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Optimized plant population for maize production in a semi-coral environment in Eastern Pemba, Tanzania

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Abstract

Crop yields are closely related and dependent, within the prevailing environment, on plant population in the field. An experiment was conducted in Eastern Pemba to test performance of four varieties of maize under varying plant densities in a semi-coral coast. Densities of 44,444; 53,333 and 66,666 plants/ha corresponding respectively to intra-row spacings of 30, 25 and 20 cm in 75 cm wide rows were used. Average plant height and harvest index increased significantly ($P \leq 0.05$) as plant population ha^{-1} increased from 44,444 to 53,33; thereafter plant height did not increase significantly while harvest index decreased significantly. Dry matter yield increased continuously and significantly as population increased from 44,444 to 66,666. Grain yield, however, increased only with population increase to 53,333 (significantly) thereafter it declined though insignificantly ($P \leq 0.05$). Highest average yield of grains was about 4.3 tons/ha at 53,333 plants/ha while lowest was 3.2 t/ha at 44,444. Varieties behaved similarly with regard to grain yield, dry matter yield and cob length as population changed from 44,444 to 66,666 plants/ha. With regard to grain weight per cob, however, for example while varieties Staha and JKU the weight decreased as population increased from 53,333 to 66,666 plants/ha; with variety TMV-1 the weight increased while with variety Situka it leveled-off. Whatever was the variety, this study results show that the maize crop grain yield was optimized at or close to the intermediate plant population of 53,333 ha^{-1}.

Keywords: Plant density, Spacing, Grain yield, Optimized, Semi-coral.

Introduction

Maize and indeed other crops yields are closely related and dependent, within the prevailing environment, on plant population in the field. Plant density generally determines efficiency of radiation interception which equates to amount of carbohydrate that is manufactured by photosynthesizing plant canopy. The more plant surface area exposed to the in-coming solar rays without any shading, the more the carbohydrates manufactured, which accumulate and are further used in the synthesis of cellular contents and stored food we harvest, for example in grains. The quantity of radiation intercepted therefore accounts much for the quantity of crop yield harvested for a species. Plant density also regulates the intensity of and balances competition for nutrients and water in the soil which supply metabolites for food synthesis and other essential plant life processes. Plant stand density can also play a significant role in rendering soil resources more available for the crop plant by suppressing non-crop plants tending to grow in competition with the crop. This occurs when the crop plant's canopy overshadows the non-crop plants (weeds) limiting their photosynthetic and growth capacity.

Plant density is most often achieved by planting the crop in rows and varying row width and the space between plants within the row, sometimes in addition varying the number of plants planted in the same hole. Row configuration is easy to achieve and allows convenience in field operations such as weeding, fertilizer application and even harvesting. In maize row widths ranging from 45 – 100cm are reported[1-4]. Plant populations as low as 10,000 plants/ha and over 100,000 plants/ha, respectively, have also been reported[5-7]. As high as 135,905 plants/ha have been suggested for Central USA as supra-optimal maize plant density where optimal density is suggested to range from 86,485 – 111,195 plants/ ha[8].

When narrow rows (45 cm) were tested against wide, 90 cm rows, the 45 cm rows were better in grain yield by 11% than the wider rows (90 cm) at a population of 60,000 plants/ha, while regardless of population (45,000 vs 60,000) the narrow rows reduced weed biomass by 58%[2]. Likewise, reducing row widths from 100 to 50 cm while testing widths of 50, 75 and 100 cm, is reported to have increased yield of maize grains linearly[3]. Closer rows are claimed to enhance early in the season maize growth rate[9] leading to higher efficiency of radiation use and greater kernel yield[10]. Some generalizations consider narrow rows in maize to be those ranging from 50 – 70 cm row width[11].

Narrowing row width is a means of increasing plant population. More often perhaps, increasing plant population is achieved by reducing inter-plant spacing within rows. Sometimes standard row spacing may be fixed where machine planting may be convenience. It also conveniences field operations in general. In such instance higher plant density can be by reducing within row spacing. In maize, within row spacing of not < 20 cm has been recommended[11]. This can result in 100,000 plants ha^{-1} density when inter-row width is 50 cm and about 71,428 plants/ha when the width is 70 cm (one plant per hill). Many experiments have tested plant densities within and beyond this range. When 50,000, 70,000 and 105,000 plants/ha were tested it was found on average that maize yield at the highest density was 48% and 44% higher than at density of 70,000 plants/ha in two consecutive years, respectively, while weed biomass was reduced respectively by 72% and 58%[7]. Testing 45, 60, 75 and 90,000 plants/ha, it also was found that the optimum was at 75,000 plants/ha[12]. In Brazil, kernel yield of maize was found to respond negatively to increasing plant density which was varied from 50, 65, 80, 95 to 110 thousands plants/ha[13]. In Pakistan, maize grain yield was found to increase with plant density increase ha^{-1} from 43,000 to 53,000 plants but remained insignificant thereafter at 67,000 plants/ha[14]. In Nepal, maize yields of 11.19t/ha at a population of 66,666 plants ha^{-1} against 10.54t/ha at 83,333 plants ha^{-1} and 9.52t/ha at 55,555 plants ha^{-1} have been reported[15]. Best plant population for yield therefore varies extensively.

Plant density can also be determined through number of seeds sown per hill rather than narrowing or increasing inter-plant spacing. At a standard row spacing of 76 cm, within row spacings of 16, 32 and 48 cm are reported to have been tested in maize varying seeds number $hill^{-1}$, where highest kernel yield (11.68t/ha) was found at the spacing of 48 cm, 3 seeds/hill and the lowest (6.51t/ha) at 48 cm one seed/hill[16]. The authors further observed that the highest yield was insignificantly different from yield at 32 cm 3 seeds/hill (11.26 t/ha) or from spacing of 16 cm one seed/hill (11.06t/ha) and concluded that kernel yield at the spacing of 16 cm decreased with per hill number of seeds, whereupon those at spacings of either 32 or 48 cm increased.

Optimum plant population for yield generally varies extensively with environmental conditions and over years. It tends to increase as environmental yield potential gets higher[6]. Accordingly to Tokatlidis I.S. low plant density recommendations are advocated for low input conditions but they suffer yield loss in occasional adequacy of resources.

Some authorities suggest that non-irrigated maize density should not exceed 70,000 plants/ha in dry-land farming systems due to moisture deficiency[17]. Earlier workers set the limit at 75,000 plants/ha for the drought prone environments[11]. Testing a rain-fed hybrid for 11 years (at the same location), it had been found further earlier that yield potential varied from 1.89 – 8.98 t/ha at optimum populations from 45,600 – 102,000 plants/ha and that as much as 100% yield loss can be expected in the driest season if the optimum population for the most favourable season is used[6]. Likewise in Hungary, averaging several maize hybrids over 3 decades, it was found that in dry years optimum population was 64,630 plants ha^{-1} with highest grain yield of 6.639t/ha, but in wet years optimum density was 80,790 plants ha^{-1} with yield 9.864t/ha; and consequently concluded that the optimum density was 20% lower in unfavorable years, and grain yield $^{1}/_{3}$rd less, than in favorable years[18].

Soil fertility is another important resource for realization of high crop yields through increasing plant density. Recommendations in China of 60,000 plants/ha maize density for medium fertility areas and 75,000 plants for high fertility areas are reported[19]. Nitrogen particularly, a major consideration in soil fertility, has been reported to interact with and was dependent upon plant density in maximizing maize yield[20]. In narrow rows with high plant density, high N uptake and N use efficiency have been reported[21]. It was argued later that narrowing row spacing enables plants to occupy uncovered spaces between plants, in so doing utilizing the applied fertilizer N that would otherwise be lost[16]. In Egypt, it is reported that under medium N rate (285kg N/ha) and high plant density (95,200 plants/ha), improved maize genotypes gave highest kernel yield of 17.6t/ha, and could result in about 19.9t/ha yield if N rate was 570kg/ha[22].

To-date improved variety genetics focuses on among other traits ability to withstand high densities (overcrowding) as a means to increase yield. Increases in corn yields over the past few decades have been correlated with breeding for tolerance to progressively greater plant densities [23]. It is documented that in the Corn belt of the United States, for example, gains in yield of 110 kg/ha/year in the period 1960–2000 correlated with increases in field population of 1000 plants/ha/year[5]. Mansfield and Mumm is noted to have further argued that in the US Corn belt plant density increased from 30,000 in the 1930s to an estimated average of 70,000 plants/ha in 2010[24]. Grain yield in the belt is reported to have increased from 1287 kg/ha in 1930 to 9595 kg/ha in 2010[25].

The same viewpoint is noted by other workers who report that average corn kernel yield in the United States increased dramatically during the 2nd half of the 20th century owing to improvements in management practices of the crop and greater tolerance of high plant densities by modern hybrids[22]. Researchers in Hungary report that optimum population density for maize hybrids increased by 8,000 plants/ha every 10 years from 1981 to 2010 and that rise in plant population density and the identification of hybrids in possession of high genetic yield potential at elevated plant population have been credible components in the increased maize yields in Hungary[18].

Thus there is no doubt that plant density studies are of great significance in efforts to maximize and optimize grain crop yields. The objective of this paper has been to highlight the importance of detailed plant population studies for increasing maize yields and to determine an optimized performance of the maize crop in the semi-coral area in the Tanzanian island of Pemba, through testing various densities with known commercial and locally adapted/cultivated varieties of the crop.

Maize is leading in importance among food crop produced in the semi-coral livelihood zone of the Pemba Island. Production of maize in the island suffers very poor yields of about 1.0 ton/ha[26]. For this reason production has never met demand. It is reported, however, that potential maize yield for the area can in the mean time be as much as 2.0 – 3.9 t/ha[26]. One of the very good reasons for poor yield is un-optimized plant density in the crop fields.

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 5^0 09′ latitude South and longitude 39^0 46′ East at an above sea level elevation of about 20 meters. The area receives a bimodal rainfall pattern, with long and sometimes heavy and erratic rains during March to June and short and normally very little rains from September to November. The mean, maximum and minimum temperatures are respectively 28, 32 and 22°C. Average humidity is 71.5% while average evaporation is 5.72 mm day^{-1}. A split plot factorial arrangement in Randomized Complete Block Design was used to lay out the experiment, which was replicated three times.

Three plant spacings (75 cm x 30, 25 and 20 cm respectively) were tested giving plant populations of respectively 44,444, 53,333 and 66,666 plants ha-1. 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 in Pemba, were used in the experiment. The varieties formed the main plots and plant population the sub-plots. Each treatment unit was planted on a 3m x 3m plot. The Main plots, sub plots and the replications were all spaced at one meter apart. Two seeds were planted each hill which seven days after emergence was thinned to one plant per hill to maintain the predetermined plant densities, then the field was managed optimally up to harvest.

Data were collected on plant height at physiological maturity, days to 50% flowering and maturity, cob parameters (length, weight), dry matter and grain yields, then analysed by ANOVA (Analysis of Variance) and mean separation using Genstat computer software.

Results and discussion

The experiment results are presented in Tables-1 - 5 and Figure-1. As indicated in Table-1 average plant height was raised significantly as plant population rose from 44,444 to 53,000 plants/ha (75cm x 30cm to 75cm x 25cm spacing) while dry matter yield increased significantly continuously even beyond the medium (53,333) plant density ($P \leq 0.05$). That is, it continued to increase even as plant density or population increased from the medium to the high (66,666) level. Unlike plant height, however, which between the medium and high density continued to rise though insignificantly, harvest index rose significantly towards the medium density then declined also significantly ($P \leq 0.05$) as population increased from medium to high.

Table-2 shows changes in reproductive cob and grain attributes as influenced by plant population. Cob parameters and size of grains were lowered by increasing plant density, while grain yield increased between low and medium density. The decrease was continuous for cob length, cob weight, grain weight per cob and size of grains (100 grain weight) but it was continuously significant only for cob length.

Between medium and high density cob weight, grain weight/cob and 100 grain weight were not significantly lowered while the same situation was observed for the 100 grain weight between the low and medium density ($P \leq 0.05$). Grain yield, whose increase between low and medium density was significant, decreased between medium and high density though the decrease was not statistically significant ($P \leq 0.05$). This pattern of population influence is further illustrated in Figure-1. Since cob length, cob weight, grain weight per cob and grain size were highest at the lowest plant density while grain yield was lowest, it is obvious that increased plant population rather than individual plant dry matter accumulation was responsible for the noted yield advantage, ideally for both dry matter and grain yields. Deduction can be made confidently from the results that plants increased in height alongside increasing plant density because of interplant competition for solar radiation. While increasing intensity of this competition was positive for growth in height, around plant population of 53,333ha^{-1} or beyond the competition became unfavourable for grain biomass accumulation.

Thus grain yield for maize production in the semi coral environment for the varieties of the crop used in this study can be optimized at plant population close to 53,333 or between 53,333 and 66,666 plants ha but not inclusive of the later. It is obvious that plant population of 44,444 (spacing 75 x 30 cm) was not desirable and that 75 x 25 cm spacing is desirable. Though it is not known what could be the actual yield in-between 53,333 and 66,666 plants/ha not inclusive, since the change in spacing between 75 x 25 cm and 75 x 20 cm is very small (5 cm intra-row), it can be practically acceptable to fix the optimum density at 53,333 plants/ha (75 x 25 cm spacing).

Results of the study also showed that there was differential response of the varieties used in this research to the variation in plant population. These interactive effects are presented in Tables-3, 4 and 5. Table-3 shows overall significant ($p \leq 0.05$) mean variation of the different growth and yield parameters measured in the study, for different varieties and the increasing plant density. Probability of significance of the differences between the various interactions of varieties with plant density, as shown in the Table range from 0.048 to < 0.001.

Table-1: Mean effects of plant population on growth and yield parameters in maize.

Population (Plants/ha)	Plant height (m)	Dry matter yield (t/ha)	Harvest index (%)
44 444	1.732 a	6.280 a	50.48 a
53 333	1.839 b	7.333 b	58.07 b
66 666	1.848 b	7.597 c	53.48 a
Mean	1.806	7.070	54.01
S.E.D	0.01619	0.0650	1.754
CV (%)	4.4	4.5	15.9
$LSD_{0.05}$	0.034	0.138	3.719
F. prob.	<.001	<.001	0.002

Table-2: Mean effects of plant density on cob and grain yield parameters in maize.

Plant densities (Plants/ha)	Cob length (cm)	Cob weight (g)	Grain wt/cob (g)	100 grain wt (g)	Grain yield (tons/ha)
44 444	19.45 c	230.6 b	164.6 b	27.65 b	3.229 a
53 333	17.80 b	179.5 a	129.9 a	26.73 ab	4.291 b
66 666	15.96 a	178.3 a	121.1 a	24.73 a	4.073 b
Mean	17.74	196.1	138.5	26.37	3.864
S.E.D	0.1157	12.26	9.33	1.098	0.1205
CV (%)	3.2	20.6	22.9	20.4	15.3
$LSD_{0.05}$	0.245	25.99	19.78	2.327	0.255
F. prob.	<.001	<.001	<.001	<.001	<.001

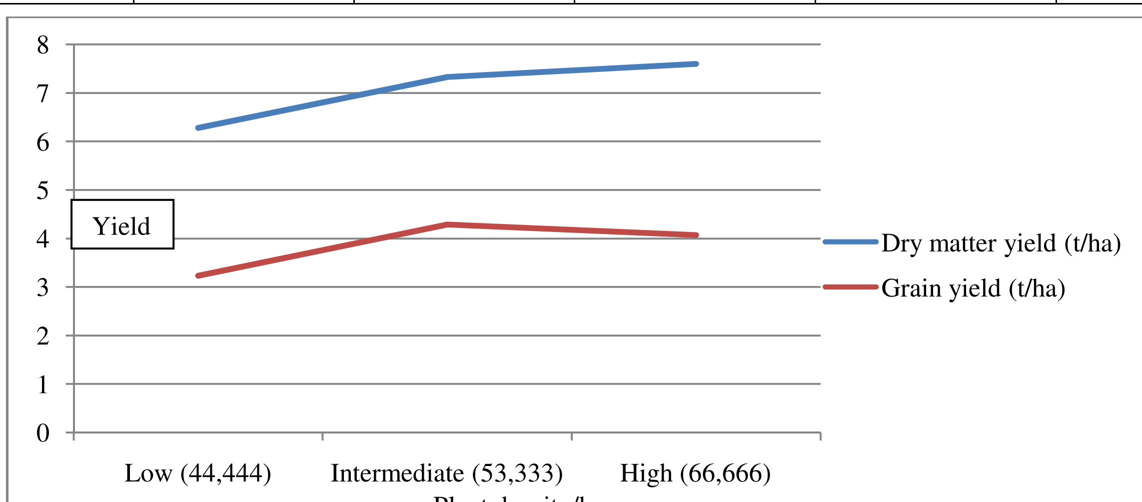

Figure-1: Response pattern of maize grain and dry matter yields under increasing plant density.

Table-3: Mean effect of variety x plant population interaction on growth and yield in maize.

Variety	Plant density (plants/ha)	Plant height (m)	Ear length (cm)	Grain wt. per/cob (g)	Dry matter (tons/ha)	Grain yield (tons/ha)
Staha	44 444	1.832 def	21.89 f	232.1 e	7.268 c	4.727 d
	53 333	1.893 ef	18.71 d	168.4 d	7.994 d	5.316 e
	66 666	1.909 f	17.37 c	143.9 cd	8.284 d	4.815 de
Situka	44 444	1.726 bcd	18.33 d	112.2 abc	5.673 a	1.958 a
	53 333	1.768 cd	17.17 c	98.2 a	7.069 c	3.462 c
	66 666	1.754 bcd	14.13 a	98.2 a	7.363 c	3.406 c
TMV-1	44 444	1.791 cde	17.47 c	101.1 ab	5.813 ab	2.801 b
	53 333	2.040 g	17.06 c	94.8 a	6.238 ab	3.420 c
	66 666	2.039 g	15.39 b	101.5 ab	6.388 b	3.268 bc
JKU	44 444	1.582 a	20.11 e	212.9 e	6.368 b	3.429 c
	53 333	1.654 ab	18.27 d	158.4 d	8.030 d	5.001 de
	66 666	1.691 bc	16.97 c	140.9 bcd	8.351 d	4.802 de
Mean		1.806	17.74	138.5	7.070	3.864
S.E.D		0.03111	0.2259	18.37	0.2720	0.2725
CV (%)		4.3	3.1	22.5	9.4	17.6
F. prob.		0.002	<.001	0.048	<.001	0.008

In a column, means with a common letter are not significantly different. Means separated by Tukey at 0.05 level.

Table-4 shows response trends of data parameters of the different varieties to varying plant density. All varieties showed the same response trend for grain and dry matter yields with respect to changes in plant population. With plant height, however, while in all varieties height increased as population was increased from 44,444 to 53,333; as population was further increased from 53,333 – 66,666 plant height for varieties Situka and TMV-1 decreased amidst increase in height for the other two varieties (Staha and JKU).

Table-5 elaborates variation of plant density effects on growth and yield parameters in different varieties of maize. Whereas there was generalized (overall) significant effect ($P \leq 0.048 - < 0.001$) of plant density on the data parameters indicated in the table, it was only with grain yield, dry matter yield and cob length that significance of the effect was uniformly the same ($P \leq 0.05$) in all varieties tested. For plant height, in the contrary, effect of plant density was significant only in varieties TMV-1 and JKU, while for grain weight per cob density effect was significant in Staha and JKU while in varieties Situka and TMV-1 it was not significant.

Conclusion

The study has shown that a small change in spacing, of only 5 cm, has resulted in significant change in yield of the maize crop. This is a cumulative effect of change in plant population accompanying spacing change. The study concludes that from intra-row spacing changes from 30 to 25 to 20 cm the intermediate spacing equivalent to plant population of 53,333 ha^{-1} was the optimum or very close to the optimum for the (highest) yield achieved (about 4.3 t/ha).

The results have also shown that the varieties tested displayed a similar trend in response to the plant populations tested. Since varieties yield response to spacing (density) is often different and is very determinant of yield performance, it is recommended that optimum plant populations should always be determined if a new variety of a crop enters into production, to assure the variety's specific response.

Table-4: Parameter trends for different varieties against increasing plant population.

Parameter and plant population increase	Response trend for different varieties			
	Staha	Situka	TMV-1	JKU
Grain yield				
44,444 – 53,333 plants/ha	Increased	Increased	Increased	Increased
53,333 – 66,666 plants/ha	Decreased	Decreased	Decreased	Decreased
Dry matter yield				
44,444 – 53,333 plants/ha	Increased	Increased	Increased	Increased
53,333 – 66,666 plants/ha	Increased	Increased	Increased	Increased
Plant height				
44,444 – 53,333 plants/ha	Increased	Increased	Increased	Increased
53,333 – 66,666 plants/ha	Increased	Decreased	Decreased	Increased
Cob length				
44,444 – 53,333 plants/ha	Decreased	Decreased	Decreased	Decreased
53,333 – 66,666 plants/ha	Decreased	Decreased	Decreased	Decreased
Grain weight per cob				
44,444 – 53,333 plants/ha	Decreased	Decreased	Decreased	Decreased
53,333 – 66,666 plants/ha	Decreased	Leveled off	Increased	Decreased

Table-5: Significance of differences of various plant performance data in different varieties of maize under varying plant densities.

Parameter	Significance of differences between plant densities in different varieties				Overall probability
	Staha	Situka	TMV-1	JKU	
Plant height	Not significant	Not significant	Significant	Significant	0.002
Cob length	Significant	Significant	Significant	Significant	< 0.001
Grain weight per cob	Significant	Not significant	Not significant	Significant	0.048
Dry matter yield	Significant	Significant	Significant	Significant	< 0.001
Grain yield	Significant	Significant	Significant	Significant	0.008

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