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ASSESSMENT OF THE EFFECTS OF LIQUID AND GRANULAR FERTILIZERS ON MAIZE YIELD IN RWANDA

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ABSTRACT

Maize (*Zea mays* L.) is the most widely grown cereal in the world**,** accounting for 1,116.34 MT of production in 2019/2020. In Africa, this crop represented approximately 56% of the total cultivated area from 1990 to 2005. About 50% of the African population depends on maize as a staple food and source of carbohydrates, protein, iron, vitamin B, and minerals**.** Lately, maize has become a cash crop which contributes to the improvement of farmers' livelihoods**.** For example, the Strategic Plan for Agricultural Transformation (SPAT) III outlined that fertilizer availability in Rwanda should increase to 55,000 MT per year, while fertilizer use should increase from 30 kg/ha in 2013 to 45 kg/ha for the 2017/18 cropping season. Only inorganic fertilizers are currently being used in maize production in Rwanda. This research was conducted to assess the effects of liquid (CBX: Complete Biological Extract) and granular fertilizers on maize crop yields in Rwanda. The study was conducted in the fields of the Rwanda Agriculture and Animal Resources Development Board (Rubona Station) during the 2018/2019 cropping season. Analysis of variance (ANOVA) was used to determine whether differences between treatments were statistically significant, with the threshold for statistical significance set at $p < 0.05$. Aboveground biomass differed significantly between treatments, with maximum and minimum values of 11,475 kg and 7,850 kg, respectively, being observed. Furthermore, the harvest index differed significantly between treatments, with minimum and maximum values of 0.2136 and 0.33, respectively, being observed. Grain yield also differed significantly between treatments, with the highest value (3,053 kg/ha) observed for a treatment which applied liquid and granular fertilizer at equal proportions (treatment 8), and the lowest one was found in treatment 3 with 1,852 kg/ha. In this study, the gap between the lowest and highest grain yields was about 39.3%. In conclusion, the combination of organic liquid fertilizer and granular fertilizer can significantly increase the grain yield of maize in Rwanda.

Key words: Aboveground biomass, Grain yield, Harvest Index, Liquid fertilizer, Zero fertilizer

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INTRODUCTION

Maize (*Zea mays* L.) is the most widely grown cereal in the world, with 1,116.3MT of grain produced in 2019/2020 [1]. In African countries**,** this crop accounted for approximately 56% of the cultivated area between 1990 and 2005. About 50% of the African population depends on maize as a staple food, with maize being a rich source of carbohydrates, protein, iron, vitamin B and minerals [2]. Maize is also becoming a cash crop in the region, contributing to the improvement of farmers' livelihoods [3]. In Rwanda, the cropping season is divided into three periods: Season A starts in September and ends in February of the following year; season B starts in March and ends in June of the same year; and season C starts in July and ends in September of the same year [4]. In 2016/2017, maize constituted 12.3% of the total cultivated area in Rwanda during cropping season A and 5.1% of the total cultivated area during cropping season B [5]. In 2017/2018**,** season A was characterized by average maize yields of 1,525 kg/ha for maize, while season B resulted in average maize yields of 1,171 kg/ha [6]. It should be noted that fertilizer use in Rwanda increased from 4kg/ha in 2006 to 30 kg/ha in 2013, while annual fertilizer availability increased from 8,000 MT to 35,000 MT [7]. It has been projected that the average productivity of key crops (measured in tons/ha) will increase between 2017-2024, with the yields of maize expected to double [8].

Before 2007, fertilizer application in Rwanda averaged 4.2 kilograms per hectare (kg/ha), well below the average for sub-Saharan Africa (16 kg/ha) at the time [9]. Fertilizer use in Rwanda has increased dramatically over the past decades; estimates suggest that the national average for annual fertilizer application increased from 8 kg/ha to 23 kg/ha in 2010 [10]. Moreover, annual fertilizer application increased even further in recent years, to average values of 29 kg/ha and 30 kg/ha in 2012 and 2013, respectively [11]. The importation of fertilizer into Rwanda grew by 23% in 2017 when compared to an initial value of 44 MT in 2013 [12]. The Strategic Plan for Agricultural Transformation (SPAT) III, launched in 2013 by the Ministry of Agriculture and Animal Resources in Rwanda (MINAGRI), was a five-year program aiming to transform Rwandan agriculture from a subsistence sector to a market-oriented, value-creating sector that would grow as fast as possible. The program focused on production and commercialization in order to increase rural incomes and reduce poverty. Notably, the SPAT program outlined that annual fertilizer availability should increase to 55,000 MT, while annual fertilizer use should increase to 45 kg/ha, by 2017/18 [7].
During the 2017/2018 cropping season (season A), the overall use of inorganic fertilizer in small-scale farming (SSF) was almost equally split between NPK 17-17-17 (27%), urea (33%), and diammonium phosphate (DAP; 35%). Diammonium phosphate was most commonly applied to hillsides (42%) and rangelands (40%), and was more rarely applied to marshlands (23%). Large-scale farming (LSF) during the same season showed a similar split in fertilizer use, namely, NPK 17-17-17 (29.5%), urea (38%), and DAP (24%) [6]. Maize requires an adequate supply of nutrients for good vegetative growth and yield; for example, nitrogen, phosphorus and potassium are required by maize for normal growth**.** Previous research has shown that soil and foliar application of N during maize silking can increase grain yield and nitrogen use efficiency by up to 15% [13]. The fertilizer shortage in Rwanda negatively affects maize production.

Furthermore, only inorganic fertilizers are used in maize production in Rwanda [14]. This research was conducted to assess the effects of liquid fertilizer application on the yield and vegetative growth of maize in Rwanda. The hypothesis was that the application of liquid fertilizer can increase maize yields and simultaneously reduce the amount of inorganic fertilizers that farmers need to use.

MATERIALS AND METHODS

Site description

This research was conducted in the fields of RAB (Rwanda Agriculture and Animal Resources Board), more specifically, those located at the Rubona Station (2^{o}29'S, 29^{o}46.3'E, altitude of 1690masl) during cropping season B of 2018/2019. The soil parameters were analyzed before planting in the Rubona Station soil laboratory, located in Huye District, Southern Province of Rwanda. Huye District covers an area of 581.5 km^2, with a population of 314,022 people and a population density of 540/km^2 (National census of 2012). Rainfall in the area ranged between 390-430 mm from March to May of 2019 [15].

Study design

The field experiment employed a Randomized complete block design (RCBD). A total of nine separate treatments were tested and replicated five times. Each plot had a size of 4m*4m, with spacing of 75*30cm. The fertilizers used were DAP (18% of N and 46% of P), urea (46% of N) used as granular fertilizers and liquid fertilizer (LF). Liquid fertilizer used was CBX (Complete Biological Extract), which is an environmentally friendly bio-stimulant that is based on nature's own processes and is an organic liquid fertilizer and it is manufactured by Envirom Green AS, Norway. This liquid fertilizer had the following chemical composition: total Nitrogen (N) 9.00%, Ammoniacal Nitrogen 2.00%, Nitrate Nitrogen 1.00%, Urea Nitrogen 6.00%, Calcium (Ca) 0.10%, Magnesium (Mg) 0.01%, Manganese (Mn) 0.01, Iron (Fe) 0.05%, Zinc (Zn) 0.05, Molybdenum (Mo) 6.0 ppm, Cobalt (Co) 300 ppm, pH 5.2-5.5, Carbon (C) 2.00%, Humic acids 0.30%, and fulvic acids 29.87% [16].

The nine tested treatments included the following:
Treatment 0: Control (Zero fertilizer),
Treatment 1: Granular fertilizers only (DAP 100% + urea 100%- DAP: 100 kg/ha, urea: 50 kg/ha),
Treatment 2: LF only (10L/ha),
Treatment 3: DAP 100% + LF (10L/ha),
Treatment 4: DAP 80% + LF (10L/ha),
Treatment 5: DAP 60% + LF (10L/ha),
Treatment 6: DAP 100% + UREA 100% + LF (10L/ha),
Treatment 7: DAP 80% + urea 80% + LF (10L/ha), and
Treatment 8: DAP 60% + urea 60% + LF (10L/ha).

The land was prepared two weeks before the planting date, i.e., second tillage was performed at this point [17].

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The plots were planted with the maize variety ZM607 on March 14th, 2019. Weeding was performed whenever it was needed. The crop was harvested on August 6th, 2019, reflecting a crop cycle of 145 days.

Fertilizer application

Each treatment was applied twice, once at planting time and again six weeks after planting. The doses and rates of fertilizer application for a 16 m^2 plot were based on recommendations from the Ministry of Agriculture and Animal Resources in Rwanda, which are, 100 kg/ha for DAP, 50 kg/ha for urea and 10 L/ha for LF for maize crop[14]. Liquid fertilizer was applied by spraying in first spilt, DAP was applied on planting date with side dressing application method and urea was top-dressed after six weeks; then liquid fertilizer was again applied in foliar application method after six weeks in the second split. Half of the total dosage was added during each of the two rounds of fertilizer application.

Insecticide application

On April 11th, 2019, four weeks after planting, the plots were scouted for pests. The field was infested by fall armyworms (FAW). Larvae had attacked every plot, and fall armyworm moths were spotted in the field. This infestation was treated with two types of insecticides, namely, Rocket (Profenofos 40% + Cypermethrin 4% EC; PI Industries Ltd, Gurgaon, India) and Profex Super (Profenofos 40% + Cypermethrin 4% EC; NACL Industries Ltd, Srikakulam, India). Rocket was applied twice per week from April 13th, 2019, and after two weeks Profex was also applied twice to suppress the damage caused by FAW [18].

Data collection

Data concerning soil parameters were collected before planting and after harvesting (Table 1), while growth and yield data from all experimental units were collected throughout the field experiments (Tables 2 and 3). Data collection from the field experiments started on April 11th, 2019, which was four weeks after planting (V8 growth stage), and ended on August 6th, 2019 after harvesting [19].

Growth parameters

Plant height was recorded two times, more specifically, four weeks after planting (V8 growth stage) and fifty days after planting (V12 growth stage). A total of ten plants in each plot were randomly selected for growth measurements [19].

Yield parameters

All of the following parameters were measured after harvesting: aboveground biomass; ear weight (with husks); and Harvest index. Harvest index (HI) refers to the proportion of a crop that is of economic use. Harvest index (HI) was calculated as the ratio of grain yield (GY) and the total aboveground biomass (B) at maturity [20], weight of 1000 grain and grain yield [19].

Data analysis

Data collected were organized in Excel software (Microsoft Corporation, Redmond, WA), while statistical analyses were performed in GenStat software (15th ed.). Analysis

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of variance (ANOVA) was used to test whether differences between treatments were statistically significant, with the threshold for significance set at $p < 0.05$. Mean values for various parameters were compared using the least significant difference (LSD) method [21].

RESULTS AND DISCUSSION

Soil analysis

Soil sampling after harvesting revealed several differences between treatments in soil properties (Table 1). For example, pH decreased by 0.24, while total N, P, Ca, Mg, and K decreased by 0.0488, 6.6028, 0.44, 0.58, and 0.29, respectively, in plots receiving LF. In contrast, the plots which did not receive LF showed a 0.16 increase in pH after harvesting, along with a 7.3972 and 1.18 increase in total P and Ca, respectively, as well as small reductions in N, C, and Mg (0.0088, 0.72 and 0.14, respectively). Furthermore, a significant portion of K (0.5) was taken up by the soil. The post-harvest decrease in pH and nutrients in plots which had received LF could be explained by the fact that LF facilitates the plant uptake of nutrients, as well as increases water penetration and retention [16]. Similar findings were observed by Sootahar *et al.* [22], who showed that fulvic acids (FA) significantly decrease soil pH. Moreover, Çelik *et al.* [23] reported that the foliar application of 0.1% and 0.2% humic acid solutions to maize grown in calcareous soils significantly improved the uptake of manganese. The increased pH values in soil which had not received LF are likely a result of high concentrations of Ca and Mg in the soil [24]. The LF increased plant uptake of nutrients in all of the plots where it was applied with the granular fertilizers.

Plant Height

After four weeks, the tallest and shortest plants (42.52cm and 34.6cm, respectively) were observed in treatments 0 (no fertilizer) and 8 (DAP 60% + urea 60% + LF) (Table 2). Significant differences between treatments ($p < 0.05$) in plant height were also noted 50 days after planting (V12). More specifically, treatments 0 and 7, along with 1 and 7, significantly differed in terms of plant height. The application of both LF and granular fertilizer (treatment 6) increased plant height by 16.9% relative to the control (treatment 0), while the application of granular fertilizer alone (treatment 1) increased plant height by 17.8% relative to the application of both granular fertilizer and LF (treatment 6). The lowest plant height (86.32 cm) was observed for treatment 7 (DAP 80% + urea 80% + LF), while the tallest plants (111.68 cm) occurred in the treatment 1 (only granular fertilizer) (Table 2). The finding that LF application was negatively associated with plant height is explained by the fact that the granular fertilizer has a much higher N content than the tested LF. The presented finding is consistent with what was reported by Iqbal *et al.* [25]; more specifically, maize growth increases as the nitrogen dose increases.

Aboveground Biomass (AGB)

Aboveground biomass (dry weight) was measured at the time of harvesting; more specifically, maize ears and stems were cut and weighed. Significant differences between treatments treatments ($p < 0.05$) in AGB were observed. The most significant difference was found between treatments 3 and 4. Treatments 2, 4, and 6 showed

16.9%, 23.7%, and 14.4% higher AGB, respectively, than the control, while treatment 4 yielded 14.4% and 10.9% higher AGB when compared to treatments 1 and 6, respectively (Table 3). The highest AGB value (11,475 kg) was observed for treatment 4 (DAP 80% + LF), while treatment 3 (DAP 100%) yielded the lowest ABG value (7,850 kg) (Table 3). The application of LF resulted in high AGB values, while AGB values were low in the plots which had not received LF. A similar finding was observed by Sootahar *et al.* [22] who stated that application of liquid or foliar forms of fulvic acids (FA) resulted in improved plant growth, as measured by several parameters. Furthermore, Eyheraguibel *et al.* [26] stated that the application of humic and fulvic acids exerted positive effects on the shoot growth of maize crops. The researchers also postulated that high water consumption explained the improved efficiency of biomass synthesis observed following the application of humic and fulvic acids. Amanullah *et al*. [27] provided empirical support for this hypothesis, as they reported that the foliar application of N-sources significantly increased biomass yields relative to the control.

Harvest Index (HI)

There were significant differences between treatments ($p < 0.05$) in HI. For example, the HI of treatment 8 was 35.3% more than that of the control. The control (treatment 0) showed the lowest HI value (0.2136), while treatment 8 (DAP 60% + Urea 60% +LF) showed the highest HI value (0.33) (Table 3). The application of LF was associated with a high HI value irrespective of the height of the plants in a plot. A similar finding was reported by Ion *et al.* [28], who observed that shorter plants could show larger HI values than taller plants. The authors explained this results through heightened grain yielding capacity; in other words, the maize plants use nutrients to produce grain instead of building vertical height. Inamullah *et al.* [29] reported that nitrogen affects the HI of maize.

Grain yield (GY) (kg/ha)

Data concerning grain yield showed significant differences among treatments based on the 95% confidence interval calculated through LSD. Treatments 1, 2, 5, and 8 showed 15.3%, 18%, 34.6%, and 37.52% higher grain yields (GY), respectively, relative to the control, while treatment 8 demonstrated 26.3%, 23.8%, and 4.5% higher GY than treatments 1, 2, and 5, respectively. Furthermore, treatment 5 showed 20.3% and 22.8% higher GY than treatments 2 and 1, while treatment 2 demonstrated higher GY than treatment 1 with 3% .

The highest GY (3,053 kg) was observed for treatment 8 (DAP 60% + urea 60% +LF) and the lowest GY (1,852 kg) occurred in treatment 3 (DAP 100% +LF). The GY of treatments 5 and 8 were 37.52% and 34.6% higher, respectively, than what was observed for the control (Table 3). The application of LF was associated with high GY; a similar result was reported by Delfine *et al.* [30], who found that HA application led to 23–26% increases in wheat GY relative to the control. In addition, Çelik *et al.* [23] found that the foliar application of 0.1% and 0.2% HA increased maize yields by 14% and 13%, respectively, relative to the control. Moreover, Dahiru *et al*. [31] reported that – in the case of maize - the foliar application of fertilizer should only be used as a supplement to soil-applied fertilizer because of the high nutrient demands of maize.

Furthermore, Inamullah *et al.* [29] observed that foliar N-sources resulted in higher GY when compared to the results for control.

Phenotypic correlation coefficients for the measured characters

Plant height was negatively correlated with aboveground biomass (r= -0.737), which can be explained by the fact that plots which did not receive LF showed the tallest plants, and the application of LF resulted in high AGB values. Plant height also showed a highly significant negative correlation with HI (r= -0.9054) (Table 4). Hence, in this study, the height of maize plants did not influence the HI. Plant height was also significantly correlated with the number of leaves (r= 0.8231), with observations showing that the number of leaves increases as plant height increases, but was negatively correlated with grain yield (r= -0.7877), which was found to be influenced by HI and AGB. These relationships were also reported by Sootahar *et al.* [22], who investigated how fulvic acid derived from different materials influences the properties of albic black soil in the Northeast plain of China. The research group found that increases in parameters related to maize yield could be explained by the direct or indirect effects of fulvic acids (FA) on plant growth and development. Aboveground biomass was positively correlated with ear weight (r= 0.9159), as this part of the maize plant showed a large increase in weight as aboveground biomass grew. Aboveground biomass and ear weight were also positively correlated with grain yield (r= 0.6669 and r= 0.8175, respectively). The relationship between ear weight and grain yield corroborates what was reported by Hay *et al.* [32], who reported that assimilate partitioning remains largely unchanged among tropical maize hybrids (varieties). Harvest Index was negatively correlated with the number of leaves (r= -0.7549), a finding which is supported by the work of Ling *et al.* [33], who stated that fertilizer may partially compensate for insufficient nutrient uptake by maize roots, as maize leaves may not be large enough to absorb all of the fertilizer applied by spraying. However, HI was positively correlated with grain yield (r= 0.816), in other words, HI was high whenever grain yield was high. It is important to note that Ali *et al.* [34] and Peymaninia *et al.* [35] both reported similar strong positive correlations, along with a direct effect of total biomass and harvest index on grain yield.

CONCLUSION

The findings in this research showed that combining liquid fertilizer containing fulvic acid and humic acid with granular fertilizer can significantly increase maize yields. Further research concerning the toxicity of this combination of liquid and granular fertilizer, along with which residues remain after harvesting and potential pollution of the environment, is recommended. Moreover, additional research should determine whether this combination of fertilizers has any obvious effects – either positive or negative – on the soil microbiome.

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Conflicts of interest

The authors have declared no competing financial and/or research interests in relation to this study.

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Table 1: Soil parameters before planting and after harvesting maize at the Rubona Station (Rwanda Agriculture and Animal Resources Development Board)

Research area	pH water	Tot. N (%)	Org. (%)	Av. P (ppm)	Ca (meq/100g)	Mg (meq/100)	K(meq/100g)
Before planting	5.54	0.1988	3.12	57.2028	2.76	0.98	0.600961538
After harvesting (Liquid fertilizer applied)	5.3	0.15	1.95	50.6	2.32	0.4	0.31
After harvesting (without Liquid fertilizer)	5.7	0.19	2.4	64.6	3.94	0.84	0.1

Table 2: Maize plant height measurements at the V8 and V12 growth stages

Treatment	Average value four weeks after planting (V8)	Average value 50 days after planting (V12)
Zero fertilizer	42.52a	110.52ab
Granular fertilizer	41a	111.68a
DAP 80% + urea + LF	34.72a	86.32c
DAP 80% + LF	38.52a	98.48abc
DAP 60% + urea + LF	34.6a	87.76bc
DAP 60% + LF	35.72a	90.44abc
DAP 100% + urea + LF	36.72a	91.84abc
DAP 100% + LF	38.88a	100.84abc
LF	40.6a	107.2abc
Overall mean for all treatments	38.14	98.34
LSD	0.021	0.002

Mean values with the same letters in each column are not significant at $p < 0.05$

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Table 3: Parameters measured for all treatments at the time of harvesting and after harvesting

Treatment	Above-ground biomass (kg/ha)	Harvest Index	Grain yield (kg/ha)
Zero Fertilizer	8750ab	0.2136b	1907a
Granular Fertilizer	9825ab	0.2284ab	2251a
DAP 80% + urea 80% + LF	9975ab	0.2888ab	2817a
DAP 80% + LF	11475a	0.2501ab	2909a
DAP 60% + urea 60% + LF	9450ab	0.33a	3053a
DAP 60% + LF	10100ab	0.2918ab	2916a
DAP 100% + urea 100% + LF	10225ab	0.2646ab	2753a
DAP 100% + LF	7850b	0.2384ab	1852a
LF	10525ab	0.2243ab	2325a
Grand Mean	9797	0.2589	2531
LSD	0.068	0.009	0.015

Mean values with the same letters in each column are not significant at $p < 0.05$.

Table 4: Phenotypic correlation coefficients for the measured parameters

Character	Plant Height	Above-ground biomass	Ear weight	Harvest Index	**No. of** Leaves	1000 grains	Grain Yield
1	1						
2	-0.1737	1					
3	-0.4095	0.9159***	1				
4	-0.9054***	0.1242	0.3821	1			
5	0.8231**	-0.1813	-0.393	-0.7549*	1		
6	0.2418	0.4622	0.2209	-0.1937	0.1028	1	
7	-0.7877*	0.6669*	0.8175**	0.816**	-0.656	0.0601	1

*significant differences at $p < 0.05$, **significant differences at $p < 0.001$, ***significant differences at $p < 0.0001$

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