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Agronomic Performance of Open Pollinated and Hybrid Maize Varieties

Results from On-farm Trials in Northern Ghana

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ABSTRACT

Maize is an important staple crop in Ghana, but maize productivity is low. Other countries with similar agroecological conditions have increased maize productivity by increasing the use of maize hybrids. This paper presents the results of maize trials in northern Ghana, in which hybrids were tested to see if they performed significantly better than the varieties planted by farmers. This paper details the procedures of the maize trials and presents descriptive statistics of the trial results. The trials demonstrated that two foreign hybrids performed consistently better than Obaatanpa, the most widely used variety in the north. The foreign hybrids performed consistently well in all districts and appear to be well-suited for planting in northern Ghana.

Keywords: Ghana; maize; hybrid

1. INTRODUCTION

Maize is an important food crop in Ghana. Yields, however, have increased only slightly over the past few decades and remain low. To address this issue, Innovations for Poverty Action (IPA) and the International Food Policy Research Institute (IFPRI) conducted an experiment to identify effective strategies to scale up the adoption of improved technologies for maize. Improved maize varieties were selected as the most effective way to increase yields. Other countries have managed to significantly increase maize productivity under similar agroecological conditions by increased use of maize hybrids (Ragasa, Chapoto, and Kolavalli 2014). Further, increased use of modern inputs, such as fertilizers, have been found to increase yields marginally, but not profits (Karlan et al. 2014). Finally, although some hybrids are available in northern Ghana, less than five percent of the maize area is planted with hybrids (Ragasa and Chapoto 2013).

The first step in determining ways to increase adoption of new maize varieties was to determine whether improved varieties, including hybrids, performed significantly better than the varieties planted by farmers. Although several improved varieties, both local and international, are marketed in Ghana, reliable information on their performance under different agroecological conditions is not available. Therefore, IFPRI and IPA collaborated with the Savanah Agricultural Research Institute (SARI) of the Council for Scientific and Industrial Research (CSIR) to conduct maize yield trials in 2015.

The trials were designed with the immediate aim of improving information about the performance of new seed varieties in varied agroecological contexts in northern Ghana, and with the longer-term goal of studying how farmers learn about and test new technologies. The project employed closely monitored trials on farmers' fields to compare the performance of two foreign hybrids, one domestic hybrid, and two local open pollinated varieties (OPVs) in northern Ghana. Demonstration plots were set up in ten districts across the Northern, Upper West, and Upper East regions. This note is a descriptive paper that details the agronomic performance of the five maize varieties. A second note (van Asselt 2018) looks at adoption factors and performance on farmers' fields.

2. MATERIALS AND METHODS

In this section, we detail the methodology. First, we present the different varieties of maize tested in the study. Second, we explain how the trial locations were chosen. This is followed by an analysis of climate and soil conditions at the trial sites. Finally, we present the experimental design of the project.

2.1. Maize genotypes

Five varieties were chosen for performance testing in northern Ghana: two local OPVs, Obaatanpa, which is the most widely used maize variety in Ghana, and Sanzal-sima, which was recently developed and introduced by CSIR-SARI; one local hybrid, Mamaba; and two foreign hybrids, Sika-Aburo and Adikanfo.

(i) **Obaatanpa**, an OPV, is a quality protein maize variety. It was released in Ghana as early as 1992 and has been recycled for generations. It matures within 110 days and yields between 4 and 5 metric tons (mt) per hectare. The grain is flinty in texture, white in color, and with a normal grain type. It is the most commonly used maize variety in Ghana.

(ii) **Sanzal-sima** is an OPV released by CSIR–SARI in 2012. Sanzal-sima is drought tolerant and is tolerant of the parasitic weed on maize, *Striga*. A medium-maturing variety, it takes about 110 days to mature. The grain is flinty in texture, white, and with a normal grain type.

(iii) **Mamaba** is a three-way hybrid with white grain color. It also has a flint grain texture and is medium maturing. It was locally developed and jointly released in Ghana by CSIR–Crops Research Institute (CRI) and CSIR-SARI. It was the only local hybrid among the genotypes tested.

(iv) **Sika-Aburo** is a maize hybrid developed by PANNAR and jointly released in Ghana by CSIR-SARI, CSIR-CRI, and Wienco. It is a medium maturing, white hybrid.

(v) **Adikanfo** is a hybrid developed by Pioneer Seed Co Ltd in South Africa. It was introduced into Ghana by CSIR-CRI and Wienco. It is a yellow, medium-maturing hybrid.

For the field trials, Adikanfo seed was obtained from Dizengoff in Accra. Sika-Aburo was purchased from Wienco in Tamale. Sanzal-sima and Mamaba were sourced from SARI in Tamale. Finally, Obaatanpa was obtained from Ganorma, a local retailer in Tamale. The Adikanfo and Sika-Aburo seed supplied had been treated with insecticides and fungicides that offer protection from soil borne diseases, fungi, soil insect infestations, and other pests.

2.2. The study areas

Northern Ghana was selected as the area of study for the project. Ten sites in ten different districts were selected to capture the agro-ecological diversity in the three regions of northern Ghana: four in Northern Region (Tolon, West Gonja, West Mamprusi, and Yendi), three in the Upper West (Nadowli Kaleo, Sissala East, and Wa), and three in the Upper East (Bawku, Bolgatanga, and Kassena Nankana). The reason behind the choice of these districts is twofold: on the one hand they ensure heterogeneity in underlying environment, soil, and climate conditions; on the other, the choice was driven by the need to ensure easy and consistent SARI staff supervision of the experiment plots, which led to the selection of communities where main SARI stations and scientists are located.

2.3. Assessment of the observed sites for maize production

All of the test sites are in Ghana's Northern Savanna agro-ecological system. This is a semi-arid area, characterized by low, erratic, unimodal rainfall. Most of the rain in the region comes as short duration, high intensity storms between May and October, with the peak of the rains in August and September. The region averages around 1100 millimeters of rain per year, with mean annual temperatures ranging from 27 to 36°C. From November to April, the region experiences a dry season. During this time, the area is under the influence of the dry north-eastern trade winds (Harmattan).

Water: Maize production requires around 400 to 600 millimeters of well-timed rainfall. The moisture requirement of maize increases up to the flowering period and then decreases again as the crop matures. Maize is especially sensitive to moisture stress when it flowers – water stress at that time can reduce yields by 30 to 50 percent. Further, maize does not perform well in drought conditions as its rate of growth decreases and yields decline considerably. The Northern Savanna Zone has on average adequate rainfall for production. At the same time, however, year to year variations in rainfall and the unpredictability of the rainfall distribution of rain means that access to water is still a challenge for maize farmers.

Temperature: The optimum temperature for maize growth and development is 18 to 32°C, while the optimum temperature for tasseling is 21 to 30°C. Temperatures above 35°C reduce grain yield. In Northern and Upper West regions, temperatures often exceed this threshold in March and April, which hinders crop establishment. Temperatures were not recorded for our test sites.

Soil Composition: Composite soil samples from 0 to 15 centimeters and 15 to 30 centimeters depths were randomly collected from each experimental field and analyzed. Soils were analyzed at the soil testing lab of the CSIR-Savanna Research Institute at Nyankpala. Standard laboratory procedures were followed in soil samples preparation. Soil samples were mixed, homogenized, air dried in the shade, ground, and passed through a 2-millimeters sieve. They then were analyzed for total N, available P, pH, organic carbon, and exchangeable cations (K+, Ca2+, Mg2+). Soil test values were determined by standard soil testing procedures. The soil characteristics together with precipitation amounts and temperature were used to characterize the project sites. Unfortunately, these soil samples were collected after the maize trials and, therefore, could not inform fertilizer dosage or variety use. The ideal soil type for maize cultivation is loamy soil, which is composed of a range of 50 to 70 percent sand, 10 to 30 percent clay, and 0 to 40 percent silt.

The analysis of the soil at the ten sites showed that the quality of the soils was adequate for maize production, but not ideal (Annex Table 1). In all the sites in the Upper East and Upper West regions, the soils were more than 70 percent sand. Further, in all the sites, the percentage of clay found in the soils was far below 10 percent, the lower limit for loamy soil. Therefore, instead of loamy, the soils were mainly laterite, sandy and sandy loam (Savanna Ochrosols) types. The soils were shallow, sandy in texture, with low moisture retention capacity, making most of the soils prone to erosion. As maize is not drought tolerant, high yields are unlikely on these soils unless there is supplementary irrigation or favorable rainfall distribution during the growing season.

Soil pH: The optimum pH for maize production is between 6.0 and 7.0. Soils with a pH of less than 5.0, which is typical in sandy soils, are less suitable for maize production, as acidic soils can have issues with aluminum and manganese toxicity, which limits the uptake of nutrients. Among the trial sites, only Wa and Nadowli in the Upper West Region and Kassena Nankana in the Upper East region recorded pHs in the recommended range, i.e., greater than 6.0 (Annex Table 1). The rest of the sites recorded pH values of 6.0, with Bolgatanga recording a pH of 4.7, far below the appropriate range.

Nutrients: Plant nutrition is extremely important when growing maize. Within the 30 to 40-day period prior to pollination, the maize plant absorbs from the soil 75 percent of its essential nutrients. If the nutrient content of the soil is poor at that time, yields will be low. On average, the levels of organic matter, total nitrogen, and available phosphorus in the trials sites were found to be low.

The results of the soil analysis at the ten sites show that none of the sites had a total nitrogen (N) content within the range of 0.13 to 0.23 percent, which is considered adequate for maize production (Annex Table 2). Further, none of the sites had phosphorus (P) within the recommended range of 20 to 40 mg/kg (Annex Table 2). Soils in the study areas were less deficient in Potassium (K) than they were in N and P (Annex Table 2). However, the results show that, apart from soils at West Gonja and Bolgatanga, which had K within the acceptable range of 61 to 120 mg/kg, no other site met the requirement of K for maize production.

Since the soil composition tests were conducted after the trials, nutrients were applied to all the sites in the same amount and ratios. All the P, K, and some of the N were applied in the form of NPK (15-15-15) at seven to ten days after planting and the remaining N was applied four weeks after planting in the form of Sulphate of Ammonia. The soil tests showed that NPK (23-10-5) should actually be applied at the rate of 250 kg per hectare followed by Sulphate of Ammonia at the rate of 125 kg per hectare to address the low level of nutrients in the soil.

2.4. Treatments and experimental design

The on-farm demonstrations were conducted using the “Mother and Baby” methodology in each of the ten sites. Field staff of SARI and Agricultural Extension Agents (AEAs) with relevant experience who were recommended by District Directors of Agriculture managed the trials under the supervision of three SARI scientists.

The mother and baby trial approach is an on-farm participatory mechanism to introduce and test on-farm a range of technology options (Snapp 2002). This on-farm research method consists of a central researcher-managed "mother trial", in which all varieties were tested, coupled with farmer-managed satellites or "baby trials" with a subset of varieties from the mother trial (De Groote et al. 2002). At each site, one mother and four baby trials were conducted. All trials were on farmers' fields and were closely monitored to ensure that the farmers implemented the recommended maize production practices. Baby trials merely served as replications.

2.4.1. Mother trials

A mother trial was done in each of the ten project districts. The experimental design was a randomized complete block (RCBD) with four replications per site. Each plot consisted of six rows, 5.0 meters long, spaced 0.80 meters apart. Spacing between plants within a row was 40 centimeters. Three seeds were planted per stand and thinned to two per stand at one week after planting, to give a target population of 62,500 plants per hectare, although the final plant population was lower than the optimum at most sites. Weeds were controlled using hand hoe cultivation at two and four weeks after planting. Fertilizer was applied at a rate of 64-38-38 kg per hectare as N, P_2O_5 and K_2O, respectively. All the P and K as well as 38 kg N per hectare were applied in the form of NPK (15-15-15) at two weeks after planting and the remaining 26 kg N per hectare was applied at four weeks after planting in the form of Sulphate of Ammonia.

2.4.2. Baby trials

Four baby trials were planted in each of the ten project districts. Each baby trial consisted of two improved varieties planted alongside a farmer's local variety. The local variety was the best available variety at each evaluated site, but differed for locations and farmers. Each plot measured 10.0 by 10.0 meters. The baby trials were managed by farmers and supervised by field officers.

Data on plant height at flowering and days to mid-tassel and mid-silk emergence (flowering date) were collected. Plant height was recorded on five randomly selected plants at maturity by measuring the height from the base of the plant to where tassel branching began. Grain yield was determined by harvesting the center two rows of each plot after physiological maturity in the mother trial and an area of 10 by 10 meters in the baby trials. Grain yield was calculated based on an 80 percent shelling percentage. Biomass (above ground dry matter) yield (kg per hectare) was also determined by harvesting the whole plot.

2.4.3. Improved agricultural practices

A detailed protocol for the on-farm trials were developed and distributed to participants. These included instructions on when and how to apply fertilizer. The key production protocols were:

- Sites for farmer trials should not be hilly or have a gradient of more than 5 percent. Land should be appropriately prepared by leveling. Slopes facilitate erosion.
- Planting should be done in rows at recommended spacing. Planting holes should not be deeper than 5.0 centimeters.
- Agronomic or cultural practices such as weeding, fertilizer application, and top-dressing should be done before tassel and silk-emergence, that is, before flowering. All fertilizers should be applied under the soil about 5.0 centimeters away from the maize rows.
- Any infestation of pests, insects, or diseases should be reported immediately so that prompt action can be taken to contain them.

- Crops should be harvested at physiological maturity and the cobs dried properly before shelling. Maize grain should then be dried to about 13percent or less moisture content for storage.

3. RESULTS

In this section, we summarize the results of the maize trials in the ten districts of northern Ghana. First, we present results regarding yield and other agronomic parameters of the different varieties across the different sites. We then look beyond yields and consider whether these varieties would be profitable for farmers given the associated costs of seeds and other inputs. We then examine the factors that explain some of the difference in yields across trials, namely soil characteristics, climatic factors, and farmer management practices.

3.1. Yields of tested varieties

Mean maize yields for the full sample of trials are presented in Table 3.1. Both foreign hybrids outperformed their local counterpart as well as the local OPVs. Adikanfo was the best performing variety in the trials. Adikanfo averaged a yield of 5.0 mt per hectare. Its mean yields were 27 percent higher than the next-highest performing variety, Sika-Aburo, and 57 percent higher than the commonly used (and third-highest yielding on average) variety, Obaatanpa. Sika-Aburo had the second highest yields, 3.9 mt per hectare. Obaatanpa only outperformed the other two Ghanaian varieties.

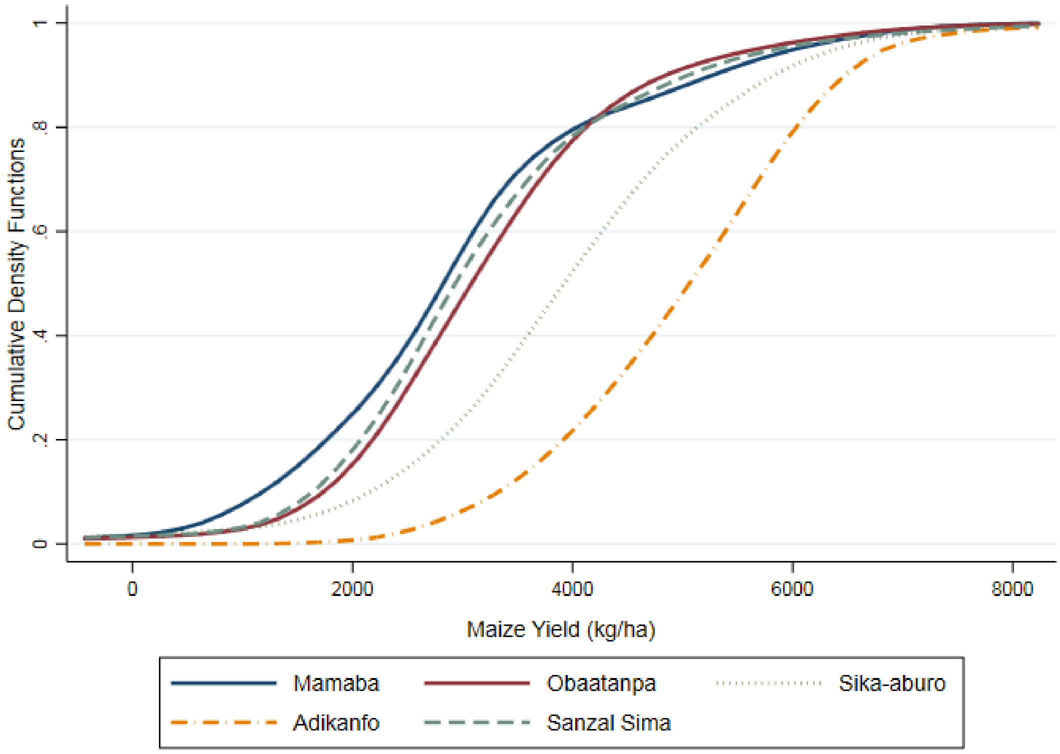
Table 3.1. Maize yields from 2015 trials

	N	Mean yield (mt/ha)	Standard deviation
Adikanfo	57	4.95	1.16
Sika-Aburo	61	3.92	1.43
Obaatanpa	78	3.19	1.27
Sanzal-sima	60	3.13	1.35
Mamaba	58	2.10	1.49

Source: Authors' calculation from 2015 trial results

Adikanfo consistently produced high yields across the sample. As shown in Figure 3.1, Adikanfo exhibited first-order stochastic dominance over all other varieties. At every point in its distribution of yields, it yielded higher than all the other varieties at the equivalent percentile. Its yield performance at the 2nd percentile was roughly equivalent to the yield performance of Obaatanpa, Mamaba, and Sanzal-sima, the three Ghanaian varieties tested, at the 40th percentiles. This suggests that the single worst performing plot of Adikanfo outperformed the yields of 40 percent of the plots planted with the three Ghanaian varieties.

Figure 3.1. Maize yields cumulative distribution



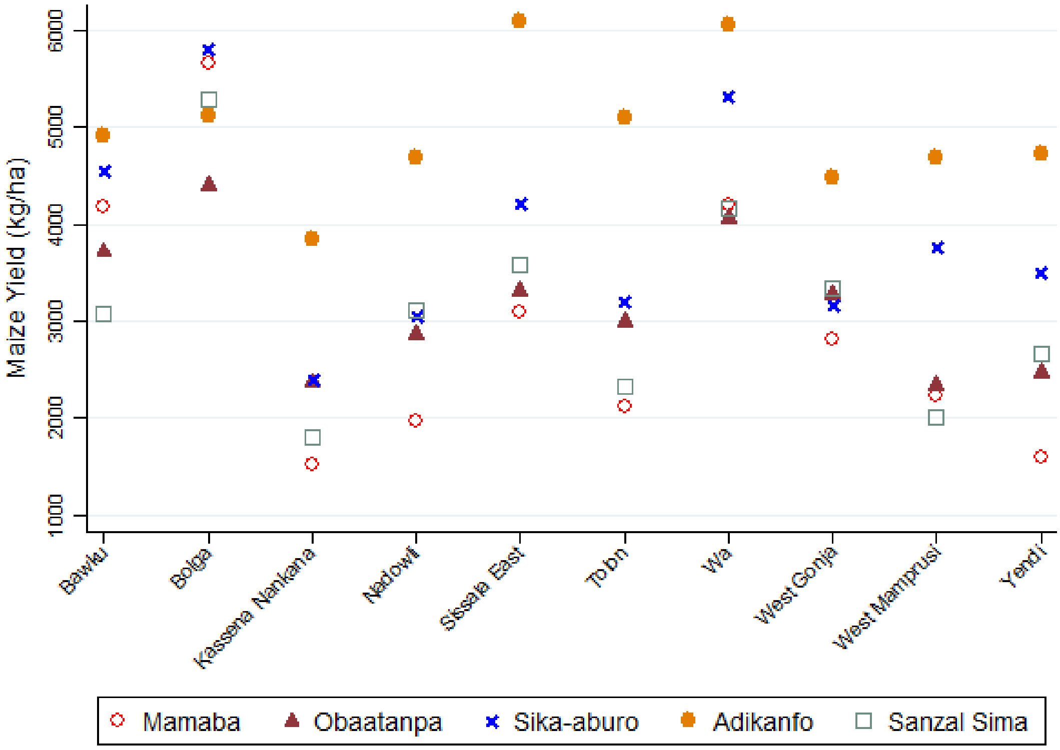
Source: Authors' calculation from 2015 trial results

Although yields of Sika-Aburo, the second non-Ghanaian variety, are consistently lower than those of Adikanfo, it still performed consistently better than the other three varieties tested. It averaged yields 23 percent higher than Obaatanpa. When Adikanfo is not considered, it also demonstrated first-order stochastic dominance over the other varieties tested, though its performance on the left side of the distribution was largely indistinguishable from that of the other three varieties. Similarly, its yields at the right side of the distribution were similar to Obaatanpa, Mamaba, and Sanzal-sima yields. This suggests that when maize performs especially poorly or especially well, Sika-Aburo is unlikely to outperform other varieties, but at all other points in the distribution, its yields may be notably higher. Like Adikanfo, Sika-Aburo did well across a variety of climates – in eight of the ten districts, it was either the best or second best performing variety.

Neither Mamaba nor Sanzal-sima had mean yields higher than Obaatanpa. The Agricultural Extension Agents reported Mamaba having a very low germination rate, requiring more replanting than the other varieties and in many cases having low germination despite replanting. This can be seen in Figure 3.1, which shows that Mamaba has the worst outcomes at the left side of the distribution. However, to the right of the distribution, Mamaba is comparable to, or even slightly better than, Sanzal-sima and Obaatanpa.

We also examine variance in varietal performance across districts. The results show that Adikanfo was the highest performing variety across all the locations except for Bolgatanga in the Upper East region, where it averaged 88 percent of the yields of the best performing variety, Sika-Aburo (Figure 3.2). Next to this variety in consistency of performance across districts was Sika-Aburo, which followed the same trend. Mamaba performed poorly at most locations, except in Bolgatanga where its yield was the second highest of all the varieties.

Figure 3.2. Maize yields across districts



Source: Authors' calculation from 2015 trial results

As shown in Table 3.2, neither Adikanfo nor Obaatanpa had a high degree of between-district variance. This shows that both varieties are appropriate technologies for a wide range of districts in northern Ghana. Nonetheless, their within-district variation is the highest among the varieties tested. However, this low inter-class correlation of Adikanfo and Obaatanpa is largely driven by high inconsistencies in yields in Bolgatanga district (Figure 3.3).

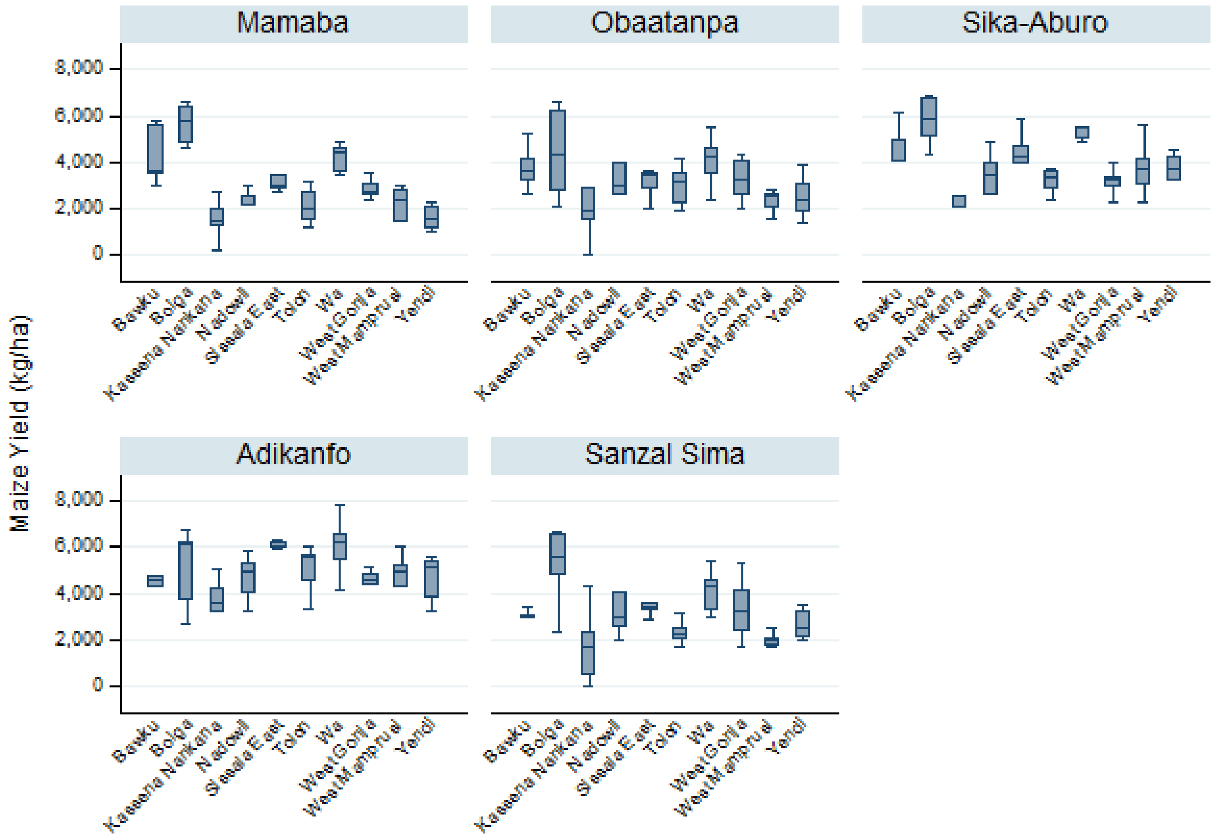
Table 3.2. Maize yield variance decomposition and inter class correlation

	Between districts standard deviation	Within districts standard deviation	Inter-class correlation
Mamaba	1,318.8	793.4	0.734
Obaatanpa	589.8	1,136.4	0.212
Sika-Aburo	1,005.8	1054.0	0.477
Adikanfo	523.7	1,045.8	0.201
Sanzal-sima	970.9	974.2	0.498

Source: Authors' calculation from 2015 trial results

Mamaba is an interesting case, because, while its between-district variance is the largest, the distribution of its outcomes within districts is relatively narrow (Bawku is an exception, see Figure 3.3). This suggests that Mamaba is only suited for certain districts within the North. In Bolgatanga, Mamaba is the second highest performing variety in terms of yield (97percent of the highest performing variety, Sika-Aburo) and the within-district variability is not large, indicating that the use of this variety might be well suited for this district. The same conclusions cannot be drawn about a variety like Sanzal-sima, which has both substantial between- and within-district variance, meaning that with our current data, it is difficult to discern whether Sanzal-sima is more appropriate in some contexts than others.

Figure 3.3. Variability of maize yield, by district and variety



Source: Authors' calculation from 2015 trial results

3.2. The influence of varieties on other agronomic parameters

Differences in yields resulted from differences in their plant height, number of days to 50 percent tasseling and silking, number of plants and cobs, grain and biomass yields, and harvest index, which is the ratio of grain to total biomass. Table 3.3 presents these characteristics for the five varieties.

Table 3.3. Influence of maize genotypes on plant height, days to mid-tassel and mid-silk emergence, plant stand, cob number, grain yield, biomass, and harvest index

	Plant height, cm	Days to 50% tasseling	Days to 50% silking	Plant stand, no.	Cob number	Grain yield, kg/ha	Biomass yield, kg/ha	Harvest index
Adikanfo	188	53	57	55,104	51,396	5,034	5,126	0.50
Sika-Aburo	192	54	57	54,994	46,156	3,832	5,082	0.43
Sanzal-sima	171	54	58	47,755	41,417	3,196	3,693	0.46
Mamaba	164	54	57	43,980	36,948	2,896	3,331	0.45
Obaatanpa	190	54	58	44,975	39,427	3,103	3,762	0.46

Source: Authors' calculation from 2015 trial results
Note: Harvest index is the ratio of harvested grain to total shoot dry matter.

Plant height is important since tall plants, i.e., plants taller than 200 centimeters, are more susceptible to damage from storms. While Adikanfo, Sika-Aburo, and Obaatanpa were significantly taller than other varieties, none of them had average heights above 200 centimeters. Fewer days to tasseling and silking is an indicator of early maturation, which is a desirable plant trait for Ghanaian farmers. The shorter the life cycle of the plant, the less likely it will be affected by dry spells, which retards growth. All the varieties averaged 53 or 54 days to 50 percent tasseling and 57 or 58 days to 50 percent silking.

Despite reseeding, optimal plant stands of 62,500 plants per hectare were not achieved. The two OPVs, Obaatanpa and Sanzal-sima, had significantly lower plant stands than the two imported hybrids, Adikanfo and Sika-Aburo, but significantly higher plant stands than Mamaba. This reflects extension agents' concerns about Mamaba's germination, as mentioned above. Except for Adikanfo, the average plant stands were in most cases proportional to the average number of cobs. Adikanfo, however, had significantly more cobs per plant stand, which likely reflects a lower rate of barren plants for Adikanfo.

Harvest index is the ratio of harvested grain to total shoot dry matter. A high harvest index means that more of the biomass produced is usable, which may reflect a more efficient utilization of soil nutrients. Adikanfo had a significantly higher harvest index than any of the other varieties, at about 0.50. In contrast, Sika-Aburo had the lowest harvest index, because it produced roughly the same amount of non-grain biomass as Adikanfo but had a much lower yield. There was no significant difference in the harvest indices of Obaatanpa, Mamaba, and Sanzal-sima.

3.3. Profitability

When evaluated purely in terms of agronomic parameters, Adikanfo and Sika-Aburo are clearly the two best performing varieties. However, both foreign hybrids are substantially more expensive than Mamaba, Sanzal-sima, or Obaatanpa. Most farmers in northern Ghana recycle seeds, thereby spending nothing on them. Even those who purchase seeds generally spend a very small amount, as one kilogram of Obaatanpa costs roughly 3.5 GHc. In contrast, when IPA procured seeds for the project, one kilogram of Adikanfo cost 59 GHc, while one kilogram of Sika-Aburo sold for 18 GHc.

Purchasing seeds instead of recycling seeds requires a new way of thinking regarding maize farming and profitability. A farmer with one acre of land will need approximately eight kilograms of seed. This will cost the farmer 28 GHc for Obaatanpa, 144 GHc for Sika-Aburo, and 472 GHc for Adikanfo. A farmer will need to be convinced that the new variety will dramatically outperform their existing seeds for them to consider making such a substantial investment. The magnitude of the investment could also increase a farmers' exposure to risk – in the event their harvest completely fails, they could have a larger negative income for the harvest.

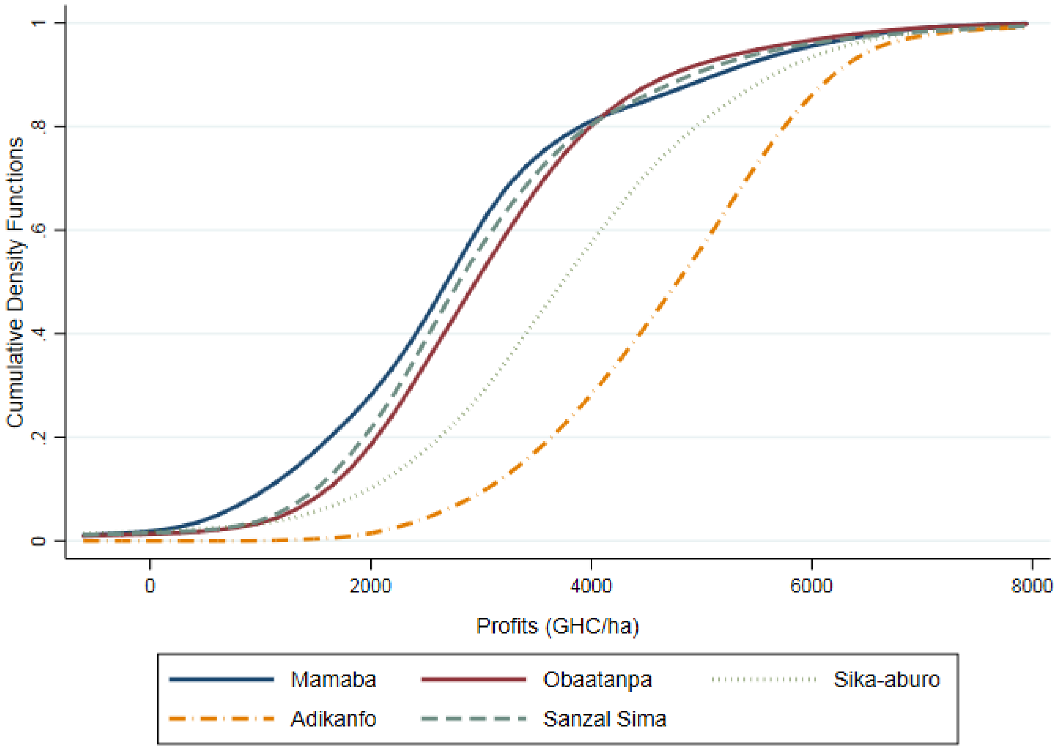
Table 3.4. Average profits by variety

	N	Mean profits, GHc/ha	Standard deviation
Mamaba	58	2,843.9	1,490.5
Obaatanpa	78	3,058.3	1,268.2
Sika-Aburo	61	3,744.7	1,427.0
Adikanfo	57	4,713.5	1,159.6
Sanzal-sima	60	2,998.7	1,346.1
Total	314	3,441.1	1,491.9

Source: Authors' calculation from 2015 trial results

To measure the extent to which these varieties are profitable, we approximate the expenses that a farmer would likely bear in planting each, and the value they could receive for their harvest. We assume that per acre a farmer would spend 50 GHc on plowing, 295 GHc on fertilizer (for two bags of NPK and one bag of Sulfate of Ammonia), and that a farmer would buy eight kilograms of seeds at the market rates. This estimate does not consider the different germination rates. We assume that one 100-kilogram bag of maize would sell for 100 GHc and then estimate profit per acre given these rates and the observed yields from our trial. Our means are presented in Table 3.4, while the distribution of profits is shown in a cumulative density function in Figure 3.4.

Figure 3.4. Profits distribution by variety



Source: Authors' calculation from 2015 trial results

Our data suggest that on average, Adikanfo and Sika-Aburo are more profitable than other varieties, despite their higher costs. Adikanfo has the highest mean profits, 16 percent higher than the profits of Sika-Aburo and 37 percent higher than Obaatanpa. The latter's mean profits are higher than both Mamaba and Sanzal-sima.

Again, an important feature of Adikanfo is that it stochastically dominates other varieties' profit distributions. On all 57 plots where Adikanfo was tested, its production results in a net positive profit. However, its profits are greater than those of all other varieties tested through the 80^{th} percentile, after which it is largely comparable to them. This suggests that on the best performing plots, the differences in profits between Adikanfo and other varieties were not especially large. Sika-Aburo's profit outcomes are in line with its yield outcomes; profits do not differ substantially from the local varieties at either end of the distribution, but at all other points its profits are higher.

However, these profits do not evaluate the opportunity cost of making the decision to purchase seeds and pay for other inputs. We do not have data on the yields of farmers who used recycled Obaatanpa seed, and do not apply any inputs, as all the plots in the trials received fertilizer.

Another important caveat of our profit analysis is that in no cases did farmers suffer extreme drought or high rainfall. For a risk-averse farmer, the knowledge that the seeds performed well in one harvest is likely insufficient information. If Adikanfo or Sika-Aburo performs poorly in years with a severe drought or high and untimely rainfall, the negative profits associated with such a substantial investment might not justify the improved profits in cropping seasons with good rains.

This sort of between-year variance limits our ability to generalize about the suitability and profitability of the varieties and complicates the decision-making process for farmers. Our data suggest that in a variety of contexts, Adikanfo and Sika-Aburo do perform well. However, a farmer might reasonably wait to see how the varieties perform in years of especially high or low rainfall before adopting.

3.4. Factors that might have affected maize yields in the study

None of the varieties tested in the study achieved their potential yield measured by CSIR in trials. Adikanfo yielded almost 5 mt per hectare, just under its 6.0 mt per hectare yield potential. Sika-Aburo on the other hand, only yielded 3.9 mt per hectare, 2.0 mt below its 6 mt yield potential. Obaatanpa and Sanzal-sima also had yields 2.0 mt below their yield potentials. Mamaba had yields 5.0 mt below its yield potential. Further, there were significant average yield differences between sites. Differences in climate, soil characteristics, and management practices can explain some of the yield differences across sites as well as the lower overall yields of the varieties in the study. Annex Table 3 shows the overall performance of maize in each of the trial sites. Maize yields were highest on average in West Gonja, Nadowli, and Wa, and lowest in Bolgatanga, Tolon, and West Mamprusi. This shows that there was variation not only within the North but also at regional level.

Each of the ten sites where the maize varieties were tested had a rainfall level above the minimum requirement for maize production. At the same time, variance in rainfall matters just as much for maize production. This was not measured. Further, while it is difficult to determine a causal relationship between maize yields and soil composition, moving forward, soil tests allowing informed use of inorganic fertilizer will address the low content of N, P, and K in the soils at the test sites, leading to more uniform yields. Finally, sites with lower pHs and more sand generally performed worse than sites with less basic soil and higher clay amounts.

Apart from the climate and soil factors described above, poor agricultural practices, such as inadequate land preparation, delayed weed removal, and late or inappropriate methods of fertilizer application, could also be responsible for the lower maize yields. Land preparation was poor at nearly all the sites because the fields were not harrowed, except for a few plots in which the field staff manually leveled the land before planting. Without harrowing, the land was rough, which caused ponding of waters on the soil, affecting plant growth and development.

Most of the weeds were removed during the land preparation phase, while those which were not were killed by both glyphosate (systemic herbicide) and Atrazine (selective herbicide for maize) before planting. Weeds should have then been removed twice more, before both rounds of fertilizer application. During the monitoring visits, it was found that these regulations were not followed, and some of the fields were weedy. This could have reduced maize grain yields because of competition with the weeds for nutrients and water.

Fertilization should have been done within 2 weeks after planting and top-dressing should have been carried out just before the maize tasseled. At most of the sites, the schedule of fertilization was not followed either due to negligence or lack of moisture for fertilizer application. Further, most farmers in northern Ghana apply fertilizer on the soil surface without burying it. If applied in this way, it can be washed away during rains. Even though this was discussed extensively during the training of the farm managers, fertilizer was still applied without burying. As these deviations from recommended practices may have affected potential yields, they could also impact our analysis of which varieties are appropriate for different agroecological zones.

4. CONCLUSION

The 2015 farmer-managed trials demonstrated that two foreign maize hybrids, Adikanfo and Sika-Aburo, performed consistently better than Obaatanpa, the most widely used variety in the north.

The two foreign hybrids are well-suited for production in northern Ghana. Neither of the other two varieties tested, Mamaba or Sanzal-sima, performed consistently better than the variety most commonly used by farmers, Obaatanpa.

Both Adikanfo and Sika-Aburo performed consistently well in all districts. Adikanfo performed well relative to other varieties throughout its distribution. Sika-Aburo also outperformed the other varieties tested, but only performed as well as Adikanfo in one district. At the same time, however, the foreign hybrids need to be tested under drought, high rainfall, and local agronomic conditions to further confirm this finding.

Maize yields for the varieties tested in the trials were lower than their potential yields obtained from CSIR study trials. This could be a result of both different climate and soil conditions and poor agricultural practices at the trial sites. Our soils tests showed that soils are poor in Ghana's northern savanna zone and, therefore, to obtain high yields of maize, fertilizer application is necessary. Furthermore, less fertilizer was applied in the trials than subsequent soil tests revealed to be optimal levels.

Further, despite training on land preparation, weeding, row planting, and fertilizer application, several of the farmers implementing the maize trials did not follow the recommended practices. For some farmers, fields were not harrowed, weeding was either not done or done too late, and fertilizer was applied at the surface. Even so, the practices used in the trials were better than the average practice on farmers' fields. This suggests that there is still considerable room to increase maize yields through improving agricultural practices.

The trials have demonstrated that adoption of the two foreign hybrid varieties, Adikanfo and Sika-Aburo, will likely improve farmers' maize productivity and raise their profits. However, additional trials are needed to validate these claims, and particularly to deal with concerns about variable rainfall levels and differences in farmer practices across sites. Of course, even if the scientific evidence points to consistently increased yields and profits for farmers using the two foreign varieties, it is not evident that farmers will necessarily adopt these varieties or achieve the same performance on their own fields. Adoption factors and performance on farmers' fields are considered in a follow-up study by van Asselt et al. (2018).

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ANNEX

Annex Table 1. Maize grain yield and soil pH and physical characteristics at ten field trial sites in northern Ghana

			Soil Properties		
	Grain yield, kg/ha	pH	Sand, %	Clay, %	Silt, %
Required or Optimum	n/a	6 - 7	50 - 70	10 - 30	0 - 40
West Gonja	3,632	5.62	69.0	0.1	30.2
Tolon	4,134	5.51	70.1	1.9	28.0
Yendi	2,161	5.57	56.1	5.8	38.1
West Mamprusi	3,675	5.00	48.1	6.0	45.9
Sissala East	4,585	5.68	78.3	1.9	19.8
Wa	4,785	6.16	95.7	2.2	2.2
Nadowli	3,210	6.20	78.8	1.6	19.6
Bolgatanga	3,015	4.74	72.3	5.8	21.8
Bawku	3,350	5.85	86.0	2.1	11.9
Kassena Nankana	3,575	6.81	78.2	1.9	19.9

Note: pH and physical soil properties recorded after analysis of the soil samples.
Source: Authors' calculation from 2015 trial results

Annex Table 2. Maize grain yield, required nutrients, and available nutrients at ten sites in northern Ghana

		Soil Chemical Properties			
	Grain yield, kg/ha	Organic Matter, %	Nitrogen, %	Phosphorus, mg/kg	Potassium, mg/kg
Required or Optimum	n/a	1.5 - 2.5	0.13 - 0.23	20 - 40	61 - 120
West Gonja	3,632	0.67	0.035	4.23	127
Tolon	4,134	0.94	0.055	2.59	55
Yendi	2,161	0.61	0.038	4.78	25
West Mamprusi	3,675	0.81	0.033	3.65	3
Sissala East	4,585	0.67	0.048	3.05	24
Wa	4,785	0.74	0.024	5.09	54
Nadowli	3,210	0.87	0.033	2.49	47
Bolgatanga	3,015	0.61	0.029	4.52	120
Bawku	3,350	0.54	0.034	1.44	43
Kassena Nankana	3,575	1.48	0.074	10.07	42

Note: Nutrients in the soil recorded after analysis.
Source: Authors' calculation from 2015 trial results

Annex Table 3. Mean characteristics of maize plants at demonstration sites

	Plant height, cm	Days to 50% tasseling	Days to 50% silking	Plant stand, no.	Cob number	Grain yield, kg/ha	Biomass yield, kg/ha	Harvest index
West Gonja	207	47	48	52,750	50,375	3,633	5675	0.38
Tolon	199	52	54	57,500	40,104	4,135	3613	0.53
Yendi	185	56	60	58,450	38,479	2,162	4515	0.32
West Mamprusi	185	49	53	47,313	52,313	3,675	3056	0.54
Sissala East	183	57	60	60,000	38,438	4,586	3794	0.54
Wa	181	57	59	38,375	46,625	4,785	4600	0.51
Nadowli	172	53	56	46,000	39,125	3,210	4725	0.41
Bolgatanga	17	51	54	47,563	44,813	3,015	3644	0.45
Bawku	170	54	60	41,313	38,604	3,350	4427	0.42
Kassena Nankana	160	63	66	44,354	41,813	3,575	3938	0.48

Source: Authors' calculation from 2015 trial results

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