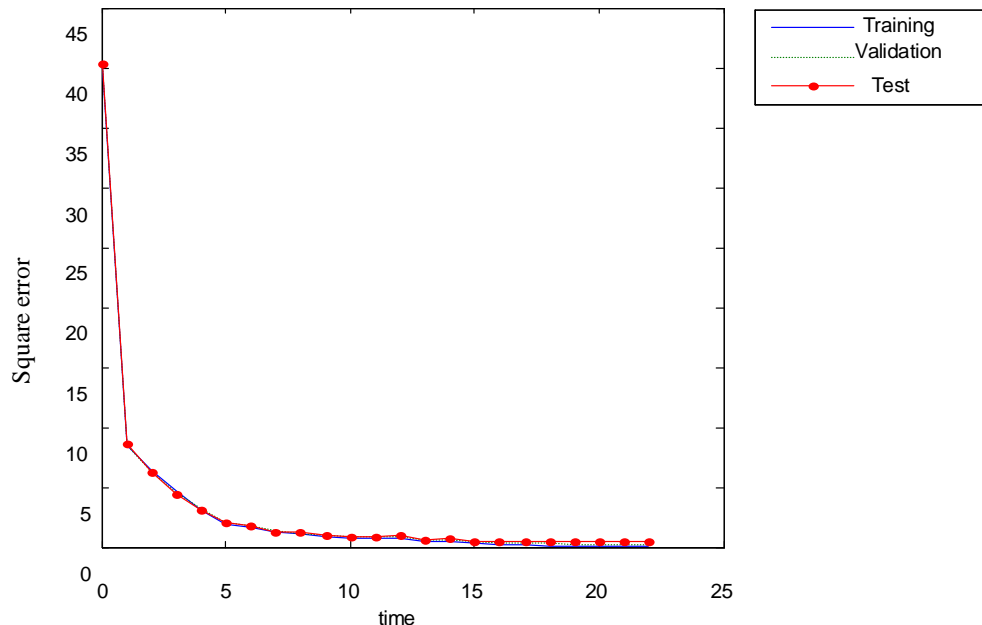


Figure 6. Curves of training error, checking error and testing error

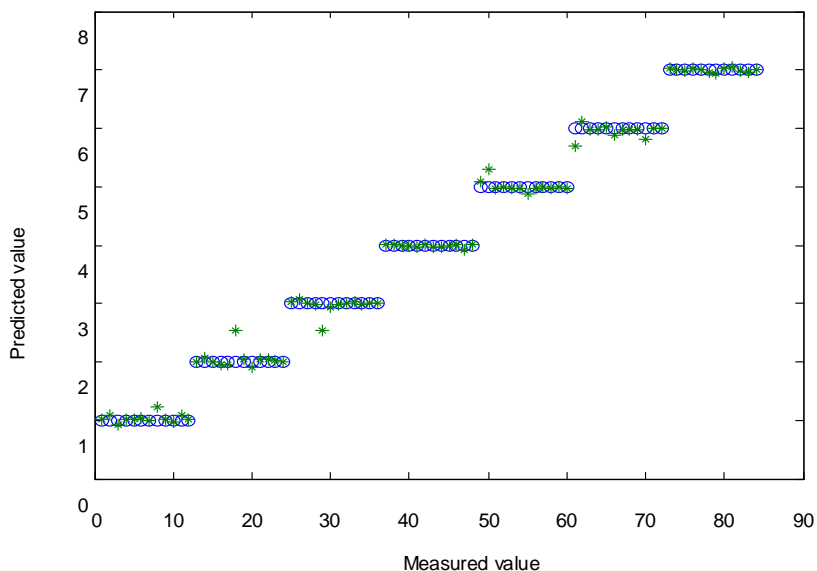


Figure 7. A comparison of predicted value and standard value

prediction (RMSEP) at 0.0189. The first derivative spectra and the second derivative spectra were also compared. The R_v was 0.9976 and 0.9835, and the corresponding SEP and RMSEP were 0.1043, 0.1437 and 0.2735, 0.2720 respectively.

The standard value, predicted value and residual data of the sample's original spectrum, first derivative spectra and second derivative spectra are shown well. Table 1 shows that all three models can distinguish different

varieties of millet, and among them, the original spectrum combined with principle components neural network has the most accurate results, with a simple accuracy rate of 100%.

Conclusions

In this paper, the NIRS of 252 samples of 7 millet

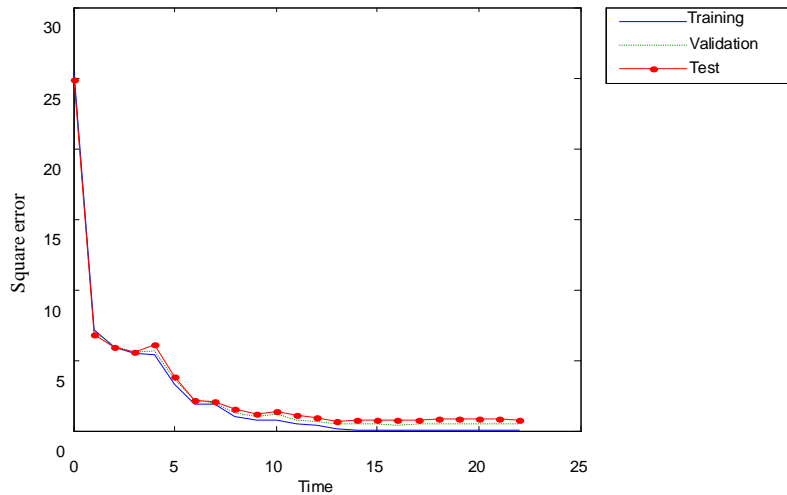


Figure 8. Curves of training error, checking error and testing error

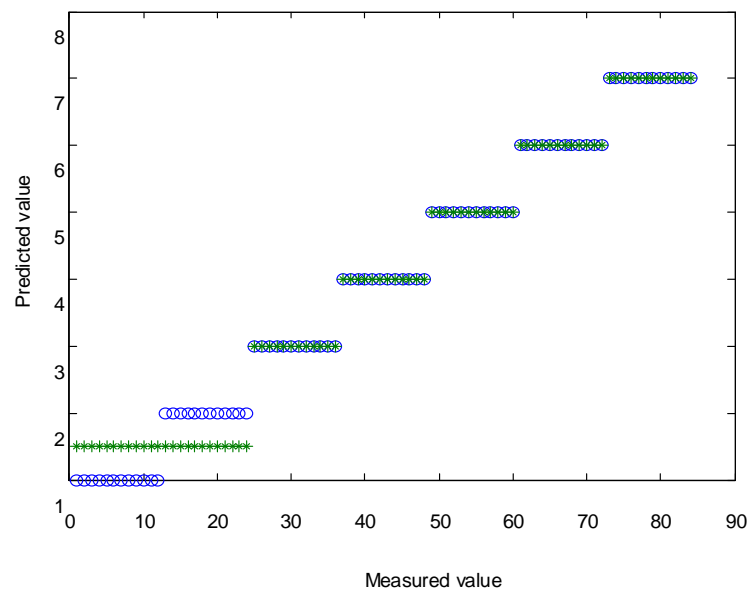


Figure 9. The comparing chart of predicted value and standard value

varieties were collected in the experiment. Characteristic wave extraction is performed within the range of 600 to 1900 nm which has a strong absorption peak. The spectral data were calibrated with a stoichiometric method. A classified discriminant model for millet varieties was established to analyze the differences among cultivars. The experimental results show that the model built with the characteristic wave has higher prediction accuracy than the whole wave model. The experimental results show that the model built with the characteristic wave has higher prediction accuracy than the whole wave model, and also shows that the characteristic wave

extraction is an effective method for model optimization.

NIRS combined with principal component neural network is used to classify the different varieties of millet. Because of the wide range of spectrometer, it can be well adapted to the discrimination of different millet varieties. The results of rapid identification analysis show that it is feasible to distinguish millet varieties by using visible/near infrared spectrum combined with principal component neural network model.

Through the analysis of the standard values, predicted values and residuals of the sample's original spectra, first derivative spectra, second differential spectrum, and

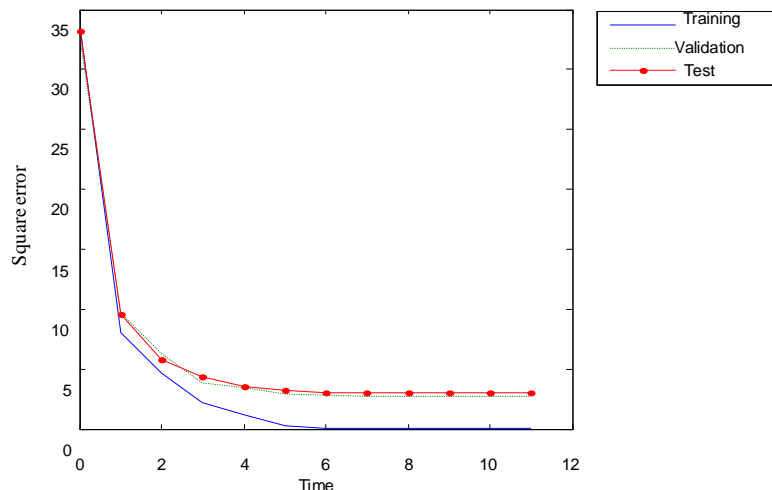


Figure 10. Curves of training error, checking error and testing error

discriminant results show that the effect of the original spectra combined with principal component neural network to identify the millet is best with a simple accuracy rate of 100%, followed by the first differential spectra and the second derivative spectra. These three models all can distinguish between different varieties.

When applying the second differential prediction model to forecast analysis, except for the first 2 varieties, the prediction error of the other 5 varieties is very small. If the interference factors are eliminated, the second differential spectrum prediction will also achieve very high prediction accuracy

NIRS is a simple, fast and no sample pretreatment method for qualitative analysis of millet varieties. It has a good classification effect and has certain application value in the field of millet variety discrimination.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGMENTS

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Full Length Research Paper

Phenotypic, socio-economic and growth features of Guinea fowls raised under different village systems in West Africa

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In Benin, family poultry farming has become an important activity in economic and social aspects that contribute to food security, poverty reduction and well-being. However, current information about poultry production and consumption is still limited. This information would be useful to improve the sustainable exploitation of agricultural and commercial genetic resources. We aimed to identify and assess the socio-economic and phenotypic features as well as to investigate phenotypic variability and growth performance of guinea fowls raised under different environments. Growth performance and survival rates of local guinea fowl varieties were recorded in three zones of Benin: Collines, Atacora and Borgou. Seven varieties, Gray, Common, Bonaparte, White, Black, Isabelle and Multicolored, were identified in Benin. The farmers choose a variety to be raised based on breeding system, agro-ecological zone, disease resistance, market price and production purpose. Bonaparte, Common and Gray varieties emerged as the most resistant whereas White, Black and Gray outperformed in growth and may be used for breeding purposes. The semi-confinement system could be recommended for startup as a temporary solution to improve production of local guinea fowls in Benin. The existence of several varieties on farms does not encourage genetic conservation and improvement of these resources. Establishing selection or crossbreeding programs in controlled environments would be more appropriate for guinea fowls raised in Benin.

Key words: Survey, agro-ecological zones, confinement systems.

INTRODUCTION

In West Africa, family poultry farming has become an important activity in economic and social aspects. Strategies to develop family poultry production at village level have been reported over the years (Riise et al., 2005). In Benin, family poultry is meat/eggs sources that contribute to food security, poverty reduction and well-

being of local people. This activity has potential profitability leading farmers to increase their production (Guèye, 2009; Moreki et al., 2010). However, current information about poultry production and consumption in Benin is still limited. In 2013, poultry population (chicken, duck, guinea fowl, turkeys and pigeons) was about 18.19

million (<http://faostat.fao.org>). Despite guinea fowl meat/eggs production is the third largest, chicken (1st) and duck (2nd), productivity is still low. This fact might be due to genetic and environmental factors as well as guinea fowl farming issues (Sanfo et al., 2007; Fajemilehin, 2010).

Chrysostome (1995) identified several guinea fowl varieties in Benin, such as Gray, Lilac, Isabelle, Chamoise, Albino, Variegated and Black. However, phenotypic features were not well reported; a fact that still limits any breeding improvement of guinea fowls. Few reports of environmental and genetic variability across varieties can be found in literature (Kayang et al., 2002; Kayang et al., 2010); thus, more efforts need to be done to better describe and evaluate local guinea fowl in terms of phenotypic and genetic diversity. This information would be useful to improve the sustainable exploitation of agricultural and commercial genetic resources.

This study try to address two hypotheses: 1) there are different guinea fowl varieties in Benin raised under different breeding systems and/or agro ecological zones not well reported or even not well established for phenotypic socio-economics aspects, and 2) the growth performance of these guinea fowl varieties might vary significantly across environments. Toward this orientation, we aimed to investigate the phenotypic variability and growth performance of local guinea fowl varieties raised under different environments to further indicate a better scenario to raise these birds. This will guarantee not only the genetic conservation and but also productivity improvement.

MATERIALS AND METHODS

Plumage color investigation and socio-economic importance

A survey was conducted on 131 village farmers in three different agro-ecological zones (Atacora, Borgou and Collines) in Central and North parts of Benin. This survey aimed to identify and assess the socio-economic and phenotypic features of local guinea fowl varieties. The Atacora and Borgou zones are characterized by semi-arid Sudanese climate, with annual rainfall ranging from 900 to 1100 mm, average temperature is 27.5°C, humidity is around 50% and there are from fair to poor grazing areas. In Collines zone, the climate is the Guinean Sudanese with average rainfall of 1200 mm per year. The annual average temperature is 27°C and humidity of 60%. This is an area of transhumance where agricultural residues are abundant and potentially used (Bertrand et al., 2013).

The surveyed farmers were chosen based on their experience in the guinea fowl production, farm accessibility, absence of exotic guinea fowls and availability of local varieties. The surveyed farmers were identified on the guinea fowl producers list made by the project between Belgium and Benin on livestock development in Borgou (FSA5) and snowball survey based on rural development

officers in the Departments of Collines and Atacora.

The survey was based on a socio-economic quiz, phenotypic aspects of different guinea fowl varieties as well as on observations and discussions with farmers. Dams (1996) and Fajemilehin (2010) identified different varieties of guinea fowl based on color and presence/absence of spots and/or beads in plumage. Information on egg source, production targets (purpose and market price), disease resistance, reproduction, management and causes of death were also performed. In general, mating within varieties is not well organized and conducted as it is between varieties in border farms. In these farms, the poultry scavenging system is better established.

Survival rates and growth performance

From birth to 12 weeks old, measurements of survival rates and growth performance for six varieties (Gray, Common, Bonaparte, White, Black and Isabelle) were recorded in Collines, whereas only three (Common, Bonaparte and White) were recorded in Atacora and Borgou zones. Guinea fowls were individually identified at birth by numbered rings (tags) on the leg and further weighted every week using a precision scale. These animals were raised in two different systems: extensive with feed additives and semi-confinement. The first system was followed-up in all zones whereas semi-confinement only in Collines.

In the semi-confinement system, farmers use many types of feed additives such as termites and crushed maize kernels; by adding or not toasted soy/sorghum or maize malt/soy beans from homemade cheese. A total of 566 individuals from different varieties, 37 incubations and 13 poultry farms, under extensive system, were recorded from birth to 12 weeks old (Table 1).

Statistical analysis

Frequency data analysis was performed by using *Proc FREQ* whereas the growth performance data using *Proc GLM* procedures from SAS software (SAS, 2002).

Sources of variation were evaluated via the following equation:

$$y_{ijk} = \mu + D_i + R_j + U_k + D_i * R_j + e_{ijk}, \quad (1)$$

y_{ijk} is the observation for dependent variables associated to the overall mean μ , the fixed effects of variety i (D_i), of zone j (R_j) and system management k (U_k); $D_i * R_j$ is the variety*zone interaction and e_{ijk} is the corresponding residual error

RESULTS

Plumage color investigation and socio-economic importance

Based on plumage color, our investigation showed that there was indeed diversity of guinea fowl varieties in Central and North of Benin. Seven varieties were identified: gray beaded (Common; Figure 1a and b), gray

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Table 1. Number of animals.

Zone/Variety	Black	Bonaparte	Common	Gray	Isabelle	White	Total
Atacora	0	72	111	0	0	69	252
Borgou	0	36	26	0	0	36	98
Collines	26	40	64	26	25	35	216
Total	26	148	201	26	25	140	566



Figure 1. Guinea fowls varieties named based on plumage color: Common^{a,b}; Bonaparte^{c,d}; White^{e,f}; Gray^{g,h}; Isabelle^{i,j,k,l}; Black^{m,n,o}; Multicolored^p.

beaded with white chest (Bonaparte; Figure 1c and d), non-beaded white (White; Figure 1e and f), Gray (Figure 1g and h), Isabelle (Figure 1i, j, k and l), Black (Figure 1m, n and o) and Multicolored (Figure 1p).

In Benin, guinea fowls have been mainly raised for dual purpose. Among all surveyed zones, 73% of farmers raise guinea fowls for that purpose, while only 18% and 9% raise them for egg and meat purposes, respectively (Table 2). This production system concerns mainly Atacora and Borgou zones. In Collines zone, 65% of farmers raise dual and 35% egg purposes fowls. The main egg source is border farmers followed up by local market (59% vs. 13% in average), whereas random

mating appeared to be the most used breeding system (Table 2). In order to improve production, from all 131 farmers, 72% adopted random and 23% close relatives mating breeding system whereas 5% keep buying eggs outside Benin. The rusticity of guinea fowl varieties raised in Central Benin (Collines) is shown in Table 3.

The Common guinea fowl variety appears to be the most rustic (75.3%), followed by Black (52%) and Bonaparte (47%). The Multicolored, White, Isabelle and Gray varieties are the most sensitive guinea fowl varieties in Benin (Table 3).

The market price of guinea fowls varied between agro-ecological zones and varieties (Table 4). The white variety

Table 2. Production purpose, eggs source and breeding system in agro ecological zones of Benin.

Characteristics	Agro-ecological zone (Number of farmers)		
	Atacora (53) (%)	Borgou (42) (%)	Collines (36) (%)
Purpose			
Egg and meat	74	83	65
Egg	14	9	35
Meat	12	8	0
Egg source			
Another village	6	8	0
Border country	1	3	6
Border farmer	62	42	65
Local market	11	25	18
Border farmer and local market	16	14	5
Own hatching sources	4	8	6
Breeding system			
Random	83	44	60
Eggs outside Benin	4	6	10
Mating close relatives	13	50	30

Table 3. Guinea Fowl variety resistance according to Benin farmers.

Resistance/Variety	Common	Bonaparte	White	Gray	Isabelle	Black	Multicolored
Intermediate (%)	23.4	23.4	23.4	23.4	23.4	23.4	23.4
High (%)	75.3	46.7	22.1	28.6	23.4	51.9	20.8
Low (%)	1.3	29.9	54.5	48.0	51.9	24.7	55.8

Table 4. Guinea fowl average market prices (standard error) by varieties and zones.

Variety/Zone	Average market price (standard error)			Zone	Variety	Zone*Variety
	Atacora ^b	Borgou ^b	Collines ^a			
Common ^c	2211 (45.5)	2367 (54.4)	2433 (47.6)	***	***	NS
Bonaparte ^c	2132 (38.8)	2206 (42.0)	2533 (55.1)	***	***	NS
White ^a	2886 (69.6)	3133 (142.3)	3278 (89.6)	***	***	NS
Gray ^c	2275 (49.6)	2256 (28.1)	2400 (53.7)	***	***	NS
Isabelle ^{bc}	2328 (60.1)	2356 (29.5)	2450 (61.5)	***	***	NS
Black ^b	2475 (46.6)	2656 (46.0)	2700 (51.5)	***	***	NS
Multicolored ^c	2193 (36.3)	2244 (28.1)	2433 (55.1)	***	***	NS

*: Significant; **: highly significant; ***: very highly significant; NS: non-significant; Zones/varieties followed by same letters (a, b, c) are not statistically different ($P < 0.05$).

was the most expensive with average prices of 2886, 3133 and 3278 CFA franc (FCFA) in Atacora, Borgou and Collines zones, respectively. Black and Isabelle market prices were similar between zones; however, these prices differed from Gray, Common, Multicolor and Bonaparte varieties (Table 4). The guinea fowl market price was higher in Collines than Atacora ($P < 0.01$) and Borgou ($P < 0.04$) zones. Nevertheless, similar prices were

observed between Atacora and Borgou ($P > 0.05$; Table 4).

Survival rates

The survival rates varied according to bird age (Figure 2). No deaths were observed for Common, Bonaparte and

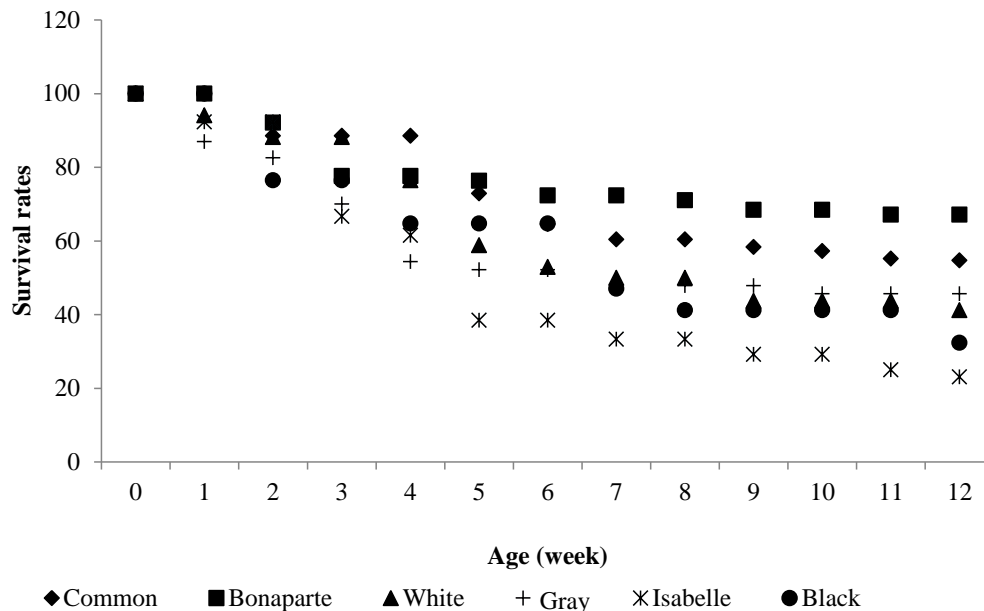


Figure 2. Survival rates of guinea fowl varieties.

Table 5. Growth performance (body weight) means for Common, Bonaparte and White guinea fowls under different zones in Benin.

Variety*Zone	Week (W)												
	W0	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
Common*Atacora	32.8 ^{aa}	53.8 ^{aa}	76.9 ^{aa}	121.8 ^{aa}	194.3 ^{aa}	231.7 ^{aa}	332.4 ^{aa}	415.9 ^{aa}	456.4 ^{aa}	519.0 ^{aa}	575.6 ^{aa}	620.1 ^{aa}	610.6 ^{aa}
Common*Borgou	25.6 ^{aa}	45.9 ^{aa}	68.8 ^{ba}	108.7 ^{ba}	193.5 ^{ba}	272.3 ^{ba}	340.0 ^{ba}	441.0 ^{ba}	465.7 ^{aa}	491.4 ^{ba}	523.6 ^{ba}	562.8 ^{aa}	610.8 ^{aa}
Common*Collines	28.7 ^{ba}	40.4 ^{ba}	60.7 ^{ca}	92.6 ^{ca}	118.3 ^{ca}	168.9 ^{ca}	228.1 ^{ca}	282.6 ^{ca}	343.6 ^{aa}	398.7 ^{ba}	492.7 ^{ca}	577.3 ^{ba}	658.3 ^{ba}
Bonaparte*Atacora	29.1 ^{aa}	51.6 ^{aa}	76.2 ^{aa}	84.5 ^{ab}	90.5 ^{ab}	130.7 ^{ab}	167.5 ^{ab}	261.0 ^{ab}	342.4 ^{ab}	401.5 ^{ab}	458.8 ^{ab}	513.3 ^{ab}	546.4 ^{ab}
Bonaparte*Borgou	30.0 ^{aa}	54.7 ^{aa}	79.8 ^{ba}	116.3 ^{bb}	168.6 ^{bb}	245.0 ^{bb}	276.0 ^{bb}	343.5 ^{bb}	364.1 ^{ab}	448.8 ^{bb}	505.8 ^{bb}	515.8 ^{ab}	561.0 ^{ab}
Bonaparte*Collines	29.6 ^{ba}	39.0 ^{ba}	54.8 ^{ca}	70.3 ^{cb}	117.1 ^{cb}	154.9 ^{cb}	210.1 ^{cb}	267.4 ^{cb}	372.3 ^{ab}	431.2 ^{bb}	480.7 ^{cb}	544.2 ^{bb}	582.7 ^{bb}
White*Atacora	26.1 ^{ab}	40.1 ^{aa}	62.7 ^{ab}	105.6 ^{ac}	185.1 ^{ac}	233.7 ^{ac}	275.9 ^{ac}	317.7 ^{ac}	357.5 ^{ac}	354.6 ^{ab}	432.1 ^{aa}	513.5 ^{aa}	612.6 ^{aa}
White*Borgou	25.9 ^{ab}	54.2 ^{aa}	93.1 ^{bb}	132.1 ^{bc}	195.1 ^{bc}	267.5 ^{bc}	299.1 ^{bc}	303.5 ^{bc}	357.9 ^{ac}	437.3 ^{bb}	521.2 ^{ba}	564.4 ^{aa}	622.8 ^{aa}
White*Collines	29.1 ^{bb}	46.3 ^{ba}	77.7 ^{cb}	119.5 ^{cc}	175.4 ^{cc}	225.6 ^{cc}	267.6 ^{cc}	304.5 ^{cc}	451.3 ^{ac}	496.4 ^{bb}	577.5 ^{ca}	706.1 ^{ba}	825.9 ^{ba}
<i>P-value (zone)</i>	**	***	***	***	***	***	***	***	NS	***	*	***	***
<i>P-value (variety)</i>	**	NS	***	***	***	***	***	***	***	***	***	***	***
<i>P-value (zone*variety)</i>	***	***	***	***	***	***	***	***	***	***	***	***	***

The first letter indicates differences for the zone and the second for the variety; means between classes in the same column followed by different letters differ significantly: *, Significant ($P < 0.05$), **, highly significant ($P < 0.01$), ***, very highly significant ($P < 0.001$); NS: non-significant.

Black varieties in the first week. At week three, survival rates of four varieties were similar (Common, Bonaparte, Gray and White; around 90%), whereas Isabelle and Black varieties presented smaller rates, 67% and 70%, respectively. From week three to eight, Isabelle and Black continued to be more susceptible, White and Gray had intermediary whereas Bonaparte and Common presented the highest survival rates (Figure 2). Survival rate stability between varieties was observed from week nine to 12, except for Black. This variety showed an abrupt decrease from week 11 to 12 (Figure 2).

Growth performance

Growth performance of Common, Bonaparte and White Guinea fowls in Atacora, Borgou and Collines zones

In general, guinea fowls growth performances differed between zones (Table 5). These differences were significant for almost all the growth period. Higher growth performances were observed in Borgou (from week 0 to 8) and Collines (from week 9 to 12) zones. In summary,

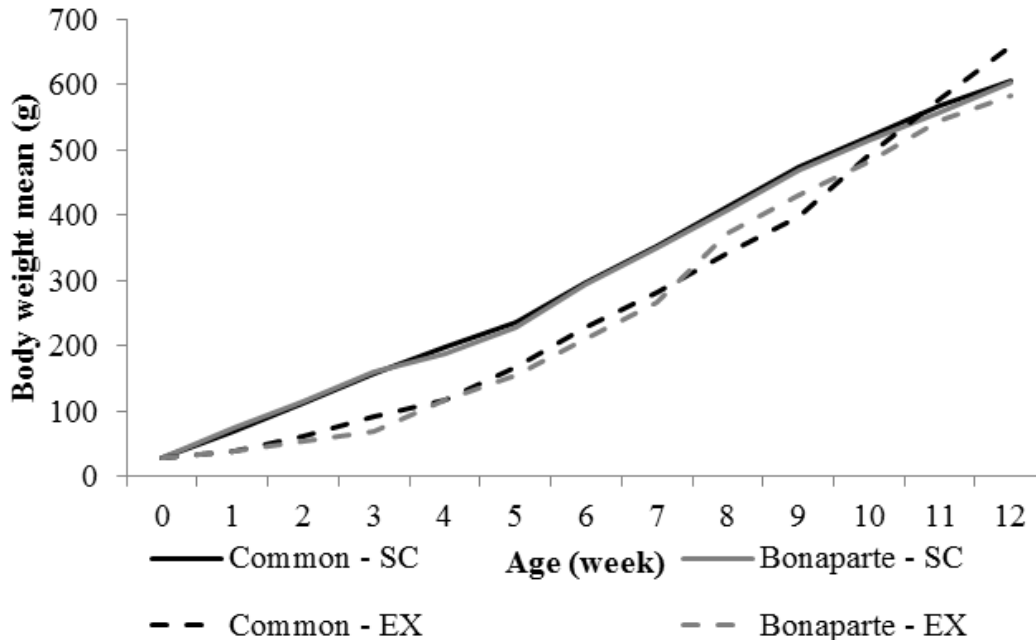


Figure 3. Common and Bonaparte guinea fowls growth performance means raised under semi-confinement (SC) and extensive (EX) systems.

better growth performances were identified in Collines followed by Borgou and Atacora, respectively. Growth performances between varieties highly differed at birth ($P < 0.01$), while there was no statistical differences at week one (Table 5). The Common variety presented higher performances from week two to eight in Atacora and Borgou zones, whereas White guinea fowls outperformed in Collines. At week 12, the White variety had better performances in all zones. Moreover, zone by variety interaction was statistically significant for all tested period (week 0 to 12; $P < 0.001$; Table 5).

Growth performance between Bonaparte and Common varieties raised under two different village systems

Although both varieties showed similar body weight at birth under extensive and semi-confinement systems, Bonaparte and Common varieties outperformed under semi-confined system from the first to the tenth week (Figure 3). Differences between these varieties were observed at weeks 12 ($P < 0.05$) where the heaviest weights were registered for Common variety under extensive system.

In summary, from week one to eight, birds under semi-confinement system outperformed in terms of growth performance compared to those under an extensive raising system (Figure 3). After week 8, when birds under the semi-confinement system were changed from confinement to extensive, growth performance were, in general, similar between systems.

Comparative growth performances between six Guinea fowl varieties raised under an extensive system in Collines zone

The Collines zone was previously reported as the best zone in terms of growth performance. Therefore, we further compared varieties raised in this zone under the most common village system (extensive). Growth performances comparisons between all guinea fowls was performed. Figure 4 showed differences in growth performances between varieties along the tested period. Highest body weights at week 12 were observed for White and Gray varieties, whereas the lowest weights were observed for Isabelle and Bonaparte. In general, the Black variety outperformed from the starting phase (weeks 2, 3, 4, 6 and 7) and White in the final period, week eight to 12. Common and Bonaparte varieties showed similar results up to week 9, whereas from weeks 10 to 12, Common outperformed. The Gray variety showed smaller performances in the beginning (weeks 0 to 7), but higher after this period compared to other varieties.

DISCUSSION

Seven (7) guinea fowl varieties have been identified in North and Central parts of Benin (Figure 1). The Common (Figure 1a and b), Gray (Figure 1g and h) and Black (Figure 1m, n and o) varieties were also identified in Nigeria by Fajemilehin (2010) and Niger by Singh et al. (2010). The Isabelle (known as Rousse or JAA) and

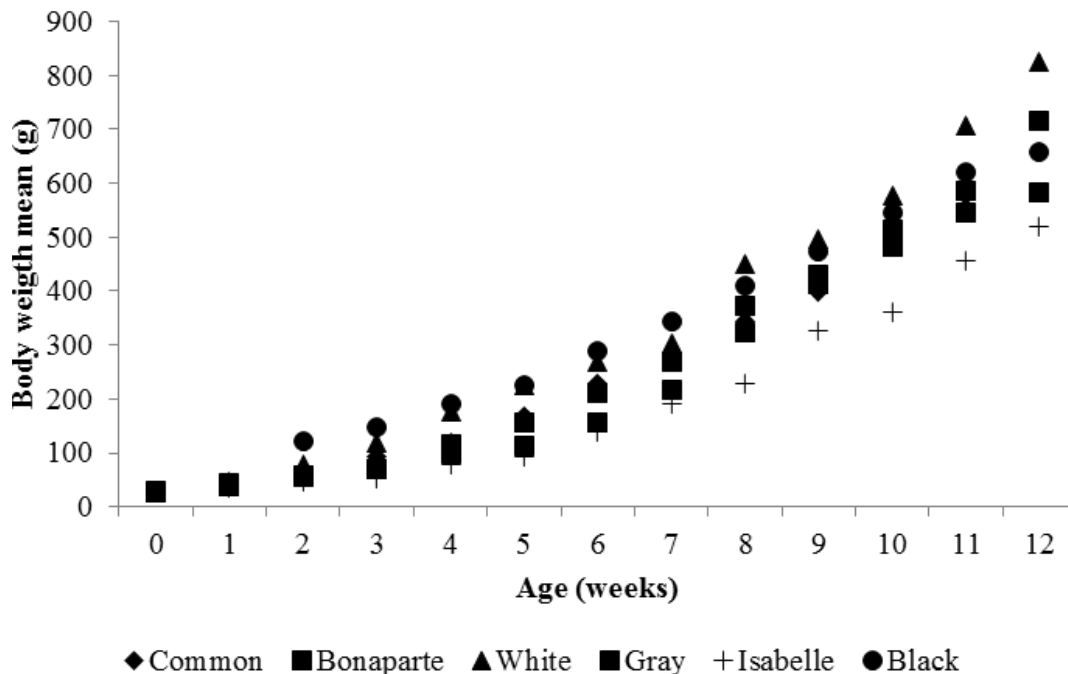


Figure 4. Growth performance means for varieties raised under an extensive system in Collines zone.

White varieties were also identified by Singh et al. (2010) with similar plumage color. In addition, the Bonaparte variety has been reported in different studies (Chenevard, 1931; Cauchard, 1971; Dams, 1996). Albino feathers on the chest and secondary flight wings are specific features of Bonaparte distinguishing it from Gray (Figure 1d), Black (Figure 1n) and Isabelle (Figure 1i) varieties. This white color on the chest and secondary wings appeared to be heritable over generations. In the plumage of young Isabelle birds can be observed an exchange from fawn to gray color (Figure 1i, j, k and l). This exchange tends to be in different degrees between fowls. Gene features related to the color of Isabelle variety would be recessive and/or related to sex (Dams, 1996), and therefore the explanation about this exchange remains unknown. Globally, some of the identified varieties in our study have already been described by Chrysostome (1995). However, one of the varieties (Chamoise) described by these authors is currently absent in Benin or currently named Isabelle. In addition, the Multicolored variety observed in our study had been described by these authors as Variegated variety and been characterized by several plumage colors unevenly distributed all over the body (Figure 1p).

Our investigations showed that most guinea fowl eggs/meat production in the agro ecological zones is under extensive system with or without feed additives. Feed additives are cooked by using termites and cereals. This food is further offer to young birds, and the amount and frequency varied depending upon farmer and zone. These results and the uniform farming system in West

African corroborated with literature (Sanfo et al., 2007; Boko et al., 2013; Konlan and Avornyo, 2013; Avornyo et al., 2016). In general, farmers choose a variety to be raised based on production purpose, diseases resistance and market price. This information agreed with those reported by Sanfo et al. (2012) who stated that White guinea fowls are not seen by farmers as one of the best to be raised. This is due to its plumage color (predator attraction), lightweight body shape and low laying performance.

The largest proportions of farmers (73%) raising dual-purpose guinea fowls are known by their higher egg production and consumer acceptance compared to local chickens. This is in agreement with literature (Sanfo et al., 2007). Some farmers (18%) prefer to have limited laying center sheds, due to limited available space in crowded areas or even robbery likelihood. These eggs are used for consumption to increase profit or both.

The higher percentage of farmers under egg purpose system in Collines compared to Atacora and Borgou might be explained by the smaller odds to be stolen and number of predators. Meat purpose farmers (9% in average) usually buy eggs, incubates them, and after hatching, the fowls are raised until sold out. The main reason for this is to not face transportation costs and risks buy selling eggs as well as robbery and predators.

The main egg source was eggs incubation from border farmers (59.49% in total). This value was higher than the 44% reported by Avornyo et al. (2016) in Ghana. This egg source is performed in order to ensure the eggs quality and fertility. This statement is consistent with

Chrysostome (1993) who believed that reproduction is ensured by incubation under hen and eggs fertility by high sex ratio.

Unlike our study where random mating is the most used breeding system by farmers (72%), Avornyo et al. (2016) reported high mating rates of close relatives. Despite random mating may lead to lower genetic improvement, close relatives mating might be carefully used in order to avoid inbreeding. Some farmers are aware from this fact and already appeal to eggs acquiring from other cities or even border countries. However, these sources remain limited due to several risks as transportation that may affect egg quality and fertility.

In Benin, guinea fowl selection by farmers is made based on mass selection guided by farmer's practices and interests. Therefore, by verifying different guinea fowl production systems in Benin, we may infer that farmers will have harsh time to achieve animal breeding improvement. This is due to the absence of controlled production and reproduction systems. It would be hard to establish animal breeding programs since there is no quality in phenotype recording as well as reliable pedigree. This observation is in agreement with Sanfo et al. (2007), who reported that some farmers randomly practice mass selection based on criteria as eggs hardness and shape, and bird body shape.

Another interesting selection criterion is disease resistance. This can guarantee fewer losses in the production system. The resistance diversity between varieties reported in this study corroborates with those results reported by Sanfo et al. (2012). According to farmers, these differences might be due to the raise condition and animal care. However, farmers appear to not take into account the frequency of each variety in their system. According to our findings, the Bonaparte variety presented a more stable survival rates testifying their adaptability to different husbandry conditions. On the other hand, the Gray variety was characterized as susceptible in the starting phase but stable after this period. This might be due to the viability of young Gray guinea fowl to outbreaks than to husbandry conditions and/or care. At last, White, Black and Isabelle were most susceptible varieties due to their survival rate instability, especially after week four. This survival rate instability may be characterized by the influence of husbandry conditions and susceptibility to parasites, bacteria and virus (Boko et al., 2013).

In general, the prices were relatively higher in Collines. Collines is a less known agro-ecological zone in Benin. The market prices of guinea fowls were significantly higher compared to those reported by Boko et al. (2011) and Dahouda et al. (2008) who reported market prices values of 1500 and 1630 FCFA, respectively. Market prices increase with demand increasing of guinea fowls or production decrease. The unexpected second reason may happen due to diseases and even outbreaks, the main responsible for a large number of deaths (Boko et

al., 2013).

Growth performances of Gray, Bonaparte and White varieties varied between zones (Atacora, Borgou and Collines). It happened due to different food availability and care providing to young birds by farmers (Table 4). These results agreed with those reported by Singh et al. (2010) who have reported different performance (range 780-925g) in different environments, for the same variety at week 12.

In Benin, the Atacora and Borgou are considered the most important zones for guinea fowl livestock. In these zones, farmers provide efficient care, whereas in Collines they are less experienced. This explained higher growth performances in Atacora and Borgou (Table 4). Care and food supplement provided by farmers enable faster growth of young guinea fowls (Sanfo et al., 2012). From eight weeks old (after critical period), farmers from Atacora and Borgou have been reduced care, and animals have been faced hard periods to adapt to the new condition of life. On the other hand, the animals from Collines are usually adapted to this condition at this point since care is minimal from the beginning. In addition, the availability of food in these zones is different and this has influenced growth performance. The Collines zone outperformed Atacora and Borgou due to its high grain production covered vegetation (<http://faostat.fao.org>). The Atacora is under desert influence and presents low soil fertility, therefore, is the less fortunate zone.

Mortality rates of young guinea fowls under semi-confinement system tended to decreased in our study. Similar results have been reported in literature (Laurenson, 2002; Dahouda et al., 2008; Boko et al., 2013). Significant improvements on growth performance were achieved compared to the extensive system, especially in the starting phase. Similar results after week eight (Figure 3) may be due to the adaptation time for birds under the semi-confinement system, i.e., fowls might had smaller gains, none or even lost weight. Nevertheless, the semi-confinement system still appeared to be most efficient to improve farms profitability. In addition, animals under this type of system are also less stressed and, therefore, to improve feed supplies in this system could be very beneficial for farmers (Laurenson, 2002; Dahouda et al., 2008).

Growth performance differences observed between varieties under extensive system in Collines (Figure 3) were in agreement with Sanfo et al. (2007) and Fajemilehin (2010). However, Sanfo et al. (2007) and Fajemilehin (2010) observed that Black and Common varieties outperformed, whereas, in our study, the White variety presented the best performance. Genetic diversity of varieties may explain differences in weight and offer an opportunity to improve growth performance of guinea fowls through selection (Sanfo et al., 2012).

However, guinea fowl growth curves can be very different. Some varieties such as Common, Gray and Black had faster growth at beginning and lower by the

end. Fajemilehin (2010) reported similar results for the same varieties. Differences in growth might be also explained by the adopted husbandry system, parasitism, bacterial diseases or even supply of feed additives (Dahouda et al., 2008; Boko et al., 2013). In summary, White, Gray and Black guinea fowls appeared to have faster growth compared to Common, Bonaparte and Isabelle varieties in North and Central parts of Benin.

Although our study was designed to cover regions known for their raising guinea fowl potential in Benin, the survey- and measurement-based data still depends upon concerns of farmers regarding production history, that is, absence of valuable recording systems at national level as well as data recording at farmer level. In this context, the guinea fowls varieties identification was mostly based on plumage color and farmers' knowledge. In general, it appears that main interests of farmers were linked to economic rather than technical issues.

To overcome these limitations, data recording in a controlled station should be encouraged towards better identification of "pure" individuals of those studied varieties. Advanced genetics/genomics techniques and novel reproduction biotechnologies should also be prioritized.

Conclusion

Seven varieties of guinea fowls were identified in Benin and farmers choose a variety to be raised based on breeding system, agro-ecological zone, disease resistance, market price and production purpose.

Bonaparte, Common, and Gray varieties emerged as most resistant whereas White, Black and Gray outperformed in growth and may be used for breeding purposes.

The semi-confinement system could be recommended for startup as a temporary solution to improve production of local guinea fowls in Benin.

The existence of several varieties on farms does not encourage genetic conservation and improvement of these resources. However, establishing selection or crossbreeding programs in controlled environments would be more appropriate for guinea fowl raised in Benin.

CONFLICT OF INTERESTS

The authors declare that there are no conflicts of interest arising from intellectual, personal, or financial circumstances of our research.

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Full Length Research Paper

Yield and yield components of potato (*Solanum tuberosum* L.) as influenced by planting density and rate of nitrogen application at Holeta, West Oromia region of Ethiopia

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Four different nitrogen levels and four plant spacing were studied in 4x4 factorial arrangements in randomized complete block design with three replications. The highest yield, number of tuber, number of tuber and dry weight of tuber were obtained with application of jointly 100 and 150 kg/ha nitrogen. Increasing plant density resulted in higher tuber yield, dry weight of tuber and total dry matter yield. Increasing nitrogen fertilizer rate 100 up to 150 kg/ha increased mean tuber weight and total dry matter yield. Since, 100 and 150 kg/ha nitrogen had no significant difference to each other producing the highest tuber yield and number of tuber, so in order to prevent environmental pollutions and excessive costs, utilization of 100 kg/ha nitrogen is recommended and any reduction in the planting density lower than 75x30 cm will lower both total yield and % marketable yield. So, 30 cm planting densities' producing the highest yield makes it suitable for planting. The combined effect of different level of nitrogen and plant spacing revealed that the highest nitrogen dose 150 kg/ha applied at the closest 75 cm x 10 cm gave the highest yield of tuber (10377.78 kg/ha). The narrower spacing of 10 cm produced numerous small-sized potatoes. These small-sized potatoes fell in grades that are not commercially accepted. The treatment combination, 150 kgN/ha applied at 75 cm x 20 cm spacing gave the second highest yield of tuber (9214.81 kg/ha). As the spacing increased to 30 cm, and with increasing nitrogen the tuber size increased with more potatoes falling in the acceptable grades. Yield of tuber per hectare was significantly and positively correlated with plant height, number of stem per plant, fresh weight, number of tuber and weight of tuber per plant. The highest marketable tuber yield of 4144.44 per plot was produced at 30 cm spacing, and the lowest marketable tuber yield was obtained at 75 cm x 10 cm (1111.11).

Key words: Yield, plant spacing, fertilizer rates.

INTRODUCTION

The food needs of the growing population required a growth in agricultural production to achieve food security

and sustain high economic growth levels with the aim ending poverty (Tesfaye et al., 2013). The yield potential

of potato is about six to seven times more compared to that of rice and wheat from a unit area and time resulting in about five fold more benefit. Therefore, potato can play a vital role in national food and nutritional security and poverty reduction. Agriculture is the mainstay of the Ethiopian economy; horticultural crops production is one of the components of the Ethiopian agriculture, of which potato crop production is a major activity. Potato (*Solanum tuberosum* L.) belongs to the family Solanaceae and is a close relative of tomato, eggplant, pepper, tobacco and the wild nightshade (Abay and Sheleme, 2011). World annual production of potato is about 330 million metric tons with area coverage of 18,651,838 ha. In Africa total production of potato is about 17,625,680 tones with total area coverage of 1,765,617 ha. In Ethiopia total production is around 572,333 tons on area coverage of 69784 ha.

Potato grows best on light soils with good aeration of the root system that helps maintain high tuber bulking rates, resulting in higher yields per unit area. However, the growing population pressure in the Ethiopian highlands is forcing farmers to grow potato on vertisol that covers about 7.6 million ha, of which 2 million hectare is under cultivation.

In potato production, nitrogen (N) is applied more frequently and in greater amounts than any other nutrient. It is also the nutrient than most often limits yield .without added nitrogen, growing plants often show a N deficiency characterized by yellow leaves, stunted growth, and lower yields, because it is an important input, N and factors affecting its availability have been the subject of much investigation (Yenagi et al., 2005). Excessive N fertilizer applied at or before tuberization can extend the vegetative growth period and delay tuber development, resulting in a lower tuber yield. Nitrogen is a mobile nutrient in the soil and its excess can lead to losses via leaching or surface run off. These factors make the appropriate N rate critical for successful potato. General fertilizer best management practices (BMPs) to help assure that the right source of nutrient is applied at the right rate, at the right time, and in the right place is contributing to the productivity, profitability, and sustainability of the potato production system. Though, farmers in study area have the awareness of the potato response to applied nutrients and they planted the crop in homesteads and irrigable areas using organic manure and commercial fertilizer, they are not acquainted with the type and the rate of fertilizers to be applied for the potato plant. Therefore, plant density and nitrogen level have to be regulated for higher yield. Thus, the knowledge of the relationships among these factors and yield is helpful to optimize potato yield through effective

use of land and rate of fertilizer. Based up on the above explained problems the present study was aimed to evaluate the effect of different plant density and nitrogen rates on yield and yield components of potato.

MATERIALS AND METHODS

Description of the study area

The field experiment was Holeta Agricultural Research Center (HARC), West Showa Zone of Oromia regional state during 2014 cropping season. Holeta is located in the Oromia special zone surrounding Finfinne of the Oromia Region. It has a latitude and longitude of 9°3'N 38°30'E/ 9.050°N 38.500°E and an altitude of 2400 m above sea level. The average annual temperature of the experimental site ranges from 6.1 to 22.2°C. Distribution of rainfall varies from one season and the Woreda has bio-modal rainfall, that is, Belg rainfall (February to April) and Mehar rainfall June to October.

Materials used for the experiment

Planting material

The potato variety named Gudanne, which was developed and released by Holeta Agricultural Research Centre in 2006, was used for the experiment.

Fertilizer material

Urea (46% N) and TSP (46% P₂O₅) were used as a source of nitrogen and phosphorus nutrient elements.

Experimental design and treatment

This research was designed to evaluate potato responsiveness to several rates of nitrogen (0, 50, 100 and 150 kg ha⁻¹) the source of nitrogen was urea fertilizer and four levels of plant spacing: 10, 20, 30 and 40 cm per row. Potato variety Gudenne was used for the experiment since it is one of the potential potato cultivars for central highlands of Ethiopia including Holeta area. The total number of plots was 48 and the size of the unit plot was 3 m × 3 m (9 m²) areas and each accommodates 4 rows of plants. The experiment was laid out in 4x4 factorial arrangements using Randomized Complete Block Design (RCBD) with three replications. A distance of 1 m was maintained between the plots and within a block 1.5 m distance was maintained between blocks and 75 cm row spacing was uniformly used. Well sprouted uniform tuber seeds of potato variety Gudenne were planted at 12 cm depth in June 24, 2014 as per the experimental details. Cultivation, weeding and harvesting was done at the appropriate time, uniformly.

Land preparation

Land of the experimental area was prepared in accordance with a

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standard practice used; i.e. the experimental plot was ploughed three times. This was carried out using a tractor plough two times at the depth of 30 to 35 cm and the land was leveled and ridges were made by hand.

Fertilizer application

Nitrogen fertilizer was applied half rate at the time of planting and the remaining half of nitrogen was applied 45 days after planting and the source of nitrogen was urea fertilizer. Phosphorus was applied to all plots equally at the rate of 90 kg TSP (triple-superphosphate).

Data collection

To evaluate the effect of plant spacing and nitrogen application on potato growth and yield, data was collected for growth parameters such as days to flowering, days to maturity, plant height, number of main stem (Bleasdale and Thompson, 1969) and yield parameters such as number of tubers per plant, marketable tuber yield, unmarketable tuber yield, average tuber weight and total tuber yield were recorded from ten randomly selected plants of the two middle rows except at the total tuber yield data which is taken per plot basis as per the procedure of Zelalem et al. (2009). The following data were collected:

1. Days to flowering: These were recorded when 50% of the plant population attained the flowering stage based on visual observation.
2. Plant height (cm): Plant height was determined by measuring height from the base of the main shoot to the apex at full blooming by taking three sample plants from each plot.
3. Stem number per plant: This was recorded as average stem count of five hills per plot at 50% flowering.
4. Days to maturity: Days to physiological maturity was recorded when the leaves of 50% of the plants in the plot turned yellowish or starting senescing based on visual observation.
5. Above ground (Shoot) biomass: Fresh weight was taken from five sample plants six weeks after flowering when the plant was fully developed and practically ceased its vegetative growth, then dry weight was measured after oven drying at 105°C to constant mass.
6. Average tuber weight: Average tuber weight was determined on the basis of total tuber weight produced per plant/total tuber number counted per plant at harvest.
7. Weight of marketable tubers: Healthy tuber with a size more than or equal to 31 g weighed using sensitive balance from five sample plants at harvest.
8. Weight of unmarketable tubers: Under-sized tubers (< 30 g) as well as diseased, cracked and rotten were measured at harvest were categorized as unmarketable.
9. Total tuber yield: Marketable and unmarketable tubers were taken at harvest.
10. Tuber size grades: Based on the weight of tubers, 5 categories of tuber size (< 30 g, 31-50 g, 51-70 g small, medium and large was recorded, respectively).
11. Tuber dry matter content (%): Dry weight was measured by taking three fresh tubers per plot and weighing at harvest, then they were thinly sliced into 6 to 8 pieces and air dried for two days and subjected to oven drying at 105°C until a constant weight was obtained.

Data analysis

All crop data collected were subjected to analysis of variance (ANOVA) using general linear model (GLM) procedures with the

help of software SAS version 9.1.3 (SAS Institute, 2002). Means separation for significant treatment effects was carried out using the least significant difference (LSD) test at 5% level of significance.

RESULTS

Effect of Nitrogen level on yield and yield components of potato

The values of all growth and yield parameters gradually increased with the gradual increase of nitrogen level and plant spacing. The maximum plant height (92.66 cm) was recorded against the application of 150 kgN/ha which was statistically higher than rest of the treatments and the minimum (54.08 kg) was found in the application of 0 kg N/ha. The highest number of stem per plant (10.83) was obtained when the highest rate of nitrogen (150 kg N/ha) was applied and the lowest (6.33 kg) was found in the control (0 kg N /ha) (Table 1). The maximum tuber weight of potato (3.35 kg/plant) was obtained from the application of (150 kg N/ha) and the lowest (1.02 kg/plant) from the control.

The highest average tuber weight (2.59 kg) was obtained when the highest rate of nitrogen (150 N/ha) was applied and the lowest (1.27 kg) was found in the control (0 kg N/ha). The maximum marketable tuber yield (2.308 kg/plant) was obtained from the application of (150 kgN/ha) and the lowest (0.15 kg/plant) from the control. The higher dose of nitrogen 150 kg N /ha produced on average weight (9.06 kg) total tuber yield per plot that was higher than produced 50 kg N /ha while the control treatment produce the lowest total tuber weight (3.125 kg). The maximum tuber number per plant (13.70 kg) was obtained from the highest level of nitrogen 150 and 0 kgN/ha gave the lowest number of tubers per plant (7.2 kg). The maximum yield of potato tubers (10007.41 kg) was obtained when the crop received 150 kgN/ha and the lowest tuber yield (3472.22 kg) was found in the control (Table 2). When the data on yield of tuber per hectare was regressed against the different level of nitrogen, a linear relationship was obtained between them. It was evident from Figure 1 that the equation $Y = 48.22x + 3611$ gave a good fit to the data and the co-efficient of determination $r = 0.968$ showed that the increase in tuber yield per hectare occurred due to the application of nitrogen was justifiable.

Rainfall

Climatic condition of the study *Woreda* is divided in to two agro-climatic zones .These is Dega, and Woina Dega. Dega part gets the maximum rainfall annually. Distribution of rainfall varies from one season to another as that of other area in Ethiopia and basically the *Woreda* has bio-modal rainfall, that is, Belg rainfall (February to April) and Mehar rainfall June to October. Rainfall annual

Table 1. Potato tuber growth components as affected by nitrogen level.

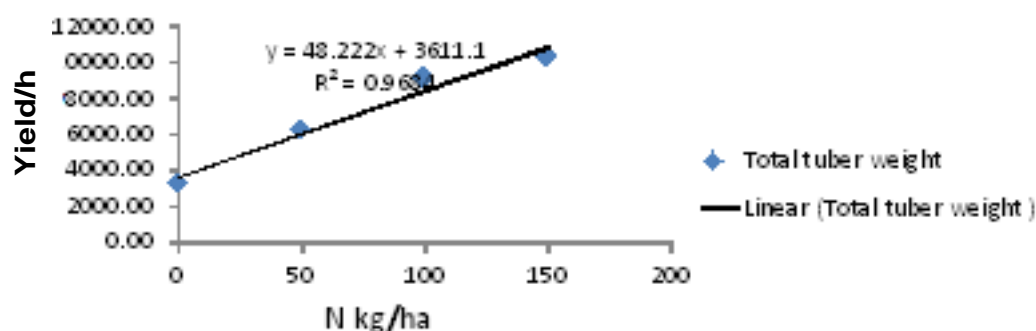
Parameter	Nitrogen level kg ha ⁻¹				LSD (0.05)	CV
	0	50	100	150		
Plant height (cm)	54.08 ^c	71.09 ^b	81.36 ^a	92.66 ^a	6.14	9.6228
Days to 50% flowering	49.75 ^d	52.48 ^c	55.85 ^b	59.67 ^a	1.8606	10.898
Days to 50% Maturity	99.96 ^c	105.94 ^{ab}	117.58 ^b	119.25 ^a	3.8789	27.7656
Stem number /plant	6.33 ^d	8.00 ^c	9.83 ^b	10.83 ^a	1.4142	19.644
Biomass weight(kg)	3.195 ^d	4.45 ^c	6.788 ^b	7.306 ^a	0.3948	8.828

Means of the same main effect within a row followed by the same letter are not significantly different at 5% probability level.

Table 2. Potato tuber yield and yield components as affected by nitrogen level.

Parameter	Nitrogen level kg ha ⁻¹				LSD(0.05)	CV
	0	50	100	150		
Average tuber weight / plant	1.27 ^d	1.30 ^c	2.35 ^b	2.59 ^a	0.0196	7.247
Marketable tuber weight	0.015 ^d	1.335 ^c	1.984 ^b	2.308 ^a	0.8162	7.3098
Unmarketable tuber weight	1.547 ^c	2.058 ^b	2.225 ^a	2.195 ^a	0.7662	6.410
Total tuber yield / plot	3.125 ^d	6.788 ^c	8.418 ^b	9.006 ^a	0.5369	9.548
Yield / hectare	3472.22 ^d	7542.59 ^c	9353.70 ^b	10007.41 ^a	596.57	9.548
Tuber number / plant	7.2 ^c	9.26 ^c	10.15 ^b	13.70 ^a	1.279	19.265
Small tuber size(kg)	11.145 ^a	9.450 ^b	7.44 ^c	5.95 ^d	1.0779	15.419
Medium tuber size(kg)	3.198 ^d	3.50 ^c	4.13 ^b	4.56 ^a	0.2795	8.826
Large tuber size (kg)	0.42 ^d	0.63 ^c	2.42 ^b	2.80 ^a	0.4705	23.4129
Dry matter weight(kg)	1.115 ^c	1.148 ^b	3.165 ^{ab}	3.182 ^a	0.0236	18.753

Means of the same main effect within a row followed by the same letter are not significantly different at 5% probability level. NS, non-significant.

**Figure 1.** Relationships between yield of tuber and nitrogen level in potato.

average was 1100 mm in the year 2014 (Figure 4).

Effect of plant spacing on yield and yield components of potato

Plant density in potato affects some of important plant traits such as total yield, tuber size distribution and tuber quality. Plant spacing is another factor which significantly influences all the parameters of growth and yield under

study where the closest spacing 10 cm produced tallest plants (83.67 cm) which was significantly different from the widest spacing 40 cm (73.11 cm). The maximum stem number per plant (12.66) was found at spacing of 40 cm (Table 3). The maximum tuber number per plant (8.41 kg/ plant) was obtained from the narrow spacing 10 cm; in addition to this, the tuber number per plant gradually declined with the increase in plant spacing 40 cm (6.52 kg/plant). Plant spacing of 30 cm gave the highest marketable tuber per plant (2.47 kg) this was

Table 3. Means value of potato growth components as affected by plant spacing.

Parameter	Intra row spacing (cm)				LSD (0.05)	CV
	10	20	30	40		
Plant height (cm)	83.67 ^a	78.78 ^{ab}	74.65 ^{bc}	73.11 ^c	6.4552	7.453
Days to 50% flowering	54.57 ^a	58.83 ^b	62.83 ^b	64.50 ^a	2.8176	9.64
Days to 50% Maturity	109.93 ^c	115.92 ^b	118.25 ^{ab}	121.94 ^a	4.1605	10.268
Stem number /plant	6.9167 ^d	7.8333 ^c	10.9167 ^a	9.3333 ^b	1.5795	16.896
Biomass weight(kg)	4.91 ^c	5.47 ^b	5.84 ^a	5.50 ^b	0.1774	9.346

Means of the same main effect within a row followed by the same letter are not significantly different at 5% probability level.

Table 4. Mean value of potato tuber yield and yield components as affected by plant spacing.

Parameter	Intra row spacing (cm)				LSD (0.05)	CV
	10	20	30	40		
Average tuber weight / plant	1.32 ^c	1.64 ^b	2.344 ^a	2.32 ^a	0.0424	6.373
Marketable tuber weight	1.47 ^d	1.79 ^c	2.47 ^a	1.93 ^b	0.8596	7.467
Unmarketable tuber weight	2.84 ^a	2.66 ^b	1.26 ^c	1.25 ^c	0.4771	7.235
Total tuber yield per plot	8.57 ^a	7.92 ^b	6.45 ^c	6.38 ^c	2.0098	14.258
Yield / hectare	8287.04 ^a	7696.30 ^b	7301.85 ^d	7090.74 ^c	2233.1	8.476
Tuber number / plant	8.41 ^a	7.96 ^b	7.25 ^{ab}	6.52 ^c	1.4093	12.453
Small tuber size(kg)	10.04 ^a	8.31 ^b	7.07 ^c	6.55 ^d	1.8149	10.562
Medium tuber size(kg)	3.92 ^b	4.12 ^a	3.87 ^b	3.47 ^c	0.4966	9.678
Large tuber size (kg)	0.43 ^c	0.74 ^b	2.68 ^a	2.41 ^a	0.5173	15.568
Dry matter weight(kg)	1.13 ^b	1.25 ^b	2.15 ^a	2.17 ^a	1.96	9.236

Means of the same main effect within a row followed by the same letter are not significantly different at 5% of probability level. NS, non-significant.

significantly higher than tuber per plant obtained from other plant spacing used. The maximum average weight of tubers per plant (2.344 kg/plant) was produced by the plant having the widest spacing 30 cm and the minimum weight of tubers (1.32 kg/plant) was found in the closest spacing 10 cm. The highest yield of tuber (8287.04 kg/ha) was obtained from the closest spacing 10 cm and the lowest (7090.74 kg/ha) was in the widest spacing, 40 cm (Table 4).

The narrower spacing of 10 cm produced numerous small-sized potatoes. These small-sized potatoes fell in grades that are not commercially accepted. As the spacing was increased to 30 or 40 cm, the tuber sized increased with more potatoes falling in the acceptable grades. The better grades were produced by the wider spacing of 40 cm with very few tubers. The value of correlation coefficient indicated that yield of tubers per hectare was positively and significantly correlated with plant spacing.

A negative linear relationship was observed between yield of tubers per hectare and plant spacing when the data was regressed (Figure 2). It was obvious that the equation $Y = 39.83x + 8589$ gave a good fit to the data and the value of the co-efficient of determination $r =$

0.956 showed that a significant increase in tuber yield per hectare occurred at closer spacing was justifiable

Effect of Nitrogen rate and plant spacing on yield and yield components of potato

Most of the growth and yield parameters of var. Gudanne were significantly influenced by the combined effects of different level of nitrogen and plant spacing as presented in Tables 6 to 8 and Figure 3.

Days to 50% flowering

Number of days to 50% flowering was significantly influenced by the planting density and quantity of fertilizer applied (Table 3). The number of flowers was observed to be higher in lower planting density than the higher planting density. The earliest days to 50% flowering was observed at intra spacing of 10 and 20 cm; whereas, days to 50% flowering was prolonged in 30 and 40 cm intra row spacing. Days to flowering was delayed by about 11.66 days in the wider spacing as compared to

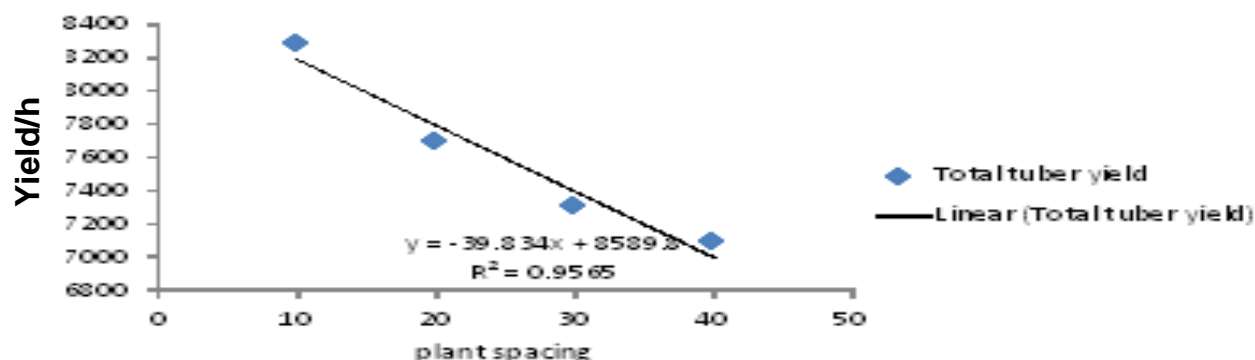


Figure 2. Relationship between yield of tuber per hectare and plant spacing in potato.

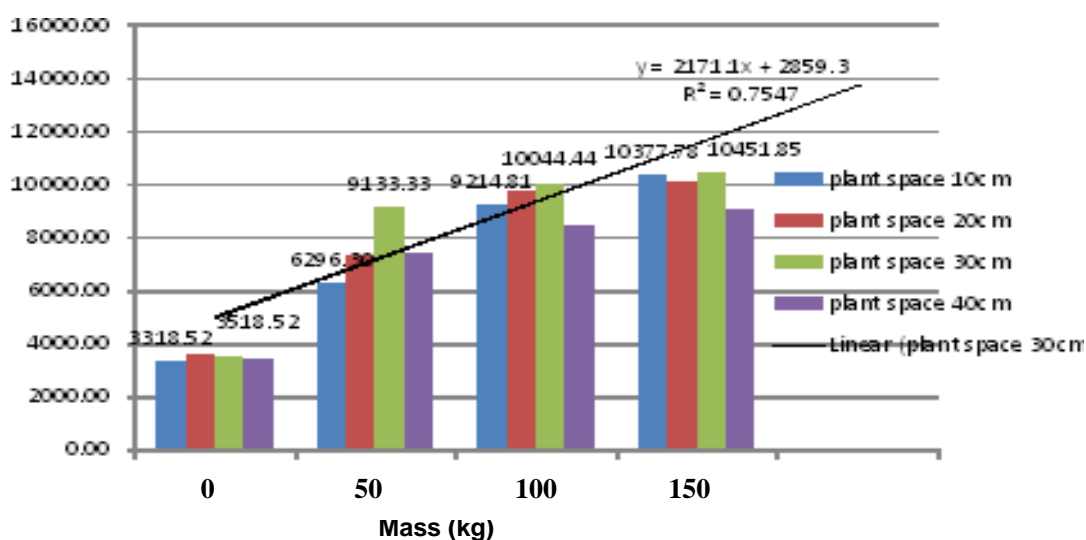


Figure 3. The effect of plant spacing and nitrogen level on total tuber yield per hectare.

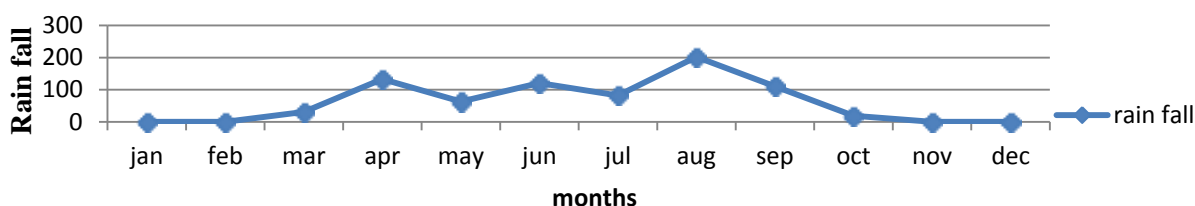


Figure 4. Annual monthly rainfall of the study area during the growing period in the year of 2014.

the closest intra row spacing of 10 cm. Generally, the flowering days decreased with lower planting density but increased as fertilizer application rate increased.

Plant height

Plant spacing of 10 cm produced plant height (90.77 cm).

Nitrogen levels affected the plant height significantly. Application of N at the rate of 150 kg/ha resulted in significantly higher plant height; whereas the minimum plant height was recorded in check plots. The highest plant height was observed from a combination of 10 cm with 150 kg N/ha. Plant height responded highly and significantly to the main effects of plant spacing and nitrogen application rates (Table 4). Decreasing plant

spacing from 40 to 10 cm resulted in significant increase in plant height from 76.89 to 90.77 cm. The rates of nitrogen from 0 to 150 kg N ha⁻¹ to increased plant height from 68.89 to 80.55 cm.

Stem number

The observed treatment means of main effects of plant spacing and nitrogen application rate had significant influence on stem number per plant (Table 6). Stem number increased with increasing plant spacing and nitrogen rate at 10 cm (8.66) and 30 cm (13.66) when stem number was considered per unit plant.

Maturity day

Plant maturity days decreased with higher planting density but increased with increasing fertilizer application rate up to 150 kg. Days to 50% maturity prolonged with increased nitrogen rates (Table 6). Hence, increasing nitrogen rates from zero to 150 kg N ha⁻¹ delayed days to 50% maturity from 99.96 to 121.33.

Aboveground (shoot) biomass

The observed interaction effects of plant spacing and nitrogen application rate on the weight of shoots are indicated in Table 4. Biomass weight significantly increased with increasing nitrogen and planting density. In general, the highest yield of biomass (3.67) was recorded for 30 cm intra row spacing and 150 kg N ha⁻¹ treatment combination. The lowest yield of biomass (1.83) was observed for the treatment combinations of 10 cm intra row spacing with no nitrogen application.

Tuber number

Number of tuber for nitrogen level and plant density was significant ($P < 0.05$). The highest number of tuber (10.46) was recorded at the closest spacing of 10 cm with 150 kg N/ha treatment combination whereas the lowest number of tubers per plant (6.00) was obtained at the wider spacing of 40 cm with no nitrogen.

Average tuber weight

The effects of plant spacing and nitrogen application rate ($P < 0.05$) was significant on average tuber weight as shown in Table 7. Hence, maximum average tuber weight (3.40 kg) was observed for treatment combinations of 30 cm spacing and 150 kg N ha⁻¹. Low average tuber weight (1.20 kg) was recorded at 10 cm intra row spacing with no nitrogen application.

Marketable and unmarketable tuber yield

The higher marketable tuber yield (3.73 kg) was obtained at the wider spacing of 30 cm with increasing nitrogen level whereas the lowest (0.01) was obtained at the closer spacing of 10 cm with no nitrogen application. The highest unmarketable tuber yield (3.67 kg) was obtained at the closer spacing of 10 cm (Table 7).

Total tuber yield

The highest tuber yield per hectare (10377.78 kg) was obtained at the closer spacing of 10 cm with increasing nitrogen level whereas the lowest (3422.22 kg) was obtained at wider spacing of 40 cm with zero nitrogen (Figure 2). With increasing nitrogen application, the number of stem including tuber, number of tubers and consequently yield were increased.

Potato tuber yield in different size classes

Small tuber size (< 30 g)

The two way interaction effects also increased the yield of small size tubers at closer spacing with high nitrogen level (Table 8). In general, the highest yield of small tuber size (13.80 kg) was observed for the treatment combination of 10 cm intra row spacing with 150 kg N ha⁻¹. The lowest yield (2.14 kg) was recorded for the treatment combinations of 40 cm intra row spacing and 150 kg N ha⁻¹.

Medium tuber size yield (31 to 50 g)

The interaction effects of intra row spacing and nitrogen application rate had highly significant influence on medium sized tuber yield (Table 8). Generally, maximum yield of medium size tubers (4.96 kg) was recorded for closer wider intra row spacing (20 cm) and 150 kg N ha⁻¹ treatment combination. Low yield of medium size tuber (1.19 kg) was observed for treatment combination of 40 cm intra row spacing with no nitrogen application.

Large tuber - size yield (51 - 70 g)

The interaction effects of nitrogen application rate affected the yield of large tuber size highly and significantly. Large tuber size yield increased at wider planting density with high nitrogen level. Thus, the highest large tuber size yield (3.18 kg) was recorded at 30 cm intra row spacing and 100 kg N ha⁻¹. Low yield of large tuber size (0.33 kg) was observed at high planting density 10 cm intra row spacing with no nitrogen application.

Table 5. Simple correlation coefficient between some parameters measured.

Traits	MD	FD	PH	STN	TN	TTW	MW	DM	BW	TTY
MD	-									
FD	0.46**	-								
PH	0.34*	0.40**	-							
STN	0.49**	0.49**	0.11 ^{ns}	-						
TN	0.26 ^{ns}	0.36*	0.36*	0.361*	-					
TTW	0.60**	0.58**	0.36*	0.75**	0.63**	-				
MW	0.48**	0.44**	0.06 ^{ns}	0.90**	0.28ns	0.72**	-			
DM	0.43**	0.53**	0.32*	0.55**	0.32*	0.57**	0.58**	-		
BW	0.56**	0.70**	0.43**	0.82**	0.37*	0.81**	0.76**	0.65**	-	
TTY	0.45**	0.59**	0.62**	0.73**	0.50**	0.73**	0.72**	0.74**	0.89**	-

** = is significant at the 0.01 level. * = is significant at the 0.05; ns = non-significant; DM = Days to maturity; FD = Flowering day; PH = Plant height, STN = Stem number; TN = Tuber number; TTW = Total tuber weight; MW = Marketable weight; DM = Dry matter; BW = Biomass weight; TTY = Total tuber yield.

Table 6. The interaction effects of plant spacing and nitrogen application rate on potato growth parameters and yield components.

Treatments	Plant height (cm)	Days to 50% flowering	Days to 50% maturity	Above ground biomass weight/plot (kg)	Stem number/ plant
N ₀ S ₁₀	65.89 ^{ab}	54.57 ^{efgh}	99.96 ^d	3.06 ^c	4.66 ^{ef}
N ₀ S ₂₀	70.22 ^{ab}	56.25 ^{hi}	102.65 ^c	3.22 ^b	5.66 ^f
N ₀ S ₃₀	68.89 ^{ab}	55.56 ^{hi}	101.25 ^c	3.20 ^c	6.00 ^{ef}
N ₀ S ₄₀	69.33 ^b	57.25 ⁱ	100.25 ^c	3.28 ^c	6.00 ^{def}
N ₅₀ S ₁₀	80.67 ^{ab}	58.83 ^{cdef}	105.94 ^c	4.24 ^b	6.33 ^{bcdef}
N ₅₀ S ₂₀	77.22 ^{ab}	59.92 ^{defgh}	109.92 ^{bc}	4.60 ^a	7.33 ^{cdef}
N ₅₀ S ₃₀	71.37 ^{ab}	57.67 ^{hi}	104.92 ^{bc}	4.72 ^b	9.25 ^{bcdef}
N ₅₀ S ₄₀	71.11 ^{ab}	58.56 ^{hi}	107.65 ^{bc}	4.24 ^b	8.33 ^{bcdef}
N ₁₀₀ S ₁₀	87.33 ^{ab}	61.83 ^{abcd}	115.58 ^{ab}	5.70 ^a	8.00 ^{abcd}
N ₁₀₀ S ₂₀	85.22 ^{ab}	63.52 ^{abcde}	117.75 ^{ab}	6.80 ^a	8.66 ^{abcdef}
N ₁₀₀ S ₃₀	77.77 ^{ab}	61.25 ^{cdefg}	110.68 ^{ab}	7.61 ^a	11.33 ^{abc}
N ₁₀₀ S ₄₀	75.11 ^{ab}	63.66 ^{ghi}	117.66 ^{ab}	7.04 ^a	10.33 ^{abc}
N ₁₅₀ S ₁₀	90.77 ^a	63.45 ^a	119.25 ^a	6.65 ^a	8.66 ^{abc}
N ₁₅₀ S ₂₀	82.44 ^{ab}	65.33 ^{abcd}	120.45 ^a	7.26 ^a	9.67 ^{abcde}
N ₁₅₀ S ₃₀	80.55 ^{ab}	64.66 ^{abc}	119.55 ^a	7.86 ^a	12.33 ^{ab}
N ₁₅₀ S ₄₀	76.89 ^a	65.75 ^{ab}	121.33 ^a	7.45 ^a	12.66 ^a
LSD(0.05)	11.541	3.6088	7.4145	0.354	1.176
CV	8.948	10.45	16.25	3.924	8.08

N=Nitrogen level, S=plant spacing, Means of the same main effect within a column followed by the same letter are not significantly different at 5% probability level.

Dry matter content of tubers

Table 8 Effect of plant density and nitrogen level on this trait was significant ($P < 0.05$). The highest tuber dry matter yield (2.20 kg) was recorded for the treatment combinations of 30 cm intra row spacing with 150 kg N ha⁻¹. Conversely, the lowest yield of dry matter (1.16 kg) was obtained from 10 cm intra row spacing with no nitrogen treatment combination. Therefore, increasing the applied nitrogen from 0 to 150 kg N ha⁻¹ increased tuber

dry matter percentage.

Simple correlation between total tuber yield and yield related trait of potato

From the correlation (Table 5), parameters with each other and total tuber yield is positive correlation significant, except harvest index, has a negative correlation non-significant with total tuber yield. Plant

Table 7. The interaction effects of plant spacing and nitrogen application rate on potato growth parameters and yield components.

Treatments	Tuber number/plant (kg)	Average tuber weight/plot (kg)	Marketable weight/plot (kg)	Unmarketable weight/plot (kg)	Total tuber/plot (kg)
N ₀ S ₁₀	6.93 ^{ab}	1.28 ^h	0.01 ^b	1.48 ^a	2.98 ^e
N ₀ S ₂₀	6.06 ^{ab}	1.25 ^{gh}	0.01 ^b	1.62 ^a	3.26 ^e
N ₀ S ₃₀	7.46 ^{ab}	1.28 ^h	0.01 ^b	1.57 ^a	3.16 ^e
N ₀ S ₄₀	6.00 ^{ab}	1.26 ^{fgh}	0.02 ^b	1.51 ^a	3.08 ^e
N ₅₀ S ₁₀	7.93 ^{ab}	1.30 ^{efg}	0.11 ^{ab}	2.72 ^a	5.66 ^d
N ₅₀ S ₂₀	6.73 ^b	1.36 ^{efg}	0.51 ^{ab}	2.77 ^a	6.58 ^d
N ₅₀ S ₃₀	7.63 ^{ab}	2.31 ^{efg}	2.67 ^{ab}	1.43 ^a	8.22 ^{cd}
N ₅₀ S ₄₀	7.33 ^{ab}	2.30 ^{efg}	2.04 ^{ab}	1.30 ^a	6.68 ^{bcd}
N ₁₀₀ S ₁₀	9.33 ^{ab}	1.35 ^{efg}	0.66 ^{ab}	3.48 ^a	8.29 ^a
N ₁₀₀ S ₂₀	8.00 ^{ab}	1.84 ^{cde}	1.18 ^{ab}	3.20 ^a	8.76 ^{abc}
N ₁₀₀ S ₃₀	8.53 ^{ab}	2.87 ^{ab}	3.45 ^a	1.07 ^a	9.04 ^{ab}
N ₁₀₀ S ₄₀	8.00 ^a	2.74 ^{def}	2.63 ^a	1.15 ^a	7.57 ^{ab}
N ₁₅₀ S ₁₀	10.46 ^{ab}	1.37 ^a	1.00 ^{ab}	3.67 ^a	9.34 ^a
N ₁₅₀ S ₂₀	8.20 ^{ab}	2.39 ^{bcd}	1.47 ^{ab}	3.07 ^a	9.09 ^a
N ₁₅₀ S ₃₀	9.60 ^{ab}	3.40 ^{ab}	3.73 ^a	0.97 ^a	9.40 ^a
N ₁₅₀ S ₄₀	8.20 ^a	3.38 ^{abc}	3.03 ^a	1.06 ^a	8.18 ^a
LSD(0.05)	2.675	0.04	0.13	NS	0.41
CV	13.93	7.30	5.60	3.56	3.61

N = Nitrogen level; S = plant spacing. Means of the same main effect within a column followed by the same letter are not significantly different at 5% probability level.

Table 8. The interaction effects of plant spacing and nitrogen application rate on tuber yield of potato.

Treatment	Small tuber size/plot(kg)	Medium tuber size/plot(kg)	Large tuber Size/plot(kg)	Yield per Hectare(kg)	Dry matter weight/plot(kg)
N ₀ S ₁₀	3.60 ^f	1.06 ^e	0.06 ^{bcd}	3318.52 ^e	1.10 ^{ed}
N ₀ S ₂₀	3.00 ^f	1.36 ^e	0.06 ^d	3629.63 ^e	1.10 ^{cde}
N ₀ S ₃₀	2.30 ^{ef}	1.36 ^e	1.19 ^{bcd}	3518.52 ^e	1.11 ^e
N ₀ S ₄₀	2.14 ^f	1.19 ^e	0.40 ^{bcd}	3422.22 ^e	1.14 ^{de}
N ₅₀ S ₁₀	9.26 ^{def}	2.50 ^{cde}	0.08 ^{bcd}	6296.30 ^d	1.12 ^{cde}
N ₅₀ S ₂₀	6.33 ^{cdef}	2.55 ^e	0.08 ^{cd}	7311.11 ^d	1.16 ^{abcd}
N ₅₀ S ₃₀	6.16 ^{cdef}	2.81 ^{de}	1.31 ^{abcd}	9133.33 ^{cd}	1.14 ^{bcd}
N ₅₀ S ₄₀	4.00 ^{def}	2.20 ^{de}	1.06 ^{abcd}	7429.63 ^{bcd}	1.16 ^{abc}
N ₁₀₀ S ₁₀	10.50 ^{abcd}	3.20 ^{abc}	0.33 ^{abcd}	9214.81 ^a	1.16 ^{abcd}
N ₁₀₀ S ₂₀	8.60 ^{abc}	4.60 ^{abcd}	1.26 ^{abcd}	9740.74 ^{abc}	1.58 ^{ab}
N ₁₀₀ S ₃₀	5.16 ^{abc}	3.13 ^{bcd}	3.06 ^{abc}	10044.44 ^{ab}	2.16 ^{bcd}
N ₁₀₀ S ₄₀	4.53 ^{bcd}	3.13 ^{bcd}	3.01 ^a	8414.81 ^{ab}	2.18 ^a
N ₁₅₀ S ₁₀	13.80 ^a	3.93 ^a	1.27 ^{ab}	10377.78 ^a	1.28 ^{ab}
N ₁₅₀ S ₂₀	9.81 ^{ab}	4.96 ^a	1.56 ^a	10103.70 ^a	1.97 ^a
N ₁₅₀ S ₃₀	4.66 ^a	3.20 ^{abc}	3.18 ^a	100151.85 ^a	2.18 ^{abcd}
N ₁₅₀ S ₄₀	5.30 ^{abc}	3.15 ^{ab}	3.17 ^a	9096.30 ^a	2.20 ^a
LSD(0.05)	0.72	0.248	0.15	457.1	0.05
CV	5.152	3.87	8.47	3.61	18.7

N = Nitrogen level; S = Plant spacing. Means of the same main effect within a column followed by the same letter are not significantly different at 5% probability level.

height, total tuber weight, dry matter, biomass weight and number of stem and tuber had the highest correlation

with yield. This result represents a very positive impact on these parameters is increased total tuber yield.

DISCUSSION

Effect of nitrogen level on yield and yield components of potato

Nitrogen fertilizer increases the leaf area which enables for higher amount of solar radiation interception and dry matter accumulation and consequently, increases plant height and dry matter production of different plant parts, days to flowering, days to physiological maturity in line with the report of Tisdale et al. (1995) which says maintaining adequate levels of soil fertility has been recognized as one of the management practices that affect growth, development and yield of plants. Therefore, nitrogen is the motor of plant growth and being the essential constituent of protein, it is involved in all the major processes of plant development and yield formation. Report of Iritani (1972) also support the present result as nitrogen application increase the total yield of potato and total tuber number and size of tuber increase with increasing rates of nitrogen. Thus, the rate of nitrogen fertilization is a very important consideration in managing fertility, because excessive applications delay maturity and reduce the partitioning of dry matter to the tubers (Berga et al., 1994).

Effect of plant spacing on yield and yield components of potato

Increase in number of tuber occurred as a result of increase in number of planting density, eventually increased tuber yield. Tuber, and consequently, number of produced tuber per stem, is increased. Plant density, directly affects the tuber size by altering the number of the tuber size by each plant which in turn depends up on stem density, spatial arrangement variety and season (Menberu et al., 2012). Variation in the spacing of seed pieces may have considerable impact on premiums or deductions, for instance, changing from a closer to wide spacing may decrease the total yield, thus decreasing the base payment, while at the same time may increase the percentage of oversize tubers and reduce the yield of small tubers, thus increasing the net return to the grower. As the yield of ware-sized tubers decreases at high plant population it would be expected that the yield of seed-sized tubers would increase as stem number per hectare increases (Birch et al., 1967).

The quantity of seed planted per hectare will have a considerable effect on average tuber size and yield. The tuber size grading is influenced by two major factors, total yield and the number of tubers. Decrease the spacing between plants or increase plants density more than desirable, due to increased competition between the plants, the plants will reduce the amount of dry matter, although dry matter per unit area increases as report of Iritani (1968) and Kleinkopf et al. (1981) saying the number of tubers is highly dependent on plant density

and yield of oversize tubers is substantial only at low densities.

Days to 50% flowering

The present result of days to 50% flowering (65.75) at 40 cm plant spacing with 150 N is in agreement with the findings of Ojala et al. (1992) who observed that high N levels promoted excessive vegetative growth and delayed flowering. This could be due to higher competition of plant for resource in the closer intra row spacing that lead the plant to stress and ultimately the plants flower early instead of prolonged vegetative growth.

Plant height

The (90.77) value of the present result is showing that plant height increased by increasing N application. As concluded by Khalafalla (2001), increasing nitrogen produces taller plants, longer internodes more sympodial axillary branches. The increased plant height at wider spacing may be due to the fact that relatively more available nitrogen and other plant nutrients available per plant than the closer spacing.

Stem number

The 12.33 value of stem number indicating that the number of stems per plant was influenced by plant density or level of fertilization. In a separate study Lynch and Rowberry (1977) observed increased branch development at higher fertility levels and wider spacing, and they concluded that this may be a form of compensatory growth and the relationship between auxiliary branch development and plant density ensured a similar leaf area index over a range of plant densities. Therefore, variation in the number of stems per plant may be associated with variation in their seed size and performance.

Maturity day

Increasing applied nitrogen from zero to 150 kg N ha⁻¹ delayed days to 50% maturity from 99.96 to 121.33. This is due to the fact that nitrogen dressing stimulates growth; prolong the growing period and delays tuber formation or crop maturity. The present result was in line with the report of Berga et al. (1994) which says excessive applications delay maturity and reduce the partitioning of dry matter to the tubers. Nitrogen fertilization delayed flowering and prolonged the time required by the potato crop to reach physiological maturity.

Aboveground biomass

Increasing nitrogen produces taller plants, longer internodes more axillary branches, higher leaf biomass, higher stem biomass, lower leaf: Stem ratios, higher root biomass, higher shoot: root ratios which is associated with the increased partitioning of dry matter to shoots rather than tubers. It resulted in a great increase in shoot biomass from high application of nitrogen. Generally, leaf area from plants heavily fertilized with nitrogen was very high compared to those that receive none. The increment of biomass yield per plant was also more apparent in plants from wider spacing. This is also may be due to less competition between plants at lower density that resulted in abundant vegetative growth for higher biomass production. The result of the present study has consistency with findings of Saluzzo et al. (1999) who noted nitrogen fertilization increased biomass accumulation in the canopy, interception of more photo synthetically active radiation, use of efficient radiation, more biomass accumulation and portioning to tubers.

Tuber number

Stem density increased by planting more tubers and number of tubers per plant decreased due to number of tubers per stem decreased. In the closest spacing there could be maximum competition among plants for spacing and resources and also low plant exposure for high radiation interception that increase the photosynthetic efficiency of the plant and finally resulting in increased number of tubers per plant. The total number of tuber increased as planting density increase, but very small under sized or unmarketable potato tuber was formed; this might be due to the effect of competition for nutrients, physical spaces and water. In case of nitrogen the increase in growth characters and yield components might be due to the role in nitrogen in stimulating vegetative growth.

Average tuber weight

Potato average tuber weight increased with reducing plant density and increased nitrogen application level. This is apparent that plant densities affect the average tuber weight as well as the total yield. By increasing intra row spacing, yield increases, but the average tuber weight decreases. Increase of density probably causes the increase of in competition between and within plants and hence, leads to decrease in availability of nutrients to each plant and consequently, results in decline of mean tuber weight (Karafyllidis et al., 1997). Yield increases are attributable to more tubers being produced at the closer intra row spacing per unit area and average tuber weight is decreased due to increased inter-plant competition with closer intra row spacing.

Marketable tuber yield

At wider spacing due to presence of minimum competition, plants absorbed the sufficiently available resources and intercepted more light. This increased their photosynthetic efficiency for higher photo assimilate production and ultimately result in marketable tuber yield.

Total tuber yield

With increasing nitrogen application, the number of stem including tuber, number of tubers and consequently yield were increased. This is due to the compensation effect of closer spaced plants per hectare than the wider spacing which result in higher yield of tuber per plant. Similarly, report of Kanzikwera et al. (2001) supports the present result as growing per unit area the number of tubers is highly dependent on plant density yield of oversize tubers is substantial only at low densities. Hanley et al. (1965) also reported that total yield was highest at the highest planting density and fertilizer application rate. This was probably due to increase in the number of plants per unit area, which might contribute to the production of extra yield per unit area leading to high yield.

Potato tuber yield in different size classes

Small tuber size (< 30 g)

The present result shows the smaller tuber size was 13.8 which agree with the findings of Mass (1963) who reported that wider spacing provided a higher yield of the larger tubers but a reduction in the yield of small and very small unmarketable tubers. Nelson (1967) and Wurr (1974) also noted that higher population resulted in slightly higher total yields and a greater number of small tubers. Similarly, Hanley et al. (1965) reported that nitrogen increased the yield of all grades and increased the weight of individual tubers slightly.

Medium tuber size yield (31 to 50 g)

Similar to the result of the current study Wurr (1974) also observed that yield of tubers in the medium and large grades increased with applied nitrogen. This is probably due to the fact that with increase in applied nitrogen, the yield of medium size tuber increases due to increase in the weight of individual tubers thus transferring the tubers from the small to the medium and large grades.

Large tuber-size yield (51-70 g)

The responses of large tuber-size yield due to the interaction effects of inter row spacing, intra row spacing

and nitrogen application levels (Table 8). The interaction effects of intra row spacing X nitrogen application rate affected the yield of large tuber size highly and significantly. The reasons that yield of large tubers increased significantly by the wider spacing with a corresponding decrease in the yield of small tubers was due to reduced inter-plant competition at low plant density (Mass, 1963).

Dry matter content of tubers

Tuber dry matter percentages increased with increased spacing. Similarly, percentage of dry matter was affected highly and significantly by intra row spacing. Bleasdale and Thompson (1969) showed that with increasing density, dry matter was decreased in each plant but was increased per unit area. Approximately it can be said that all factors affecting tuber yield, affect total plant dry matter, as well. Nitrogen applications also influenced tuber dry matter percentage highly and significantly. This is attributed to the prolonged active vegetative growth, delayed maturation and accumulation of dry matter in tubers. Hence, tubers tend to be harvested immature with low dry matter percentage (Mass, 1963).

Simple correlation between total tuber yield and yield related trait of potato

From the correlation (Table 5), parameters with each other and total tuber yield is positive correlation significant, except harvest index, has a negative correlation non-significant with total tuber yield. Plant height, total tuber weight, dry matter, biomass weight and number of stem and tuber had the highest correlation with yield. This result represents a very positive impact on these parameters is increased total tuber yield.

Conclusions

Considering the above result, conclusion may be drawn that the highest nitrogen dose 100 kg/ha or 150 kgN/ha applied at the closest spacing 10 cm gave the highest yield of tubers. Eventually, it may be concluded that different N level and plant spacing had significant effect on yield of potato tuber per plot as well as per hectare. The highest total tuber yield (10377.78 kg/ha) and unmarketable tuber yield (4077.77kg/ha) was produced at the closest spacing of 10 cm. The narrower spacing of 10 cm produced numerous small-sized potatoes, but from the total tuber yield produced in the closest spacing of 10cm 40.78% was unmarketable or commercially not accepted and hence, significantly the highest marketable tuber yield (4144.44 kg/ha) was obtained at the wider spacing of 30 cm similarly the highest total tuber yield (10007.41 kg/ha) and marketable tuber yield (2564.44 kg/ha) was produced at the 150 kg/ha nitrogen rate. In

conclusion, the results of the study have revealed that tuber production could be maximized either for seed or ware potato by manipulating planting density and rates of nitrogen application.

RECOMMENDATIONS

According to the results in both treatments, high nitrogen levels could overcome the inter plant competitions caused by the high densities limiting the environmental resources for plants. Nitrogen fertilization recommendations must optimize crop yield and quality, and at the same time maximize profitability, to reduce the risk of environmental pollution. Nitrogen rate of 150 kg/ha caused increase of tuber yield. Since, 100 and 150 kg/ha nitrogen had no significant difference to each other producing the highest tuber yield and number of tuber, so in order to prevent environmental pollutions and excessive costs, utilize of 100 kg/ha nitrogen is recommended and any reduction in the planting density lower than 75 x 30 cm will lower both total yield and % marketable yield. So, 30 cm planting densities' producing the highest yield makes it suitable for planting. Therefore this study verify that growth and yield of potato is influenced by spacing and nitrogen level and accordingly 30 cm spacing in combination with nitrogen rate of 100 kg/ha can be used for optimum growth and the highest marketable tuber yield of Varsity Gudanne potato on the vertisols of the study area.

CONFLICT OF INTERESTS

The authors has not declared any conflict of interests.

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Full Length Research Paper

Determinant of Sheno butter (cows' butter) market chain: The case of Kimbibit District in North Shewa Zone of Oromia National Regional State, Ethiopia

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This study was carried out to assess the determinants of Sheno butter market participation decision and level of participation in Kimbibit District. The study took a random sample of 126 butter producer households by using multi-stage sampling procedure and employing a probability proportional to sample size sampling technique. The Heckman two-stage econometric estimation procedure is employed to identify factors that determine butter market participation decision and volume of participation. The result of descriptive statistics revealed that there were significant mean and proportional difference among participant (79%) and non-participant (21%) households in terms of livestock holding, total food crop yield, non-dairy farm income and edible oil and vegetable butter consumption. Likewise the result of the Heckman first stage (probit) showed that butter market entry decision was significantly affected by age, education level, distance to nearest butter market and access to market information of households. The second stage estimation result revealed that total butter output, total butter consumption, number of cross bred milking cows, edible oil and vegetables butter consumption and market information were found to be significantly affect the volume of marketed butter.

Key words: Market participation, determinants, Heckman's procedure, Sheno butter, Kimbibit

INTRODUCTION

Ethiopia has one of the largest livestock inventories in Africa with a national herd estimated of 52.13 million cattle, 50.8 million sheep and goats, 9.92 million pack animals and 44.89 million poultry. All livestock currently support and sustain livelihoods for 80% of all rural poor. Of these resources, 20% of cattle and 25% of sheep are found in the lowland pastoral areas of the country. The

estimated annual growth rates are 1.2% for cattle, 1% for sheep and 0.5% for goats. The percentage of total livestock population found in highlands of Ethiopia including per-urban and urban areas are 70-80% of the cattle, 48 - 75% of sheep and 27 - 55% of goats (CSA, 2012). Market-oriented development of smallholder dairying has a potential to spur economic growth and

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alleviate poverty (Bennett et al., 2006).

The major species used for milk production in Ethiopia are cattle, camel and goats. Cattle produce 83% of the total milk and 97 % of the cow milk comes from indigenous cattle breeds. The total population of animals used for milk production is 13,632,161 tropical livestock units (TLU). Although milk production is increasing by 1.2% per annum, the demand-supply variance for fresh milk is ever widening and the per capita consumption is diminishing (CSA, 2012). The key development issues in dairy are low milk production, complicated by widespread food insecurity, growing gap between supply and demand in urban areas, and low average milk productivity (MOARD, 2004).

Butter is an important source of food (cooking oil), cosmetics and common marketable form of dairy product for per-urban and rural community. Butter produced from whole milk is estimated to have 65% fat and is the most widely consumed milk product in Ethiopia. Of the total milk produced, around 40% is allocated for butter while only 9% is for cheese (Ahmed et al, 2003). This study was, therefore, carried out to assess the determinants of Sheno butter market participation decision and level of participation.

Dairy production, among the sectors of livestock production system, is a crucial issue in Ethiopia where livestock and its products are important source of food and income. However dairies have not been fully exploited and promoted in the country. Despite its huge numbers, the livestock subsector in Ethiopia is low in production in general, and compared to its potential, the direct contribution it makes to the national economy is limited. A number of fundamental constraints underlie these outcomes, including traditional technologies, limited supply of inputs (feed, breeding stock, artificial insemination and water), poor or non-existent extension service, high disease prevalence, poor marketing infrastructure, lack of marketing support services and market information, limited credit services, absence of effective producers' organizations at the grass roots levels, and natural resources degradation (Berhanu et al., 2007). Therefore, this study is basically aimed at identify determinants of market participation decision and level of participation and to identify major production and marketing constraints of butter in study area. Hence, the findings of this study would be useful to help policy makers in designing appropriate policies for private investment and nongovernmental organizations that are engaged in the development of livestock sub-sector.

METHODOLOGY

Study area

The research was conducted in Kembibit District, located in North Showa Zone, Oromia National Regional State at distance of 78 km from Addis Ababa on the way to Dessie. The total population living in the District is estimated to be 83,817 of which 41,729 male and

42,088 were female (Central Statistics Agency, 2011). The administrative center of this District is Sheno town. Kimbibit District is familiar in production of organic Sheno butter/dairy butter. Butter produced in this area is named by the town name as Sheno butter. The District annual mean of butter marketed was about 864,000 kg. Because of its preferable accepted, vegetables butter producer named their product as "Sheno butter".

Sampling procedures and sample size

Out of the 18 District found in North Showa Zone, Kimbibit District was selected based on their Sheno butter production potential and high demand of the product. A multi-stage technique was used to draw an appropriate sample. In the first stage, among 29 rural *kebele* administrations (RKAs) found in the District 8 *kebeles* were selected based on their potential of Sheno butter production and market access. Finally by using simple random sampling technique 4 RKAs (Gara chatu, Golelcha, Tuka Abdola and Moyona qumdingay) are selected. In the second stage, list of households involved in Sheno butter production was obtained from District Livestock Development and Livestock Health Office as well as RKAs. Thirdly, at survey time 2,315 households involved in Sheno butter production were identified from the list they belong in each RKAs. Finally, among several approaches to determine the sample size, Yamane (1967) is used and totals of 126 sample producers are selected for interview.

Heckman's two stage model specification

The empirical specification of the probit model to be estimated by maximum likelihood estimation is defined as participation equation or binary probit equation:

$$Y_i^* = \beta_j X_i + \varepsilon_i \quad (1)$$

$$Y_i = 1 \text{ If } Y_i^* > 0 \text{ (Participated)}$$

$$Y_i = 0 \text{ If } Y_i^* < 0 \text{ (Not participated)}$$

Where Y_i = BMPRT, butter market participation decision

X_i = vector of explanatory variables

β = is the vector of parameter coefficients

Y_i^* = is the estimated butter market participation probability

ε_i = Random error term for the selection equation

The probit functional form compels the error term to be homoscedastic because the form of probability depends only on the difference between error terms associated with one particular choice and other (Amemiya, 1985). The marginal effects were estimated on the variable means. This calculation involved taking the partial derivatives that measures the change in the probability of participation per unit change in the independent variable. The second stage of Heckman's two stage procedure for this study was specified as:

$$TBS_j = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \dots + \beta_n X_n + \eta_n \lambda_n(X_i \beta) j + \varepsilon_j \quad (2)$$

Where TBS_j = Total butter market supply by the j^{th} producer

X_j = exogenous variables in the second stage

β_j = parameter coefficients

$\lambda_j(X_i \beta)$ = the Inverse Mill's Ratio derived from the first stage

ε_j = error term in the second stage

The model parameters were estimated by Heckman selection model.

As a result, employing OLS to estimate the model may introduce a sample selectivity bias and the parameter estimates may not be consistent and efficient. Therefore, to remove the selectivity bias,

the study used Heckman's (1979) two step procedure. The first step of the procedure involves establishing the probability of participation in the butter market by estimating a probit model. The level or magnitude of sales or second stage was derived from first stage. Before running the Heckman selection model multicollinearity test was carried out. According to the results, significant problem of multicollinearity was not observed.

Definition and measurement of the study variables and hypothesis

In order to explain butter producer's market participation, continuous and discrete variables were identified based on economic theories and the findings of different empirical studies. Accordingly, the following variables were included.

Dependent variables

Butter market participation decision (BMPRT): Is a dummy variable that represents the probability of market participation of the household in the butter market that was regressed in the first stage of two stages estimation procedure. It takes a value of 1 for households who participated in the market and 0 otherwise.

Total butter market supplied (TBS): It is continuous dependent variable in the second step of the Heckman selection equation. It is measured in kg and represents the volume of sold butter by households to the market which is selected for regression analysis that takes positive values.

Independent variables

Independent variables are assumed to influence butter market entry decision and level of market supply. The omission of one or more relevant variables or inclusion of one or more irrelevant variables may result in error of specification which may reduce the capability of the model in exploring the economic phenomena empirically. The following variables were identified to be included in the estimation equations.

Size of butter output (TOUT): It is continuous variable measured in kilogram. The variable is expected to have a positive contribution to smallholder dairy market participation decision and level of butter market participation. A marginal increase in dairy production has obvious and significant effect in motivating market participation. As the number of dairy cow increases, production also increases and the percentage share of consumption declines and sales increases (Holloway and Ehui, 2002). Study conducted by Singh and Rai (1998) identified factors affecting marketed surplus of buffalo milk in Haryana. They observed that milk production significantly affected marketed surplus positively.

Distance to nearest dairy product market (DNM): Is location of the dairy household from the nearest butter market and is measured in kilometer. The closer the dairy market to dairy households' the lesser would be the transportation charges and better access to market information and facilities. A study conducted by Holloway and Ehui (2002) on expanding market participation among smallholder livestock producers in the Ethiopia high lands revealed that distance to milk market was negatively related to milk market participation decision of dairy households. Therefore, in this study, distance from nearest butter market will be hypothesized to be negatively related to market participation decision and marketable butter surplus.

Edible oil and vegetables butter consumption (OVC): Is a dummy variable takes the values of one if the households consume edible oils and vegetables butter and zero otherwise. This is expected to have positive effect on participation and level of market participation, as the households uses edible oil, vegetables butter and cosmetics gel, market participation and volume of butter supply will be increases.

Number of milking cows/CB for cross breed, LB for local breed: This variable is continuous and is measured in number of milking cow owned. The entry to butter market and marketed butter volume are assumed to be positively influenced by the number of milking cows owned. The study conducted by Holloway and Ehui (2002) in the Ethiopian high lands on expanding market participation among smallholder livestock producers indicated positive and significant relation between milking cow numbers and market participation and marketable milk volume.

Education Level of the Household Head (EDU): It is continuous variable and is measured in years of formal schooling of the household head. Education plays an important role in the adoption of innovations/new technologies. Further, education is believed to improve the readiness of the household to accept new idea and innovations and get updated demand and supply price information which in turn enhances producers' willingness to produce more and increase butter market entry decision and volume of sale. Study conducted by Rehima (2006) showed that formal education was positively related to household market participation and marketed volume.

Experience in butter production (EXP-B): This variable is measured in terms of the number of years of butter producing of the household head. It is expected to have a positive effect on market participation and sale volume due to experienced household would more likely produce more.

Age of the household head (AGE): It is a continuous variable and measured in years. Age is a proxy measure of farming experience of household and age of the household head was expected to have positive effects on market participation decision and level of supply. The positive and significant relationship between the two variables indicates that older dairy household head could have more milking cows which increases the probability of the households market entry decision (Birhanu, 2012).

Sex of the household head (SEX): It is a dummy variable taking one for male and zero for female household head. In mixed farming system, both men and women take part in livestock management. Generally, women contribute more labor input in area of feeding, cleaning of barns, butter and cheese making and selling of dairy products. However, obstacles, such as lack of capital, access to institutional credit, access to extension service, may affect women's participation and efficiency in livestock production (Tanga et al., 2002). Therefore, it is not possible to tell a priori about the likely sign of the coefficient of sex in market participation and sales volume.

Income from non-dairy/ non-farm sources (NDI): Financial income from non-dairy/farm sources has positive effect on sale volume. The positive relation between the variables indicates that any additional financial income enables the dairy household to purchase more number of improved dairy cows which can contribute to increased milk production per household per day and then contribute to increased market participation decision by dairy households. Gizachew (2005) showed that financial capital from different sources has positive effect and indicating that such resources strengthen the ability of smallholder dairy producers' for coping with different risks of production and consumption as well as enter to economic transactions.

Frequency of extension contact (FREXTCO): It is a continuous variable measured in numbers of days dairy experts contact with dairy producers per year. It is expected that extension service widens the household's knowledge with regard to the use of improved dairy production technologies and has positive impact on butter market participation decision and sale volume. Number of extension visits improves the household's intellectual capitals, which improves dairy production and divert dairy production resources. Different studies revealed that extension visit has direct relationship with market entry decision and marketable output. Gizachew (2005) and Embaye (2010) identified that extension visit was positively related to dairy market entry decision and marketed dairy volume. Therefore, number of extension visits will hypothesize to impact household butter market entry decision and marketed volume of butter positively.

Children below the age of five (CHIL5): It is a continuous variable measured in numbers of children belong to household head. Mostly milk is a major food for children and its importance in children growth is widely accepted and recognized both in rural and urban areas. Children have natural priority in consumption of milk in the household and increase in the number of children in this age category usually decreases the marketable surplus and reduces the ability of the smallholder in butter market participation.

Access to market information (MIFO): It is a dummy variable taking value of 1 if household access to market information, 0 otherwise. Farmers marketing decisions are based on market price information, and poorly integrated markets may convey inaccurate price information, leading to inefficient product movement. Therefore, it will be accepted that, market information is positively related to market participation and marketable surplus. Study conducted by Embaye (2010) on butter supply chain showed that better information significantly raises the probability of market participation for potential selling households.

Access to credit (CACE): Access to credit will be measured as a dummy variable, taking value of 1 if the farmer had access to credit and 0 otherwise. This variable is expected to influence the marketable supply of dairy product positively on the assumption that producers use the credit for production purpose (Gizachew, 2005).

Total butter consumption (TCONS): It is continuous variable measured in kilogram. The variable is expected to have inverse on butter market participation decision and level of butter market participation. As households butter consumption at home level increases the butter market participation and volume of supply will be decreases.

Other livestock in TLU: This is the number of live animals measured in tropical livestock unit, excluding lactating cows. This variable will have positive impact on both participation and level of participation.

RESULTS AND DISCUSSION

The results revealed that out of 126 sample households, about 100 households are market participants, while the rest 26 of them are non-participants.

Determinants of butter market participation decision

Table 1 presents the results of the probit estimation of

factors that influenced the decision to sell butter. The model chi-square tests applying appropriate degrees of freedom indicated that the overall goodness of fit of the probit model was statistically significant at 1% probability level. This shows that jointly the independent variables included in the probit model regression explain the variations in the households' probability of market participation decision. The probit model explained 72.89% of the variations in the likelihood of dairy farmers to butter market participation and predicted about 90.85% of the cases correctly.

The empirical results in Table 1 showed that the age of butter producer household head (AGE), education level of butter producer household head (EDU), distance to nearest butter market (DNM) and access to market information (MIFO), are significant variable that affect the probability of households butter market participation decision among responding households in study area. The age of butter producer household head have a positive and significant impact on butter market participation decision of the sample dairy producer at 1% probability level. The marginal effect also confirms that when the household head age increases by one year, the probability of participating in the butter market increases by 1.13%. This is in line with Woldemichael (2008) who illustrated that if dairy keepers get older, the milk market participation of household increases. Because, according to Ethiopian context, elders hold huge land size and younger ones hold less size of land; thus, it is quite challenging for youngest men to be raising number of livestock or land holding increases butter market participation of butter producer household. Education level of butter producer's house hold also has positive effect on probability of butter market participation decision and is significant at 1% probability level. The marginal effect indicates that addition of one-year formal schooling leads to raise the probability of dairy households butter market participation by 1.81%. This is in line with Gizachew (2005) who found positive and significant relationship indicating that education improves the dairy household's capacity to process production and market related information, which in turn improves bargaining position.

Access to information is also positively affected market participation at 1% significance level. The marginal effect of the variable also confirms that as household head has access to market information the probability of butter market participation increases by 18.45%. The implication is that obtaining and verifying information helps to participate more. Study conducted by Embaye (2010) on butter market supply chain analysis identified that better information significantly raises the probability of market participation. Distance to nearest butter market (DNM) had positive effect on butter market participation decision and found to be statistically significant at 5% significance level. The positive relationship indicates that the farther the household from the milk market, the more

Table 1. Probit results of butter market participation decision

Variables	Coefficients	Robust Std. Err.	t-ratio	Marginal effects
AGE	0.011***	0.0031	3.6	0.0113
SEX	0.064	0.0414	1.54	0.0639
EDU	0.018***	0.0055	3.27	0.0181
TOUT	0.011	0.0094	1.16	0.0108
TLU	-0.001	0.0013	-0.80	-0.0010
TCONS	-0.048	0.0330	-1.45	-0.0478
CHIL5	0.047	0.0332	1.44	-0.0479
CB	0.001	0.0271	0.05	-0.0014
LB	0.023	0.0208	1.14	0.0238
MIFO	0.185***	0.0564	3.27	0.1845
FREXTCO	-0.001	0.0027	-0.25	0.0006
NDI	0.011	0.0442	0.25	0.0284
DNM	0.001**	0.0031	3.23	0.0099
OVC	0.128	0.0837	1.53	0.1283
EXP_B	-0.004	0.0037	-0.96	-0.0035
CACE	-0.036	0.0378	-0.94	-0.0357

chi²(1) = 8385.36***
 Percentage of correctly predicted = 90.85%, n = 126
 Log likelihood function = -28.78; Likelihood function = 72.89%
^a= predicted values ** = 5% sign level, *** = 1% sign level

Sources: Own computation (2013).

difficult and costly it would be to get involved in the milk market every day and households would be obligate to further process milk and participate in butter market. The marginal effect also confirms that a one kilometer increase from nearest market from the dairy owner residential house increases the probability of market participation by 0.99%. In other words, as the dairy households become closer to urban center by one kilometer, the probability of his/her participation in butter market declines by 0.99%.

Table 2 shows the determinants of volume of marketed butter, the R² explains about 94.25% of total variation in the determinants of volume of marketed butter is attributed to the specified independent variables in the model. The F statistic of 147.42 is statistically significant at 1% probability level; this means that the estimated R² is statistically significant. The empirical result showed that total butter output (TOUT), total butter consumption by producers (TCONS), number of cross breed milking cows own (CB), oil and vegetable butter consumption by cow butter producer (OVC) as well as access to butter market information (MIFO) are significantly determining the level of butter market participation (Table 2).

The total butter production is positively related with quantity supplied and significant at less than 1% probability level. The result showed that a one kg increase in the butter output causes a 0.707 kg increase in the amount of marketed supply per month. Total butter production influenced the amount of marketed supply of

butter positively showing that farmers who produce more also sell more, which is consistent with the general expectation. Coefficient of butter consumption variable was negatively related with quantity supplied and significant at less than 1% probability level. The result indicated that a one kg increase in butter consumption causes a 1.32 kg decline in the amount of marketed supply of butter per month. Total butter consumption influenced the amount of marketed supply of butter negatively showing that farmers who consume more sell less, which is consistent with the general expectation.

Number of cross breed milking cows (CB) was significant at 10% probability level and had positive effect on marketable butter volume. The model predicted that the addition of one crossbreed cow causes the marketable butter surplus of the dairy household to rise by 1.208 kg per month. This result suggests that marketable butter surplus of the households in the study area is more responsive to number of cross breed milking cows. Similarly, studies conducted by Holloway (2002), Gizachew (2005), Woldemicheal (2008) and Embaye (2010) found that household with larger number of dairy cows was positively associated with volume of sale of dairy products.

Oil and vegetables butter consumption (OVC), the consumption of butter substitute products is influenced butter marketed positively and significant at 10% probability level. When the households' consumption of butter substitute products increases by one liter or kg, the

Table 2. Results of the Heckman second step (outcome equation).

Variables	Coefficients	Robust Std. Err.	t – ratio
AGE	0.079	0.695	1.07
SEX	0.334	0.2952	1.13
EDU	0.016	0.0787	0.20
TOUT	0.312**	0.1315	2.38
TLU	-0.010	0.033	-0.30
TCONS	-1.318***	0.3180	-4.15
CHIL5	-0.012	0.0090	-1.35
CB	1.208*	0.6361	1.90
LB	0.110	0.2535	0.43
MIFO	0.931**	0.4037	2.31
FREXTCO	0.020	0.0291	0.69
NDI	-0.220	0.4049	-0.54
DNM	0.014	0.0273	0.53
OVC	0.780*	0.4333	1.80
CACE	0.014	0.3337	0.04
LAMBDA	-0.384	0.1842	-0.21

R-squared = 0.9490; Number of observations (n) = 126 ,
Adj R-squared = 0.9425; F = 147.42***
Predicted values * = 10% sign level, ** = 5% sign level, *** = 1% significant level

Sources: Model output (2013).

volume of butter sale is increases by 0.780kg per month. Access to market information (MIFO), Information access was also another factor, which positively affected level of participation at 5% significance level. Thus implies that having market information increases the quantity of marketed by 0.931 kg per month. The implication is that obtaining and verifying information helps to supply more. Finally, Lambda (Inverse Mills Ratio) or selectivity bias correction factor had negative coefficient, but statistically insignificant impact on marketable Sheno butter surplus.

CONCLUSION AND RECOMMENDATIONS

The econometric model result of Heckman's first and second stage come up with significant coefficient of market information. The problems associated with market information seem lead to low awareness of butter transaction. Hence, market information is the important component for improving the whole marketing system. The availability of timely information to farmers can increase farmers' bargaining capacity and participation. Therefore, market information service has to keep on aiming to provide information for all farmers involving in butter production and has to inform them how to reduce cost of production and marketing.

The study result revealed that consumption of butter is influenced level of participation negatively. The implication is that there was a consumption of edible oils and vegetables butter which in turn increases level of

participation highly. Therefore, local government should introduce integrated edible oil and vegetable butter producers into the area as well as enhances quality and standard control for human health assurance. But butter fats were superior to vegetable butter because they contained vitamin A, which was not found in the vegetable butters. Therefore, this is recommended when removal of fat from milk and replacing it with an oil and vegetable butter. Overall, the study area is agro ecologically suitable for livestock raring, specially milking cows. Therefore, by using this piece of insight information any interested private, local government, individual and non government organization can take part in Sheno butter production. Finally, future research should focus on chemical components and nutrient contents of Sheno butter and long term dairy development in *kimbibit* district.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Effects of plant density on the performance of selected African upland rice varieties

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The effects of plant density on yield and yield components in upland rice cultivation were examined by conducting a series of field experiments in Central Uganda, using three African and one Japanese improved upland rice varieties. The estimation of plant-density response functions with respect to yield components and yield revealed that an increase in plant density significantly decreased the number of panicles per hill, number of spikelets per panicle, and 1000-grain weight, and significantly increased the number of panicles per square meter. The percentage of filled grain was not affected by plant density. Compared to the Japanese variety, the three African varieties were characterized by more numbers of panicles/hill, less numbers of spikelets/panicle, higher grain-filling ratio and lighter 1000-grain weight, but differences in the degrees of response to plant density were less distinct between them. Rice yield increased in the range of plant density tested, though the marginal increase in yield due to an increase in plant density by 1 hill/m² diminished from 100 kg/ha at the plant density of 11 hills/m² to 30 kg/ha at 33 hills/m². No significant differences were found among the four varieties for the level of yield as well as for its degree of positive response to plant density. The yield components that determined the increase in yield were the number of panicles per square meter and the number of spikelets per panicle, or combined together, the number of spikelets per square meter, which was estimated to reach the maximum at the plant density of 35 hills/m². When the differences among the treatments in the costs of seeds and weed-control were considered, the optimum plant density was found to be 22 hills/m² (plant-spacing of 30 cm × 15 cm), lower than the plant density that gives the maximum yield.

Key words: Economic optimum, maximum yield, NERICA, plant-density response function, yield components.

INTRODUCTION

Rice is a crop of importance in sub-Saharan Africa (SSA), the demand for which has been increasing most rapidly among major staple crops in the region (Seck et al., 2013). As the demand has largely been satisfied by increasing rice import from outside the region, SSA's self-sufficiency in rice has been declining. In order to enhance

food security, it is imperative for SSA countries to increase domestic rice production. Since rice production in SSA is mostly dependent on rainfed upland ecosystems (Rodenburg et al., 2014; Saito et al., 2015), the future of rice production in SSA critically depends on the development of upland rice cultivation. The advent at

the turn of the century of NERICA (New Rice for Africa), a series of upland rice varieties that are the interspecific progenies of *Oryza glaberrima* and *O. sativa* developed by the Africa Rice Center (AfricaRice, then WARDA) (Jones et al., 1997), coupled with national as well as international efforts toward the development of rice production in SSA (AGRA/JICA, 2008), has helped to develop adapted upland varieties and promote upland rice cultivation in SSA.

There are, however, technical challenges to be addressed for the wider diffusion of upland rice cultivation in SSA, many of which stem from the fact that rice is relatively new, exotic, and unfamiliar crop for upland farmers in many parts of the region, particularly in East Africa, except for Madagascar (Badawi et al., 2010). The optimum plant density in upland rice production and crop management is an example of such challenges. In monsoon Asia, the effects of plant density in lowland rice cultivation have been relatively well studied (Kondo, 1944; Yamada et al., 1960; Yoshida and Parao, 1972; Akita, 1982a, b; Patel, 1999; Hossain et al., 2003; Hayashi et al., 2006; Gendua et al., 2009; Roshan et al., 2011; Huang et al., 2013), but less effort has been devoted to optimal plant population for upland rice production (Kawatei et al., 1966; Lampayan et al., 2010; Chauhan and Johnson, 2011; Clerget et al., 2016). In SSA, Oyedokun (1977), Oyedokun and Sobulo (1977), Yamaguchi (1982), Akobundu and Ahissou (1985), Oikeh et al. (2009), and Oghalo (2011) studied the effects of plant density in upland rice cultivation in West Africa, but no substantial efforts have been made to study on the effects of plant density and/or plant population in East Africa, except for NaCRRRI (2010) that gives recommendations for upland rice plant spacing without published data.

The objective of this paper is to search the optimum plant density / plant spacing for upland rice in an East African environment. Since high plant density could suppress weed growth, many past studies on plant density investigated it in relation to weed infestation (Kawatei et al., 1966; Akobundu and Ahissou, 1985; Hossain et al., 2003; Chauhan and Johnson, 2011). This paper looks for the optimum plant density under the standard crop management situation that is usually kept weed-free while considering the cost of weeding.

MATERIALS AND METHODS

Experiment

Field experiments were conducted in the 1st- and 2nd-seasons of 2012 and the 1st-season of 2013, at the experimental farm of the

National Crops Resources Research Institute (NaCRRRI) in Namulonge, Central Uganda (latitude 00°30' 46.4N, longitude 32°38' 03.6E, altitude 1120 m above sea level). An upland field in the farm was divided into experimental plots, 6 m × 3.9 m each, laid out in randomized-block design with three replications.

For plant density, three treatments, 16.7 hills/m² (the spacing of 40 cm × 15 cm), 22.2 hills/m² (30 cm × 15 cm), and 33.3 hills/m² (20 cm × 15 cm), were adopted in the 1st- and 2nd- seasons of 2012, and four treatments, 11.1 hills/m² (60 cm × 15 cm), 13.3 hills/m² (50 cm × 15 cm), 16.7 hills/m², and 22.2 hills/m², were adopted in the 1st-season of 2013. For each hill, 11 seeds were dibbled at the sowing depth of 3 cm and, after germination, thinned to five plants per hill.

Four upland varieties, NERICA 4 (*O. sativa* / *O. glaberrima* // *O. sativa*; henceforth denoted as N4), NERICA 10 (*O. sativa* / *O. glaberrima* // *O. sativa*; N10), ITA 325 (*O. sativa* L. ssp. *Javanica*, known in Uganda as NARIC 2; ITA325), and Yumenohatamochi (*O. sativa* L. ssp. *japonica*; Yume), were used. For fertilizer, N-P-K were applied three weeks after sowing at a rate of 60-30-30 kg/ha as basal fertilizers and 30 kg/ha of N was applied at the 50 days after sowing (DAS) as additional fertilizer. The field was not irrigated but standard agronomic practices were followed under rainfed conditions. Weeds, whenever emerged, were pulled out to keep the plots weed free. Data were collected on the number of panicles per hill (denoted henceforth as panicles/hill), the number of spikelets per panicle (spikelets/panicle), the percentage rate of filled grain per panicle (grain-filling rate), 1000-grain weight and yield. The number of panicles per square meter (panicles/m²) was obtained by multiplying the number of hills per square meter to panicles/hill. The grain weight was adjusted to a moisture content of 14% fresh weight. In addition, the intensity of labor that was needed to keep the experimental plots weed-free was monitored. The dates of sowing and harvesting were April 2 and August 1 in the 2012 1st-season, September 29 and January 16 in the 2012 2nd-season, and March 6 and July 1 in the 2013 1st-season, respectively.

The total rainfall and its within-season distribution differed among the three study seasons. The 2012 2nd-season recorded the total rainfall of 800 mm with a relatively better within-season distribution. The total rainfall of the 2013 1st-season was 650 mm, but about 90% of it fell during the first half of the season, leaving only a little rainfall during the critical period of anthesis from 70 to 90 DAS. The total rainfall of the 2012 1st-season was only about 400 mm, but the fields received more rain during the 70 to 90 DAS period than the 2013 1st-season.

Data analysis

Multiple regression model

The effects of plant density on yield components and yield were analyzed quantitatively by estimating the following multiple regression model for each of them:

$$Y_i = \alpha + \beta PD_i + \left(\sum_{j=1}^3 \gamma_j V_{i,j}\right) + \left(\sum_{k=1}^2 \delta_k S_{i,k}\right) + \left(\sum_{j=1}^3 \varepsilon_k V_{i,j} PD_i\right) + \left(\sum_{k=1}^2 \omega_k S_{i,k} PD_i\right) + \left(\sum_{j=1}^3 \sum_{k=1}^2 \theta_k V_{i,j} S_{i,k}\right) + \mu_i$$

$$i = 1, 2, \dots, n \quad (1)$$

where Y is the variable to be explained, that is, panicles/hill, panicles/m², spikelets/panicle, filled-grain ratio (%), 1000-grain

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weight (g), or yield (t/ha), PD is plant density (the number of hills/m²), V s are dummy variables for varieties, S 's are dummy variables for seasons, μ is random error, i stands for observation, n is the total number of observations ($N = 120$), j stands for variety (1 = N4, 2 = N10, and 3 = ITA325), k stands for season (1 = the 2012 1st-season and 2 = the 2013 1st-season), and $\alpha, \beta, \gamma, \delta, \varepsilon, \omega$ and θ are regression parameters to be estimated.

The response of yield components and yield to plant density could be non-linear (Akita, 1982a, b; Yoshida, 1981). In the estimation of Equation 1, three functional forms, linear, semi-log linear, and quadratic, are tried out for each of yield components and yield, and the best fitting form was selected. Depending on the functional form adopted, Equation 1 should be read accordingly. For example, in the case of the quadratic form, Equation 1 is read as including PD^2 , in addition to PD .

The dummy variables for varieties and seasons were introduced to control the variations due to variety and season. For variety dummy, Yume was set as the base variety for comparison. Similarly, for season dummy, the 2012 2nd-season was set as the base season. The regression coefficients of the linear term, $\gamma(\delta)$, for the varieties (seasons) account for the differences in the intercept term between the varieties (seasons) and the regression coefficients of interaction terms between varieties (seasons) and plant density, $\varepsilon(\omega)$, account for the differences in the slope between varieties (seasons). Note that Equation 1 is parallel to the ANOVA model with plant density, variety, season as the experimental factors, except that plant density is treated as a continuous variable. In the estimation of Equation 1, all explanatory variables were 'centered' by converting all observations to mean deviations in order to avoid multi-collinearity (Aiken and West, 1991).

Plant-density elasticity and mathematical relation between panicles/hill and panicles/m²

The estimated parameters of plant-density response function give an estimate of the plant-density elasticity. With respect to panicles/hill, for example, the elasticity is given as $\eta_{p/h} = (dP_h/dPD)(PD/P_h)$, where $\eta_{p/h}$ = the plant-density elasticity of panicles/hill and P_h = panicles/hill. Since panicles/m² = $P_m = P_h PD$, $dP_m/dPD = P_h(1 + \eta_{p/h})$. The condition for this equation to be positive is $\eta_{p/h} + 1 > 0$ or, with the negative response of panicles/hill to plant density, $|\eta_{p/h}| < 1$. As long as the plant-density elasticity of panicle/hill is less than unity in the absolute value, the response to plant density of panicles/m² is positive.

Economic performance

A difference in plant density results in differences in the required amount of seeds per unit of planted area and the required intensity of weeding. In order to search the optimum plant density for farmers, the profit for each plant-density treatment was estimated as follows:

$$R_i = (Yield)_i \times P_y$$

$$C_i = [(Seed)_i \times P_s] + [(Weeding Labor)_i \times P_w]$$

$$\pi_i = R_i - C_i$$

where i (= 1, 2, ..., 5) stands for the plant-density treatment, R is revenue, C is cost, π is profit, $Yield$ is rice yield by treatment, $Seed$ is the quantity of seeds sown by treatment, $Weeding labor$ is labor input required for weeding by treatment, P_y is the paddy price, P_s is

the seed price, and P_w is the wage rate.

RESULTS AND DISCUSSION

The effects of plant density

Preliminary analyses

The means by season, varieties, and plant density treatment and by yield component indicated that an increase in plant density (the number of hills/m²) decreased panicles/hill and spikelets/panicle and increased panicles/m² and yield, although large variations across replications made the mean differences among the plant density treatments not significant for many cases (Table 1). No appreciable effects of plant density were found for grain-filling rate and 1000-grain weight. The simple correlation analysis for the four varieties as a whole confirmed these observations partially (Figure 1). The negative impacts of plant density on panicles/hill and the positive impacts on panicles/m² and yield were statistically significant at $p < 0.01$. The relation with plant density was negative for spikelets/panicle and 1000-grain weight, but not significant. Grain-filling rate seemed not to be affected by plant density.

Response-function estimation

The results of the estimation of Equation 1 revealed that among the functional forms tried out, the semi-log linear form performed better for panicles/hill, panicles/m², 1000-grain weight, and yield and that the linear form did better for spikelets/panicle and grain-filling rate (Table 2). The quadratic form performed poorest in all the equations.

The regression coefficient of plant density in the panicle/hill equation was negative and highly significant (Table 2). A lower plant density allows plants to receive more sunlight, which facilitates the increase in the number of panicles per plant. This has been widely observed for upland as well as lowland rice. Akita (1982a, b) found for a lowland rice variety that tillers/hill and panicles/hill decreased as plant density increased in his experiment with 10 density levels from 1 to 100 hills/m². Kondo (1944), Yamada et al. (1960), Hossain et al. (2003), Hayashi et al. (2006), and Zhang and Yamagishi (2010) found the same for lowland rice and Oyedokun (1977), Akobundu and Ahissou (1985), Yamaguchi (1982), and Clerget et al. (2016) for upland rice. Akita (1982b) reported for lowland rice that shading by thickly growing leaves due to higher plant density caused the withering of lower layer leaves, resulting in lower tillering. In the study, upland rice experiment, such withering of leaves was not observed until just before harvest even in plots of the highest density.

The regression coefficient of plant density in the panicles/m² equation was negative and highly significant

Table 1. Yield components and yield by season, variety and plant density^a.

Season	Plant density (no. of hills/m ²)	Panicles (no. /hill)	Panicles (no. /m ²)	Spikelets (no./panicle)	Grain filling (%)	1000-grain weight (g)	Yield (t /ha)
2012^{1st}							
N4	16.7	11.5 ^a	192.6 ^a	93.9 ^a	72.5 ^a	27.2 ^a	3.52 ^a
	22.2	10.9 ^a	241.6 ^a	96.1 ^a	69.6 ^a	26.2 ^a	4.19 ^a
	33.3	8.0 ^a	265.3 ^a	88.2 ^a	76.8 ^a	27.8 ^a	4.98 ^a
N10	16.7	10.9 ^a	182.0 ^a	72.8 ^a	73.2 ^a	26.5 ^a	2.57 ^a
	22.2	11.4 ^{ab}	252.3 ^b	67.6 ^a	71.9 ^a	26.2 ^a	3.17 ^a
	33.3	8.9 ^a	297.5 ^b	93.2 ^a	72.4 ^a	26.6 ^a	5.36 ^a
ITA325	16.7	10.9 ^a	182.3	79.2 ^a	69.7 ^a	30.3 ^a	3.11 ^a
	22.2	10.6 ^a	236.1	79.4 ^a	66.0 ^a	30.7 ^a	3.74 ^a
	33.3	7.9 ^a	261.4	76.7 ^a	74.4 ^a	30.5 ^a	4.55 ^a
Yume	16.7	7.6 ^a	126.9 ^a	108.3 ^a	67.2 ^a	34.1 ^a	3.13 ^a
	22.2	7.0 ^a	156.1 ^{ab}	109.9 ^a	65.1 ^a	33.0 ^a	3.69 ^{ab}
	33.3	6.1 ^a	203.7 ^b	100.2 ^a	67.3 ^a	33.1 ^a	4.44 ^b
2012^{2nd}							
N4	16.7	10.3 ^a	171.5 ^a	85.3 ^a	68.7 ^a	27.9 ^a	2.95 ^a
	22.2	8.8 ^a	196.1 ^a	88.2 ^a	80.5 ^a	27.6 ^a	3.83 ^a
	33.3	8.5 ^a	283.6 ^b	84.7 ^a	79.9 ^a	27.4 ^a	5.24 ^a
N10	16.7	11.7 ^a	194.8 ^a	78.9 ^a	87.3 ^a	27.8 ^a	3.75 ^a
	22.2	9.3 ^{ab}	205.7 ^a	93.3 ^a	76.5 ^a	27.0 ^{ab}	3.94 ^a
	33.3	6.5 ^b	217.6 ^a	105.6 ^a	76.3 ^a	25.7 ^b	4.22 ^a
ITA325	16.7	9.9 ^a	164.6 ^a	107.2 ^a	81.4 ^a	32.2 ^a	4.63 ^a
	22.2	8.0 ^{ab}	176.5 ^{ab}	99.1 ^a	85.0 ^a	32.0 ^a	4.76 ^a
	33.3	6.3 ^b	209.2 ^b	82.4 ^a	82.6 ^a	32.4 ^a	4.61 ^a
Yume	16.7	7.5 ^a	126.0 ^a	90.7 ^a	73.1 ^a	36.1 ^a	3.06 ^a
	22.2	6.7 ^a	147.6 ^a	82.0 ^a	66.5 ^a	36.2 ^a	2.84 ^a
	33.3	5.5 ^a	183.2 ^a	73.5 ^a	73.0 ^a	35.8 ^a	3.42 ^a
2013^{1st}							
N4	11.1	15.4 ^a	170.4 ^a	126.0 ^a	71.4 ^a	28.2 ^a	4.31 ^a
	13.3	14.8 ^a	196.2 ^a	121.2 ^a	75.1 ^a	28.1 ^a	4.95 ^{ab}
	16.7	9.7 ^b	161.5 ^a	83.0 ^{ab}	68.4 ^a	27.5 ^a	2.50 ^c
	22.2	8.6 ^b	189.8 ^a	83.2 ^b	70.1 ^a	28.3 ^a	3.10 ^{ac}

Table 1. Contd.

N10	11.1	13.0 ^a	144.3 ^a	103.7 ^a	71.8 ^a	29.3 ^a	3.13 ^a
	13.3	13.2 ^a	175.4 ^a	81.7 ^a	70.6 ^a	29.5 ^a	3.08 ^a
	16.7	11.0 ^{ab}	183.2 ^a	86.7 ^a	70.4 ^a	28.3 ^a	3.15 ^a
	22.2	8.3 ^b	185.0 ^a	86.6 ^a	73.7 ^a	28.2 ^a	3.29 ^a
ITA325	11.1	12.4 ^a	137.8 ^a	99.7 ^a	80.2 ^a	32.6 ^a	3.53 ^a
	13.3	11.4 ^a	151.2 ^a	68.4 ^a	80.0 ^a	32.6 ^a	2.67 ^a
	16.7	10.3 ^a	171.8 ^a	76.1 ^a	70.2 ^a	30.1 ^a	2.79 ^a
	22.2	8.6 ^a	191.7 ^a	86.5 ^a	78.0 ^a	30.6 ^a	4.15 ^a
Yume	11.1	10.3 ^a	114.1 ^a	100.0 ^a	78.2 ^a	36.9 ^a	3.38 ^a
	13.3	10.8 ^a	143.2 ^{ab}	112.0 ^a	71.3 ^a	36.2 ^a	4.07 ^a
	16.7	10.4 ^a	174.3 ^{ab}	101.7 ^a	72.5 ^a	36.7 ^a	4.71 ^a
	22.2	8.5 ^a	187.6 ^b	85.0 ^a	69.5 ^a	35.9 ^a	4.07 ^a

^aThe means followed by the same letter are not different statistically at $p = 0.05$ (by Tukey).

(Table 2); the number of panicles per unit area increased as plant density increased, which implied that the plant-density elasticity of panicles/hill lies between 0 and -1. All the previous studies mentioned in the previous paragraph are unanimous in showing the positive relation between panicles/m² and plant density. The same response was found by Harrell and Blanche (2010) for direct seeded rice in the USA and by Nakano et al. (2012) for a Japanese high-yielding rice for feed use. Huang et al. (2013) reported an exceptional case for Chinese hybrid varieties that while the effect of plant density on panicles/m² was positive and significant for crops planted early, no significant relation was found for crops planted late.

The spikelets/panicle equation revealed that its negative relation with plant density was significant, when variations due to varieties and seasons were controlled (Table 2). The negative effect of plant density on spikelets/panicle, which is expected result from the competition among plants

at higher plant density, has also been widely reported for lowland and upland rice varieties alike (Kondo, 1944; Matsushima, 1966; Akita, 1982b; Yamaguchi, 1982; Hossain et al., 2003; Zhang and Yamagishi, 2010; Nakano et al., 2012; Clerget et al., 2016), and it is hardly possible to find plant-density studies that reported otherwise.

The regression coefficient of plant density in the grain-filling-rate equation was not significant at all and those in the 1000-grain-weight equation were negative and significant (Table 2). These yield components are affected negatively by shading (Matsushima, 1966). More tillers/m² and panicles/m² resulted from higher plant density in earlier growing stages may also induce competitions for fertilizer nutrients and soil water, resulting in lower grain-filling rate and grain-weight/grain, which could be particularly important in upland rice cultivation that is usually practiced under rainfed conditions with low fertilizer application. All these suggest the negative effects of plant density on these yield components. However, the effects of

plant density on these components are more complex than the other yield components, for upland and lowland rice alike. For filled-grain rate of upland rice varieties, Kawatei et al. (1966) reported for a Japanese variety significantly positive responses to plant density, whereas Yamaguchi (1982) found the opposite for IITA varieties. In both studies, the response to plant density was found insignificant for 1000-grain weight. Oyedokun (1977) for IITA upland rice varieties and Clerget et al. (2016) for a recent upland variety of NSIC-Rc222 found no significant effects of plant density for both components. For lowland rice, Kondo (1944), Takeda and Hirota (1971), Hossain et al. (2003), Gendua et al. (2009), and Harrell and Blanche (2010) found negative responses for both components, Akita (1982b), Hayashi et al. (2006), and Nakano et al. (2012) found positive responses for both components, and Yoshida and Parao (1972), Lampayan et al. (2010), and Roshan et al. (2011) found insignificant responses for both components.

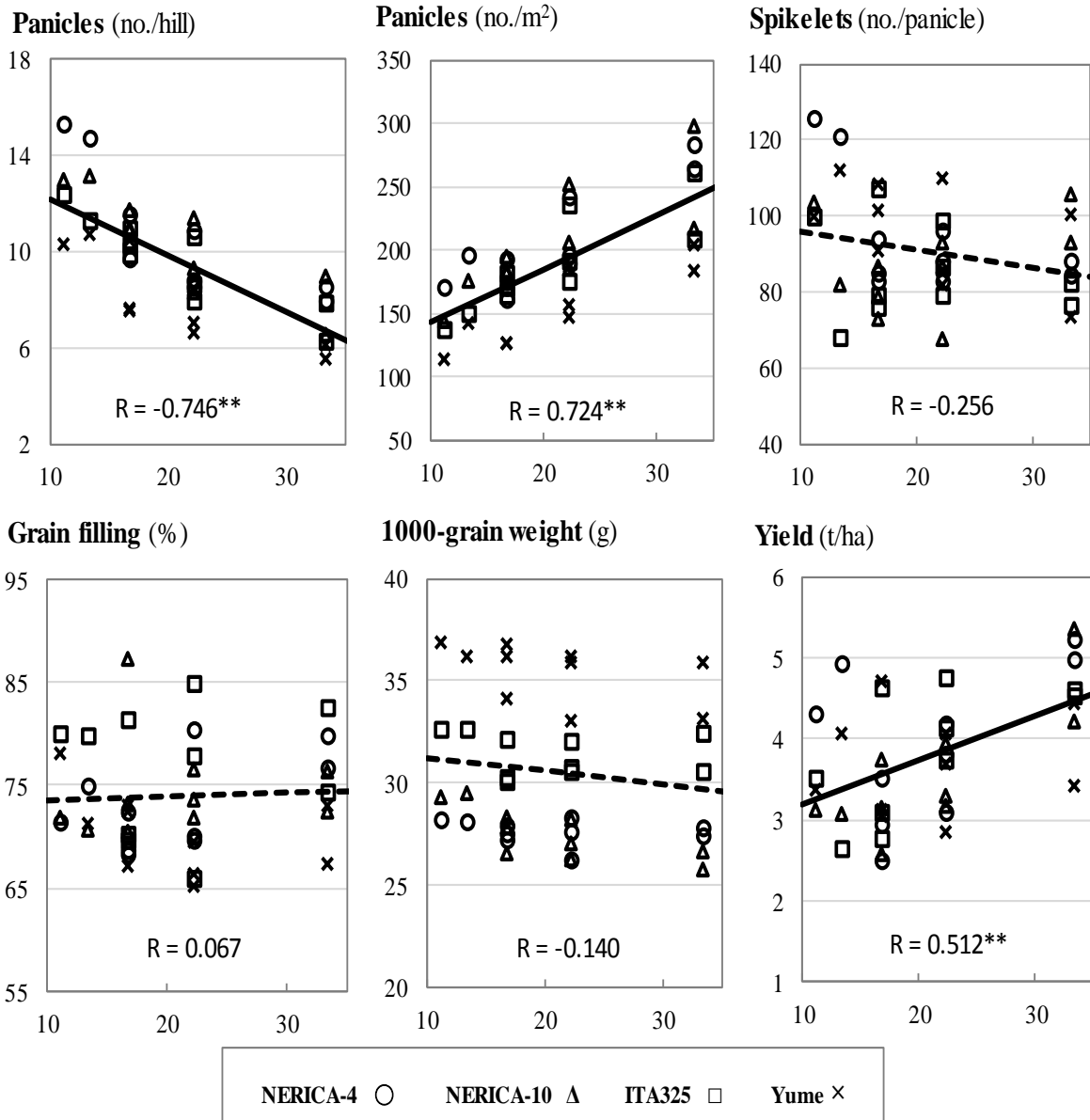


Figure 1. Relation between plant density (horizontal axis) and yield components or yield (vertical axis) (n=40); Correlation coefficient (R) with ** are statistically significant at $p < 0.01$

All these suggest that some factors other than plant density were at work in regulating the plant-density responses of these components.

Finally, the regression coefficient of plant density in the yield equation was positive and significant for the range of plant density tested (Table 2). All the plant-density studies referred to in this sub-section are consistent in this respect: yield increases as plant density increases throughout the density range tested, or it increases until it reaches the maximum or plateau at about the plant density of 30 hills/m² or higher. In an experiment in the Philippines with an upland rice, Apo, and two levels of

row spacing, Chauhan and Johnson (2011) reported that row-spacing of 15-cm yielded better than that of 30-cm, which is consistent with our findings.

Differences among varieties

The response of panicles/hill to plant density differed significantly among the varieties (Table 2). The intercept dummy variables for variety were all positive and highly significant, which means that, with respect to plant density, the regression lines of three African varieties

Table 2. Estimated plant-density response function of yield components and yield (N=120)^a.

Variable	Panicles (no./hill)		Panicles (no./m ²)		Spikelets (no./panicle)		Grain filling (%)		1000-grain weight (g)		Yield (t/ha)	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Ln (PD)	-5.10	0.000	87.4	0.000					-0.93	0.009	1.07	0.001
PD					-0.8	0.016	0.0	0.715				
N4	2.60	0.000	50.6	0.000	-1.4	0.781	2.9	0.105	-7.8	0.000	0.27	0.279
N10	2.38	0.000	47.5	0.000	-9.3	0.058	4.0	0.027	-7.9	0.000	-0.11	0.652
ITA325	1.58	0.000	32.0	0.000	-10.9	0.028	6.4	0.001	-4.0	0.000	0.17	0.497
2012 1st	0.96	0.016	21.0	0.006	-1.5	0.760	-7.5	0.000	-1.5	0.000	-0.30	0.263
2013 1st	0.43	0.286	7.3	0.335	-5.3	0.330	-5.5	0.007	-0.1	0.808	-0.21	0.434
[PD] x N4	-3.76	0.006	-10.4	0.685	-0.1	0.946	0.4	0.212	1.0	0.321	-0.33	0.719
[PD] x N10	-3.31	0.016	-18.5	0.472	1.9	0.019	-0.1	0.674	-0.7	0.495	0.48	0.602
[PD] x ITA325	-2.42	0.076	-15.5	0.546	0.2	0.779	0.2	0.574	-0.1	0.897	-0.12	0.897
[PD] x 2012 1st	0.69	0.565	35.1	0.123	0.3	0.610	0.1	0.568	1.0	0.276	1.42	0.083
[PD] x 2013 1st	-2.14	0.068	-24.3	0.273	-1.6	0.048	-0.3	0.339	-0.8	0.375	-1.19	0.135
N4 x 2012 1st	0.57	0.552	6.1	0.737	-17.5	0.168	0.9	0.840	2.1	0.004	-0.42	0.521
N4 x 2013 1st	-2.09	0.049	-44.4	0.028	-0.8	0.950	-4.0	0.427	0.4	0.589	-1.38	0.057
N10 x 2012 1st	0.89	0.352	27.9	0.127	-38.8	0.003	-3.3	0.484	2.3	0.001	-0.92	0.162
N10 x 2013 1st	-2.57	0.016	-44.2	0.029	-4.6	0.737	-11.4	0.024	1.3	0.083	-1.56	0.031
ITA325 x 2012 1st	1.42	0.140	33.2	0.071	-41.9	0.001	-8.7	0.065	1.0	0.174	-1.51	0.022
ITA325 x 2013 1st	-1.77	0.096	-29.3	0.146	-29.3	0.033	-6.5	0.197	-1.1	0.143	-2.38	0.001
Intercept	9.43	0.000	184.7	0.000	87.5	0.000	73.0	0.000	30.4	0.000	3.58	0.000
R ²	0.730		0.716		0.302		0.309		0.925		0.319	

^aExcept for PD (Plant density), which is a continuous variable, all other explanatory variables (factors) are dummy variables. For PD, among the three functional forms tried out, the form that gives the highest R² is taken. The functional form of PD for the cross-terms follows that of its linear term; if the linear term is in the log form, [PD] in the cross terms should be read as in the log form. No multi-collinearity is suspected with the maximum VIF (Variation Inflation Factor) of 2.91. Coefficients that are statistically significant at p < 0.05 are in bold letters.

were located significantly above that of Yume. Moreover, the slope dummy variables of N4 and N10 (the interaction terms between plant density and N4 or N10) were negative and significant, which means that the rate of decrease in panicles/hill was significantly larger for these NERICA varieties than for Yume. In comparison with Yume, the three African varieties under study, the two NERICA varieties in particular, are

characterized by larger panicles/hill and higher negative response to plant density. For panicles/m², too, the intercept dummy variables for variety were all positive and highly significant for all three African varieties, but the slope dummy variables, which were significant for N4 and N10 in the panicles/hill equation, turned insignificant. With respect to spikelet/panicle, the intercept dummy variables for variety had negative

coefficients for African varieties, but significant only for ITA325 (Table 2). The intercept dummy variables for variety in the grain-filling equation were positive and significant, except for N4, and those in the 1000-grain-weight equation were all negative and significant, but no slope coefficient was significant in these two equations. The yield equation did not show any significant coefficient for variety-related dummy variables.

Table 3. Actual and estimated yield components and yield at the plant density of 22.2 hills/m², their marginal changes resulted from an increase in plant density of 1 hill/m², and the decomposition of the rate of change in yield^a.

		Panicles (no./m ²)	Spikelets (no./pncl)	Grain filling (%)	1000-grain weight (g)	Total ^e	Yield (t/ha)
Actual ^b	(1)	197	88.1	72.7	30.2		3.73
Estimate ^c		196	86.3	73.0	30.2		3.71
Marginal change ^d	(2)	3.9	-0.8	ns	-0.04		0.05
Rate of change (%)	(2)/(1)	2.0 (209)	-0.9 (-94)		-0.1 (-14)	1.0 (100)	1.3(136)

^aFigures in parenthesis are percentages. 'ns' stands for 'non-significant'. ^bActual means at the plant density of 22.2 hills/m². ^cestimated using the regression equations in Table 2 for PD = 22.2 hills/m², while controlling all variables other than PD at their means. ^dPartial derivatives of the regression equations in Table 2 with respect to plant density, evaluated at PD =22.2 hills/m². ^eThe summation of the rates of change in yield components.

Critical yield components and the optimum plant density

In order to analyze how changes in plant density affects to yield, the change in yield due to a unit increase in the plant density was decomposed into the changes in the yield components due to a unit increase in the plant density. The response functions of three yield components, for which plant density gave significant effects, were of the semi-log linear form and so was the response function of yield. This means that the rate of change due to a change in plant density is not constant over the range within which plant density changes. Let us examine the rates of change in the yield components and yield at the plant density of 22.2 hills/m² which is the density treatment closest to the mean of the plant density of 20.8 hills/m² in the estimation of the response functions (Table 3). The 'estimated' figures of the yield components and yield, estimated by using the response functions in Table 2, were close to the 'actual' figures with projection errors less than 2% for all the response functions. It was estimated that a unit increase in plant density (1 hill/m²) increases panicles/m² by 3.9 with the rate of change of 2%, decreased spikelets/panicle by 0.8 with the rate of change of 0.9% and 1000-grain weight by 0.04 g with the rate of change of 0.1%, and increased yield by 50 kg/ha. The rates of change of four yield components summed up to 1%, which was the estimated rate of change in yield due to the change in plant density. Although there was a discrepancy of 36% between this estimate and the rate of change derived from the yield equation, it was apparent that the increase in yield due to a unit increase in plant density was brought about by the increase in panicles/m². Spikelets/panicle moved the opposite direction, but its rate of change was less than that of panicle/m², resulting in a positive change in the number of spikelets per square meter. The negative change in 1000-grain weight further reduced the rate of change in yield, but its contribution to the change in yield was less important. Therefore, the direction as well as the degree of changes in yield due to changes in plant density was largely determined by the changes in the number of spikelets

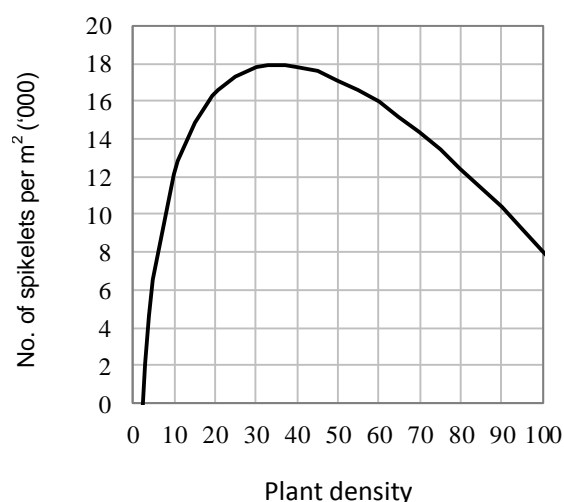


Figure 2. Relation between plant density (horizontal axis) and the number of spikelets per m² (vertical axis), derived as the locus of the product of the response functions of panicles (no./m²) and spikelets (no./panicle) in Table 2

per square meter. It is generally the case, upland and lowland rice alike, that at lower levels of plant density till 25 to 50 hills/ha, panicles/m² is the most important yield component that determines the positive effects of plant density on yield (Yoshida, 1981; Akita, 1982b; Yamaguchi, 1982; Harrell and Blanche, 2010; Clerget et al., 2016).

As Akita (1982b) and Hossain et al. (2003) showed for lowland rice, the rate of increase in panicle/m² diminishes as plant density increases and eventually becomes smaller than the rate of decrease in spikelet/panicle in the absolute values, which results in decreases in spikelet/m² and in turn in yield. This applies to the present study on upland rice. The response function of spikelet/m², which was derived from the estimated response functions of panicle/m² and spikelet/panicle is depicted in Figure 2.

The maximum number of spikelets per m² is reached at

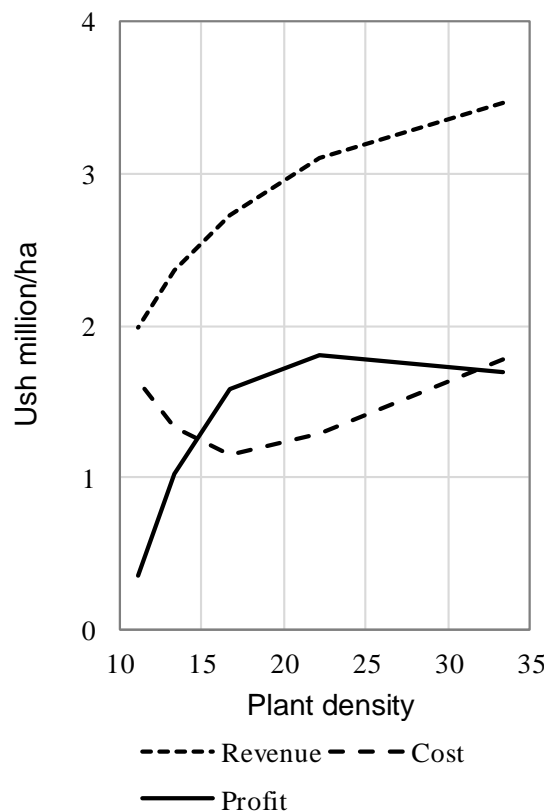


Figure 3. Plant density, revenue, cost (seeds + weeding), and profit.

the plant density of 35 hills/m², and the number starts to decline towards higher density. Considering the heavy weight that spikelet/m² takes in determining the rate of change in yield due to changes in plant density, it is expected that the maximum yield would have been attained at around this density level, which is slightly higher than the highest density treatment of 33 hills/m² in the present study. The yield equation in Table 2 gives that the marginal increase in yield as plant density increases by 1 hill/m² declined from 100 kg/ha at the density of 11 hills/m² to only 30 kg/ha at the density of 33 hills/m².

Comparable results were obtained for lowland rice by Akita (1982b). Hossain et al. (2003) reported that the maximum yield as well as the maximum number of spikelet/m² was attained at the plant density of 25 and 27 hills/m², respectively. For upland rice in West Africa, mixed results have been reported. In Nigeria, Oyedokun and Sobulo (1977) showed, using five TOS-numbered upland varieties released by IITA with three plant-density treatments from 11 to 100 hills/m², that the maximum yield was attained at the density of 50 hills/m²; in an experiment in Nigeria using seven ITA varieties and four other improved upland varieties with five levels of plant density from 2 to 100 hills/m², Yamaguchi (1982) reported that as plant density increases the rate of increase in

yield as well as spikelets/m² diminished but never declined; and in an experiment in Nigeria with two ITA varieties and one local upland variety, Oghalo (2011) reported that, among three plant-density treatments from 8 to 17 hills/m², rice yield was highest at the mid-density of 11 hills/m². In an experiment in Benin using four upland rice varieties including NERICA 1, 2, and 4, Oikeh et al. (2009) reported that the spacing of 30 cm × 30 cm (11 hills/m²) or 20 cm × 20 cm (25 hills/m²) was optimum for NERICA varieties. The present study in Uganda indicated that the plant density of 11 hills/m² was too sparse to attain the optimum rice yield. Whether the plant density as low as 11 hills/m² could be an optimum plant density for upland rice in SSA should be examined carefully in the future.

Economic consideration

When the cost of seeds and weed control were taken into account, the highest profit was attained at the plant density of 22 hills/m², instead of 33 hills/m² (Figure 3). In this estimation, the quantity of seeds for each treatment was obtained by multiplying the seeding rate of 11 seeds/hill with the mean 1000-grain weight of 30.4 g and the hill density of each treatment. The intensity of manual labor needed to keep the plots weed free was lowest for the 17 hills/m² treatment (row-spacing of 40-cm). Relative to this treatment, the needed labor intensity for other treatments were measured as follows: 1.1 for 22 hills/m² (30 cm), 1.2 for 13 hills/m² (50 cm), and 1.5 for 33 hills/m² (20 cm) and 11 hills/m² (60 cm). The labor requirement for weeding per ha for the 17 hills/m² (40 cm) treatment was assumed to be 65 person-days/ha, referring to Miyamoto et al. (2012). The farm-gate prices of seeds and paddy rice were assumed to be Ush 2000/kg and Ush 1000/kg, respectively, and the wage rate was assumed to be Ush 8000/day, referring to Haneishi et al. (2013). The result of the study is consistent with the findings for upland rice by Kawatei et al. (1966) and Akobundu and Ahissou (1985) that the inter-row spacing of 30 cm was preferable for higher yields as well as for easier weed control. The hill density of 22.2 hills/m² is close to the recommended hill densities of 25 hills/m² in West Africa (Oikeh et al., 2008) and of 26.7 hills/m² in East Africa (NaCRRI, 2010).

Comparison with farmers' actual practices

Upland farmers in East Africa, when they plant upland rice, usually adopt line seeding (drill). A typical method of their line seeding is to place a seed in 1.8 cm interval in a row, with a row spacing of 30 cm, in which case the seeding rate is 185 seeds/m². If the germination rate is 100%, the plant density in terms of the number of plants per m² is 185 plants/m². Since the number of plants in

this study is 5 plants/hill, the plant density of 185 plants/m² corresponds to the plant density of 37 hills/m², which is slightly higher than the biologically optimum hill density of 35 hills/m² given in this study as the hill density that maximizes the number of spikelets/m². This suggests that upland farmers in East Africa are rational in selecting the plant density in upland rice cultivation, or that their rate of seeding may be slightly exceeding the economically optimum level.

It should be reminded, however, that this study is based on the plant density obtained by hill spacing. The effects of plant density could be different if plant density is measured in terms of row spacing or seeding rate. Although Lampayan et al. (2010) and Chauhan and Posner (2011), both of which adopted row spacing, and Harrell and Blanche (2010), which used seeding rate, report plant-density responses the patterns of which are essentially the same as those reported by the studies, including ours, which adopted the hill density, further research is needed to confirm differences in the effects of plant density among the different measures of plant density.

Conclusions

The estimation of plant-density-response-functions for yield components and yield revealed that an increase in plant density significantly decreased the number of panicles per hill, the number of spikelets per panicle, and 1000-grain weight, and significantly increased the number of panicles per m². Grain-filling rate was not affected by plant density. As a result, rice yield responded to plant density positively throughout the plant density range from 11 hills/m² (plant spacing of 60 cm × 15 cm) to 33 hills/m² (20 cm × 15 cm), though the marginal increase in yield as plant density increased by 1 hill/m² diminished from 100 kg/ha at the lowest density to 30 kg/ha at the highest density. The critical yield components that determined this increase in yield were the number of panicles per square meter and the number of spikelets per panicle, or combined together, the number of spikelets per square meter, which was estimated to reach the maximum at the plant density of 35 hills/m². When the differences among the treatments in the costs of seed and weed control were taken into consideration, the optimum plant density was reduced to 22.2 hills/m² (plant spacing of 30 cm × 15 cm), lower than the plant density that give the maximum yield. Whether this conclusion, that is, the optimum plant density of recently developed African upland rice varieties is about 20 hills/m² or higher, is applicable in other growing environments in SSA should be examined carefully in the future.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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