Growth and Yield Performance of Maize Hybrids on the Vertic soils of Accra Plains Ghana

Y.O. Kugblenu Darrah[1], B. Ofori[1], D. K. Puozaa[2]

[1] *Soil and Irrigation Research Centre, University of Ghana*
[2] *CSIR-Animal Research Institute*

*Corresponding Author: *ykublenu@ug.edu.gh*

Abstract

Maize is the most important food staple in Ghana however yield potential of 6t/ha for this cereal has yet to be realized. Increasing yield productivity has become crucial in recent times due to food security pressures as a result a growing population and a rapidly expanding use in the local industry. Maize hybrids offer the opportunity to significantly increase yields in the country and this has led to an increasingly greater number of hybrids being developed and released. There is therefore the need to test maize hybrids before recommending them to farmers under specific agroecological areas. In this study, a recently released hybrid '*Legon Aburo*' (released by West African Centre for Crop Improvement - WACCI), tested alongside two commonly used hybrids '*Opeaburo*' (local hybrid) and '*Pan 53*' (imported hybrid) and two Open Pollinated Varieties (OPVs) ('*Obatanpa*' and '*Abontem*'), in the coastal savannah agro-ecological zone with distinctive vertic black heavy clayey soils.

The results show significant differences ($p < 0.05$) in the leaf area index (LAI) among the maize varieties and was highest in '*Obantanpa*' in both seasons. Biomass which varied significantly among varieties was highest in '*Legon Aburo*' and '*Pan 53*' and lowest in '*Abontem*'. In terms of yields the most popular OPV '*Obatanpa*' was comparable to the local hybrid '*Opeaburo*' and the foreign hybrid '*PAN 53*'. The OPV '*Abontem*' had the lowest grain yield whiles the WACCI hybrid '*Legon Aburo*' produced the highest grain (<7t/ha) for both years. This novel hybrid variety may offer an opportunity for farmers in the Coastal Savannah with predominantly vertic clayey soils to increase their yields.

Introduction

Maize is the most important cereal in Ghana, grown almost exclusively as a food staple for nearly the entire population. It accounts for 55 % of the total grain output and it has over the years surpassed that of rice (accounting for 23%) and replaced traditional cereals like sorghum and millet (accounting for 13 and 9 % respectively) (Macauley et al., 2005). It covers an area of one million hectares and is cultivated in all the six agroecological zones of the country encompassing a diverse range of soil types, temperature, humidity, rainfall patterns and other edaphic conditions, (MoFA, 2018).

Currently, production levels stand around 2.8 million MT (FAOSTAT, 2022) with 57 % of that consumed directly or traded locally by rural and peri-urban family households ensuring food, nutritional and economic security for more than half of the population. Additionally, owing to the diversification of its use in the poultry and brewing industries the demand for maize has increased in recent times. For instance, 13 to 15% of locally produced maize is used as feed in the poultry sector and this is expected to increase as the sector continues to grow (Andam et al., 2017). The projected population of Sub-Saharan Africa, which is expected to double in the next 30 years (UN DESA,2022) makes it imperative to increase maize productivity in the country to improve current and address future growth demand for this crop.

Maize cultivation in Ghana is done largely by poorly resourced smallholder farmers with restricted access to many of the inputs they need to increase yields. This has led to very low maize productivity levels especially when

West African Journal of Applied Ecology, vol. 31(2), 2023: 57 - 68

compared to similar agroecological regions of the world (Ragasa et al., 2014).The current levels are only 20% of the potential achievable yields, however, reports from research and experimental fields indicate that higher output can be achieved if farmers adopt innovative strategies such as the use of high-yielding hybrid varieties (van Loon et al., 2019).

Reports show that the use of maize hybrid in Ghana is only 3% (Ragasa et al., 2014) with majority of farmers using primarily OPVs even though, in the same report, yields of hybrids were 18-70% higher and 60 -90% more profitable when compared with the OPVs. Hybridization, therefore, addresses the issues of yield increase per acreage as they can give yield gains of 15 to 25% compared with inbred lines (Li et al., 2014).

The National Agricultural Research Institutions since the 1960s have developed and released 58 improved varieties of maize mostly starting with OPVs but with a progressively higher number of hybrids being included each year (CSIR, 2019). Potential yields of new hybrids varieties released are almost double that of old hybrids and non-hybrid varieties released. For instance, the WACCI hybrid varieties released recently has the potential of 10 t/ha compared to the 4.5 t/ha Obatanpa OPV released in the 90s and 6.5t/ha of Mamaba released in 2015. Regasa et al. (2014) noted however that the adoption rate of new varieties in the country has been very low (estimated at only 2%) and this has most especially affected the uptake of hybrids. Their report also indicated that about 96 percent of the certified seeds produced in Ghana is the OPV '*Obatanpa*' variety (developed by CYMMT and released by CSIR in 1992) because half of the farmers in the country plant this variety.

One major reason this variety has unusually dominated the maize industry for several years has been attributed to the varying performance of new varieties compared with '*Obatanpa*' with some farmers reporting lower yields compared to the '*Obatanpa*' variety. Akpo et al. (2021) pointed out that since the major focus is to increase productivity, farmers will adopt a new variety only if it has an advantage of higher yields.

In other parts of world, it has been clearly shown that hybrids increase yields considerable due to their higher yield potential, however performance of a variety is also dependent on environmental factors such as soil, moisture, temperature, light intensity, humidity, rainfall as well as cultural practices prevalent in a particular location (Kandel and Shrestha, 2020). The variable performance of hybrids in the country may likewise be due to the vast difference among and within agroecological areas in terms of temperature, humidity, rainfall patterns, light intensity, soil type, and other edaphic conditions. This creates microclimates which vary across farmers' fields. Testing new hybrids in specific microclimate conditions is therefore important before they are presented to farmers.

The coastal savannah of Accra plains is one of the important agricultural zones in the country highly known for its rice and mango production as well as other crops such as okra, onion, and maize. The soils in this area are mostly vertic black heavy, highly clayey soils and underutilized because they are difficult to work with (too sticky when wet and too hard when dry for simple or heavy farm implements) (Antwi and Asiamah, 1996; Abunyewa et al. 2004). These soils are also one of the sparsest in the country, covering a total 1820 km^2 and the coastal savanna area is among the only two areas in Ghana where these soils can be found (Brammer, 1967) decreasing the chances of the inclusion of these soils in most crop varietal testing programmes. They have however been long established as some of the most productive soils in the world because of their high water-holding capacity, which are especially important for crop production in semi-arid environments with highly erratic rainfall distribution (Kumar, 1982).

Our objective, therefore, was to evaluate maize hybrid varieties including a new hybrid from WACCI which even though is recommended for the coastal savannah has yet to be tested on for growth and yield performance on vertisols of Accra plains.

Materials and Method

Experimental sites

The trial was established at the University of Ghana's Soil and Irrigation Research Centre (SIREC) located at Kpong in the Eastern Region (6°09'N, 00°04'E) with an altitude of 22 m above mean sea level. The area lies in the Coastal Savannah agro-ecological zone of Ghana and has bi-modal rainfall pattern with mean annual rainfall of 1200 mm. The mean annual temperature is 27.2°C. The soil is clayey and classified as a Typic Calcicustert, a Vertisol derived from garnetic—Ferrous hornblende gneiss parent material (Amatekpor and Dowuona, 1995).

Design and management of trials

Two consecutive plantings were done: 2019 (June 4 - September 18) and 2020 (June 2 -September 15) on the same field. The experimental design was a randomized complete block (RCBD) with three replications. Five maize varieties including three hybrids and two OPVS from various sources and with different agronomic characteristics were used (Table 1). Land preparation entailing one ploughing and two harrowing were done two weeks prior to each planting. Ridges were constructed 0.80 m apart. Six ridges were used for each plot and seeds were sown and were spaced 0.40 m apart. Three seeds were sown and thinned out to one plant per stand a week after emergence. The weather conditions during the period in both years are represented in Table 2. The Centre had low precipitation during both periods. the plants were therefore supplemented with irrigation which was given after 5 days of no rain. The same amount of Nitrogen (N) Phosphorus (P) Potassium (K) was applied at rates of 90 kg/ha N, 60 kg/ha P, and 60 kg/ha K for both experiments. The full amount of P, K and half the amount of N was applied ten days after planting and the remaining amount of N was applied at tasseling. Pest control was done, spraying with Akate Master ® (Active Ingredient 27 G/Lt bifenthrin) periodically at the recommended rate mainly to lessen the destructive action of fall armyworms (*Spodoptera frugiperda*) on the maize leaves.

Data on plant development was collected on 8 record plants located within the four inner rows and included leaf area at 2, 6 and 10 weeks after emergence (WAE) which was used to compute the Leaf area index (LAI) with the following formula:

$$Leaf\ area\ index\ (LAI) = Leaf\ area\ \frac{m2}{Ground}\ cover\ (m2)$$

Data was also collected on plant height and leaf number at tasseling. At maturity three non-record plants within the plots were harvested and separated into shoots and roots. Plant materials were dried at ≈ 70 ◦C to a constant weight and weighed for total biomass. At harvest, yield parameters namely 100 seed weight, cob weight, ear weight (which is the harvested maize with the husk still intact), husk weight, number of rows per cob, number of seeds per row, total number of seeds per cob, cob length and total grain weight per plant were collected. Total grain weight was used to extrapolate the grain yield in tonnes

TABLE 1

List of maize varieties used in the study

Name	Source	Year of release	Colour	Type	Maturity (days)
'Obatanpa'	IITA/CIMMYT	1992	White	OPV	105
'Legon Aburo'	WACCI	2019	White	Single cross hybrid	85-95
'Opeaburo'	CRI	2012	White	Top cross hybrid	115
'Abontem'	IITA	2010	Yellow	OPV, QPM	75-80
'Pan 53'	Pannar	2015	White	3-way hybrid	115-120

Source (Catalogue of crop varieties released and registered in Ghana, 2019; OPV-open pollinated variety, QPM-quality protein maize)

TABLE 2

Weather conditions during period of the experiment for 2019 and 2020

Year	Parameters	June	July	August	September	Monthly Mean
2019	Max. temp (°C)	33.1	31.0	30.2	31.1	31.4
	Min. temp (°C)	22.4	21.4	20.4	21.4	21.4
	Relative Humidity (%)	90.0	90.0	86.1	91.6	89.4
	Rainfall amounts (mm)	211	42	15	134	100
	Number of rainy days	8	4	2	8	6
2020						
	Max. temp (°C)	34.1	28.2	33.1	29.2	31.2
	Min. temp (°C)	22.4	21.0	21.4	21.0	21.6
	Relative Humidity (%)	88.5	88.6	82.0	90.0	87.3
	Rainfall amounts (mm)	119	160	4	136	105
	Number of rainy days	9	3	1	5	5

per hectare for each variety.

Results

The results showed that during the first year (2019), significant difference (P<0.05) were observed among the maize varieties for leaf area index at 2, 6, 10 WAE, plant height at tasseling, total biomass, 100 seed weight, total grain weight, total grain yield, cob weight,100 seed weight, and cob weight (Table 3). In the second experiment (2020) all the parameters except for leaf area index at 10WAP and number of leaves at tasseling showed significant differences (P<0.05) among the maize varieties. The study generally observed higher variability in agronomic and yield performance among the maize varieties during second season compared with the first season as seen in the high coefficient of variation. For instance, plant height at tasseling ranged from 121.9 to 183.3 cm in 2019 whiles it ranged from 58.0 to 174.2 cm in 2020. Similar response was also observed for total grain weight per plant, grain yield,

TABLE 3

Summary of analysis of variance for all parameters measured (vegetative growth, yield, and yield traits) over the two consecutive growing seasons

	2019					2020				
					p-value					**p-value**
	min	**max**	**mean**	**cv**	**(0.05)**	**min**	**max**	**mean**	**cv**	**(0.05)**
Leaf area index at 2WAE	0.008	0.013	0.01	22.1	**ns**	0.006	0.027	0.01	37.9	**<0.001**
Leaf area index at 6WAE	0.054	0.089	0.07	18.9	**0.04**	0.022	0.114	0.06	41.5	**0.009**
Leaf area index at 10WAE	0.160	0.285	0.20	25.6	**0.05**	0.102	0.257	0.17	33.5	**ns**
Plant height at tasseling	121.9	183.3	152.4	7.7	**0.04**	58.0	174.2	107.1	31.1	**<0.001**
Number of leaves at tasseling	11	15	13	3	**ns**	11	16	13	8	**ns**
Total biomass (kg/plant)	3.2	7.4	5.3	16.9	**0.04**	3.0	8.0	5.0	14.1	**0.008**
Total Grain weight (kg/plant)	1.1	1.7.	1.4	13.7	**0.04**	0.8	2.0	1.2	18.2	**0.01**
Grain yield (t/ha)	4.9	7.6	6.3	2.8	**0.04**	3.5	8.8	5.5	13.1	**0.01**
Ear weight (g)	157.0	262.0	215.0	3.8	**0.01**	104.2	282.7	181.7	13.1	**0.006**
100 seed weight (g)	28.5	36.1	32.3	2	**0.01**	25.4	42	32.7	6.9	**0.001**
Cob weight (g/cob)	138.0	231.0	192.0	3.7	**0.04**	94.6	258	163.7	16.3	**0.002**
Husk weight (g)	10.2	34.6	23.4	6	**ns**	19.66	85.1	45.6	35.1	**0.05**
Cob length (cm/cob)	14.4	17.7	15.9	2.8	**ns**	12.4	18.6	15.1	8.2	**0.01**
Number of rows /cobs	13	16	14	2.1	**ns**	11	14	13	2.9	**0.002**
Number of seeds /rows	29	37	32	2.7	**ns**	26.6	41	32	6.6	**<0.001**
Total number of seeds /cobs	393	544	448	10.1	**ns**	314	525	417	9.3	**<0.001**

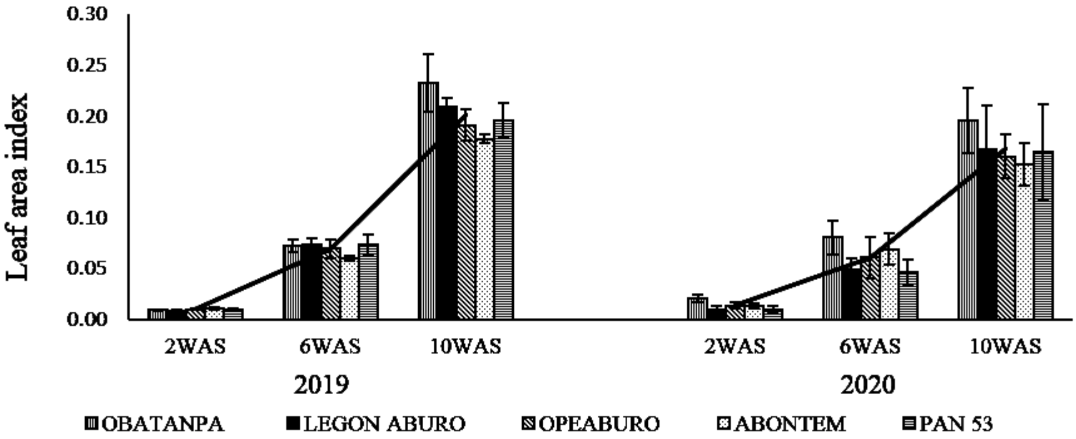

Figure 1 Leaf area index of five maize varieties tested on vertisols during two consecutive major rainy seasons

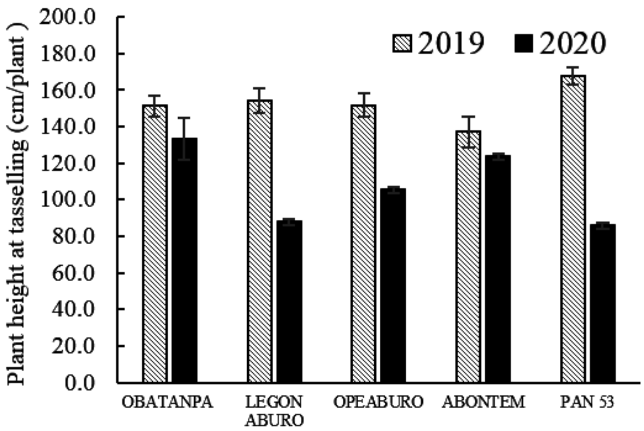

Figure 2 Plant height at tasseling of five maize varieties tested on vertisols during two consecutive major rainy seasons

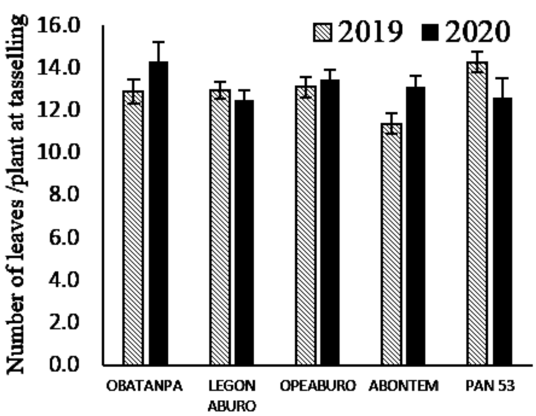

Figure 3 Number of leaves at tasseling of five maize varieties tested on vertisols during two consecutive major rainy seasons

cob weight and husk weight. Similar trends were also observed in total grain weight, grain yield, ear weight cob weight and husk weight. The high variability observed in 2020 may be explained by low rainfall amounts during the early establishment stage of the maize in 2020 compared to 2019 (Table 2).

Leaf area index (LAI) was generally higher in '*Obatanpa*', and this is most evident in 2020 where it was consistently higher at all the stages measured (Figure 1). This was followed by '*PAN 53*' however there was no significant differences between these two varieties. The study also observed very low LAI in the maize variety '*Abontem*'.

Plant height at tasseling (Figure 2) was generally higher in 2019 compared to 2020. The maize variety '*PAN 53*' had significantly higher plant height followed by '*Legon Aburo*', '*Obatanpa*' and '*Opeaburo*'. In 2020 '*Obatanpa*' had significantly higher plant height followed by '*Abontem*'.

Number of leaves per plant at tasseling (Figure 3) was similar in both season for all the varieties. The highest number of leaves obtained was 14 by both '*PAN 53*' in 2019 and '*Obatanpa*' in 2020. The lowest number of leaves of 11 was observed in '*Abontem*' in 2019.

Total biomass produced was significantly different ($P<0.05$) among the maize varieties in both years (Table 3). In both seasons, "*Abontem*" produced the least amount of biomass whiles the highest total biomass was observed in "*Legon Aburo*" and '*PAN 53*' (Figure 4). Grain yield was also significantly highest in '*Legon Aburo*' in both seasons (Figure 5). This was followed by '*Opeaburo*', '*PAN 53*' and '*Obatanpa*' in the first season however they were not significantly different from each other. In the second season, it was followed by '*PAN 53*', '*Obatanpa*' and '*Opeaburo*' and as in the first season they were not significantly different from each other. As in total biomass, the lowest grain yield was observed in '*Abontem*'.

Ear weight with the husk intact, showed significant differences among the maize varieties in both years (Figure 6). It followed similar trend as the grain yield and in order from highest to lowest is as follows '*Aburo Legon*', '*PAN 53*,' '*Obantapa*,' '*Opeaburo*' and '*Abontem*'). The 100 seed weight was highest in '*Obatanpa*', '*Legon Aburo*' and '*PAN 53*' however there was no significant difference among these varieties' whiles '*Opeaburo*' and '*Abontem*' had lowest 100 seed weight (Figure 7).

Cob weight was generally higher in 2019 than in 2020 (Figure 8). In the first season, the highest cob weight was observed in '*Legon Aburo*', and it was 82% higher than the '*Abontem*' which obtained the lowest cob weight Similarly, in the second season, '*Legon Aburo*' obtained the highest cob weight and was 90% higher than '*Abontem*' which

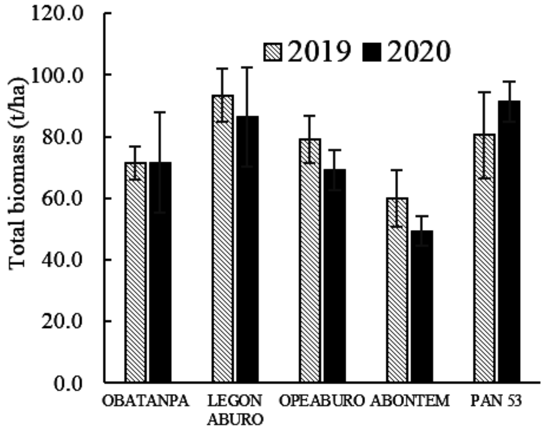

Figure 4 The total biomass production (t/ha) of five maize varieties tested on vertisols during two consecutive major rainy seasons

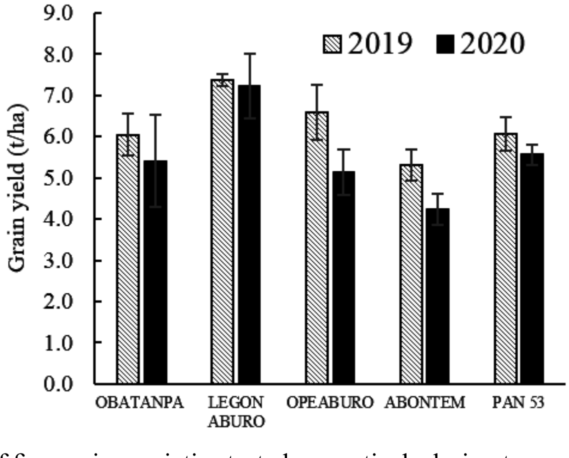

Figure 5 Grain yield (t/ha) of five maize varieties tested on vertisols during two consecutive major rainy seasons

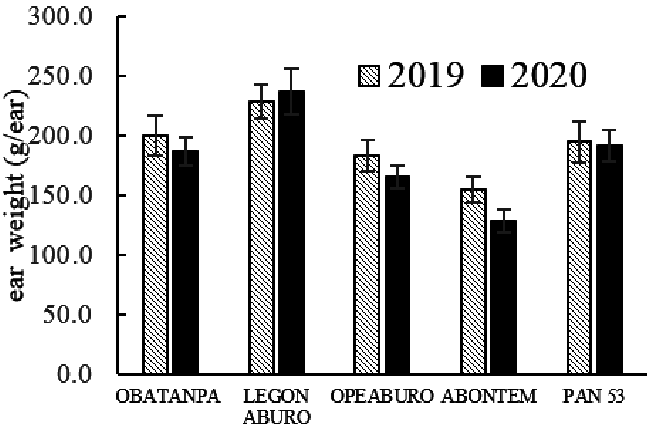

Figure 6 Ear weight (g) of five maize varieties tested on vertisols during two consecutive major rainy seasons

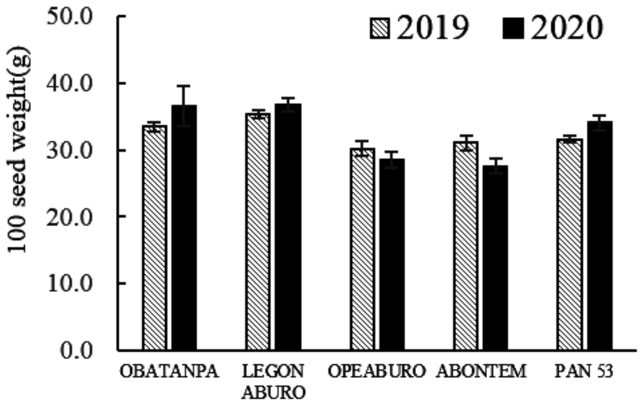

Figure 7 The 100 seed weight (g) of five maize varieties tested on vertisols during two consecutive major rainy seasons

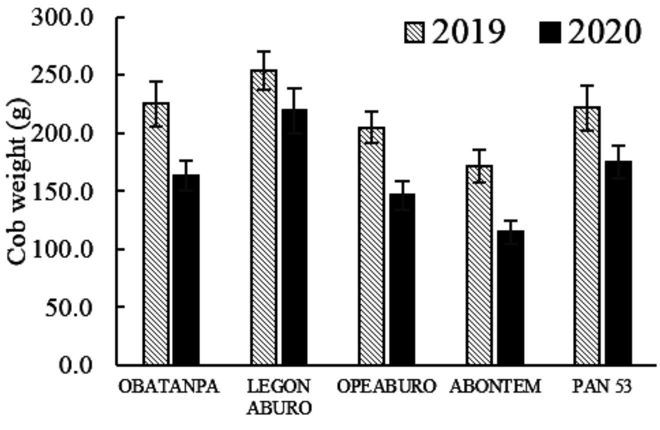

Figure 8 Cob weight (g) of five maize varieties tested on vertisols during two consecutive major rainy seasons

obtained the lowest cob weight.

The husk weight measured was generally two times higher during the second season compared to the first season (Figure 9). The maize varieties showed no significant differences ($P<0.05$) in husk weight in 2019 however significances among the maize varieties were observed in 2020.

Husk weight ranged from 17.0g in '*Abontem*' to 27.0 g in '*Legon Aburo*' during the first season and from 37.0g in '*Abontem*' to 62.3g in '*Legon Aburo*' during the second season of

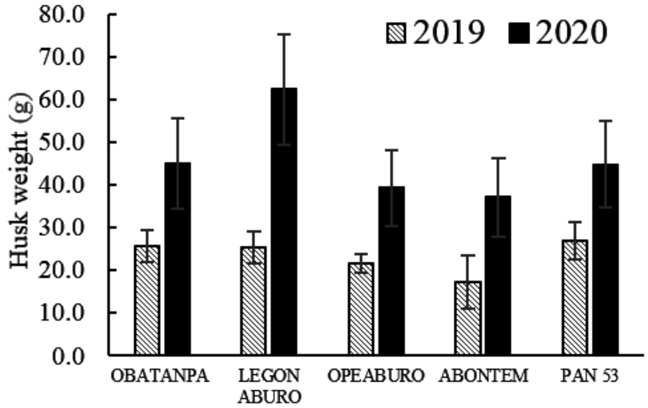

Figure 9 Husk weight of five maize varieties tested on vertisols during two consecutive major rainy seasons

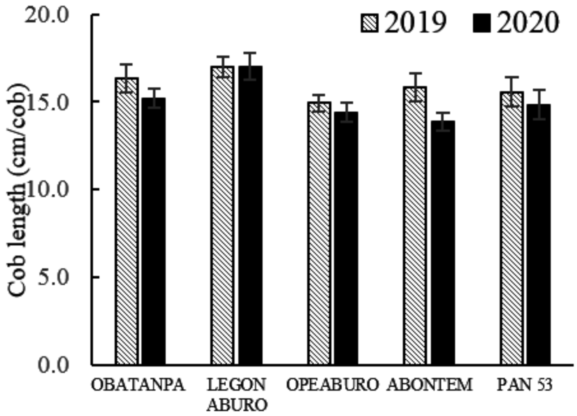

Figure 10 Cop length of five maize varieties tested on vertisols during two consecutive major rainy seasons

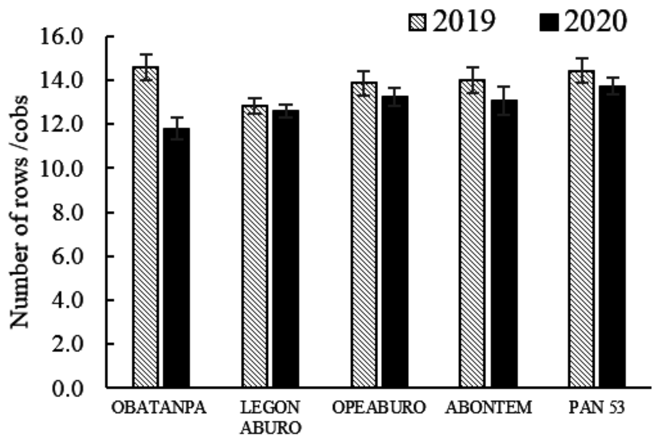

Figure 11 Number of rows per cob of five maize varieties tested on vertisols during two consecutive major rainy seasons

production.

Cob length (Figure 10) and number of rows per cob (Figure 11) showed no significant differences among the maize varieties in both seasons. Cob length was highest in '*Legon Aburo*' for both consecutive growing seasons. Number of seeds per row and number of seeds per cob were also not significantly different ($p < 0.05$) among the maize varieties (Table 3). '*Legon Aburo*' which had the highest cob length showed highest number of seeds per row (Figure 12) in both years (35 in 2019 and 38 in 2020).

Total number of seeds per cob was significantly different among the maize varieties in 2020 but not in 2019 (Figure 13). The unusual decrease in '*Obatanpa*' and '*Abontem*' in 2020 may have resulted in the significant differences observed. In 2019 it ranged from 435 in '*Abontem*' to 460 in '*PAN 53*' and in 2020 ranged from 363 in '*Obatanpa*' to 477 in '*Legon Aburo*'.

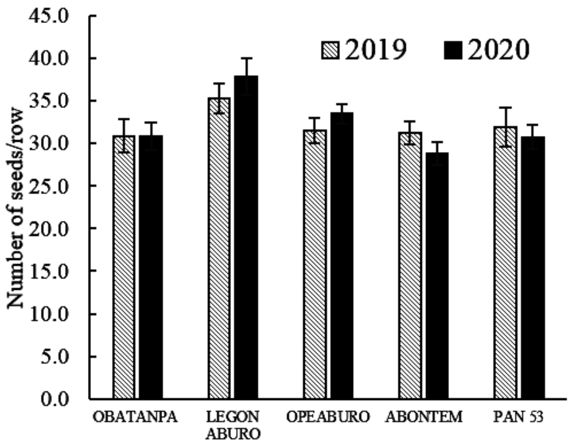

Figure 12 Number of seeds per rows of five maize varieties tested on vertisols during two consecutive major rainy seasons

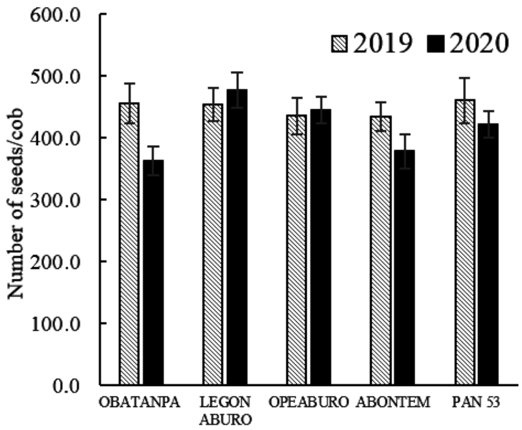

Figure 13 Number of seeds per cob of five maize varieties tested on vertisols during two consecutive major rainy seasons

Discussion

Maize hybrids offer a great opportunity for small holder farmers to significantly increase yields. Maize hybrid industry in Ghana, although still underdeveloped, continues to make significant yield improvements on released varieties of maize hybrids. However, even with their high yielding capabilities, the varying performance of hybrids means testing still must be in specific agroecological areas before they are recommended to farmers.

In this study, a recently released hybrid '*Legon Aburo*' (released by WACCI) was tested alongside two commonly used hybrids (local hybrid '*Opeaburo*') and (imported hybrid '*Pan 53*') and two OPVs ('*Obatanpa*' and '*Abontem*'), in the coastal savannah agro-ecological zone with distinctive vertic black heavy clayey soils.

The hybrid '*Legon Aburo*' outperformed the other varieties used in the study. The significantly high yields of this variety confirm studies that hybrids can increase yields significantly compared with OPVs (Sallah et al., 2004; Ragasa et al., 2014).

The potential yields of the '*Legon Aburo*' as well as the other hybrid varieties, (indicated in parenthesis) were not realized; '*Legon Aburo*' (10t/ha) 'Opeaburo' (7.5t/ha) and 'Pan 53' (7-10t/ha). This is also the case on farmers' fields where yields of hybrids sometimes do not reach 50% of the potential yields indicated under research trials even when inputs such as fertilizers are supplied (Ragasa et al., 2014; Van Asselt et al., 2018b).

The yields of the two OPVs exceeded their potential, with yields of 'Obatanpa' comparable with that of '*PAN 53*'. This is in contrast to previous reports where '*PAN 53*' showed significant yield advantage over OPVs (Tripp et al., 2015; Van Asselt et al., 2018a). The yield of '*Obatanpa*' was also comparable to the local hybrid '*Opeaburo*' which agrees with reports by Tripp et al. (2015) that local hybrids had no yield advantage over OPVs. They further indicated that the order of maize performance in the country was foreign hybrid, local OPVs and then local hybrids.

As in this study the potential yield of '*Obatanpa*' (4.6t/ha) was also exceeded by Sallah et al. (1997) obtaining more than 5.5 t/ha. The OPV '*Obatanpa*' which is identified as being suitable for all the different agroecological areas in Ghana, has been grown on vertisols by previous workers (Yangyuoru et al. (2001), Yangyuoru et al. (2003), Nyalemebge et al. (2011) and MacCarthy et al. (2015) and yields have ranged from 1.3t/ha -4.3 t/ha which are lower than obtained in the present report.

Yields of '*Legon Aburo*' on vertisols notably in Ghana have yet to be reported perhaps due to its newness however recent reports revealed yields of 7.6 t/ha on Coastal Savannah (Azinu, 2014) which was comparable to the yields obtained in this report. For the same variety the reporter also observed yields of more than 10t/ha in the Transitional Forest and 5.5t/ha in the Guinea Savannah.

The biomass production of the maize varieties used were lower than have been previously reported (Sallah et al., 1997; Azinu, 2014; Bawa, 2021) . Interestingly, '*Obantanpa*' biomass was similar to other reports of when grown on vertisols (Yangyuoru et al. 2003, Nyalemebge et al., 2011 and MacCarthy et al., 2015). The yield trait such as 100 seed weight was higher in this report than was reported by Asare-Bediako et al. (2020) for '*Abontem*', '*Obatanpa*' and PAN 53 but was lower than reported by Bawa (2020) for '*Obatanpa*'.

Conclusion

The yields of the OPV '*Obatanpa*' were comparable to the local hybrid '*Opeaburo*' and foreign hybrid '*PAN 53*'. The study found that yield of '*Legon Aburo*' hybrid was the highest among the five maize varieties when grown for two consecutive years on vertisols at Kpong. It is therefore recommended for production on vertisols to increase maize productivity of farmers' fields. The use of hybrids should be extensively promoted to smallholder farmers to increase their yields.

Acknowledgements

The authors thank Dr. Ifie from WACCI and Dr. Ewool from CSIR-Crops Research Institute, Kumasi-Ghana for the seeds of maize varieties used for study.

References

Abunyewa A. E., K. Aseidu and Y Ahenkorah (2004). Fertilizer phosphorus fractions and their availability to maize on different landforms on a vertisol in the coastal savanna zone of Ghana. *West African Journal of Applied Ecology*. **5**, 63 -73

Akpo E, Ojiewo CO, Kapran I, Omoigui LO, Diama A, Varshney RK. (2021) Enhancing smallholder farmers' access to seed of improved legume varieties through multi-stakeholder platforms: learning from the TLIII project experiences in sub-Saharan Africa and South Asia. Springer, Singapore (p. 205). Singapore: Springer Nature.

Amatekpor, J.K. and G.N.N Dowuona (1995). Site characterization. IBSRAM Vertisol Project. Department of Soil Science, University of Ghana, Legon. 42pp.

Andam K. S., M. E. Johnson, C. Ragasa D.S Kufoalor, S. D Gupta (2017). A chicken and maize situation: The poultry feed sector in Ghana. IFPRI Discussion paper 1601. Washington, D.C.: *International Food Policy Research Institute (IFPRI)*

Antwi, B. O., and R.D Asiamah (1996) Morphological and Hydraulic Properties of the Soils of Kpong Irrigation Project, SRI Technical Report No. 186, SRI, Ghana.

Asare-Bediako, E., Taah, K. J., Puije, G. C. van der, Amenorpe, G., Kubi, A. A.,

Lamptey, J. N., Oppong, A., Mochiah, B., & Adama, I. (2021). Phenotypic and molecular evaluation of maize (*Zea may* L.) genotypes under field conditions in the Volta region of Ghana. *African Journal of Food, Agriculture, Nutrition and Development*, **20(7)**.https://doi.org/10.18697/ajfand.95.19040

Azinu, A. R. (2014). Evaluation of Hybrid Maize Varieties in Three Agro-Ecological Zones in Ghana. [MPhil Thesis, University of Ghana]. http://ugspace.ug.edu.gh:8080/handle/123456789/7148

Bawa, A. (2021). Yield and Growth Response of Maize (*Zea mays* L.) to Varietal and Nitrogen Application in the Guinea Savanna Agro-Ecology of Ghana. *Advances in Agriculture*, 2021, e1765251. https://doi.org/10.1155/2021/1765251

Brammer, H. (1967). Soils of the Accra Plains. Soil Research Institute. Memoir No.3. Pub. Academy of Science, Kumasi, Ghana. 146pp.

CSIR. (2019). Catalogue of crop varieties released and registered in Ghana. Accra. Ghana: Council for Scientific and Industrial Research.

FAOSTAT (2022) Retrieved from http://www.fao.org/faostat/en/#data/QC. Accessed on July 1, 2022.

Kandel, B. P., and Shrestha, K. (2020). Performance evaluation of maize hybrids in inner-plains of Nepal. *Heliyon*, **6(12)**, e05542.https://doi.org/10.1016/j.heliyon.2020.e05542

Kumar J.S. (1982) Problems and potentials of vertisols and alfisols; the two important soils of SAT - ICRISAT experience. Tropical Agriculture Research Series, No.15. Ibaraki. Japan

Li, G., Zhang, J., Yang, C., Song, Y., Zheng, C., Liu, Z., Wang, S., Tang, S., and Ding, Y. (2014). Yield and Yield Components of Hybrid Rice as Influenced by Nitrogen Fertilization at Different Eco-Sites. *Journal of Plant Nutrition*, **37(2)**, 244–258. https://doi.org/10.1080/01904167.2013.859695

van Loon, M. P., S. Adjei-Nsiah, K. Descheemaeker, C. Akotsen-Mensah., M. van Dijk, T. Morley, M. Kvan Ittersum, M. K., and P. Reidsma. (2019). Can yield variability be explained? Integrated assessment of maize yield gaps across smallholders in Ghana. *Field Crops Research*, **236**, 132–144 https://doi.org/10.1016/j.fcr.2019.03.022

Macauley, H. and T. Ramadjita (2015). Cereal Crops: Rice, Maize, Millet, Sorghum, Wheat Cereal. University of Cape Coast

MacCarthy, D. S., Akponikpe, P. B. I., Narh, S., and Tegbe, R. (2015). Modeling the effect of seasonal climate variability on the efficiency of mineral fertilization on maize in the coastal savannah of Ghana. *Nutrient Cycling in Agroecosystems*, **102(1)**, 45–64. Scopus. https://doi.org/10.1007/s10705-015-9701-x

MoFA (Ministry of Food and Agriculture). 2018. Agriculture in Ghana: Fact and Figures. Accra: Ministry of Food and Agriculture, Statistics, Research and Information Directorate.

Nyalemegbe K. K., E. O. Darkwa, M. Yangyuoru, F. D. Mawunya, D. K. Acquah, J. W. Oteng, P. J. Terry, and T. J. Willcocks (2010). The Effect of Camber Bed Drainage. Landfrms Landforms on Soil Nutrient Distribution and Grain Yield of Maize on the Vertisols of the Accra Plains of Ghana. *West African Journal of Applied Ecology*, **16(1)** 1-8. doi: 10.4314/wajae.v16i1.55863

Ragasa, C., A. Chapoto, and S Kolavalli. (2014). Maize Productivity in Ghana. GSSP Policy Note 5. Washington, D.C.: International Food Policy Research Institute (IFPRI). http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/128263

Sallah, P. Y. K., Twumasi-Afriyie, S., and Kasei, C. N. (1997). Optimum planting dates for four maturity groups of maize varieties grown in the Guinea savanna zone. *Ghana Journal of Agricultural Science*, **30(1)**, Article 1. https://doi.org/10.4314/gjas.v30i1.1979

Tripp R. and C. Ragasa (2015). Hybrid maize seed supply in Ghana. *GSSP Working Paper 40*. Washington, D.C.: International

Food Policy Research Institute (IFPRI) https://ebrary.ifpri.org/digital/collection/p15738coll2/id/129746

United Nations, Department of Economic and Social Affairs, Population Division 2022. World Population Prospects. Summary of Results. UN DESA /POP/2022 /TR/NO.3.

Van Asselt, J., F. DI Battista, S. Kolavalli and C.R. Udry. (2018). Agronomic performance of open pollinated and hybrid maize varieties: Results from on-farm trials in northern Ghana. *GSSP Working Paper 44*. Washington, D.C.: International Food Policy Research Institute (IFPRI). http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/132265

Van Asselt, J., F. DI Battista, S. Kolavalli, C. R. Udry, and N. Baker. (2018). Performance and adoption factors for open pollinated and hybrid maize varieties: Evidence from farmers' fields in northern Ghana. *GSSP Working Paper 45*. Washington, D.C.: International Food Policy Research Institute (IFPRI). http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/132286

Yangyuoru, M., E.O. Darkwa, J.W. Oteng, K. Nyalemegbe, P.J. Terry, T. J Willcocks, D. Acquah and F. Mawunya, (2001). Yield of maize and cowpea under variable seasonal rainfall, landform, tillage and weed management on the vertisols of Ghana. *West African Journal of Applied Ecology*, **2(1)**. https://doi.org/10.4314/wajae.v2i1.45568

Yangyuoru, M., T. Kawachi, K. Unami, S. Adiku, F. Mawunya, and S. Quashie. (2003). Comparison of rainfed and potential yields of maize and cowpea on the vertisols of Ghana. *Journal of Rainwater Catchment Systems*, **9**, 7–12. https://doi.org/10.7132/jrcsa.KJ00000795218