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Effects of Population Density and Water Stress on Morphology of Tropical Maize Genotypes

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Abstract

The growth and yield of maize is below potential, one of the reasons being water stress and low plant densities. Crop and field management combinations are required to sustain growth and reproduction in stress environments. Field experiments were carried out in the years 2015-2016 and 2016-2017 to evaluate the effects of water stress induced by population densities of 2.7 plants/ m^2, 5.3 plants/ m^2 and 7.9 plants /m^2 on minimum stem width, maximum stem width, stem height, stem volume, primary ear length and width and secondary ear length and width of four tropical maize genotypes, PAN413, PAN53, SC403 and SC727. The experiments were laid out as a Split-Plot Design with three blocks. Density of 5.3 plants/ m^2 led to a significant increase in minimum stem width, maximum stem width and stem volume but had no significant effect on primary ear length and width and secondary ear length and width. Interactions between the effect of density and hybrid had significant effect on minimum stem width, stem height, stem volume and secondary ear width. Results also showed a high reproductive effort of tropical maize hybrids because despite the larger stem volume being achieved at 5.3 plants/ m^2, the effect of density on reproductive morphology was not significant.

Keywords: Density; Hybrid; Water stress; Morphology; Interaction and reproductive effort

Introduction

Background

Maize productivity depends on genotype, soil fertility, water availability and the photo-thermal environment throughout the cropping season. That means for maize to achieve potential productivity there is need for optimum resources at the most critical phases of growth. The availability of these resources can be manipulated by sowing time, fertilization, population density and row configuration [1].

Worldwide, water is the most limiting resource for crop production. Environmental degradation, increasing demands for water by agricultural industries and the threat of global climate change challenge the sustainability of agriculture and socio-economic development in the semi-arid tropical areas [1]. Maize is monoecious and protandrous, so the unavailability of resources like water and nutrients will affect the synchronization of pollen shed from the tassels and silking due to sink strength of tassels hence poor kernel setting and more kernel abortion [2].

Problem Statement

Maize productivity in sub Saharan Africa is below potential, one of the reasons being low plant densities. Crop productivity increment requires new genotype and crop management combinations that support growth and partitioning to the reproductive organs in stress environments. However, conventional field based agronomic and breeding trials can incorrectly identify stress tolerance when the adaption mechanism is stress avoidance because the resource supply and demand ratio is not measured or estimable for each genotype. The maize crop might develop a deeper root system and reduce stomata conductance to reduce the rate of transpiration thereby enabling the crop to sustain water stress, thus drought

Drought tolerance is therefore the ability of a crop to sustain biochemical reactions and physiological development despite water stress [3]. More detailed characterization on crop management and environment effects on growth, development and yield formation of each genotype can accelerate yield gains with a combination of empirical and crop modeling approaches [4]. Grain number per unit area explains 80% of cereal yield variability globally and maize kernel number per plant is related to growth and partitioning during a critical four week period before and after silking. Temperate maize biomass can be estimated from the dimensions of stems and cobs [5]. However, the morphometric relationship is not established for tropical maize. In addition, the effect of stressed environment on the relationship between plant dimensions and biomass is not yet established for the semi-arid and sub-tropics.

Justification

Farmers in the semi-arid and sub-tropics do not have enough inputs to supplement the poor availability of resources to support growth, development and yield of maize. Farmers need to increase the yield by maximizing use of the available land especially in the smallholder sector, hence high plant population densities need to be used thereby inducing water stress. This experiment will assess the effect of density on the morphology for a range of genotypes of maize. Morphometric relationships with biomass will then be developed for pre-and-post-anthesis maize and therefore be used to support the eco-physiological analysis of yield formation in tropical maize.

Aim

To assess the effects of water stress and population density on vegetative and reproductive morphology of tropical maize genotypes to support yield formation.

Hypothesis

There is a negative effect of water stress and population density on maximum, minimum stem width and stem height of tropical maize genotypes at levels relevant for the semi-arid and sub tropics.

There is a negative effect of water stress and population density on primary ear length and width of tropical maize genotypes at levels relevant for the semi-arid and sub tropics.

There is a negative effect of water stress and population density on secondary ear length and width of tropical maize genotypes at levels relevant for the semi-arid and sub tropics.

Objectives

To evaluate the effect of water stress and population density on maximum stem width, minimum stem width, stem height and stem volume of tropical maize genotypes.

To evaluate the effect of water stress and population density on primary ear length and width of tropical maize genotypes.

To evaluate the effect of water stress and population density on secondary ear length and width of tropical maize genotypes.

Literature Review

Water Stress

According to Simpson [6], water stress in plants is the shortage of water within a plants' system which leads to reduction in the physiological processes like photosynthesis. Water stress in field conditions can be due to high rates of evapotranspiration to uptake ratio, high plant density per unit area or low soil moisture content. Water is of significance to the growth and development of plants since for most pivotal physiological processes like photosynthesis to initiate and progress, water is a pre-requisite. Limited water availability causes the leaves to wilt thereby closing the stomata which are the gateway for essential gases like carbon dioxide during photosynthesis and oxygen in respiration leading to poor growth and development and biomass accumulation [6].

Genetic by Environment Interactions

Phenotype is due to genotype plus environment plus genotype by environment interactions [7]. Maize hybrids differ in their growth characteristics depending on the genetic make-up [8]. That means different hybrids have continuous variation in performance even under similar environment conditions depending on the heritability of the desired character. For example, plant height is a quantitative trait, meaning it is affected by many genes, each with a minor and insignificant contribution to the trait of interest. Hence, the more the genes of tallness, the taller the plant compared to the other plant which has less genes of tallness under similar environments [7]. Heritability of a trait is summarized as: $Vp = Vg + Ve$, where Vp is phenotypic variation which is as a result of genetic variation (Vg) and environmental variation (Ve) [7].

Effects of Plant Density

Plant population density has major effects on vegetative growth and reproduction. Generally, yields tend to be reduced as the population density is reduced because of poor leaf area plasticity for each plant [9,10]. According to Trewavas [11], maize has poor capacity to develop new reproductive structures in response to an increase in available resources per plant. High plant densities lead to reduced availability of resources per plant in the period surrounding silking, generating a marked fall in yield per plant that is not offset by the increase in the plants number [12].

Soltani and Sinclair [13] show that high plant density led to an increase in dry matter production and a decrease in harvest index. However, an optimum plant density of 90cm by 30 cm eliminated such effects. Total leaf area and the vertical arrangement of the leaf profile affects the interception and utilization of photosynthetically active radiation of maize crop canopies, thus leading to poor maize dry matter accumulation and grain yield especially in planophile as compared to erectophile leaves [2]. Leaf area is influenced by genotype, population, soil fertility and climate [2]. Some experiments show that a leaf area index between 3 and 4 may be optimal for achieving maximum yield. Reduction in row spacing and increasing in row spacing at the same field population, thus rectangular planting pattern, reduces the leaf area index required to intercept 95% of the incident radiation due to an increase in the light extinction coefficient [14].

Crop growth rate is directly related to the amount of radiation intercepted by the crop [15]. Dehdashti and Riahinia [16] evaluated the effect of different row spacing and density of maize on total dry weight, leaf area index, net assimilation rate and crop growth rate. An increase in plant population increases leaf area index, total dry weight and crop growth rate, but decrease net assimilation rate [14]. Saberali [17] investigated the effects of density and planting pattern on growth and physiological indices of maize. The results showed that at high maize density, leaf area index, total dry weight and crop growth rate increases more than at low maize density.

An experiment was conducted in a tropical climate in Brazil with three row widths of 50cm, 75cm and 100cm. The outcome showed that high plant density reduced stem diameter, number of leaves, plant height, leaf length, cob length and cob weight [18]. Maximum stem width is obtained by increasing plant spacing thereby increasing light absorption through reduction in plant competition [18]. Increase in density can increase height relating to interplant competition over light and disruption of plant growth regulators [19]. Maximum stem diameter and leaf length is obtained from low densities since there is high per plant assimilate share hence ear length increases [20].

Adaptations to Stressed Environments

According to Trewavas [11] some adaptations to stressed environments are commonly associated with the capacity to withstand water-deficit stress. This is achieved through drought escape, dehydration postponement and dehydration tolerance mechanisms.

Drought-escaping species avoid stress by completing life cycles or reproductive phases before the onset of drought conditions. They exhibit phenological plasticity of reproduction by varying flowering time. In semi-arid environments, selection for earlier maturity generally results in the greatest yield. Maize yield is most sensitive to drought stress during the reproductive phase. Maize is protandrous, thus anthesis precedes silking and reports show that drought resistance is most directly associated with resisting silk delay [9].

Silk receptivity and growth is a function of atmospheric temperature and water stress. Pollen viability lasts for only a few days, thus when physiological stresses delay silk emergence until after anthesis there is poor pollination and reduced kernel number [13]. Synchrony of anthesis and silking is enhanced in some varieties by production of multiple ears and tillers. Usually, subtending ears and tillers flower after the tassel and upper ear of the main stalk. Thus, when stress delays silk emergence, the later flowering of tillers provides an additional opportunity for effective pollination [13]. Increased growth and development of female inflorescences is associated with water-deficit stress during initiation of tassel development [9]. Thus, water deficits at specific stages may promote ear prolificacy and tillering. Prolific and tillering maize hybrids extract more water and produce more grain than single-eared hybrids under water-deficit conditions thereby stabilizing yields and minimizing barrenness. Early development, phenological plasticity, synchrony of anthesis and silk emergence may be involved in the apparent drought escape of maize resulting in a high harvest index due to a high grain to vegetative biomass ratio [11].

Dehydration postponement mechanisms contribute to better yields by developing deeper roots, thick cuticles, reduced stomata conductance and leaf rolling. Moreover, dehydration tolerance consists of molecular adjustments that allow membrane and cellular structures and enzymes to be maintained during periods of water-deficit stress and to recover quickly when conditions become favorable. These characteristics may include osmotic adjustments, heat-shock proteins and hormonal changes [2].

In addition, reduced plant height results in the production of fewer leaves, earlier flowering, reduce lodging and increase reproduction, thereby increasing grain yield and harvest index. In an environment where water is limiting the smaller plant size reduces the water expenses for vegetative growth and maintenance, resulting in greater resource availability for grain production. Such maize varieties exhibit a higher grain production per unit leaf area and harvest index, consistent with the dry matter partitioning pattern of desert ephemerals, which emphasizes seed production with minimum vegetative growth [9]. However, under high densities it may not be realistic since the plants tend to grow tall in competition for light [13]. This high grain production per unit leaf area suggests that smaller leaf area does not limit grain productivity through less photosynthetic area; it also reduces surface area for transpiration [2]. Since light is not limiting in semi-arid and tropical environments, reduction in photosynthetic surface area may be compensated by water conservation strategies, thus reduced surface area for transpiration. Furthermore, a reduced leaf area enables stressed plants to maintain open stomata and continue photosynthesis [11].

Most maize hybrids maintain about 60% of their green leaf area at flowering distributed at or above the ear, and some ears located closer to the ground level especially of early-maturing maize varieties with small total leaf area index, and have greater proportions of leaf area above the ear. This arrangement improves grain productivity because leaves above the ear have higher photosynthetic rates and supply most of the photo-assimilates during grain-fill [11]. Breeding for higher grain yield in maize using increased selection densities has led to varieties that are adapted to grow at high population densities [21]. Yield being a quantitative trait, it is less heritable thus requiring high environmental back up [22].

Effect of Population Density on Growth

Maximum growth rates for ear length, ear biomass, stalk biomass, and tassel biomass reduce with increasing density [21,38]. For most traits, high plant density also leads to decreased phenotype thus poor gene expression. Final ear lengths and ear biomass are lower at high population densities compared with low population densities, tassel biomass decreases by almost 50% with an increase in density and also stalk biomass decrease with density [21]. Longer phenological stages have a positive association with yield and this is highly driven by density, with more stressful environments having shorter phenological phases and lower yield [23].

The Allometry of Reproduction within Plants

Plants produce biomass that is distributed to various structures and functions, including reproduction [24]. Plants first accumulate resources and build reproductive machinery through growth because resources allocated to functions or organs are unavailable for other functions or organs [24,36]. Maize is primarily composed of carbohydrates, so the dry biomass of a plant is usually proportional to the plant's energy content [25]. A portion of this energy is mobile, for example sugars and starches, and can be used for the production of reproductive structures. Therefore a plant's vegetative biomass represents the energy potentially available for reproduction [24]. Allocation is considered to be a ratio-driven process called 'partitioning'. A plant with a given amount of resources partitions them among different organs or functions [24]. This lead to the concept of 'reproductive effort' (RE=reproductive biomass/total biomass), which measures reproductive allocation [36]. Therefore in different population densities, maize shows varying efforts to reproduce due to more resources being partitioned to vegetative growth in order to compete for sunlight especially at high densities to prevent etiolating [24].

Research Methodologies

Study Site

The research trials were conducted at the University of Zimbabwe Farm, located eight kilometers from the University Mount Pleasant Campus along the Mazowe Road, under dryland conditions on clay soil. The farm is 1518m above sea level (-17.697880, 32.03731)and falls under natural farming region 2a which receives 700mm- 1000mm/ annum [26].

Crop Husbandry

Machine sowing was done at 3-4 seeds per station. The plots were thinned to one plant per station at the end of the heterotrophic phase. All plots were rain fed, thus water stress was only due to intra-specific competition amongst the maize crops and the plots were kept weed free. A rate of four hundred kilograms of compound D (N7P14K7) per hectare for basal dressing and two hundred kilograms of nitrogen per hectare was added as ammonium nitrate (N34.5%) at V6, because differences in plant growth among plants tends to stabilize at this stage [27,37,28].

Treatments and Experimental Design

Four maize genotypes, PAN413, PAN53, SC403 and SC727 were assessed for their morphological response to different stand densities (Table 1). A prioritization classified as contrasting in the stability of grain yield response to increased stand density across environments [28]. Each hybrid was grown at three stand densities 2.7, 5.3 and 7.9 plants per m^2. Treatments were distributed in a split plot design, density as main plot and all hybrids by stand density combinations were sub plots. The trial was carried out twice thus; 2015-2016 and 2016-2017 seasons and the data was combined for analysis.

Table 1: Maize genotypes

Genotype	Grain colour	Maturity
PAN413	White	Early
SC403	White	Very early
PAN53	White	Medium
SC727	White	Late

Data Collection

Data collection was done following the methodology of Rossini et al. [5]. Five plants from each experiment that were of similar size (visual assessment) were tagged at V3 in each plot. Vegetative (Vn) and reproductive (Rn) stages were analysed for all tagged plants [29]. Measurements included maximum stem width at the base of the stalk, minimum stem width, plant height from ground level to the ligule of the last fully expanded leaf, primary ear length and width and secondary ear length and width. Stem volume was obtained from the cylinder formula, using average stalk diameter and stem length for its computation. Prolific varieties' yield compensation was classified as primary ear, secondary ear.

Statistical Analysis

The effect of stand densities of 2.7, 5.3 and 7.9 plants per m^2 was evaluated for all described traits using Genstat package. Mean separation was done using Fisher's protected LSD. Response to treatment was analyzed by ANOVA. A confidence interval of 95% was used for estimating significant differences between hybrids.

Methodological Limitations

Biomass was not included because of time and labor constraints.

Results

Minimum Stem Width

There was a significant interaction between the effects of density and hybrid on minimum stem width (P-value =0.028). The thickest minimum stem width was observed at 5.3 plants/ m^2 (Table 2).

Table 2: Interaction between the effect of density and hybrids on minimum stem width

Density (plants/ m^2)	PAN53 (mm)	PAN53 (mm)	SC403 (mm)	SC727 (mm)
2.7	24.99b	22.35c	22.32c	25.23b
5.3	28.55a	28.59a	28.59a	27.40a
7.9	25.59b	24.14b	25.12b	24.79b
P-value LSD0.05 CV%	0.028 1.622 16.7			

Means followed by different letters are significantly different from each other at P α = 0.05.

Maximum Stem Width

Interaction between the effects of density and hybrid treatments on maximum stem width was not significant. Hybrid differences on maximum stem width were not significant (Table 3) whereas density treatment had significant difference (P-value <0.001) with the thickest maximum stem width being achieved at 5.3 plants/ m² (Table 4).

Table 3: Hybrid means of maximum stem width

Hybrid	Means (mm)
Pan413	29.59
Pan53	27.99
SC403	28.14
SC727	29.20
P-value LSD0.05 CV%	0.186 NS 19.1

NS = Not significant (P >0.05)

Table 4: Density means of maximum stem width

Density (plants/ m²)	Means (mm)
2.7 5.3 7.9	26.61c 31.90a 27.68b
P- value	<0.001
LSD0.05	0.979
CV%	19.1

Means followed by different letters are significantly different from each other at P α = 0.05.

Stem Height

There was a significant interaction between the effects of density and hybrid treatment (P-value <0.001). Density means also showed PAN413 etiolating with increase in density (Table 5).

Table 5: Interaction between the effect of density and hybrids on stem height

Density (plants/ m²)	PAN413 (cm)	PAN53 (cm)	SC403 (cm)	SC727 (cm)
2.7	106.2h	111.9ef	120.3b	115.2c
5.3	110.0g	123.1a	112.6e	110.2g
7.9	121.6ab	113.2de	114.6cd	110.8fg
P-value LSD0.05 CV%	<0.001 1.59 13.2			

Means followed by different letters are significantly different from each other at P α = 0.05.

Stem Volume

There was a significant interaction between the effects of density and hybrid treatments (P-value = 0.025). The biggest stem volume was achieved at 5.3 plants/ m² but SC727 had constant stem volume across densities (Table 6).

Table 6: Interaction between the effect of density and hybrids on stem volume

Density (plants/ m²)	PAN413 (cm³)	PAN53 (cm³)	SC403 (cm³)	SC727 (cm³)
2.7 5.3 7.9	568ef 829ab 690cd	492f 887a 591def	547ef 799ab 621cde	648cde 726bc 615de
P-value LSD0.05 CV%	0.025 106.3 29.8			

Means followed by different letters are significantly different from each other at P α = 0.05.

Primary Ear Length

Interaction between the effects of density and hybrid treatments was not significant. Hybrid differences on primary ear length were not significant (Table 7) and density treatment differences on primary ear length were also not significant (Table 8).

Table 7: Hybrid means of primary ear length

Hybrid	Means (cm)
Pan413 Pan53 SC403 SC727	34.99 35.10 34.15 34.93
P- value LSD0.05 CV%	0.730 NS 10.7

NS = Not significant (P > 0.05)

Table 8: Density means of primary ear length

Density (plants/ m²)	Means (cm)
2.7 5.3 7.9	34.22 35.65 34.51
P- value LSD0.05 CV%	0.453 NS 10.7

NS = Not significant (P >0.05)

Primary Ear Width

Interaction between the effects of density and hybrid treatments was not significant. Hybrids had a significant difference on primary ear width (P- value = 0.037). SC727 had a thicker primary ear width compared to SC403 but was not significant to PAN413 and PAN53 (Table 9). Differences in density treatment on primary ear width were not significant.

Table 9: Hybrid means of primary ear width

Hybrid	Means (cm)
Pan413 Pan53 SC403 SC727	5.735ab 5.828ab 5.518b 5.971a
P- value LSD0.05 CV%	0.037 0.3013 12.3

Means followed by different letters are significantly different from each other at P α = 0.05.

Secondary Ear Length

Interaction between the effects of density and hybrid treatments was not significant. Hybrid differences in secondary ear length were not significant (Table 10) and differences in density treatment on secondary ear length were also not significant (Table 11).

Table 10: Hybrid means of secondary ear length

Hybrid	Means (cm)
Pan413 Pan53 SC403 SC727	18.52 17.12 18.38 23.87
P- value LSD0.05 CV%	0.162 NS 27.7

NS = Not significant (P >0.05)

Table 11: Density means of secondary ear length

Density (plants/ m²)	Means (cm)
2.7 5.3 7.9	16.62 22.69 19.09
P- value LSD0.05 CV%	0.303 NS 27.7

NS = Not significant (P >0.05)

Secondary Ear Width

There was significant interaction between the effect of density and hybrid on secondary ear width (P- value = 0.031). Most hybrids had similar secondary ear width across all densities except PAN 53 which had thin secondary ear width at 2.7 and 7.9 plants/ m² (Table 12).

Table 12: Interaction between the effect of density and hybrids on secondary ear width

Density (plants/ m²)	PAN413 (cm)	PAN53 (cm)	SC403 (cm)	SC727 (cm)
2.7 5.3 7.9	1.88bc 2.69ab 2.83ab	1.15c 3.25a 1.87bc	1.54bc 2.47abc 2.33abc	2.19abc 2.03abc 2.30abc
P-value LSD0.05 CV%	0.031 1.347 29.0			

Means followed by different letters are significantly different from each other at P α = 0.05.

Discussion

Effects of Water Stress and Density on Minimum and Maximum Stem Width of Tropical Maize Hybrids

Results presented in Table 2 and Table 4 showed that a density of 5.3 plants/ m² gave hybrids the ability to accrue the thickest minimum stem width at the level of the fully expanded leaf and maximum stem width at the base of the stalk. This may have been due to less competition for moisture and nutrients amongst the plants at 5.3 plants/ m² compared to 7.9 plants/ m² and also due to a higher leaf area forming an even surface coverage at the density of 5.3 plants/ m² than at 2.7 plants/ m² which allowed the maize hybrids to capture enough sunlight for photosynthesis and reduce water loss through evaporation. In addition, the poor ground cover at 2.7 plants/ m² would have reduced leaf area index and left the field susceptible to surface evaporation. According to Stein et al. [21], increased density lowered maximum growth as shown in the current experiment. However, the current experiment has also shown that extremely low density also reduced maximum growth.

Effects of Water Stress and Density on Stem Height of Tropical Maize Hybrids

Density treatments had differences in stem height as presented in Table 5. Results showed a typical etiolating response of the maize hybrid PAN413 to density treatment, specifically at 7.9 plants/ m² in search for sunlight which was a result of intra specific competition for sunlight at increased density [24,39]. There was interaction between the effects of density and hybrid treatment on stem height with PAN413 being taller at 7.9 plants/ m², PAN53 being taller at 5.3 plants/ m² and SC403 being taller at 2.7 plants/ m². This response indicates that competition for light among plants and density of a crop is asymmetric [30,31]; thus light is captured more by dominating than by dominating individuals of the stand, thus mutual shading.

Effects of Water Stress and Density on Stem Volume of Tropical Maize Hybrids

The biggest stem volume was observed at 5.3 plants/ m² as presented in Table 6 which was different to stem volumes of both 2.9 plants/m² and 7.9 plants/m². Stein et al. [21] produced similar results where increasing density reduced stem volume. This also indicates maximum utilization of resources, whereby the leaf area harnessed enough photosynthetically active radiation and at the same time maintaining a less severe intra-competition for moisture. Competition for moisture could reduce photosynthesis which is a vital biochemical process for synthesis of plant biomass; hence biomass was related to volume. Stem volume at 5.3 plants/ m² represents the energy potentially available for reproduction [24]. A density of 2.7 plants/ m² had the smallest volume maybe due to poor leaf area index and exposure of the field to surface evaporation. Smaller stem volume at 7.9 plants/ m² might be due to intra specific competition for moisture. Similar results were observed by Edmeades and Daynard [32,33] where stalk volume decreased when den-sities increased. They attrib¬uted much of this decrease to shading caused by compet¬ing neighbors. Deng et al. [34] studied the effect of light competition on total biomass per unit area and showed that biomass per unit area increases linearly with plant density up to a point of maximum biomass per unit area.

Effects of Water Stress and Density on Primary Ear Length and Width of Tropical Maize Hybrids

The effect of density on primary ear length and width were not different as presented in Table 8 and Table 13 respectively. Hybrids had no difference in the primary ear length but SC727 had a thicker primary ear width compared to SC403 as presented in Table 4.8. This may be because of the differences in sink strength and reproductive effort of maize hybrids [35,28]. However, Stein et al. [21] presented contradicting results where increasing density led to a reduction in ear size.

Table 13: Density means of primary ear width

Density (plants/ m²)	Means (cm)
2.7	5.604
5.3	5.919
7.9	5.766
P- value	0.117
LSD0.05	NS
CV%	12.3

NS = Not significant (P >0.05)

Effects of Water Stress and Density on Secondary Ear Length and Width of Tropical Maize Hybrids

There was no difference of secondary ear length for the four hybrids and three density treatments. On the other hand, there was interaction between the effects of hybrid and density treatments, with PAN53 having the thinnest secondary ear width at 2.7 plants/ m² and 7.9 plants/ m². This is due to almost similar abilities of the plant to proliferate, similar reproductive sink strengths and partitioning of assimilates to reproductive components as observed by Weiner et al. [24], except for PAN53 which showed to have a bigger prolific sink at moderate densities.

Lastly, the results have also shown a high reproductive effort and a high harvest index at 2.7 plants/ m² and 7.9 plants/ m² because despite the bigger stem volume being achieved at 5.3 plants/ m², there was no difference in reproductive morphology. According to Rossini et al. [5], nitrogen application smoothed inter-plant variation, increased kernels per plant and reduced barrenness. Stein et al. [21] stated that breeding for higher yield in maize using increased selection densities has led to varieties that are adapted to grow and reproduce at high population densities.

Conclusions and Recommendations

Conclusion

In an effort to try and exploit the effect of population density and water stress on morphology of tropical maize genotypes, observations from this experiment have shown that density and the interaction between the effect of density and hybrid have effects on vegetative morphology of tropical maize hybrids but has no effects on reproductive morphology, thus tropical hybrids have a high reproductive effort.

Recommendations

I recommend that farmers should plant tropical maize hybrids at higher density since high density gives more plants and ears per unit area which cannot be compensated by either prolificacy or flexibility of the maize ears at lower density. It would be interesting to further assess the effects of density on soils with low water holding capacity like sandy soils which also lose water through percolation.

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