

Harnessing Striga-Tolerant Varieties and Enhanced Crop Nutrition: Synergistic Strategies for Managing *Striga hermonthica* in Maize.

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Abstract

Background and aims

In Ghana, maize production is currently faced with low yields due to the infestation of *Striga hermonthica*. As a result, this study was conducted to examine the combined effect of *Striga*-tolerant maize varieties and integrated nutrient management (INM) on *Striga* control and host performance.

Methods

The experiment was a factorial design laid out in a Randomized Complete Block in triplicate. In a *Striga*-infested field, the maize varieties (Wang-dataa and Omankwa) were evaluated under three levels of poultry manure (0, 5, and 10 t ha⁻¹) and four levels of ammonium sulfate (0, 30, 60, and 120 kg ha⁻¹).

Results

The ANOVA revealed that the interaction effect between the soil amendments and maize varieties significantly ($p < 0.001$) influenced the emergence of *Striga* plants and the productivity of the maize varieties. The Wang-dataa variety exhibited higher tolerance than the Omankwa variety under 10 t ha⁻¹ PM + 120 kg ha⁻¹ AS. Across the range of PM and AS applications, the highest growth and yield outputs were obtained by Wang-dataa with the application of 10 t ha⁻¹ PM + 120 kg ha⁻¹ AS. The percentage increase in grain yield for Wang-dataa and Omankwa varieties was 82 and 35%, respectively, over the control. Grain yield was positively correlated with plant height ($r = 0.61^*$), leaf area index (0.53^*), and cob weight (0.90^{***}).

Conclusion

This study has established that a higher tolerance and productivity of Wang-dataa over the Omankwa variety were achieved with the highest combination rate of PM and AS under *S. hermonthica* infestation.

1. Introduction

The genus *Striga*, obligate hemiparasitic plants known as "witchweeds," is a significant barrier to the production of cereal crops in sub-Saharan Africa (Dugje et al. 2006; Rodenburg et al. 2010; Parker et al. 2013). The most commercially significant species among the 28 species and six subspecies that cause damage to cereal crops like sorghum, millet, rice, and maize are *S. asiatica*, *S. forbesii*, *S. aspera*, and *S. hermonthica*, respectively (Parker et al. 2009). *Striga*'s wide range of hosts and considerable adaptation to environmental conditions enable it to be one of the most common and successful parasitic plants (Mohamed et al. 2006).

Due to the threat it poses to food security, the worsening of famine, and poverty in many African nations, including Ghana, the *Striga* scourge has drawn considerable attention from numerous stakeholders (Khan et al. 2014; Menkir et al. 2020). Some estimates of the negative consequences of *Striga* indicate that it affects more than 300 million people's lives in Africa and causes enormous yield losses worth between 7 and 10 billion US dollars annually (Rodenburg et al. 2010; Runo et al. 2018). About 75% of land under maize cultivation is endemic to *Striga* in sub-Saharan Africa (Akaogu et al. 2013; Runo et al., 2018). Yield losses can be 70% or as high as 100% in maize under extreme *Striga* infestation (Spallek et al. 2013). Severe infestations in some regions of Ghana have compelled farmers to abandon cereal cultivation for other crops (Atera et al. 2012). Over the years, extensive efforts have been made to provide simple, effective, and affordable control methods that can be employed alone or in combination to

manage the *Striga* problem because of its severity and persistence. Crop rotation, hand pulling, intercropping, fallowing, nitrogen fertilization, and the use of tolerant and resistant varieties are some of the suggested *Striga* control methods (Barberi 2019; Hearne 2009). However, when employed separately, none of these offer reliable control (Hearne 2009). (Gasura et al. 2019). The tolerance trait only enhances the host plant's ability to withstand the harmful effects of the already attached parasite and may not reduce *Striga* infection and reproduction rates. Resistance, on the other hand, stimulates germination but prevents the attachment of the *Striga* to its roots through defense mechanisms. Nevertheless, this attribute could also collapse in a few generations, resulting from a high genetic difference within *Striga* populations with an emerging adapted ecotype population (Tippe et al. 2017; Joel et al. 2018; Mutuku et al. 2020; Kamara et al. 2020).

Striga flourishes in less fertile soil, and using organic and inorganic fertilizers as part of sound soil management practices has proven to be an effective way to suppress *Striga*. The parasite may have negative effects from urea and ammonium nitrogen, which could stunt its growth by reducing the production of germination stimulants (Strigolactones) that induce *Striga* seed germination (Yoneyama 2020). Also, sulfur and sulfur-containing compounds function as signaling molecules in the regulation of biotic and abiotic stresses and enhance plant physiological performance (Prakash et al. 2022). In addition to the macronutrients (N, P, and K), poultry manure also contains micronutrients, such as zinc, manganese, iron, and others, that promote plant growth while reducing the parasitism of *Striga* (Dimkpa and Bindraban 2016; Yang et al. 2018).

Striga management cannot be effective with a single control method and therefore necessitates the integration of diverse methods (Sibhatu 2016; Mrema et al. 2020;). Integrated nutrient management approaches that combine both organic and inorganic nutrients with tolerant or resistant hosts have been commonly recommended to sustain higher maize crop productivity under *Striga* infestation (Ayoola and Makinde 2009; Shayanowako et al. 2020). However, several studies have evaluated the influence of phosphorus and nitrogen on the *Striga*-host interaction, with less emphasis placed on integrated nutrient management (INM). Some nutrient combinations could also have an antagonistic effect, which thereafter weakens the host plant's defense mechanism. Therefore, this study was conducted to examine the combined effect of *Striga*-tolerant maize varieties and soil amendments on *Striga* control and host performance.

2. Materials and Method

2.1 Study Location

The experiment was conducted at the experimental site of the Savannah Agricultural Research Institute (SARI), Nyankpala (about 16 km west of Tamale) in the Northern Region of Ghana. It lies within the Guinea savannah zone with an altitude of about 183 m above sea level and is located at longitudes 0 ° 58 'W and 9 ° 25 'N. The location experiences a unimodal annual rainfall of about 1000–12000 mm, unevenly distributed from April to November. The temperature distribution is uniform, with mean monthly minimum and maximum values of 21°C and 32°C, respectively. The minimum and maximum relative humidity are 53% and 80%, respectively.

2.2 Experimental design and treatments

The study was a 2 * 3 * 4 factorial laid out in a randomized complete block (RCB) design in triplicate. A plot size of 3 x 2 m, with 1 m and 2 m between plots and blocks, and a planting distance of 75 x 40 cm were used. According to Table 1, the treatments were *Striga*-tolerant maize varieties (*Wang-dataa* and *Omankwa*), poultry manure (0, 5, and 10 t ha⁻¹), and ammonium sulfate (21% N + 24% SO₃) at (0, 30, 60, and 120 kg ha⁻¹). The agronomic attributes of the

various varieties are presented in Table 2. The experimental plots were artificially inoculated with *Striga* seeds. Holes of 8 cm in depth and 10 cm in diameter were created every 0.4 m in the center of each ridge labeled for *Striga* seed infestation. *Striga* seeds were then applied as a seed-sand mixture using the calibrated scoops. Each hole received 7 g of the mixture, which was about 3000 germinable seeds and lightly covered with soil to create a depression for easy identification. Two maize seeds were planted at a depth of 3 cm, seven days after *Striga* seeds were conditioned. Designated plots received poultry manure two weeks before planting, and ammonium sulfate was applied at 14 and 28 DAP using the "4R" nutrient management method (Mikkelsen 2011). Weeds other than *Striga* were manually removed at 21 and 42 DAP.

2.3. Soil and poultry manure analyses: Before planting, collected soil sample at a depth of 0–30 cm was air-dried, ground, and sieved using 2mm sieve and analyzed (Table 3). Chemical composition of the organic nutrient was determined according to the procedures outlined by Richards (1954).

2.4. Agronomic Data collection

Data were collected three weeks after planting and at three-week intervals until harvesting. Observations were recorded on the two center rows of each plot for the number of days to 50% tasselling and silking, plant height, stalk lodging, and leaf area index (LAI). LAI was computed according to Dugje and Odos (2006) procedure (Eq. 1). For the yield parameters, stover and cob weights were determined, and grain yield was computed at a 15% moisture level according to the ASTM (2001) method (Equations 2, 3, and 4).

$$[LAI = \frac{(P \times LXA)}{GA}] \text{ ————— (1)}$$

Where:

[P = Plant population/ground area (ha); A = single leaf area (cm²); L = number of fully expanded green leave/plant; GA = Ground area or hectare]

$$[MC_{(ad)} = \frac{(100 - MC)}{85}] \text{ ————— (2)}$$

$$V1 \text{ GY}(\text{kg ha}^{-1}) = \frac{G.Y(PP) \times 0.83 \times 10,000 \text{ m}^2 \times MC(ad)}{6 \text{ m}^2} \text{ — (3)}$$

$$V2 \text{ GY}(\text{kg ha}^{-1}) = \frac{G.Y(PP) \times 0.81 \times 10,000 \text{ m}^2 \times MC(ad)}{6 \text{ m}^2} \text{ — (4)}$$

Where:

[GY_(PP) = Grain yield per net plot (kg)]; [MC_(ad) = Adjusted moisture content]; [0.83, 0.81 = Shelling coefficients of V1 and V2, respectively]

2.4.1. *Striga* count. Emerged *Striga* plants were counted at 56 and 70 DAP from each net plot. For the reason that variances of *Striga* counts tend to be heterogeneous; collected data were transformed before statistical analysis using Eq. (5).

$$[Y = \log(x + 1)] \text{ ————— (5)}$$

Where: [x = original *Striga* count]

2.4.2. *Striga* damage symptoms

Damage symptoms were visually rated at 70 DAP using a scale of 1 to 9, where 1 = no visible *Striga* damage symptom and 9 = all leaves completely scorched, resulting in premature death (Kim 1994).

2.4.3. Statistical Data Analysis. Data were subjected to analysis of variance (ANOVA) using the GenStat statistical package (software version 12). Means were separated using the least significant difference (LSD) at a 5% level of probability. The correlation and stepwise regression analyses were used to detect the significant relationship between the growth and yield parameters. Moreover, Duncan's Multiple Range Test (DMRT) at a 5% level of probability was used to determine the significant differences among the treatments. Results were represented in tables and figures.

3. Results

3.1. *Soil and organic nutrient.*

The physical and chemical properties of the soil before the experiment, as well as the chemical analysis of poultry manure, are presented in Tables 4 and 5, respectively. The results indicated the soil was sandy loam with a pH of 5.35. The soil organic matter was 0.30%; nitrogen and available phosphorus were 0.05% and 3.50 mg kg⁻¹, respectively. The K⁺ was 37.00 cmol kg⁻¹, while the Ca²⁺ and Mg²⁺ respective values were 3.20 and 2.30 cmol kg⁻¹. Also, the low C/N ratio (9.90) of the poultry manure would enhance quick mineralization and the release of nutrients to the soil to promote plant growth. The study area was evidently low in essential nutrient concentrations and therefore required a better nutrient management strategy for efficient and sustainable crop production.

3.2. Interaction Effect of Treatments on *Striga* Emergence and damage

3.2.1. *Striga* emergence: According to the ANOVA, the interaction effect between the soil amendments and maize varieties significantly ($p < 0.001$; $p < 0.001$) influenced the emergence of *Striga* plants at 56 and 70 days after planting (DAP), respectively (Table 6). At 56 DAP, the Omankwa variety treated with 0 t ha⁻¹ of poultry manure (PM) and 120 kg ha⁻¹ ammonium sulfate (AS) exhibited the lowest *Striga* count of 22.70/ 6m². On the other hand, the combined application of 10 t ha⁻¹ PM and 120 kg ha⁻¹ AS to Wang-dataa variety had a higher *Striga* count of 24.00/ 6m² (Table 7). However, the analysis showed that this difference was not statistically significant. The lowest *Striga* count (14.00/ 6m²) was observed under 10 t ha⁻¹ of PM and 120 kg ha⁻¹ of AS at 70 DAP. Higher *Striga* incidence (108.7 and 100.70; 41 and 71) was promoted under no fertilization in both varieties at 56 and 70 DAP, respectively.

3.2.2. *Striga* damage: The ANOVA indicated that the combined effect of the maize varieties and soil amendments had a significant ($p < 0.001$) impact on the *Striga* damage (Table 6). The Wang-dataa variety exhibited higher tolerance over Omankwa variety under 10 t ha⁻¹ PM + 120 kg ha⁻¹ AS, with lower injury score of 2.3. However, this results was not statistically different from Omankwa variety under the same treatment (Table 7). Generally, the results further indicated that both varieties without any soil amendment treatment suffered higher *Striga* injuries.

3.3. Main and Interaction Effects of Treatments on Growth Parameters

3.3.1. Days to 50% tasseling and silking: The NOVA revealed that the main effects of the maize varieties and poultry manure (PM) significantly ($p = 0.05$, $p < 0.001$) influenced days to 50% tasseling, respectively (Table 6). Likewise, this significance effect ($p < 0.001$, $p = 0.05$) was experienced by the main effect of poultry manure (PM) and the interaction between the maize variety and ammonium sulfate (AS), respectively. In terms of days to tasseling, the Wang-dataa variety exhibited an earlier tasseling at 54 days, while the Omankwa variety with the same treatment showed a later tasseling at 56 days (Fig. 1a). Moreover, in comparison to the control plants, increasing the application rate of PM at 5 and 10 t ha⁻¹ significantly promoted early tasseling days of 54 and 53, respectively (Fig. 1b). Additionally, shorter silking days (57 and 56) were observed under increasing application rates (5 and 10 t ha⁻¹) of PM, respectively (Fig. 2a). Likewise, with the exception of the application of 30 kg ha⁻¹ AS, the same early days of 57 were obtained across 60 and 120 kg ha⁻¹ AS applications to the Wang-dataa variety. The late days of 59 were recorded under the Wang-dataa and Omankwa varieties in combination with AS at 30 and 60 kg ha⁻¹, respectively (Fig. 2b).

3.3.2. Plant height at maturity: According to the ANOVA, there was a significant ($p = 0.002$) secondary interaction effect between the maize varieties and soil amendments on plant height at maturity (Table 6). The results presented in Table 8 revealed that the combined application of PM and AS at 10 t ha⁻¹ and 120 kg ha⁻¹, respectively, to the Wang-dataa variety resulted in a plant height of 152.3 cm at maturity (Table 8). In contrast, the Omankwa variety obtained the height of 145.1 cm under the application of 5 t ha⁻¹ of AS and 120 kg ha⁻¹. Shorter plant heights were observed in both varieties without fertilization.

3.3.3. Leaf area index (LAI): The interaction effect between the different soil amendments and maize varieties demonstrated statistical significance ($p = 0.016$) on LAI according to the ANOVA (Table 6). In this study, it was observed that higher rates of organic and inorganic nutrient applications led to a significant increase in the LAI of the maize plants. The Wang-dataa variety combined with the application of 5 t ha⁻¹ PM and 0 kg ha⁻¹ AS resulted in the highest LAI value of 4.10, which was statistically equivalent to LAI (3.33) under the application of 10 t ha⁻¹ PM and 120 kg ha⁻¹ AS of the same variety (Table 8). The LAI result (3.06) was obtained by the Omankwa variety under the treatments (10 t ha⁻¹ PM and 120 kg ha⁻¹ AS). Generally, plots that received zero nutrients had lower leaf area indexes in both varieties.

3.4. Interaction Effects of Treatments on Yield Parameters

3.4.1 Cob weight: According to the ANOVA, there was a significant ($p = 0.05$) difference in the results of soil amendment combinations with the maize varieties for cob weight. The Wang-dataa variety combined with the highest treatment rate (10 t ha⁻¹ PM + 120 kg ha⁻¹ AS) gave the result of 2,833 kg ha⁻¹, whilst the Omankwa best result of 1,967 kg ha⁻¹ was obtained under the treatments (10 t ha⁻¹ PM + 30 kg ha⁻¹ AS). Decreasing cob weight results were observed under decreasing combination levels of PM and AS, with the lowest (1433 and 1300 kg ha⁻¹) being recorded for Wang-dataa and Omankwa varieties, respectively.

3.4.2 Grain yield: The grain yield was significantly ($p = 0.003$) enhanced by the combined effect of the maize varieties and soil amendments with reference to the AOVA (Table 6). Wang-dataa achieved the highest grain yield of 3,085 kg ha⁻¹ when treated with 10 t ha⁻¹ PM and 120 kg ha⁻¹ AS, whereas the Omankwa variety yielded its best result (2,458 kg ha⁻¹) with the application of 5 t ha⁻¹ of PM and 120 kg ha⁻¹ of AS (Table 8). The percentage increase in grain yield for both varieties resulting from soil amendments was 82 and 35% for Wang-dataa and Omankwa varieties in comparison to no soil amendments, respectively. Grain yield was positively correlated (r) with plant height

($r = 0.61^*$), leaf area index (0.53^*), and cob weight (0.90^{***}), with the additive effect being stover weight (0.51^{***}) and cob weight (0.86^{***}) according to the regression (r^2) analysis (Tables 9 and 10).

3.4.3 Stover weight: The ANOVA indicated that the interaction effect between the maize varieties and soil amendments was significant ($p < 0.001$) on stover weight. The Wang-dataa variety recorded the highest stover weight of $1,762 \text{ kg ha}^{-1}$ under the treatment (10 t ha^{-1} of PM + 120 kg ha^{-1} AS), whilst the Omankwa variety yielded $1,358 \text{ kg ha}^{-1}$ under the same treatment (Table 8). Decreasing cob weight results were observed under decreasing combination levels of PM and AS, with the lowest (1035 and 1011 kg ha^{-1}) being recorded for Wang-dataa and Omankwa varieties, respectively.

3.4.4 Stalk lodging: With reference to the ANOVA, there was a significant interaction ($p < 0.001$) between the maize varieties and soil amendments, resulting in significant differences (Table 6). The Wang-dataa variety recorded the stalk lodging (1.50%), while the Omankwa variety obtained the same result under no fertilization. However, the highest value (4.07%) was recorded by the Wang-dataa variety under no fertilization. With the exception of the treatments (10 t ha^{-1} PM and 120 kg ha^{-1} AS) under Omankwa, its results (increasing PM + AS = increasing lodging values) were opposite to Wang-data's (increasing PM + AS = decreasing lodging values) across the different treatment ranges.

4. Discussion

The results indicated that the interaction effect between soil amendments (PM + AS) and maize varieties had a significant influence on *Striga* plant emergence. The Omankwa variety had a lower *Striga* count under 0 t ha^{-1} PM + 120 kg ha^{-1} AS compared to the Wang-dataa variety under 10 t ha^{-1} PM + 120 kg ha^{-1} AS. These different responses would be primarily caused by the differences in genetic adaptation strategies and associated nutrient uptake and utilization among the varieties. The specific combination of soil amendments used in both varieties significantly influenced the effectiveness of *Striga* suppression. The higher *Striga* emergence in the plots that received no nutrients established this result. With the exception of the moderate potassium level, the soil of the study area was inherently low in essential nutrients such as organic matter, nitrogen, and available phosphorus. *Striga* germination and haustorium formation are two steps of the life cycle that can be disrupted by improved host nutrition (Ghassemi et al. 2018; Teixeira-Costa 2021). The nutrients provided by the soil amendments (PM and AS) enhanced the competitiveness of the maize varieties against *Striga*, reducing the ability of the parasite to establish itself and emerge (Yoneyama 2010). Similarly, the nitrogen and phosphorus nutrition from the nutrient pool may have limited the exudation of germination stimulants (Strigolactones) by the host plants, which adversely affected *Striga* seed germination. (Yoneyama 2020). The degree to which host plants exude these compounds is a function of the deficiency of mainly nitrogen and phosphorus in the soil (Jamil et al. 2014; Yoneyama 2020). Likewise, temperature and water potential, which are dormancy initiation factors, induced dormancy in the *Striga* seeds because dormancy periods are normally distributed within *Striga* seed populations (Dzomeku and Murdoch 2007).

Additionally, damage from *Striga* injury decreased significantly with increasing nutrient application in both varieties. A nutrient combination of 10 t ha^{-1} PM and 120 kg ha^{-1} AS was highly effective in reducing the severity of *Striga* damage in both varieties. This suggests that the soil amendments (PM and AS) used in this study, in relation to their specific combination with genetic factors, have the potential to boost the overall health and tolerance of the maize varieties (Wang-dataa and Omankwa) against *Striga* injury. These nutrients combinations contributed to improved plant growth, vigor, and resilience to stress, including *Striga* infestation. The macro and micronutrient combination from PM and AS promoted high water use efficiency (WUE) and CO_2 assimilation rates (Yang et al. 2018). The

decreased damage symptoms observed across the range of soil amendment treatments, compared to the control group, further highlight the positive influence of integrated soil amendments on mitigating *Striga*-induced injury. The findings also established the detrimental impact of unfertilized conditions on *Striga* infestation, underscoring the importance of implementing appropriate soil fertility management practices.

Furthermore, there was a significant sole effect of the maize varieties and poultry manure on tasseling. The earlier days obtained by Wang-dataa over Omankwa suggest the major influence of inherent genetic disparities between the two varieties. Moreover, earlier tasselling under poultry manure at increasing doses ($5\text{--}10\text{ t ha}^{-1}$) would be partly explained by the additive effect of the low (9.90) C/N ratio that promoted high mineralization and nutrient release to the maize plants (Echarte et al. 2008; Kuzyakov 2010; Sánchez et al. 2019). This result was affirmed by the maize varieties in the control plots, which took much longer to tassel. Similarly, the decreasing days to silking recorded under an increasing application rate of poultry manure further validates the significance of PM in improving soil fertility and the corresponding growth in the maize plants. When considering the interaction between the variety and inorganic nutrient, the statistically similar early silking days observed for Wang-dataa and Omankwa varieties under 30 and 60 kg ha⁻¹ AS, respectively, indicate that different combinations of variety and inorganic nutrient can result in similar silking timings, emphasizing the complex relationship between genetic factors and external nutrient inputs.

Moreover, plant height, leaf area index, cob weight, grain yield, and stover weight were significantly affected by the secondary interaction between the maize varieties and soil amendments. For all the parameters measured, the soil amendment combination (10 t ha^{-1} PM + 120 kg ha^{-1} AS) supported the highest outputs in Wang-dataa. The correlation analysis conducted in this study revealed significant positive relationships between various growth parameters and grain yield. Specifically, the results showed that grain yield had a positive correlation with plant height, leaf area index, and cob weight, as presented in Table 9. These findings suggest that as these growth parameters increased, there was a corresponding increase in grain yield. The correlation between grain yield and leaf area index (LAI) highlights the importance of maximizing the photosynthetically active leaf area. Moreover, leaf area expansion, plant height, cob weight, and stover weight were influenced by genetic factors and nutrient provision. The adequate nutrient supply, as facilitated by the soil amendments, likely contributed to the development of a larger leaf area, enhancing photosynthetic efficiency and grain yield (Huang et al. 2010; Zhao et al. 2015; Ndung'u et al. 2021). Moreover, the capacity of both soil amendments to supply plants with regular and sustained available nitrogen during the vegetative period promoted growth and yield (Mahetele and Kushwaha 2011). Likewise, better timing and placement of nutrients to coincide with the stages of peak crop requirements played a critical role (Khan et al. 2008). Nutrients such as manganese, copper, zinc, iron, sulfur, and magnesium played a significant role in the maize plant's photosynthesis pathways and minimized *Striga*-negative effects on host plants (Dimkpa and Bindraban 2016; Yang et al. 2018).

In addition, soil fertility has a significant influence on stalk quality. With the exception of the treatments (10 t ha^{-1} PM + 120 kg ha^{-1} AS) under Omankwa, its opposite results (increasing PM + AS = increasing lodging values) to Wang-dataa (increasing PM + AS = decreasing lodging values) emphasized the complex relationship between genetic factors and external nutrient inputs. The Wang-dataa variety possibly partitioned more carbohydrates to the stalk than the *Omankwa* variety, combined with a higher level of resistance to stalk rot or injury, and this would account for the lower stalk lodging values (Ye et al. 2022)

5. Conclusion

The study examined how the productivity of the *Striga*-tolerant maize varieties (Wang-dataa and Omankwa) can be enhanced by using poultry manure and ammonium sulfate under *Striga* infestation. The outcomes showed that the Wang-dataa variety exhibited higher tolerance over Omankwa variety. Across the highest range of poultry manure and ammonium sulfate applications, the highest growth and yield outputs were obtained by Wang-Dataa. The productivity of the maize varieties (Wang-dataa and Omankwa), in relation to their inherent genetic factors, was enhanced under *Striga hermonthica* conditions with the combination of soil amendments (PM and AS).

Declarations

Data availability

The raw data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of interest

The authors declare no conflict of interest.

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Tables

Table 1: Treatment combinations used for the study

Vr.	AS		PM	Vr.	AS		PM
	(kg ha ⁻¹)		(kg ha ⁻¹)		(kg ha ⁻¹)		(kg ha ⁻¹)
	0	+	0		0	+	0
	0	+	5		0	+	5
	0	+	10		0	+	10
	30	+	0		30	+	0
	30	+	5		30	+	5
	30	+	10		30	+	10
V1				V2			
	60	+	0		60	+	0
	60	+	5		60	+	5
	60	+	10		60	+	10
	120	+	0		120	+	0
	120	+	5		120	+	5
	120	+	10		120	+	10

V1= Wang-dataa variety, **V2** =Omankwa variety, **PM** = poultry manure, **AS**= ammonium sulfate

Table 2: Agronomic attributes of the maize varieties used for the study

Variety	Maturity Days	Variety Type	Yield Potential (t ha ⁻¹)	Tolerance
Wang-dataa	90	OPV	4-7	Striga/ drought
Omankwa	90	OPV	4-5	Striga/ drought

Source: Seed Guide (2016) || OPV = Open-Pollinated Variety

Table 3: Soil analysis

Parameter	Reference
pH 1:2.5	Van Reeuwijk (1992)
Organic matter and carbon, total nitrogen	Bremner (1965)
Available phosphorus, and exchangeable cations (Ca ²⁺ , K ⁺ , Mg ²⁺)	Bray and Kurtz (1945)
<i>Physical properties</i>	Gee and Bauder (1986)

Table 4: Physio-chemical characteristics of the soil (0–30 cm) prior to planting.

Parameter	Unit	Value
pH 1:2.5	—	5.35
Organic matter (OM)	%	0.30
Organic Carbon (OC)	%	0.20
Total Nitrogen (TN)	%	0.05
Available Phosphorus (P)	mg kg ⁻¹	3.50
Exchangeable Calcium (Ca ²⁺)	cmol (+) kg ⁻¹	3.20
Exchangeable Potassium (K ⁺)	cmol (+) kg ⁻¹	37.00
Exchangeable Magnesium (Mg ²⁺)	cmol (+) kg ⁻¹	2.30
Clay	%	16
Silt	%	34
Sand	%	50
Silt + Sand	%	84
Textural class	Sandy loam	

Table 5: Nutrient Composition of the Poultry Manure used in the study

Parameter	Unit	Concentration
C/N Ratio	—	9.90
Total Nitrogen (N)	%	2.10
Total Phosphorus P ₂ O ₅	%	1.78
Total Calcium (Ca)	%	1.00
Total potassium (K ₂ O ₅)	%	1.20
Total Magnesium (Mg)	%	0.65
<u>Micronutrients</u>		
Mn	ppm	254
Fe	ppm	980
Zn	ppm	230
Cu	ppm	38

Table 6: Summary of analysis of variance (ANOVA) of Striga count and damage, growth and yield parameters of maize plants.

		<i>Striga</i> Count/plot			<i>Growth parameters</i>				<i>Yield Parameters</i>			
	df	56DAP	70DAP	SDS	DT	DS	PH	LAI	SL	GY	CW	SW
Variety	1	0.789 ns	0.001***	0.001***	0.053*	0.201ns	0.020*	0.234ns	0.001***	0.001***	0.004**	0.001***
organic	2	0.164 ns	0.001***	0.962ns	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
inorganic	3	0.001***	0.001***	0.001***	0.789ns	0.895ns	0.100ns	0.434ns	0.001***	0.001***	0.005**	0.001***
Variety*organic	2	0.001***	0.001***	0.001***	0.779ns	0.083ns	0.005**	0.689ns	0.001***	0.010*	0.011*	0.001***
Variety*inorganic	3	0.351ns	0.279ns	0.001***	0.680ns	0.050*	0.067ns	0.587ns	0.001***	0.030*	0.015*	0.002**
Organic* inorganic	6	0.043*	0.692ns	0.001***	0.098ns	0.074ns	0.001***	0.269ns	0.001***	0.005**	0.002**	0.001***
V*O*I	6	0.013**	0.031*	0.001***	0.855ns	0.994ns	0.002**	0.016*	0.001***	0.003**	0.058*	0.001***

***Highly significant at (P < 0.001), **Moderately Significant at (P < 0.01) and *Significant at (P < 0.05) || GY= grain yield|| CW= Cob weight || PH=Plant height || LAI=leaf area index || DT =days to 50% tasseling || 50% DS=days to 50% silking|| SDS =Striga damage score|| SL =Stalk lodging

Table 7: Mean number of emerged *Striga* and damage as influenced by the maize varieties, ammonium sulfate and poultry manure at **56** and 70 DAP

Vr.	Treatments			Striga count/plot		SDS
	AS		PM	56 DAP	70 DAP	(1-9)
	(kg ha ⁻¹)		(t ha ⁻¹)			
	<i>0</i>	<i>+</i>	<i>0</i>	108.7ab	41.3 fghij	6.0 a
	<i>0</i>	<i>+</i>	<i>5</i>	102.7 ab	60.0 cde	2.3 g
	<i>0</i>	<i>+</i>	<i>10</i>	89.7 abcd	50.3 efg	4.0 def
	<i>30</i>	<i>+</i>	<i>0</i>	50.7 efg	40.3 fghij	2.3 g
	<i>30</i>	<i>+</i>	<i>5</i>	94.7 abc	49.7 efgh	3.0 fg
	<i>30</i>	<i>+</i>	<i>10</i>	62.3cdef	48.3 efghi	3.0 fg
V1						
	<i>60</i>	<i>+</i>	<i>0</i>	34.0 fg	40.0 fghij	2.3 g
	<i>60</i>	<i>+</i>	<i>5</i>	55.3 defg	37.0 fghijk	2.3 g
	<i>60</i>	<i>+</i>	<i>10</i>	39.3 fg	32.3 hijkl	3.0 fg
	<i>120</i>	<i>+</i>	<i>0</i>	27.7 fg	17.3lm	4.0 def
	<i>120</i>	<i>+</i>	<i>5</i>	27.0 fg	28.3 jklm	3.3 efg
	<i>120</i>	<i>+</i>	<i>10</i>	24.0 fg	14.0 m	2.3 g
	<i>0</i>	<i>+</i>	<i>0</i>	100.7 ab	71.7 bc	5.0 bcd
	<i>0</i>	<i>+</i>	<i>5</i>	44.0 efg	42.3 fghij	6.3 a
	<i>0</i>	<i>+</i>	<i>10</i>	117.7 a	96.3 a	4.3 cde
	<i>30</i>	<i>+</i>	<i>0</i>	78.7 bcde	54.3 def	3.3 efg
	<i>30</i>	<i>+</i>	<i>5</i>	43.3 efg	33.3 ghijkl	3.3 efg
V2	<i>30</i>	<i>+</i>	<i>10</i>	94.0 abc	79.7 b	3.3 efg
	<i>60</i>	<i>+</i>	<i>0</i>	32.3 fg	36.3 ghijk	3.3 efg
	<i>60</i>	<i>+</i>	<i>5</i>	45.3 efg	31.7 ijkl	5.3 abc
	<i>60</i>	<i>+</i>	<i>10</i>	80.0 bcde	72.3 bc	6.3 a
	<i>120</i>	<i>+</i>	<i>0</i>	22.7 g	20.7 klm	2.3 g
	<i>120</i>	<i>+</i>	<i>5</i>	26.3 fg	22.0 klm	2.3 g
	<i>120</i>	<i>+</i>	<i>10</i>	46.0 efg	68.3 bcd	2.4 g
Grand Mean:				60.3	45.3	3.6
LSD (5%):				32.4	14.9	0.5
CV (%):				32.7	20.0	16.7

Means followed by similar letter (s) in a column are not significantly different at 5% probability level according to Duncan's Multiple Range Test (DMRT) || CV= Coefficient of variation || LSD = Least significant difference || VR= variety, SD= Striga damage score

Table 8: Plant height, leaf area index, cob weight, grain yield, stover weight, and Stalk lodging as influenced by the interaction effect between maize varieties, poultry manure and ammonium sulfate.

Treatments					Growth / Yield Parameters				
Vr	AS (kg ha ⁻¹)		PM (t ha ⁻¹)	Plant Height (cm)	Leaf Area index	Cob weight (kg ha ⁻¹)	Grain yield (kg ha ⁻¹)	Stover weight (kg ha ⁻¹)	Stalk lodging (%)
	0	+	0	94.3 ij	1.84 bcd	1433 efgh	1692 gh	1035 j	4.07a
	0	+	5	136.3 abcde	4.10 a	1700 cdefgh	1952defgh	1323 e	1.90hij
	0	+	10	112.3 fghi	2.01 bcd	1500 efgh	1756 efgh	1312 e	1.70 ijk
	30	+	0	102.33 hij	1.78 cd	1433 efgh	1679 gh	1126 h	2.30cdef
	30	+	5	119.3 efgh	2.77 abcd	1933 cdef	2186 cde	1328 e	1.83hij
	30	+	10	140.3 abcd	2.9 abcd	1933 cdef	2186 cde	1408 cd	1.70 ijk
V1									
	60	+	0	92.0 j	2.50 bcd	1467 efgh	1721 fgh	1199 fg	2.33 defg
	60	+	5	138.3 abcde	2.10 bcd	2133 bc	2391 cd	1316 e	1.90 hij
	60	+	10	133.3 abcde	3.34 ab	2567 ab	2818 ab	1439 c	1.50 k
	120	+	0	112.3 fghi	2.41 bcd	1533 defgh	1788 efgh	1229 f	2.00 fghi
	120	+	5	130.3 bcdef	2.56 bcd	2067 cd	2322 cd	1523 b	1.93 ghi
	120	+	10	152.3 ^a	3.33 ab	2833 ^a	3085 ^a	1762 ^a	1.50 k
	0	+	0	136.7 abcde	1.76 cd	1400 fgh	1820 efgh	1011j	1.50 k
	0	+	5	130.3 bcdef	1.53 d	1900 cde	1750 efgh	1035j	2.23 defg
	0	+	10	123.3 defg	2.77 abcd	1600 cdefgh	1853 efgh	1319 e	2.50 bcd
	30	+	0	95.7 ij	1.48 d	1300 h	1555 h	1046 j	1.60 jk
	30	+	5	145.3 abc	2.98 abcd	1867 cdefg	2116cdefg	1066 lj	2.40 bcde
V2	30	+	10	137.3 abcde	2.96 abcd	1967 cde	2153cdef	1332 e	2.40 bcde
	60	+	0	108.3 ghij	2.32 bcd	1333 gh	1592 h	1117 hi	2.26 cdef
	60	+	5	145.1 ab	2.52 bcd	17331cdefgh	1988defgh	1147 gh	2.67 b
	60	+	10						2.53 bcd

			125.4 ^{bdefg}	2.57 ^{bcd}	1867 ^{cdefg}	2122 ^{cdefg}	1358 ^{de}	
120	+	0	126.2 ^{bcdefg}	2.34 ^{bcd}	1567 ^{defgh}	1822 ^{efgh}	1187.0 ^{fg}	2.30 ^{cdef}
120	+	5	123.4 ^{defg}	2.79 ^{abcd}	1867 ^{cdefg}	2458 ^{bc}	1346.7 ^e	2.56 ^{bc}
120	+	10	136.3 ^{abcde}	3.06 ^{abc}	1733 ^{cdefgh}	1987 ^{defgh}	1438.7 ^c	1.73 ^{ijk}
Mean:			124.9	2.53	1778	2033	1267	2.13
LSD (5%):			16.81	1.24	462.3	377.2	26.17	0.28
CV (%):			8.20	29.80	15.8	11.30	3.0	8.0

Means followed by similar letter (s) in a column are not significantly different at 5% probability level according to Duncan's Multiple Range Test (DMRT) || CV= Coefficient of variation || LSD = Least significant difference ||

Table 9: Linear correlation coefficients (r) of agronomic parameters

	50% T	50% S	PH	LAI	GY	CW	SW
50%T	-						
50%S	0.91***	-					
PH	-0.59*	-0.58*	-				
LAI	-0.44	-0.46	0.42	-			
GY	-0.65*	-0.65*	0.61*	0.53*	-		
CW	-0.69*	-0.70*	0.67*	0.51*	0.90***	-	
SW	-0.57	-0.59*	0.33	0.51*	0.64*	0.58*	-

***Highly significant at (P < 0.001), **Moderately Significant at (P < 0.01) and *Significant at (P < 0.05) || GY= grain yield|| CW= Cob weight || PH=Plant height || LAI=leaf area index || DT =days to 50% tasseling || DS=days to 50% silking|| SL =Stalk lodging

Table 10: Regression coefficients (r²) of agronomic parameters on grain yield under Striga influence

Parameters	Equation	R ²	F. pr
Days to 50% tasseling	$y = -109.28x + 8064.5$	0.35	0.001***
Days to 50% silking	$y = -94.673x + 7511$	0.32	0.001***
Plant height	$y = 12.209x + 508.25$	0.31	0.001***
Leaf area index	$y = 164.53x + 1616.3$	0.12	0.003**
Cob weight	$y = 0.8928x + 445.88$	0.86	0.001***
Stover weight	$y = 1.6449x - 50.643$	0.51	0.001***

Figures

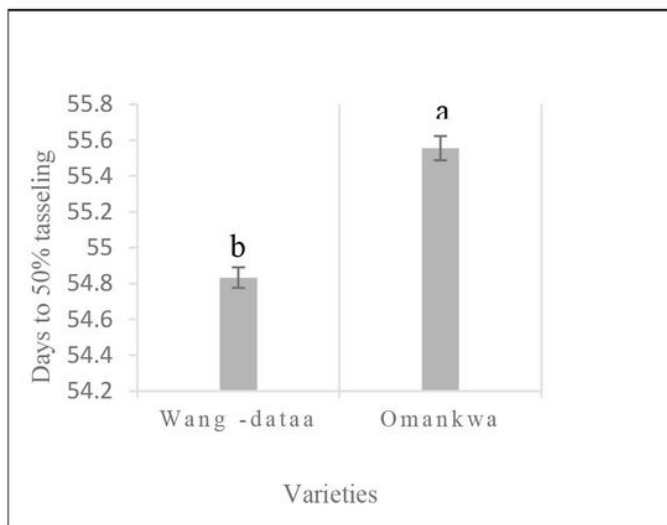


Figure 1a:

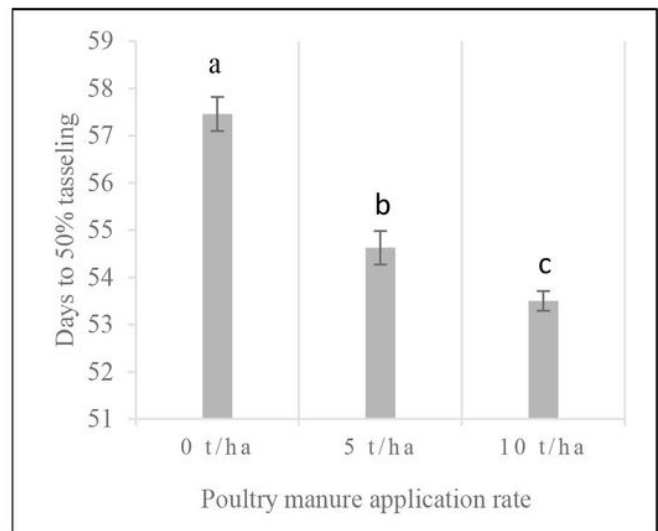


Figure 1b:

Figure 1

1a: Days to 50% tasseling as influenced by maize varieties || Means followed by similar letter (s) are not significantly different || Bars = Standard error of means ||

1b: Days to 50% tasseling as influenced by poultry manure || Means followed by similar letter (s) are not significantly different || Bars = Standard error of means ||

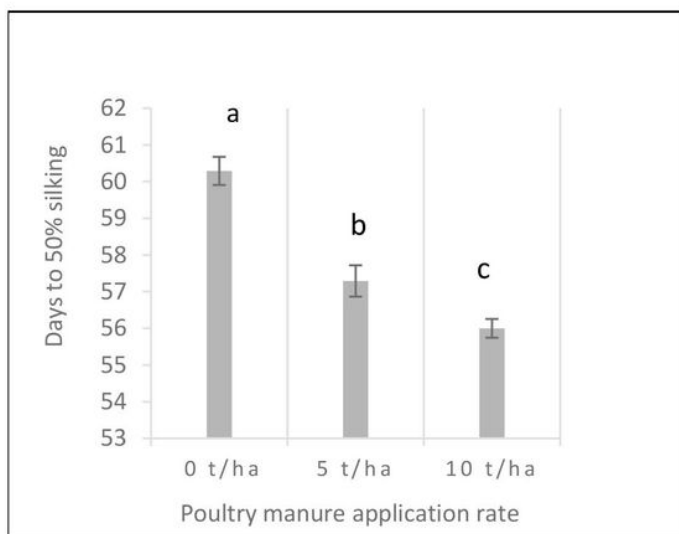


Figure 2a:

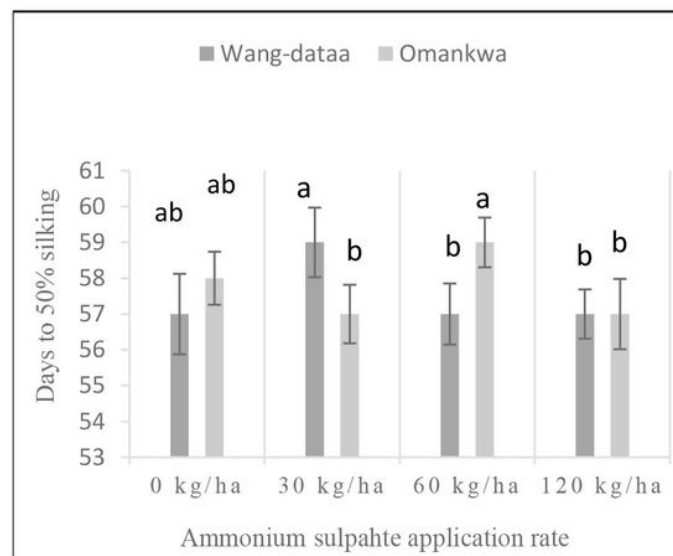


Figure 2b:

Figure 2

2a: Days to 50% silking as influenced by poultry manure || Means followed by similar letter (s) are not significantly different || Bars = Standard error of means ||

2b: Days to 50% silking as influenced by ammonium sulfate || Means followed by similar letter (s) are not significantly different || Bars = Standard error of means ||

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [ANOVA.rtf](#)
- [RANGETEST.rtf](#)
- [RAWDATA.xlsx](#)