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GRAIN YIELD RESPONSE OF FONIO (*DIGITARIA EXILIS*) VARIETIES TO FERTILIZER AND COST- EFFECTIVENESS UNDER TWO DIFFERENT PRODUCTION SYSTEMS IN THE GAMBIA

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ABSTRACT

Fonio is an easy crop to grow because it grows well even on poor sandy soils, as well as in areas with low rainfall. The crop can withstand long dry spells during the production season which are becoming a common occurrence in the West African sub-region. In The Gambia, the common name for the crop is "Findi". It is commonly grown in fields that were previously cultivated with groundnut. Fonio is one of the oldest cereal crops grown in the country; however, its cultivation has drastically declined to the extent that it is currently considered a minor crop in the country. Fonio is a very fast-growing crop and matures earlier than most cereals. Its ability to withstand dry spells and its high nutritive value makes it an ideal climate-smart crop. For this reason, there is renewed momentum in promoting the crop in the country. Despite these renewed efforts in its promotion, there still exists a huge gap in terms of information on improved production practices that could help uplift the existing low yields. Appropriate agronomic practices that can boost fonio productivity are not well documented at national level. To gather information on the input requirements and utilizations, adaptability and productivity of fonio in The Gambia, experiments were conducted in 2018 and 2019 with the aim of generating important production information that could guide efficient production and enhance productivity. Results obtained showed that fonio responded positively to application of fertilizer. Application of 100 kg ha $^{-1}$ comprising half NPK (15-15-15) and half urea was sufficient to produce financially beneficial yields. Results also indicated that "Findiba", which is a landrace may not be suitable for cultivation anymore due to its long growth period amidst the short and erratic nature of the rainfall. The Momo and the Momosato varieties which are of shorter durations and high-yielding are more suitable in the existing climatic conditions of the country.

Key words: Crop, fonio, fertilizer, variety, production, yield, adaptability, The Gambia

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INTRODUCTION

Fonio (*Digitaria exilis*) is one of the oldest native, but neglected, cereal crops of cultural, nutritional and economic importance of West Africa [1]. Fonio seeds are rich in methionine and cystine, two vital amino acids in human nutrition that are lacking in some major cereals such as rice, wheat, and sorghum [2]. Fonio is an easy crop to grow because it grows well even on poor sandy soils, as well as in areas with low rainfall. The crop can also withstand long dry spells during the production season which are becoming a common occurrence in the West African sub-region including The Gambia [3].

Fonio is a highly palatable cereal that is often consumed in West Africa well before most other crops are ready to harvest because it is one of the world's fastest maturing cereals. It is believed to be one of the oldest cereals in West Africa where it is indigenous [4]. Regional average yields range between 0.6 t ha^{-1} and 0.9 t ha^{-1} with the best productivity reaching 1.5 t ha^{-1}[5]. In many countries in the region such as Mali, Burkina Faso, Guinea, The Gambia, Benin and Nigeria, it is a major part of the diet and in some places it is even considered the staple [6]. Therefore, the crop has a great potential of playing major role in addressing the food insecurity situations faced in the region mainly due to climate change consequences. However, despite the important role that fonio plays in West Africa food supply, the crop has not received adequate research attention in the sub-region [7].

In The Gambia, Fonio is called Findi and is one of the oldest cereal crops cultivated in the country. The crop is cultivated mainly for its edible grain and remains one of the most expensive cereals in both urban and rural markets of the country. Farmers in The Gambia commonly grow fonio on fields used for groundnut cultivation in the previous season. It was one of the most cultivated cereals in The Gambia, however, in the past two decades, the cultivation has seriously declined to the extent that it is described as a neglected crop in the country.

The common system of cultivation of fonio in The Gambia requires very little labor and inputs. After clearing their fields of shrubs and grasses, farmers till the land using tractors, power tillers or animal drawn shine hoes; broadcast the seeds and use rakes to incorporate them into the soil. Farmers most of the times do not apply fertilizers and do not weed but only handpick tall grasses. No other operations are carried out until crops reach maturity at which time they use sickles to harvest. Threshing and milling are done manually and these two operations are the most challenging aspects of fonio cultivation in The Gambia.

Fonio is regarded as a climate-smart crop because it is highly adapted to marginal land farming, most varieties have short growth period, minimal input requirement, ability to grow on poor soils and can withstand long dry spells in the season [8]. When compared to the other cereal crops grown in the country such as rice, maize and millet; the earliest varieties of these crops in the country have a growing period of at least 90 days whereas all the fonio varieties in the country except one has a growth period of 75 days or less. Because of these good traits, in addition to its nutritive value, the crop is being

promoted in The Gambia by development partners such as the United Nations Food and Agriculture Organization (FAO), international and local Non-Governmental Organizations and government agricultural institutions and projects. Consumption of dishes made from fonio is increasing in urban and semi-urban areas. Thus, its production has to be increased to meet this growing demand. Despite these renewed efforts in promoting fonio, there still exist a huge gap in terms of scientific information on the production, diversity and adaptability of the crop in the country. Appropriate agronomic practices in the fonio cropping systems that can boost its productivity are not well documented at national level.

Experiments were conducted during 2018 and 2019 rainy seasons to gather key information on the input requirements and utilization, adaptability and productivity of fonio varieties in the country. The aim was to generate important production information to guide the efficient production and enhance productivity of fonio in the country. The specific objectives of the study were to assess the effect of fertilizer application on fonio grain yield in different parts of the country and to determine the cost-effectiveness of the fonio production systems developed by research.

MATERIALS AND METHODS

In 2018 and 2019 rainy seasons, experiments were conducted in two different Agro-ecological zones (AEZ) of the country, that is, Yundum experimental site III and Sapu Kerewan fields. Exactly the same experimental designs and procedures were used in both locations in both years.

Descriptions of the Study Areas

Yundum experimental site III is located within the Sudano-Guinean zone of The Gambia. This zone is named as AEZ 3. Sapu Kerewan field on the other hand is located within the Sudano-Sahelian zone of the country and is named as AEZ 2. Yundum is located on Latitude 13^0 22′ 0″ N and Longitude 16^0 39′ 0″ W; while Sapu is located on Latitude 13^0 32′ 43″ N and Longitude 14^0 51′ 54″ W. Both locations of the country experience one rainy season per year which normally begins in late June and ends in mid-October.

The Sudano-Sahelian zone is characterized by lower precipitation volumes ranging between 600-900 mm per annum and the length of the growing season lasts between 80-119 days. The Sudano-Guinean which covers mainly the West Coast of the country and few portions of the Upper River Region receive rainfall of 900-1200 mm per annum with the growing season lasting between 120-139 days [9]. The soils of the study areas are characterized by pH values of 5.8 and 5.9; and organic matter contents of 1.26 % and 0.57 % for Yundum and Sapu, respectively. The soils are of sandy loam texture and are classified as Arenosols according to the FAO's soil classification system.

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Figure 1: The location of the two study sites in The Gambia (Yundum and Sapu)

Experimental Design and Conduct

The design of the experiments was split-plot in a randomized complete block design with three replications. Treatments comprised four fertilizer application rates assigned to the main plots and four fonio varieties assigned to the sub-plots. The fertilizer rates were: 0, 50, 100, and 150 kg/ha of combined compound NPK + urea; and fonio varieties were: Findiba, Momo, Momosato and NARI 1. The Momo, Momosato and NARI 1 are exotic varieties with shorter growth periods of less than 90 days. They were obtained from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The Findiba is a landrace with longer growth period of close to 120 days. It is the oldest and native fonio variety in The Gambia, but is also found in the sub-region for instance in the southern region of Senegal called Casamance.

The seeds were drilled in rows with spacing of 30 cm between rows. Weeding was carried out immediately after each of the two fertilizer applications. This was meant to also enable incorporation of the fertilizer.

The sources of fertilizer were NPK (15:15:15) applied at two weeks after planting (WAP) and Urea (46 % N) top dressed at four WAP. The fertilizer rates stated in the treatment description section were the combined NPK and Urea quantities. The 50 kg rate comprised 15.25 kg N, 3.75 kg P_2O_5 and 3.75 kg K_2O; the 100 kg rate comprised 30.5 kg N, 11.25 kg P_2O_5 and 11.25 kg K_2O and the 150 kg rate comprised 38 kg N, 15 kg P_2O_5 and 15 kg K_2O.

Determination of Grain Yield and Data Analysis

Yield data were obtained from crops harvested within a 2 m^2 net plot area inside the gross plots. The plants were harvested, stacked, dried and threshed. Grain weights were recorded after threshing.

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All data were subjected to Analysis of Variance (ANOVA) using the GenStat Statistical Package. The means were separated using the Least Significant Difference (LSD) at 0.05 probability level.

Analysis of Production Costs

To compare the cost related to the different practices of fonio production, farmer practice and those recommended by research, an economic cost-benefit analysis was conducted to determine the most cost-effective way of producing fonio in the country.

The opportunity cost related to each fonio production practice from planting to harvesting such as planting, weeding and fertilizer were identified and the yield information was also obtained and used to run the cost-benefit analysis.

The costs of inputs used in the production of fonio were specified in order to calculate the production costs. The costs of inputs were those of fertilizer, human labor (clearing, weeding, harvesting), land preparation, and milling costs. The output was a milled fonio yield value. The input and output were calculated per hectare and then, these input and output data were multiplied by their costs. Net return, benefit/cost ratio and productivity were calculated as shown in Equation 1, 2 and 3 according to [10, 11]:

Net return = Total Revenue – Total Costs (1)
Benefit to Cost ratio = (Total Revenue) / (Total Cost) (2)
Productivity = (Yield) / (Total Costs) (3)

RESULTS AND DISCUSSION

The results presented in the figures below are for the calculated two-year averages. The data presented in Figure 2 showed that zero fertilizer application which is the common farmer practice produced lower grain yield than the fertilized plots. Grain yield increased with increase in fertilizer rate up to 100 kg/ha after which no further significant yield increase was observed at both locations. Whilst the effect of fertilizer at the lowest of 50 kg/ha, did not result in significant yield increase, grain yield differences at 100 kg/ha was statistically significant ($P<0.05$) at both Sapu and Yundum. This observation is an indication that fonio grain yield could increase significantly with application of fertilizer. It was also reported in a previous study that fonio grain yield increased up to 22 % with application of only 15 kg N ha^{-1} when P and K were not limiting [12].

Grain yield, on average, was observed to be higher at Yundum than at Sapu (Figure 2) and this was consistent at all fertilizer rates. The average yield difference between Yundum and Sapu was 0.18 tons/ha which is a huge difference. The higher performance of fonio at Yundum which lies within the Sudano-Guinean zone than at Sapu which lies within the Sudano-Sahelian zone could be attributed mainly to the soil and weather differences. The soil organic matter (OM) content of 1.26 % at Yundum was twice more than at Sapu (0.57 %). Soil organic matter plays a major role in maintaining soil quality as it positively influences a wide range of soil properties such as the provision of nutrients, enhanced water retention, improved soil aeration and

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reduction of soil compaction and erosion [13]. Therefore, crops grown on soils with higher OM levels have a much higher chance of producing higher yield than those on soils with lower OM contents.

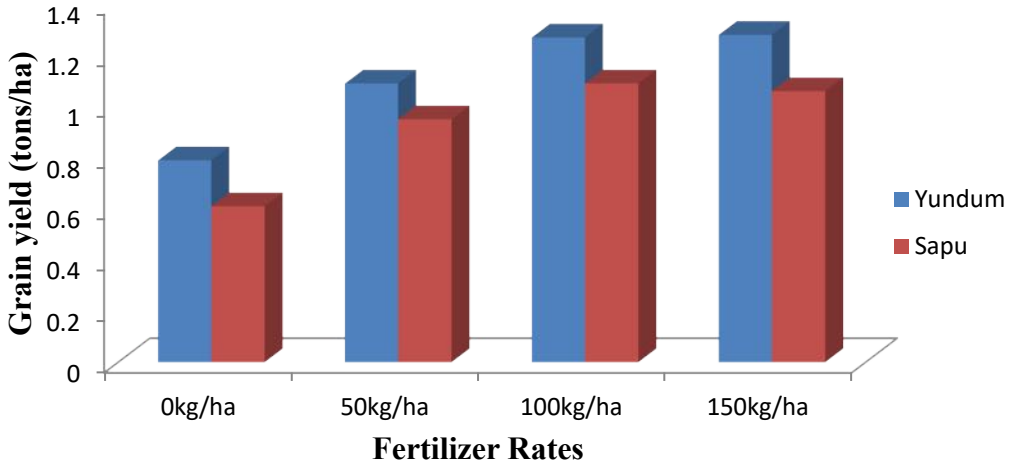

Figure 2: Effect of fertilizer application on grain yield of fonio at Yundum and Sapu

Differences in grain yield of the same crop variety at different locations aside from soil differences could also be associated with differences in weather parameters such as rainfall and temperature. However, the huge mean grain yield difference (180.5 kg/ha) that was observed between Yundum and Sapu may not be attributed to rainfall because rainfall figures recorded at the two locations in the two years were very similar, and in fact in some cases the later received more rain than the former. For example, in 2018, rainfall figures recorded at Yundum from June to October (880 mm) was less than that of Sapu (1,015 mm) during the same period. This result points to the fact that fonio grain yield performance is more dependent on the fertility status of the soil than the amount of rainfall the crop receives. After all, fonio is known to require less water to grow and perform to expectation than most cereal crops. Therefore, grain yield differences between the two locations could be largely attributed to differences in soil fertility status.

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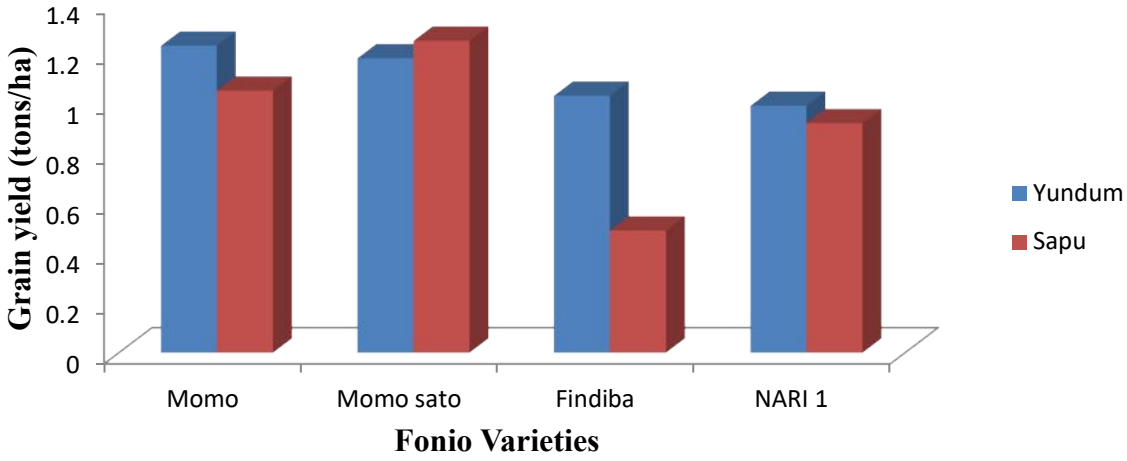

Figure 3: Grain Yield Performance of Fonio Varieties at Yundum and Sapu

The Momo and Momosato varieties out-yielded the other two varieties, that is, Findiba and NARI 1 at both locations (Figure 3). These two varieties demonstrated more consistent higher grain yield potentials than the other varieties. They maintain yields ranging between 1 and 1.25 tons/ha at both locations. Momo yielded higher than Momosato at Yundum but with a yield difference of only 50 kg/ha. At Sapu, Momosato also out-yielded Momo with a yield difference of 200 kg/ha which is quite huge. This result points to the ability of fonio varieties performing differently in different agro-ecological environments. This difference could be due to difference in genotype × environment interaction (GEI). A study on barley in Ethiopia also showed varieties responding differently in different locations of the country [14].

Financial Analysis

Valuation of the inputs and outputs

The output used in the financial analysis is the yield of fonio per hectare. This value is the average of all the four varieties of fonio cultivated during the on-station research trials at Sapu and Yundum for the two-year (2018 and 2019) period. This was done in order to take into account environmental and seasonal variations in yield. The price per kilogram of fonio was computed by taking the average of a price data collected during the on-station trials in 2018 and 2019 at Sapu and Yundum. This helps to minimize the seasonal and locational differences in prices.

Both grain yield and seeds of fonio were valued at 1.8 USD/kg. Currently, there are no established seed outlets within the country that sell fonio seeds to farmers. Fonio producers use their own saved and recycled seeds or acquire seeds from their neighbors. For this reason, we were obliged to use the prevailing market prices of fonio grains to estimate the cost of fonio seeds.

The labour cost estimate used were all based on manual work. No mechanical or animal traction was used in the analysis. To account for the variation in labour cost across the

different geographical areas within the country, the prevailing market prices of labour in Sapu and Yundum for both men and women were used to estimate the production cost of fonio per hectare and the averages taken to represent the data used in the analysis for this study.

Cost-benefit analysis

Results obtained from the cost-benefit analysis are presented in Table 1. The main operations relating to fonio cultivation using common farmer practice in The Gambia are seeds, land preparation, harvesting, threshing and milling. These costs are estimated at 347 USD. The costs attached to the research recommended practices used in this study are as follows: Application of 50 kg fertilizer per hectare and weeding twice ((518 USD), application of 100 kg fertilizer per hectare and weeding twice (575 USD) and application of 150 kg fertilizer per hectare and weeding twice (581 USD).

The main differences between the farmer and research- introduced practices are connected to seeds, weeding and fertilizer usage. The farmer practice of fonio cultivation uses broadcasting methods of seed sowing to produce fonio. This practice uses between 30 to 50 kg of fonio seeds per hectare. On the other hand, the research-introduced practice encourages farmers to sow fonio seeds in straight lines, which has a seeding requirement of 6 to 10 kg of seeds per hectare. In the financial analysis presented in Table 1, 30 kg of seeds were used to estimate the seed usage by farmers when broadcasting fonio seeds, and it was estimated at 54 USD per hectare. In comparison, 10 kg of seeds were used to estimate the seeding rate for the research-introduced method of fonio production, which costs about 18 USD per hectare (see Table 1).

Based on the results obtained, row sowing of fonio coupled with regular weeding and fertilizer application of 100 kg NPK per hectare has yielded the highest (798 USD) net return. This practice has also produced the highest benefit/cost (2.39) and productivity (1.33) ratios. The benefit/cost ratio indicates that for every 1 USD spent on this practice it will produce 2.39 USD in return whereas every 1 USD spent will produce a yield of 1.33 kg in return. This makes the practice the most cost- effective method of fonio production.

The economic cost-benefit analysis results presented in Table 1 indicate that the farmer practice of broadcasting the seeds with no weeding and no fertilizer application produced a net return of 422 USD/ha whereas the research practice of row sowing coupled with weeding and application of 100 kg fertilizer per hectare yielded 798 USD net return per hectare. These results show that farmers can increase their income by 376 USD/ha or more than 80 % if they adopted the research-recommended practice.

CONCLUSION

From the results obtained at both locations and for all fonio varieties across fertilizer rates, it can be concluded that fonio responded positively to fertilizer application. However, results indicated that under Gambian conditions, fonio should be able to

yield to potential with application of 100 kg/ha fertilizer which should comprise 50 kg NPK applied as basal and 50 kg urea top dressed at 4 weeks after planting.

It can also be concluded from the results obtained from the economic analysis that row planting of fonio accompanied by weeding and fertilizer application of 100 kg/ha is more cost- effective, yielding at least 80 % net return.

In terms of variety comparisons, the study reveals that the Momo variety has higher yield potentials in the Sudano-Guinean zone than the other varieties. On the other hand, in the Sudano-sahelian area, the Momosato variety showed higher yield potentials. The Findiba which is a landrace is a long duration variety. Thus, the sporadic nature of rainfall which includes common occurrences of late on-set, intermittent dry spells and early cessations makes it almost impossible to obtain much harvest from it at both locations.

Overall, the results of this study have shown that fertilizer application, choice of variety and researcher recommended agronomic practice are key to increasing the productivity of fonio in The Gambia.

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Table 1: Cost-effectiveness of production of Fonio under farmer practice and research- introduced systems in The Gambia

Cost and Revenue($/Ha)	Farmer Practice (0 fertilizer)	50 kg fertilizer	100 kg fertilizer	150 kg fertilizer
Yield (kg/Ha)	427	665	763	742
Sale price ($kg^{-1})	1.8	1.8	1.8	1.8
Costs ($Ha^{-1})				
Seeds	54	18	18	18
Fertilizer	0	15	30	45
Clearing	20	20	20	20
Ploughing	40	40	40	40
Weeding	0	90	90	90
Harvesting	50	50	50	50
Threshing	122	190	218	212
Milling	61	95	109	106
Total cost of production	347	518	575	581
Revenue ($Ha^{-1})				
Gross return	769	1197	1373	1336
Net return	422	679	798	755
Benefit/cost ratio	2.22	2.31	2.39	2.30
Productivity	1.23	1.28	1.33	1.28

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