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Effect of inorganic fertilizers and planting density on growth and yield of selected maize varieties in eastern Rwanda

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Abstract

Maize grain yield is needed worldwide due to its potential to fight against hunger and many other industrial uses. This study was done in the effort to improve maize grain yield by using high genetic potential hybrid and adequate management technologies. Its aim was to determine the effect of varying N, P, & K fertilizers rate and planting density on growth and yield of selected maize varieties. Trials were conducted in Rwanda, Bugesera district in Karama and Musenyi sites during short rain season from October 2017 to March 2018. RCBD under 2×3×4 factorial arrangement was used with 3 replications. RHM 104 new hybrid variety and ZM 607 OPV were used. Planting densities were 83,334, 68,334, and 53,334 plants/ha. Fertilizer rates were NPK 175-68-68, NPK 150-59.5-59.5, NKP 97-51-51 and control. Plot size was 5 m × 4.5 m with 6 rows/plot and 32, 26 and 20 hills/row following each planting density. The density of 83,334 plants/ha showed significant differences in control plots on days to antes is and silking with mean of 70.33 and 72.42 days respectively (P = 0.026 and 0.008). The interaction of RHM 104 hybrid variety × 83,334 plants/ha x NPK 150-59.5-59.5 (P =0.022) on ear height was significant with highest ear at 95 cm. NPK fertilizers rates showed no effect on grain yield. The interaction of RHM 104 variety × 68,334 plants/ha gave best grain yields with mean of 5975 Kg/ha, (*P = 0.003*) site combined and 8679 Kg/ha with maximum of 11,606 Kg/ha at Karama site.

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Introduction

Maize is an important crop in the economy of Rwanda due to its potential to fight against hunger and poverty. It is for this reason that the Government of Rwanda has put maize into priority crops (RAB, 2013) which benefit special programs to improve their yields. National level maize grain yield improved with crop intensification program (CIP) and Land Use Consolidation (LUC) from 0.7 t/ha in 2005 to 2.2 t/ha in 2013 (Factfish, 2016). Maize yield was improved due to importation of hybrid seed including among others DH04 by Kenya seed, Sc 403 Seedco, Pannar 53 by Pannar (Context Network, 2016). The breeding of local hybrid seeds gave first results in 2016 year by releasing new hybrids namely RHM 104, RHM 1407, RHT 132, RHM 1409, RHM 1402, RHM 111, RHM 113, RHM 1520 and RHM 1521 among others (The newtimes, 2017).

These released new maize hybrids were bred with a static planting density of 53,334 plants/ha which is not necessarily the best agronomic plant population. In Rwanda, maize is cultivated with blanket fertilizer recommendation based on agro-ecological zones that suggest 1 to 10 t/ha for organic manure, 250 to 300 kg for NPK 17.17.17 fertilizers and 100 kg/ha of urea (46% N) for side dressing fertilizer (Kelly and Murekezi, 2000). Maize yield in Rwanda are low compared to yield potential in tropical environment that range from 6 to 15.6 t/ha under high input cultivation and 3.5 to 10.5 t/ha under intermediate input cultivation (Jones, 2003). Maize yield can be improved by increasing the number of plants and ears per unit area (Abuzar *et al.,* 2011); (Fischer *et al.,* 2014). Best yield have been reported under high input fertilizer level ranging between 140 and 160 kg/ha (kilograms per hectare) of N (Ali, *et al.*, 2002); (Shapiro and Wortmann, 2006); (Arif *et al.*, 2010); (Dawadi & Sah, 2012) and (Khan *et al.*, 2014). Reported planting density for best yields ranged from 60,000 to 80,000 plant/ha. Considering low level of maize grain yield and the focus of government to make Rwanda self-reliant on maize production and stop maize importation, this research was conducted to increase maize grain yield by adapting maize current new production technologies to local conditions with objectives to determine the effect of varying N, P, and K fertilizers rates and plant density on growth and yield of selected maize varieties.

Materials and methods

Experimental site

Two experiments were installed in Eastern Rwanda in Bugesera district: Karama site with coordinates of 30.281 E & 2.252 S and Musenyi site with coordinates of 30.033 E and 2.172 S.

Experimental material

Two varieties were used as plant materials including RHM 104 hybrid variety and ZM 607 OPV (open pollinated variety). RHM 104 hybrid have been released by RAB in 2016 year. This variety is cultivated in low and medium altitude regions with white color,125 days to maturity and with yield of 7.89 t/ha (The newtimes, 2017). ZM 607 OPV is widely used by farmers in Rwanda in low and medium altitude regions. It is white in color, with yield of 6.5 t/ha (Gashamura, 2009). N, P and K fertilizers rate source were NPK 17-17-17 and Urea 46 %.

Experimental design and treatments

Randomized complete block design (RCBD) with 3 replications under 2 × 3 × 4 factorial arrangement was used. Two varieties, three planting densities and four fertilizer rates were mixed to form 24 treatments. Planting densities were 83,334 plants/ha and 68,334 plant/ha for increased plant population and 53,334 used by RAB scientists to breed released hybrids. Fertilizer levels were NPK 175-68-68 and NPK 150-59.559.5 as increased rates, NPK 97-51-51 as recommended rate (Kelly and Murekezi, 2000) and control without fertilizer application.

Crop management

The experiment was conducted from October to March season of 2017 – 2018 cropping year. Sowing was done in plots of 5 x 4.5 m with 2 seeds/hill which were later thinned to 1 plant/hill. Rows were spaced at 0.75 m with 32, 26 and 20 hills/row following planting density levels. Weeding was done 3 times during crop cycle. Supplementary irrigation was used in dry spell characterized by a rainfall less than 8.3 mm during five days (Table 2), at the rate of 700-800 mm/ha. This amount was applied to refill soil at field capacity (the amount of moisture remaining after the soil has drained away excess of water and downward movement has become minimal) (Ngure, 2003). Dry spells were observed at the end of December 2017 and in February 2018. Stem borer pest was controlled with Roket 44 EC insecticide (active ingredients: Profenofos 40% + Cypermethrin 4%).

Data collection and analysis

Soil sampling and analysis was done before sowing. Data was collected on variable of plant stand (PS) after thinning, plant height (PH), ear height (EH), days to anthesis (Ant), days to silking (Sil), plant aspect (PA), ear aspect (EA), number of plants harvested (NPH), number of barren plants (Bar), number of ear harvested (NEH), field weight (FW), grain moisture at harvesting (GMH), weight of 100 grains (GW 100) and grain yield (GY).

Statistical analysis was done to find out ANOVA between different variables using Genstat 15th edition.

Results and discussion

Effect of soil fertility baseline

Soil pH was 7.08 in Karama site and 5.4 in Musenyi site. Total nitrogen was 0.20 at Karama site and 0.116 at Musenyi site. Phosphorus was 27.00 ppm at Karama site and 9.5 ppm at Musenyi site. Potassium was 2.06 meq/100g at Karama site and 0.090 meq/100g at Musenyi site (Table 1).

Table 1. Soil analysis before planting at Karama and Musenyi sites.

Sample identification	pH water	T N (%)	Av. P (ppm)	K (meq/100g)
Karama 1	7.5	0.17	26	2.2
Karama 2	7.2	0.18	30	1.8
Karama 3	7.1	0.22	27	1.5
Karama 4	6.3	0.21	24	2.3
Karama 5	7.3	0.22	28	2.5
Mean	7.08	0.20	27.00	2.06
Musenyi 1	5.9	0.09	7.6	0.09
Musenyi 2	5.1	0.12	10.7	0.09
Musenyi 3	5.2	0.11	8.8	0.09
Musenyi 4	5.4	0.13	5.7	0.09
Musenyi 5	5.4	0.13	14.9	0.09
Mean	5.4	0.1160	9.5	0.090

With TN: Total Nitrogen, Av P: Available Phosphorus, and K: Potassium.

Nitrogen was moderate at Karama site and deficient at Musenyi site. Phosphorus was adequate at Karama site (28 ppm) and deficient at Musenyi site (9.5 ppm) (Hazelton and Murphy, 2007). Potassium at Karama site was very high and insufficient at Musenyi site (SMART, 2017). Temperature varied from 15 °C to 27 °C. The rainfall during research period was enough (638.4 mm, Table 2) compared to maize rainfall requirement of 500 - 700 mm per season (Chandrasekaran *et al.*, 2010); but it was not well distributed hence supplemental irrigation used in dry spells.

Soil pH at Karama site was adequate and may have had positive effect on maize growth and grain yield due to its impact on availability of plant nutrients in soil solution from where plant can use them. In contrast, pH at Musenyi was strongly acid (Jones, 2003) and out of accepted pH range for maize growth that varies from 5.5 to 7.8 (Lafite, 1993).

At Musenyi site, soil pH may have led to toxicity or deficiency of crop nutrients. When pH is below 5.5, aluminum & manganese become toxic and phosphorus & magnesium become deficient.

Phosphorus moderate to high deficiency was observed at Musenyi site based on purple color symptom that had mean ranking of 2.18, on score line from 1 to 5 (1 plants have no apparent symptoms and five severe symptoms) (Maroof, *et al.*, 1993).

Table 2. Temperature and rainfall during research period.

Month	Temperature (°C)		Rainfall (mm)			
	Max.	Min.	Decade 1	Decade 2	Decade 2	Total
October, 2017	27	16	N/A	28.1	65	93.1
November, 2017	25	15	40.9	65.6	17.7	124.2
December, 2017	27	15	35.1	5.5	44.5	85.1
January, 2018	27	15	35.5	49.5	12.8	98.2
February, 2018	27	15	6.4	7.7	6.9	21
March, 2018	26	16	131.3	33.3	51.2	216.8
Total	159	92	249.2	189.7	198.1	638.4
Mean	26.5	15.3	49.84	31.6	33.0	37.5

Source: Meteo Rwanda (2018). Rainfall recorded on ten days interval periodicity from second week of October on the 11th, 2017 to March the 31st, 2018.

Effect of treatments on plants and ears height

Maize plants and ears showed significant difference in heights between sites (P < 0.001). Field view of plant distribution (Fig. 1) displays the difference in plant and ear heights between Karama and Musenyi sites. Highest plant heights were observed at Karama site with mean of 207 cm compared to 156 cm at Musenyi site. No significant differences were observed between varieties, planting densities, fertilizer rates and their relative interaction on plant height. Highest ears were also seen at Karama site with mean of 113 cm compared to 58 cm at Musenyi site. Fertilizer rates had significant differences on ear height (Table 3).

Table 3. Interaction of varieties × planting densities × fertilizer rates on ear height.

Fertilizer Rates(R) / Variety	Planting density(D)	R1	R2	R3	R4	Mean
V1	D1	94 ab	77 d	88 abcd	83 bcd	85.5
	D2	80 cd	95 a	90 abcd	83 bcd	87.0
	D3	88 abcd	84 abcd	85 abcd	80 cd	84.2
V2	D1	82 cd	89 abc	87 abcd	88 abcd	86.5
	D2	83 bcd	81 cd	92 abc	83 bcd	84.7
	D3	83 bcd	80 cd	95 a	83 bcd	85.2
Mean		85.0	84.3	89.5	84.3	
Fpr (V)		0.947ns				
Fpr (D)		0.848ns				
Fpr (R)		0.042*				
Fpr (V x D x R)		0.022*				
LSD (0.05%) (V)		3.2				
LSD (0.05%) (D)		3.9				
LSD (0.05%) (R)		4.6				
LSD (0.05%) (V x D x R)		11.2				
CV %		11.4				

The treatment of NPK 97-51-51 exhibited highest ears with a mean of 90 cm. There was significant interaction (P = 0.022) of varieties x planting density x fertilizer rates on ear height. RHM 104 hybrid variety at the density of 68,334 plants/ha & fertilizer rate of NPK 150-59.5-59.5; ZM 607 OPV at the density of 53,334 plants/ha & fertilizer rate of NPK 97-51-51 displayed highest ears with the mean of 95 cm. There was no significant interaction observed between varieties and planting densities as well as their other relative interactions.

Table 4. Interaction of planting density and fertilizer rates on days to anthesis and silking.

	Anthesis					Silking				
Fertilizer rates (R) / Planting density (D)	R1	R2	R3	R4	Mean	R1	R2	R3	R4	Mean
D1	69.7ab	69.08abc	69.42ab	68bc	69.06	71.58abc	71.17abcd	71.42abc	69.83bcd	71.00
D2	69.25abc	67.33c	69.08abc	69.92ab	68.89	71.75ab	69.25d	71.08abcd	71.92a	71.00
D3	69.33ab	70.17a	68bc	70.33a	69.45	71.08abcd	72.25a	69.67cd	72.42 a	71.30
Mean	69.44	68.86	68.83	69.41		71.47	71.89	70.72	71.39	
Fpr (D)	0.524 ns					0.733 ns				
Fpr (R)	0.575 ns					0.519 ns				
Fpr (D x R)	0.026*					0.008 *				
LSD (0.05%) (D)	1					1.02				
LSD (0.05%) (R)	1.16					1.18				
LSD (0.05%) (Dx R)	2					2.05				
CV %	3.6					3.6				

With units in day, D1: 83,334 plants/ha, D2: 68,334 plants/ha, D3: 53,334 plants/ha; R1: NPK 175-68-68, R2: NPK 150-59.5-59.5, R3: NPK 97-51-51, R4: Control (no fertilizer applied). Means with the same letter(s) are not statistically different using LSD of D x R interaction, *: statistically significant, ns: statistically not significant.

Significant difference observed on plant and ear heights between sites can be attributed to difference in soil fertility baseline especially on pH that favored availability and uptake of NPK crop nutrients for efficient maize growth at Karama site. Considering pH and NPK content, Karama site field was fertile with favorable pH and adequate N, very high P and very high K compared to Musenyi site where field was highly degraded with strongly acid soil pH and low NPK content (Table 1) (Hazelton & Murphy, 2007 and SMART, 2017). At Musenyi site, crop nutrients may have been limited in soil solution for adequate uptake and growth of maize hence shorter plants and ears height.

Table 5. Effect of site on number of plant and ear harvested.

	Mean		Fpr	LSD	
	Karama site	Musenyi site		5 %	0.1 %
Number of plants harvested	150	145	0.311	8.6	
Number of ears harvested	139	113	<.001	8.8	15.1

According to Nduwumuremyi (2013) inadequate soil pH and aluminum toxicity predominant in acidic soils may led to reduced fertilizer use efficiency and poor crop performance. In addition, Krstic *et al.,* (2012) found that crop performance declined in poor soil pH condition due to aluminum toxicity that injures roots and reduces nutrients and water uptake. Significant interaction of variety x planting density x fertilizer rates on ear height (P = 0.022) revealed that RHM 104 hybrid variety responded positively to increased fertilizer rates and planting density. RHM 104 hybrid variety may have genetic make-up to use increased fertilizer rates of NPK 150-59.5-59.5 and tolerate high intraspecific competition for light from increased planting density of 68,334 for best vegetative growth hence highest ears. In their work, Jeschke *et al.* (2018) found that ear height increased with plant density up to optimum of 36,000 plants/acre (~90,000/ha). Highest ears were seen associated with higher planting densities of 83,334 plant/ha (Dawadi & Sah, 2012). Increased ear height was attributed to intraspecific competition for light that resulted in longer internode in higher planting density (Mandić *et al.,* 2016). Compared to RHM 104 hybrid, ZM 607 OPV may have limited genetic capacity to tolerate high level of fertilizer and planting density. Too high fertilizer rates may lead to toxicity and/or deficiencies that resulted in plant stunting and shorter internode. Increased fertilizer rates above NPK 97-51-51 and higher planting density above 53,334 may have been too high for a best vegetative growth of ZM 607 OPV.

Table 6. Grain moisture at harvesting and interaction of sites x varieties x rates of fertilizers on weight of 100 grains (S x V x R).

Site (S)	Variety (V)	Interaction of S x V x R on weight of 100 grains (g)					GMH (%)
		Fertilizer rates (R)					
		R1	R2	R3	R4	Mean	
S1	V1	43.33 abcd	46.67 abc	50.00 a	42.22 bcde	45.55	22.42
	V2	42.22 bcde	46.67 abc	43.33 abcd	47.78 ab	45.00	
S2	V1	35.56 efg	32.22 g	34.44 fg	40.00 cdef	35.55	30.32
	V2	37.78 defg	37.78 defg	36.67 defg	34.44 fg	36.66	
Mean		39.72	40.83	41.11	41.11		26.37
Fpr (S)		<0.001 **					<0.001**
Fpr (V)		0.827 ns					
Fpr (R)		0.846 ns					
Fpr (SxVxR)		0.034 *					
LSD (5%)(S)		2.522					
LSD (5%)(V)		2.522					
LSD (5%)(R)		3.566					
LSD (5%) (S x V x R)		7.132					
C.V %		18.7					

With V1: RHM 104 hybrid, V2: ZM 607 OPV; S1: Karama site, S2: Musenyi site; R1: NPK 175-68-68, R2: NPK 150-59.5-59.5, R3: NPK 97-51-51, R4: Control (no fertilizer applied) **: statistically highly significant, *: statistically significant, ns: statistically not significant, means with the same letter(s) are not significantly different using using LSD of S x V x R interaction, GMH: Grain moisture at harvesting.

Effect of treatments on days to flowering

There was significant interaction of planting density × fertilizer rates on days to anthesis (P = 0.026) and silking (P = 0.008) (Table 4). The density of 83,334 plants/ha in control (without fertilizer application) and 68,334 plants/ha at fertilizer rate of NPK 150-59.5-59.5 lagged more than others to attain 50 % anthesis stage with a mean of 70.33 and 70.17 days respectively. The density of 83,334 plants/ha in control (no fertilizer application) delayed than others to reach 50 % silking stage with mean of 72.42 days. There was no significant difference observed between variety, planting density and fertilizer rate and their other corresponding interactions on day to anthesis and silking.

Delayed anthesis and silking observed in control plots (no fertilizer applied), on one hand, may be attributed to insufficient nutrients, due to maize high demand of nutrients, especially nitrogen, required 30 days after planting from 8th leaf (V8) to tasseling (VT) (Butzen, 2016). Nitrogen is implicated in many physiological processes especially protein synthesis that are imbalanced when it is not sufficient. Delayed anthesis in fertilizer rate of NPK 150-59.5-59.5 may be attributed to high amount of nitrogen fertilizer that caused slowed growth. Excessive amount of nitrogen may also lead to delayed growth due to deficiency of other nutrient elements and depletion of carbohydrates (Jones, 2003). Imran *et al.* (2015) reported that increased nitrogen extended days to anthesis. Our results didn't confirm with this observation at the rate of NPK 175-68-68 as plants had no delay compared to the lower preceding plant density. On the other hand, in conformity with Amanullah *et al.* (2009), (Arif *et al.,* 2010) and (Imran *et al.*, 2015), the delay may be attributed to higher plant density that slowed maize growth due to intraspecific competition hence increased time to reach 50 % anthesis and silking periods. High planting density increased between plants competition for water and soil nutrients therefore slowed growth and retarded anthesis and silking (Mandić *et al.*, 2016).

Table 7. Effect of sites and interaction of varieties x planting densities on grain yield.

Planting densities Varieties	D1	D2	D3	Mean
V1	4649 b	5975 a	5070 b	5231
V2	5434 ab	4600 b	5315 ab	5116
Mean	5041	5287	5192	5174
Fpr (V)	0.663 ns			
Fpr (D)	0.742 ns			
Fpr (V x D)	0.003*			
LSD (5%) (V)	519.6			
LSD (5%) (D)	636.4			
LSD (5%) (V x D)	900.1			
Karama site				7724
Musenyi site				2624
Fpr (S)	<.001**			
LSD (S)	519.6			

With: Units in Kg/ha; V1: RHM 104 hybrid, V2: ZM 607 OPV; D1: 83,334 plants/ha, D2: 68,334 plants/ha, D3: 53,334 plants/ha; Means with the same letter(s) are not significantly different, **: statistically highly significant, *: statistically significant, ns: statistically not significant.

Effect of treatments on number of barren plants, plant harvested and ear harvested

Significant difference was revealed on number of ear harvested between sites (P < 0.001) (Table 5). High number of ears harvested was observed at Karama site with mean of 139 ears compared to 113 ears at Musenyi site.

Treatment had no significant difference on number of plant harvested. Increase in barrenness was seen to be in close relation with decrease of grain yield. There was linear relationship between grain yield and number of barren plants (P <0.001) with correlation coefficient of – 0.675 (Fig. 2). Considering plots that had up to 20 % of barren plants, yields were below 3 t/ha while highest yields were seen in plots with low level of barren plant (7%) (Table 8).

Significant difference observed between sites on number of ear harvested may be attributed to the difference in soil fertility especially soil pH that affected crop performance. High number of ear at Karama site may be linked to adequate pH and availability of crop nutrients from different rates of fertilizers applied. Low number of ears at Musenyi site may be the result of acidic soil and aluminum toxicity predominant in acidic soils that reduced fertilizer use efficiency and provoked poor crop performance (Nduwumuremyi, 2013). Barrenness percentage was highest in 83,334 plants/ha which was the highest planting density used.

The reason may be that at higher plant population, competition on available growing factors such as light, nutrients and water become intensified hence plant inability to produce viable ears (Dawadi & Sah, 2012). In such conditions, tassel development leads over ear development creating imbalance in anthesis-silking interval (ASI). ASI interval varied from 2 to 4 days with barrenness percentage of 22 %, 21 % and 18 % for 83,334, 68,334 and 53334 plants/ha respectively.

Table 8. Grain yield in relation to plant aspect, ear aspect and barrenness.

No	PA	EA	% of barre-nness	Grain yield							
				Range (in t/ha)	Mean (Kg/ha)	Karama site		Musenyi site		Total	
						NPR	%	NPR	%	NPR	%
1	1.9	1.2	7	Up to 10	10725	10	13.9	-	-	10	6.9
2	1.7	1.3	6	9 to 9.9	9403	12	16.7	-	-	12	8.3
3	1.8	1.5	6	8 to 8.9	8599	10	13.9	-	-	10	6.9
4	2.4	1.9	6	7 to 7.9	7289	8	11.1	-	-	8	5.6
5	2.7	2.4	14	6 to 6.9	6458	18	25	1	1.4	19	13.2
6	2.8	2.6	16	5 to 5.9	5681	11	15.3	1	1.4	12	8.3
7	3.1	2.9	9	4 to 4.9	4513	3	4.2	8	11.1	11	7.6
8	3.4	3	14	3 to 3.9	3395	-	-	14	19.4	14	9.7
9	3.7	3.3	21	2 to 2.9	2513	-	-	26	36.1	26	18.1
10	4.1	3.8	29	1 to 1.9	1418	-	-	15	20.8	15	10.4
11	4.5	4.3	45	Below 1	846	-	-	7	9.7	7	4.9
Total	3	2.7	16	5 to 5.9	5174	72	100	72	100	144	100

With PA: Plant aspect and EA: Ear aspect (in ordinal ranking good ears with small numbers), NPR: Number of plots per grain yield range.

The same ASI interval was reported by Helland (2012) with a barrenness percentage of 10 % for low plant density (45,000 plants/ha) compared to 25 % for higher plant population (155,000 plants/ha).

Other factors have been reported to increase the level of barrenness such as low temperature (Hayashi *et al.*, 2015), hot weather and drought condition (Helland, 2012). These factors had no effect on our results as temperatures were favorable for maize growth (15 °C to 27 °C, Table 2) and drought was controlled through supplementary irrigation in dry spells.

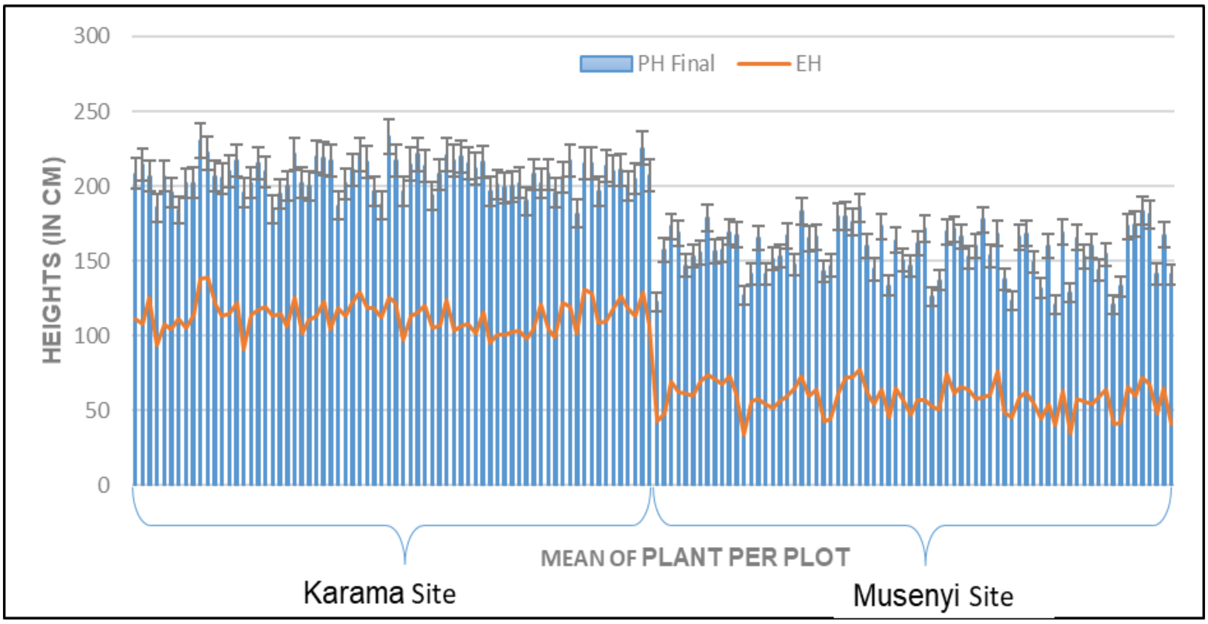

Fig. 1. Field view of plant height (PH) and ear height (EH) insertion.

Effect of treatments on grain moisture at harvesting and weight of 100 grains

Significant differences were revealed between sites on grain moisture at harvesting and weight of 100 grains ($P < 0.001$). Musenyi site grains had more moisture up to 30.32 % compared to 22.42 % at Karama site. There was significant interaction of sites x varieties x fertilizer rates ($P = 0.034$) on weight of 100 grains (Table 6). At Karama site, RHM 104 hybrid variety under fertilizer rate of NPK 97-51-51 had heaviest grains with a mean of 50 g/100 grains.

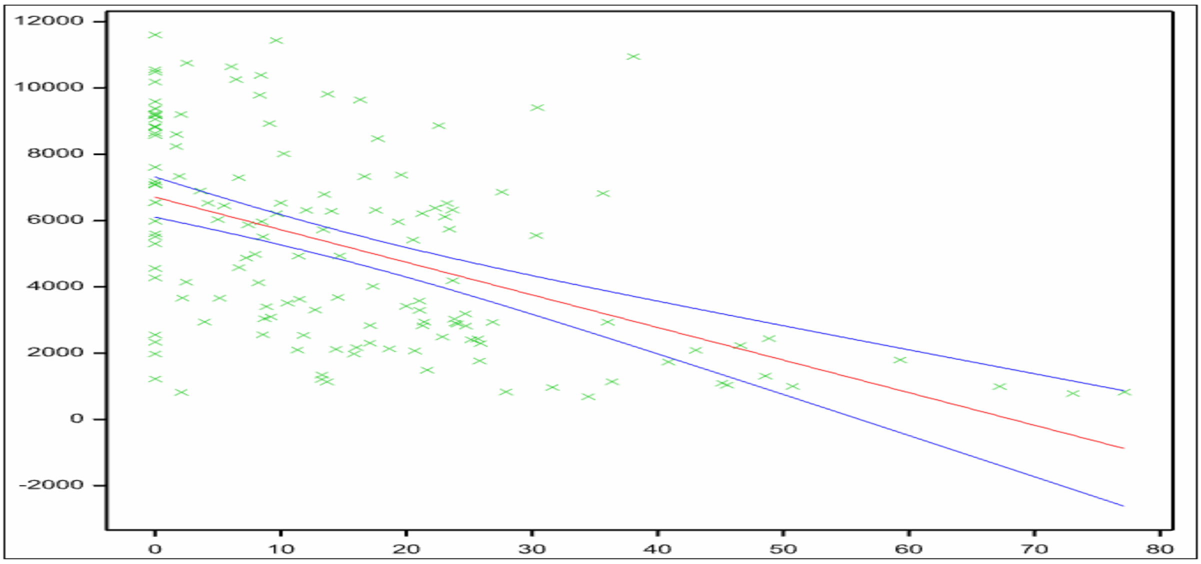

Fig. 2. Relationship between grain yield and barrenness percentage at 95 % confidence limits.

High grain moisture at Musenyi site during harvesting may be explained by high amount of rainfall during harvesting period (Table 2).

However, this rainfall has not influenced the weight of hundred grains (GW 100) as heavier grains were observed at Karama site with mean of 45.28 g.

Heavier grains at Karama site may be attributed to effect of adequate pH that allowed efficient use of different rates of fertilizers and maximum grain filling while poor pH condition at Musenyi site interfered with better use of fertilizer and produced lighter grains. Other fertilizer rates were too high (NPK 175-68-68 and NPK 150-59.5-59.5) or too low (control) for maximum grain weight.

In conformity with Jones (2012), fertilizer rates beyond optimum resulted in nutrient deficiency and reduced grain weight due to inhibition of other nutrient elements by the excessive nutrient element or due to limited amount of fertilizer in the soil solution.

Effect of treatments on grain yield

Grain yield at moisture level of 13.5 % revealed significant difference between sites ($P < 0.001$). Considering site factor, Karama site had best grain yield (mean yield = 7724 Kg/ha) compared to Musenyi site (mean yield = 2624 Kg/ha) with site combined mean of 5174 Kg/ha. There was significant interaction of variety x planting density (P 0.003).

RHM 104 hybrid variety at the planting density of 68,334 plants/ha gave the best grain yield with interaction mean of 5975 Kg/ha (Table 7).

Considering individual site, the interaction of variety x planting density was significant at Karama site ($P = 0.032$). RHM 104 hybrid variety at the density of 68,334 plants/ha produced the best grain yield with a mean of 8679 Kg/ha. Highest grain yield above 10 t/ha (Table 8) was achieved in Karama site with a maximum yield of 11606 Kg/ha from the interaction of RHM 104 hybrid variety x 68,334 plants/ha. No significant difference was observed between varieties, planting densities and fertilizer rates as well as their respective interactions at Musenyi site on grain yield. NPK fertilizer rates applied had no significant effect on grain yield of cultivated maize varieties in this study. Obtained results differ from a high number of authors who reported a positive effect of N, P and K fertilizers on grain yield of maize including among others Bakht *et al.*, (2006), Dawadi & Sah (2012), Khan *et al.*, (2014), Adeniyan (2014) and Dibaba *et al.*, (2014).

The lack of response to NPK fertilizer rate may be attributed firstly to soil fertility of experimental fields during research period. Karama site field was adequately fertile for satisfactory crop nutrient demand and Musenyi site was highly degraded. In such condition, the response to fertilizer application may not be revealed (Kihara, Nziguheba *et al.*, 2016). Kihara, Huising, *et al.*, (2016) reported that response to fertilizer was low to none if control yields were higher than 6 t/ha. At Karama site, mean grain yield in control plots was 8215 kg/ha classifying Karama site field in non-responsive fertile fields. Musenyi site field was non-responsive due to high degradation of fields, in accordance with Vanlauwe *et al.* (2015). Soil pH was 5.4 which is below accepted range for maize growth and phosphorus deficiency symptoms were observed.

The second reason of non-responsiveness of our trials' fields may be the genetic capacity of cultivated varieties. Some varieties may respond significantly to NPK fertilizer application, others may give slight yield increase in response to NPK fertilizer levels (Hallof, 2008). According to Pepó & Karancsi (2014), there are four groups of maize varieties taking into consideration their response to NPK fertilization: (i) varieties with high genetic capacity of nutrients use and give high yields response to NPK application, (ii) varieties with moderate genetic capacity of nutrients use and give high yields response to NPK application, (iii) varieties with high genetic capacity of nutrients use and give moderate yields response to NPK application and (iv) varieties with moderate genetic capacity of nutrients use and give moderate yields response to NPK application. RHM 104 hybrid and ZM 607 OPV may be in group 3 and 4 of varieties of moderate response to NPK fertilizer application hence poor response to increased NPK fertilizer rates applied.

Significant interaction of planting densities x varieties was observed from RHM 104 hybrid variety under the density of 68,334 plant/ha. The increase in yield may be attributed to increased number of ears/unit area from optimum number of plants and ear harvested, adequate plant and ear quality (aspect), optimum weight of 100 grains and low number of barren plants. RHM 104 hybrid produced highest grain yield (above 10 t/ha) (table 8) due to tolerance to higher planting density with optimum density of 68,334 plants/ha, plant aspect of 1.9, ear aspect of 1.2, hundred grain weight of 52 g and 7 % of barren plants. These variables improved at lower planting density (53,334 plants/ha) in line with Mandić *et al.* (2016). However, below optimum planting density, the number of ears was not enough for a higher grain yield. At very high planting density (83,334 plants/ha), ears and plants aspect were worse (thin plants, small size ears and/or incomplete kernel set), 100 grains were lighter and barrenness level was higher hence low number of ears/unit area and reduced grain yield. Arif *et al.*, (2010) reported that grain yield increased with increasing planting density, but above optimum planting density, the number of ears is unable to cover yield decline from ear size decreasing with increasing planting density (Jeschke *et al.,* 2018 and Amiri *et al.,* 2014).

Conclusion

In this research, NPK fertilizers rates had non-significant response on grain yield mainly due to high fertility and high degradation of fields used in Karama and Musenyi sites respectively. Planting density levels had significant effect on grain yield. The density of 83,334 plants/ha was too high and the density of 53,334 was too low for a maximum grain yield. Maximum grain yield of 11,606 kg/ha was achieved from the optimum planting density of 68,334 plants/ha in interaction with RHM 104 hybrid variety. Further researches are needed to determine site specific fertilizer recommendations that take into account heterogeneity of fields and avoid to apply fertilizer in non-needed amount in fertile fields resulting in poor or none response to NPK fertilizers application. Only maintenance fertilizer amount may be enough for highly fertile fields. Poor non-responsive fields like Musenyi site may need correction of acidity by liming before being responsive to fertilizer application. Pioneer farmers may start to cultivate RHM 104 hybrid variety using 68,334 plants/ha due to its best grain yield achieved under this density.

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