Agronomic Package for Maize Production in Semi-coral Environment of Pemba, Zanzibar

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Abstract
Maize is an important food crop in the semi-coral area of Pemba Island. Production has however never met demand due to very poor yields, about 1.0 t/ha in the area. An experiment was conducted to establish agronomic recommendations for increasing the maize crop productivity. Three improved varieties (Staha, Situka, TMV-1) were tested against variety JKU, a locally grown type in the area. Treatments included four nitrogen rates (23, 46, 70 and 90 kgN/ha) and three plant densities (44,444; 53,333 and 66,666 plants/ha). The treatment sources of variation (varieties, densities and fertilizer rates) had significant effects on growth and yield of the maize crop. Use of variety Staha significantly (P < 0.05) improved yield compared to the local variety (JKU) and the other tested varieties. Yield difference between best performing and least performing variety was about 69%. Through optimized spacing yield difference as much as 32.9% was achieved while through improved Nitrogen fertility yield was increased by as much as 28.8%. The use of variety Staha, grown at a spacing of 75 cm × 20 cm giving a plant population of 66,666 ha-1; and the use of nitrogen at 70 kgN/ha is recommended for best maize yields in the area. The best practice is to optimize all the three factors in combination

Keywords: Optimized spacing, Plant density, Nitrogen rate, Grain yield

Introduction

Maize is the most important food crop produced in the semi-coral area in Pemba, an island forming part of the Zanzibar archipelago in the Indian Ocean territorial waters of Tanzania. Production of Maize in Pemba, however, has never met the demand due to very poor yields. Reasons for poor yield include poor agronomic practices such as sub-optimal plant population and insufficient or no use of fertilizers to improve soil fertility.

The semi-coral area is one of the five livelihood zones of Pemba Island, running all along the eastern side of the Island from far north to the far south. It also constitutes part of the North-West of the island, making one-third of the total agricultural land in Pemba. In the semi-coral area crop production is the most important livelihood activity followed by animal keeping. Fishing is another livelihood activity but is very seasonal, persisting only for three to four months in a year.

In most parts of the semi-coral area, the soil is very shallow. This characteristic makes the semi-coral area not suitable for deep rooted crops such as clove and coconut which are the major plantation crops in Pemba. Agriculture in the area is dominated by small-holder subsistence production of annual crops such as cowpeas, sorghum, pea nuts, sweet potatoes and cucurbits, with maize being grown by almost every household as the major food security and cash crop. Maize flour is also one of the leading food items outside the semi-coral area. According to the Zanzibar Ministry of Agriculture (2012), total supply of maize flour in Zanzibar increased from 6000 metric tons in 2007 to 8000 tons in 2011, at an average growth rate of 11.67%. Average supply from domestic production was just 2400 metric tons per year, with growth rate of only 4.17%. The gap between demand and the domestic supply is covered by importation of more than 3500 metric tons per year from Tanzania mainland.

Tremendous crop yield increases have been attributed to genetic improvement. In maize, most impressive record is perhaps in the US corn belt and Canada where on-farm grain yield of maize is reported to have increased by almost 700% in less than 70 years of intensive new varieties development efforts (Lee and Tollenaar, 2007; Gonzalez *et al.,* 2018). Many grain yield genetic gain study results in maize are documented. In the US corn belt, Argentina and Brazil, genetic gains of about 74 – 123kg/ha/year for periods between 1930 – 2001 have been reported (Eyherabide *et al.,* 1994; Duvick, 1996; Cunha and Franzon, 1997; Duvick *et al.,* 2001;2004;; Duvick, 2005; Encharte *et al.,* 2013). In Eastern and Southern Africa according to study by Masuka *et al.* (2017a), genetic grain yield gain in maize derived from 67 best performing hybrids across 6 countries of the Region over the period 2000 – 2010 was about 109.4 under optimal conditions; and 32.5, 22.7, 20.9 and 141.3 kg/ha/yr under managed drought, random drought, low N and Maize streak virus (MSV), respectively. For Open pollinated varieties (OPVs), the gain was 109.9, 29.2, 84.8 and 192.9kg/ha/yr, respectively under optimal conditions, random drought, low N and MSV for early maturity varieties. For intermediate and late maturity (>70 days to anthesis) varieties it was respectively 79.1, 42.3, 53 and 108.7 kg/ha/yr, and all these were for the period 1999 – 2011 (Masuka *et al.,* 2017b). In West and Central Africa, Badu-Apraku *et al.* (2013, 2015) estimated genetic gain in OPVs only, and the gain was 40 kg/ha/yr (1% per yr) under optimal conditions and 14 kg/ha/yr under managed stress, for the period 1988 – 2010.

Among best technically known environmental attributes that always impact on crop yields are soil fertility and plant density. Most limiting of soil fertility nutrients is obviously Nitrogen, N. Recent study by Schlegel and Havlin (2017) combining N and P application found that grain yield of maize increased by 20% with P alone, and by 103% with N alone; while N + P applied together increased yields up to 225% compared to unfertilized control. They further found average economic optimal rate for N to be 170 – 180 kg N/ha, at which P application was 20kg P/ha; and that doubling the P rate (20 – 40kg P/ha) resulted in only minimal increase of approximately 4% grain yield. In 12 irrigated maize trials continuously for 3 years, Doberman *et al.* (2011) found an economic optimum rate for maize to be 171 kg N/ha, with optimum grain yield of 14.8t/ha. Inherent low soil fertility and poor nutrient management have been one of the major factors limiting maize yield (Shehu *et al.,* 2018), especially in Africa. In a study on 940 demonstration sites across Malawi, Mozambique, Zambia and Southern highlands of Tanzania, Bashir *et al.* (2017) found that growing maize without N inputs results in loss of land productivity and profitability; and that application of 50% or more of the recommended N rate ensures substantial increases in yields and profitability.

Plant density is also of paramount importance in grain yield determination. For this reason wide plasticity in maximizing yields alongside plant density exists. Sangoi (2001) reports that plant density for maximum maize economic grain yield varies from 30,000 to over 90,000 plants/ha, depending on soil fertility, water availability, maturity rating, row spacing and planting date. Ibid argues that when number of plants per unit area increases beyond optimum, there is a series of consequences detrimental to ear ontogeny and results in barrenness.

Of greater yield increasing impact nowadays is perhaps the interaction between genotypes and the manipulated environmental attributes rather than any of the factors alone. Gonzalez *et al.* (2018) points out that actually maize yield potential has not undergone genetic improvement during the hybrid era, yet substantial genetic improvement has occurred for tolerance to high plant population densities.

The density tolerance is what has led to changes from about 30,000 plants/ha in the 1950s to more than 80,000 plants/ha in current time, as reported by Lee and Tollenaar (2007). Genetic potential is expressed in yield per plant while improved density tolerance is expressed in yield per unit area. De Bruin *et al.* (2017) argue that modern hybrids have benefited greatly from increased plant density. Similarly, Masuka *et al.* (2017b) have reported that many current commercial varieties have very low yields under low soil fertility conditions.

Current maize yield in the semi-coral area (1.0 ton ha^{-1}) is lower than the potential yield (2.0 – 3.9 tons ha^{-1}) reported from Kizimbani research station in Zanzibar (Shin-Gu *et al.,* 2011). This means that yield can be more than doubled in the mean time if production constraints are resolved. An important constraint responsible for poor yields is inappropriate agronomic practices. This research intended to investigate production practices that can lead to improved maize production in the research area.

Materials and Methods

An experiment was conducted at Kangagani village in Pemba Island during the period March to August, 2013. This village is located at latitude 5°09′ South and longitude 39°46′ East about 20 meters above sea level. The area is characterized by a bimodal rainfall pattern, long and sometimes heavy rains during March to June and short and normally very little rains from September to November. The mean, maximum and minimum temperatures are 28, 32 and 22°C, respectively. Average humidity is 71.5% while average evaporation is 5.72 mm day^{-1}. The experiment was laid out in a Randomized Complete Block Design in split plot arrangement with three replications.

Three plant spacings (75 cm x (30, 25 and 20 cm) were tested giving plant populations of 44,444, 53,333 and 66,666 plants ha^{-1}, respectively. Three improved maize varieties (Staha, Situka and TMV-1) which were selected from the maize varieties list recommended for the Eastern zone of Tanzania, and one local variety, JKU which is commonly grown in the semi-coral area of Pemba, were used in the experiment. The varieties formed the main plots and plant population the sub-plots. Four different rates of fertilizer Nitrogen (23, 46, 70 and 90 kg N/ha) were used as sub-subplots. Each treatment unit was planted on a 3m x 4m plot. The Main plots, sub plots, sub-subplots and the replications were all spaced at one meter apart. Two seeds per hill were sown and then thinned to one plant per hill seven days after emergence to maintain the predetermined plant densities. The field was managed with proper weed control up to harvest. Soil analysis of the experimental area revealed 3.83 ppm extractable Phosphorus and 0.16% total Nitrogen, both of which were the nutrients deficient conditions. Prior to planting, triple superphosphate (TSP 46 % P_2O_5) was applied uniformly to all treatment units at a rate of 20 kg P ha^{-1}. The Nitrogen fertilizer was applied in form of Urea (46 % N) in two splits, 50% at four weeks after seedlings emergence and another 50% three weeks later.

Data were collected on plant height, days to 50% flowering and maturity, cob length, cob weight, dry matter yield, grain weight per cob, 100 grain weight and grain yield. Plant height was measured at physiological maturity by recording the length using a meter rule from the base of the plant to the tip of the tassel. Days to 50% flowering and maturity were recorded by counting how long it took to have half the number of plants in a plot reach flowering and maturity, respectively. Cob length for ten sampled cobs per plot was measured using the meter rule. Their weights and weights of grains thereof were measured using a chemical balance. Dry matter weight was measured after chopping ten sampled plants per plot then dried in an oven at 105°C for 24 hours. Grain yield was measured from the two central row plants in each plot. Harvesting and threshing the cobs was done. The grains were dried to about 12% moisture content then grain weight was measured using a chemical balance. Then, 100 grains were counted for each experimental unit and 100 grain weight was determined also using an electronic chemical balance. The data were then subjected to Analysis of Variance using GenStat computer software 14th Edition. Mean separation was done using Least Significant Difference (LSD).

Results and Discussion

The results have generally shown that agronomic practices have quite a strong influence in determining performance of the maize crop in the study area. Table 1 shows growth and yield performance of maize in the study area as influenced by choice of the crop varieties. It is evident from the data that variety of crop used can have profound influence on yield and production efficiency of the crop. Results show that variety Staha, had a yield advantage of more than 2.0 tons/ha as compared to variety Situka, it also flowered and matured significantly earlier. Variety Staha was also better in grain yield than the local variety used in the area (JKU), by about 542 kg equivalent to more than 5 bags 100 kg each per hectare. This difference was significant according to LSD (P=0.05), as shown in the Table. JKU was however the earliest in flowering and maturing. The variety (JKU) matured significantly earlier than all the other varieties. Compared to the latest maturing variety, Situka, variety JKU matured 25 days earlier, while it was 19 days) earlier than Staha. From results of this study, variety Staha is worthy consideration as an improvement option for maize cultivation in the study area. Under late planting, however, the local variety JKU can be a better option because it matures significantly earlier than Staha. The other two varieties, Situka and TMV-1, were inferior to JKU which performed significantly better than the two varieties. The data also show that all cob parameters (length, weight, grain weight/cob) and 100 seed weight were at their highest with variety Staha. These parameters' values for Staha were significantly higher compared to the other tested varieties. This is evidence that grain yield in the variety Staha is contributed by larger cobs and larger kernels. Variety JKU was second to Staha in all those attributes.

Results of growth and yield of the maize crop as influenced by plant density are presented in Table 2. Plant height and dry matter yield per hectare increased with increasing plant population but grain yield increased only up to the intermediate plant population level of 53,333 plants/ha. At this density grain yield was highest at about 4.3 tons/ha, significantly higher than at the lowest density ($P<0.05$). This yield improvement was slightly more than 1.0 ton/ha (ten 100 kg bags), approximately 33 % improvement. Grain yield then declined slightly but not significantly ($P<0.05$) towards the densest plant population. Biomass was highest at the highest plant density but Harvest Index (HI) followed the trend of

Table 1: Effects of varieties on growth, yield and yield parameters of maize in Semi-coral environment

Varieties	Plant height (m)	Days to 50% silking	Days to maturity	Cob length (cm)	Cob weight (g)	Grain weight/ cob (g)	100 grains wt (g)	Dry matter (tons/ha)	Grain yield (t/ha)	Harvest index (%)
Staha	1.878c	63.78c	123.6c	19.32c	240.7b	181.5b	30.27c	7.849b	4.953c	63.37c
Situka	1.749b	68.75d	129.6d	16.54a	174.2a	102.8a	24.56ab	6.702a	2.930a	43.03a
TMV-1	1.957d	58.72b	114.1b	16.64a	173.6a	99.1a	23.67 a	6.146a	3.163a	51.70b
JKU	1.642a	47.00a	104.7a	18.45b	196.1a	170.7b	26.97 b	7.583b	4.411b	57.95bc
Mean	1.806	59.56	118.0	17.74	196.1	138.5	26.37	7.070	3.864	54.01
F. prob.	<.001	<.001	<.001	<.001	<.001	<.001	0.006	0.002	<.001	0.006
S.E. +	0.01639	0.456	0.475	0.1237	12.77	10.26	1.188	0.2504	0.1958	3.529
CV %	3.9	3.3	1.7	2.9	27.6	21.4	19.1	15.0	21.5	27.7
LSD0.05	0.041	1.117	1.162	0.303	31.260	25.100	2.906	0.613	0.479	8.636

grain yield (highest at intermediate spacing).

Table 2: Effects of plant density on growth, yield components and yield of maize in Semi-coral environment

Plant densities	Plant height (m)	Cob length (cm)	Cob weight (g)	Grain wt/cob (g)	100 grains wt (g)	Dry matter wt (tons/ha)	Grain yield (t/ha)	Harvest index (%)
44 444 plants/ha	1.732a	19.45c	230.6b	164.6b	27.65b	6.280a	3.229a	50.48a
53 333 plants/ha	1.839b	17.80b	179.5a	129.9a	26.73ab	7.333b	4.291b	58.07b
66 666 plants/ha	1.848b	15.96a	178.3a	121.1a	24.73a	7.597c	4.073b	53.48a
Mean	1.806	17.74	196.1	138.5	26.37	7.070	3.864	54.01
F. prob.	<.001	<.001	<.001	<.001	<.001	<.001	<.001	0.002
S.E. +	0.01619	0.1157	12.26	9.33	1.098	0.0650	0.1205	1.754
CV %	4.4	3.2	20.6	22.9	20.4	4.5	15.3	15.9
LSD0.05	0.034	0.245	25.990	19.780	2.327	0.138	0.255	3.719

Table 3 shows performance of the maize crop under varying levels of Nitrogen fertilization. Response to the nutrient element was very pronounced. All data parameters under consideration were significantly ($P<0.01$) influenced by the level of N fertilization. Days to flowering, days to maturity and dry matter yield increased consistently with increasing quantity of N application. Cob and grain parameters including grain yield, however, increased only until when N application was 70 kg/ha, then declined as the application rate increased further to 90kg N/ha. Harvest Index also followed this trend. It can be argued from these findings that 70 kg N/ha is an optimum N application rate for the semi-coral environment. Excess N is extensively reported to lower crop grain yield (FAO, 2003; Hobben *et al.,* 2011; Wang *et al.,* 2011).

This research has shown that recommendable agronomic practices individually and in combination have contributed to improved production. As already shown in previous Tables that best maize yield could be achieved with variety Staha, at the intermediate spacing of 75 cm x 25 cm (53,333 plants/ha) and with fertilizer application of 70 kg N/ha, Table 4 shows in addition the crop performance when the agronomic recommendation variants tested are considered in combination. It is at the

Table 3: Effect of nitrogen levels on growth, yield and yield parameters in maize in Semi-coral environment

Nitrogen levels	Plant height (m)	Days to 50% silking	Days to physiol. maturity	Cob length (cm)	Cob weight (g)	Grain weight/ cob (g)	100 grains wt (g)	Dry matter (t/ha)	Grain yield (t/ ha)	Harvest index (%)
23kgN/ha	1.699a	55.50a	112.7a	17.21a	187.8a	134.9a	25.69a	6.379a	3.406a	52.95b
46kgN/ha	1.776b	58.14b	115.7b	18.06b	195.8a	137.2a	27.29b	7.020b	3.762b	53.13b
70kgN/ha	1.845c	61.33c	120.0c	18.40c	214.4b	152.1b	28.00b	7.261c	4.386c	59.25c
90kgN/ha	1.906d	63.28d	123.6d	17.29a	186.6a	129.9a	24.50a	7.619d	3.902b	50.72a
Mean	1.806	59.56	118.0	17.74	196.1	138.5	26.37	7.070	3.864	54.01
F. prob.	<.001	<.001	<.001	<.001	0.004	0.002	<.001	<.001	<.001	<.001
S.E. +	0.01837	0.676	0.885	0.1269	8.24	5.81	0.672	0.0954	0.0763	1.016
CV %	4.3	4.8	3.2	3.0	17.81	17.79	10.8	5.7	8.4	8.0
LSD0.05	0.036	1.347	1.764	0.253	16.420	11.570	1.339	0.188	0.152	2.026

combined package that yield was maximized (6.415 t/ha) and this was higher than the best of the individual variants by percentages ranging from 29.5 – 49.5%. That is, the best combination of recommendations (Variety Staha, planting density of 66,666 plants/ha and fertilizer rate of 70 kgN/ha), whose yield was 6.415 t/ha; was 29.5% higher than the best variety (Staha) yield of 4.953 t/ha. It was also 49.5% higher than the best plant density yield of 4.291 t/ha and respectively 46.3% than the best fertilizer rate yield of 4.386 t/ha. Yield improvement of the best performance combination is overwhelming, to the tune of 278.02%, when compared with the lowest yield combination (Situka + 44,444 plants/ha + 23 kgN/ha), that is, improvement to 6.415 t/ha from 1.697 t/ha.

combination. This perhaps suggests that plant population density (competition for nutrients, solar radiation and water) is a more sensitive determinant of yield than varieties (genotypes) or respectively quantity of nutrients available in the soil. In other words, population change may perhaps have more profound effects than change in genotypes or soil nutrients fertility levels. Definitely this will also depend on what are the varieties changed and the magnitudes of fertility changed.

There is extensive literature pointing out various agronomic attributes to be responsible for improved or poor crop yields. Among them definitely is choice of varieties. Of more than 100 % increase in cereal crop yields worldwide

Table 4: Comparative grain yield quantity of best performance combination of variety x spacing x N fertilizer application rate with individual agronomic management variants in maize experiment

Variable	Range of variables	Highest yield	Best performing variant	Combination of variables percentage improvement
Varieties	JKU, TMV-1, Situka, Staha	4.953	Staha	29.5 %
Plant population (spacing)	44 444, 53 333, 66,666 plants/ha	4.291	53,333 plants/ha	49.5 %
Fertilizer application	23, 46, 70, 90 kgN/ha	4.386	70 kg N/ha	46.3 %
Combination	All variants : varieties, Spacing, Fertilizer	6.415	Staha x 66,666 plants/ha x 70 kgN/ha	0
Compared with lowest yield combination			Lowest yield	Lowest yield variants
Lowest yield combination	Varieties, Spacing, Fertilizer	1.697	Situka x 44,444 plants/ha x 23kgN/ha	278.02 % (The best combination improvement)

Results embracing the combined performance have also shown that the best performance combination was achieved at the highest plant population or closest spacing (75 cm x 20 cm). When spacing was considered alone (generalized for all tested varieties and nitrogen rates) yield was maximized at the intermediate level (75 x 25 cm; 53,333 plants/ha). This contrasts the other performance variants (Varieties and N application rate) which have shown that the same varieties (Staha) or N rate (70 kg/ha) that were best individual variant performers were also the variants responsible for the best performance

reported for the period 1961 – 2005 (FAOSTAT, 2006; Hazell and Wood, 2008), about 50% of the increase is considered to arise from the use of improved crop varieties seeds (Evenson and Gollin, 2003). Other attributes, notably plant population, soil fertility, weed management and availability of moisture in the soil are also known to be determinants of yield. Their individual contribution to yield may be less precisely generalized but each or in combination can have devastating effects and no doubt they are by large extent responsible for low crop yields very often times reported.

Conclusion and recommendation

This study concludes that improving crop production practices has great potential to increase yield and production. From average yield of 1.0 t/ha that farmers harvest it was found that through optimized agronomic practices, yield can be as high as 6.4 t/ha. Combined as well as individual agronomic attributes have proved to increase yield. Farmers in the semi-coral area of Pemba are advised to use variety Staha when rainfall shortage is not suspected while JKU can be used instead if planting is late perhaps due to very late commencement of rains or any other reason. A spacing of 75 cm x 25 cm can be best option when optimization of fertilizer use cannot be assured. When 70 kgN/ha is assured, however, a closer spacing of 75 cm x 20 cm is recommended.

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