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EVALUATION OF HYBRID VARIETIES OF MAIZE AT DIFFERENT PLANTING DISTANCES

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Abstract. In semi-arid region, resource availability is a key factor limiting crop performance, and the effect of genotype × plant population density is great on maize (Zea mays L.) productivity. The main and interactive effects of four maize genotypes (SAGUNTO (V1), CRYSTAL F1 (V2), P2 700 (V3), and 720 (V4)) and three intra-row spacings (20, 25, and 30 cm) were evaluated for growth parameters, yield components, and grain yield under field conditions in Mosul, Iraq. This experiment was designed in a factorial randomized complete block design and replicated three times. The results showed that there were substantial genotypic differences for most of the agronomic traits. With a mean grain yield of 9.18 tons ha^{-1}, the 20-cm spacing recorded the highest yield, which was 18.2% and 39.2% higher than the 25-cm (7.77 tons ha^{-1}) and 30-cm (6.60 tons ha^{-1}) spacings, respectively. Genotype V1 (SAGUNTO) was the best of all the genotypes, obtaining the highest yield of 10.68 ton ha^{-1} at 20 cm spacing. A significant genotype × spacing (G×S) interaction was observed with V4 (720) being highly tolerant of wider spacing (7.23 tons ha^{-1} at 30 cm). The first two components, explaining a total of 62.94% of the variation, were strongly loaded with yield associated traits in the principal component analysis. The results highlight the need to optimize the density of maize plants to maximize productivity of the crop in semi-arid environments, depending on the specific genotype.

Keywords: Genotype, intra-row spacing, plant density, grain yield, yield components, semi-arid environment, genetic parameters, principal component analysis, maize, Zea mays L.

Introduction

Maize (Zea mays L.) is a key cereal crop worldwide for both human and livestock food and feed, and for industrial use. The genotype/crop management/environmental conditions interactions will affect the ultimate productivity. Agronomic practices, particularly plant density and plant arrangement, have a direct impact on inter-plant competition for light, water, mineral nutrients and soil volume and are the most important. Thus, the choice of planting geometry determines the plant architecture, root distribution, dry matter partitioning, yield components and final grain yield [1]. Evidence from planting-geometry research further supports this relationship [2].

A fundamental change in the balance between plant performance and yield/area occurs with variation in plant density. Narrow rows will increase the number of plants per unit area, but may also increase inter-plant competition and reduce growth of the plants. However, more space will increase the resource available per plant, but reduce the number of productive plants per hectare. Therefore, the spacing/overall productivity issue cannot be completely understood with the per plant productivity. Recent publications have emphasized the sensitivity of maize to planting geometry and the sensitivity is highly dependent upon planting environment and genotype [3]. Further work also identifies density-dependent responses [4].

Genotypic variation is more important because there is a significant variation in the hybrids of modern maize crops with respect to canopy structure, leaf angle, root system development, source–sink relations, and crowding stress tolerance. Therefore, the optimum planting rate for one hybrid might be different from that of another hybrid. There has been significant variation among commercial maize hybrids in their response to intra-row spacing both documented and reported recently [5] and there is a strong interaction between the maize hybrid and intra-row spacing for some yield components.

Despite all the research carried out around the world to investigate the maize planting density effect on yield, very little is known about the variation in response to intra-row spacing of different maize genotypes under specific edaphic and climatic conditions, such as those in northern Iraq. It is essential to undertake in-depth field evaluation for the successful local adaptation of introduced or commercially available genotypes under target production environments. Therefore, the objectives of this study were to evaluate the main effect of genotype and intra-row spacing on growth and yield traits, to investigate the genotype x intra-row spacing interaction and to explain the multivariate relationships between the growth and yield traits by using principal component analysis (PCA).

Methods

The experimental site and growing season vary.The experimental site and growing season are variable.

The field experiment took place at the Center for Arid Farming and Conservation Agriculture Research, research station, University of Mosul, Iraq in the autumn cultivation season of 2024. The experiment was carried out under the environmental conditions of the region and irrigation and the usual agronomic techniques were used in accordance with the requirements of the crop's phenology.

Genetic Materials

Four maize genotypes were tested:

Origin: Spain.SAGUNTO V1 – Origin: Spain.

1. V2: CRYSTAL F1
2. V3: P2 700 (Origin: Türkiye)
3. V4: 720 (Origin: USA)

The materials used in seed were purchased from the Department of Field Crops with College Agriculture, University of Kirkuk.

Separate designs for experimental and treatments. Experimental design and treatments separate.

The study was based on factorial experiment in randomized complete block design (RCBD) with three replications. The factors were:

Factor A (Genotype): V1, V2, V3, V4

Inter-row spacing was kept at 75 cm while the intra-row spacing was set as 20, 25 and 30 cm. The experimental plots were two rows long, 2 m each, for a total of 3.0 m². Three seeds were planted on each hill and thinned to 1 plant on each hill after germination to get uniform stand establishment.

Crop Management

The land preparation consisted of two plows perpendicular to each other with a moldboard plow, followed by harrowing and leveling. At planting, triple superphosphate was applied at a rate of 200 kg ha^{-1}. The total application of urea (46% N) was 400 kg ha^{-1} which was split into two applications as 400 kg ha^{-1} of 46% N urea – planting and 400 kg ha^{-1} of 46% N urea – 1 month after planting. Irrigation was controlled according to the agronomic needs of the crop, according to the usual recommendations of the region.

Traits Evaluated

Observations were made on the following traits: Plant height (PH, cm), Leaf number (LN), Leaf area (LA, m²), Ears number per plant (ENP), Ear weight (EW, g), Ear diameter (ED, cm), Kernel rows per ear (KRPE), Kernels per ear (KPE), 500-kernel weight (KW500, g) and Grain yield per plant (GYPP, g). Grain yield per hectare (GYH, tons ha^{-1}) was determined from the actual plant density at each plant spacing treatment.

Statistical Analysis

Analysis of variance (ANOVA) using SAS software was conducted on the data in a factorial RCBD. Duncan's Multiple Range Test ($P<0.05$) was used to separate means for treatment. It was observed that the statistical model used was: $Y_{ijk} = \mu + R_k + G_i + S_j + (G\times S)_{ij} + \epsilon_{ijk}$, where Y_{ijk} is the observed value; μ is the overall mean; R_k is the replication effect; G_i is the genotype effect; S_j is the spacing effect; $(G\times S)_{ij}$ is the interaction effect; and ϵ_{ijk} is the experimental error.

Genetic Parameter Analysis

Standard quantitative genetics formulae were used to determine genotypic (σ^2_G), phenotypic (σ^2_P) and environmental (σ^2_E) variances, broad-sense heritability (H^2_B), genetic advance (GA) and genetic advance as a percentage of the mean (GAM%).

Principal Component Analysis (PCA)

Multivariate relationships were summarized using PCA of standardized trait data. The contribution of each trait to the principal components were interpreted using component loadings to pinpoint the most important yield-determining traits and the ideal ideotypes.

Results and Discussion

Analysis of Variance

By ANOVA, the genotypic effects were extremely significant for the plant height (PH), leaf area (LA), ear weight (EW), ear diameter (ED), kernel weight per ear (KRPE), kernel per ear (KPE), kernel weight 500 (KW500) and grain yield per plant (GYPP). Intra-row spacing significantly influenced on PH, LN, EW, KRPE, KW500 and GYPP. More important, there was a large genotype × spacing interaction for PH, LN, EW, KPE, KW500 and GYPP indicating that the genotype × spacing interaction is not uniform among all the hybrids and traits.

Genotypic Performance

There were differences in agronomic profiles among the genotypes. Vigorously vegetative plants of V3 produced the tallest plants (253.45 cm) as it reflects good vegetative vigour. V1, however, showed significantly better reproductive performance, as reflected in the highest mean ear weight (161.50 g) and grain yield per plant (158.60 g plant-1) along with better ear and kernel parameters which reflected efficient allocation of assimilates to the sink organs.

Table 1. Mean performance of maize genotypes for key agronomic traits

Genotype	PH (cm)	LN	EW (g)	KPE	KW500 (g)	GYPP (g plant⁻¹)
V1 (SAGUNTO)	230.41 b	12.96	161.50 a	134.76 a	733.28 a	158.60 a
V2 (CRYSTAL F1)	213.96 c	13.44	126.30 c	86.65 b	692.83 a	137.34 b
V3 (P2 700)	253.45 a	13.11	138.20 bc	93.86 b	667.60 a	131.80 b
V4 (720)	207.07 d	13.07	143.70 b	95.92 b	577.94 b	147.88 ab

Means followed by different letters within a column are significantly different at P ≤ 0.05

Effect of Intra-Row Spacing on Grain Yield per Hectare

These differences among the treatments were significant when the per-plant yields were expressed as area-based yields (Table 2). The spacing of 20 cm gave the highest mean grain yield of 9.18 tons ha⁻¹ which was significantly higher than the 25-cm (7.77 tons ha⁻¹) and 30-cm (6.60 tons ha⁻¹) spacings.

Table 2. Grain yield per hectare (tons ha⁻¹) as affected by intra-row spacing

Spacing (cm)	Plant Density (plants ha⁻¹)	Mean GYPP (g plant⁻¹)	GYH (tons ha⁻¹)
20	66,666	137.70	9.18 a
25	53,333	145.59	7.77 b
30	44,444	148.41	6.60 c

Means followed by different letters within a column are significantly different at P ≤ 0.05

Genotype × Spacing Interaction for Grain Yield per Hectare

The genotype × spacing interaction was found significant in the case of grain yield per hectare (Table 3). The highest yield (10.68 tons ha⁻¹) came from V1 × 20-cm combination, and the lowest yield (5.96 tons ha⁻¹) came from V3 × 30-cm combination. Specifically, V4 (720) exhibited an outstanding response at 30-cm spacing (7.23 tons ha⁻¹) which proves its tolerance to wider spacing and lower plant densities.

Table 3. Grain yield per hectare (tons ha⁻¹) as affected by genotype and intra-row spacing interaction

Genotype	20 cm	25 cm	30 cm	Mean (tons ha⁻¹)
V1 (SAGUNTO)	10.68 a	9.07 a	6.47 c	8.74
V2 (CRYSTAL F1)	8.26 b	7.28 b	6.74 bc	7.43
V3 (P2 700)	7.96 b	7.57 b	5.96 c	7.16
V4 (720)	9.82 ab	7.13 b	7.23 b	8.06
Mean (tons ha⁻¹)	**9.18**	**7.77**	**6.60**	**7.85**

Means followed by different letters within rows or columns are significantly different at P ≤ 0.05 according to Duncan's multiple range test

Multivariate Insights: Principal Component Analysis (PCA)

Principal Component Analysis (PCA) was useful for summarising multivariate data structure, the first two components which together accounted for 62.94% of the total variance (PC1: 46.12% and PC2: 16.82%). The PC1 was highly positively loaded on the ear weight (0.432), kernel per ear (0.403), 500 kernel weight (0.415) and the grain yield per plant (0.397) and was thus considered as the most important "Yield Potential" factor. On the other hand, PC2 had a high negative loading on plant height (−0.611) and moderate negative loadings on leaf area (−0.447) and kernel rows per ear (−0.348), suggesting a physiological tradeoff between the vegetative investment and reproductive efficiency in this plant. A logical extension of the above would be that a corresponding PCA biplot visualization would cluster the high yielding genotypes (e.g. V1) in the positive quadrant of PC1 away from the genotypes with excessive vegetative growth (e.g. V2). The approach is a multivariate one, which plays a key role in the

selection of the optimum phenotypes (ideotypes) which is desirable to combine desirable traits and which directly helps in using the targeted hybridization strategy in maize breeding program [6].

Table 4. Principal component loadings for studied maize traits

Trait	PC1 Loading	PC2 Loading
Plant Height (PH)	0.041	-0.611
Leaf Number (LN)	-0.014	0.327
Ears Number per Plant (ENP)	0.250	-0.272
Ear Weight (EW)	0.432	0.021
Ear Diameter (ED)	0.391	0.195
Kernel Rows per Ear (KRPE)	0.227	-0.348
Kernels per Ear (KPE)	0.403	0.224
500-Kernel Weight (KW500)	0.415	0.171
Leaf Area (LA)	0.228	-0.447
Grain Yield per Plant (GYPP)	0.397	0.082
Explained Variance (%)	**46.12%**	**16.82%**

Genetic Parameters

Genetic parameters estimates are essential for breeding programmes. The broad-sense heritability and genetic advances per cent of mean (GAM) of these traits were high; plant height (32.29%) and grain yield per plant (61.19%) indicating that they are highly responsive to direct selection based on their phenotypic traits. The same conclusion could be drawn for ear weight with high heritability (88.15%) and a moderate-high genetic advance (29.86%), as there was little environmental masking effect and the phenotypic selection of ear weight for this crop was a reliable one in similar semi-arid regions.

Table 5. Genetic parameters for studied maize traits

Trait	Mean	σ^2g	σ^2p	GCV (%)	PCV (%)	H^2 (%)	GA	GAM (%)
PH (cm)	226.22	1270.96	1284.60	15.76	15.84	98.94	73.05	32.29
LN	13.15	0.025	0.337	1.19	4.41	7.33	0.088	0.67
EW (g)	142.43	484.48	549.57	15.45	16.46	88.15	42.53	29.86
GYPP (g)	157.38	3490.07	5573.59	37.54	47.44	62.62	96.30	61.19

Discussion

The large differences in the genotype were due to differences in canopy structure and partitioning of assimilates. The high per plant production of V1 is consistent with its genetic composition, and the high vegetative growth of V3 is typical of its genetic makeup; under the conditions evaluated, it was an extremely efficient source–sink system. Previous agronomic research also highlights the influence of nutrient uptake and water-use efficiency on maize performance [7].

From this it is concluded that the importance of the management lever of space management is proved if there is a significant response to intra-row spacing. The spacing of 20 cm was achieved and the yield of 9.18 ton ha^{-1} was realized, which is similar to the high yielding maize production system under optimum management of semi-arid areas. This compares with the per plant yield analysis in which wider spacing sometimes resulted in higher yield per plant, but lower yield per plant area due to fewer plant areas. A long-term synthesis found that both

optimal population density and increased per-plant productivity contributed to maize yield gains [9]. Yield–density responses also vary by productivity environment and hybrid characteristics [10].

The significant G×S interaction is of paramount importance for breeding and agronomy. It shows the significance of considering the production system when assessing the genotype. The spacing of 20 cm is one of the favorable interactions and V1 displays an outstanding performance. The high yield of V4 at 30-cm spacing (7.23 ton ha−1) compared to other genotypes at the same spacing (5.96–6.74 ton ha−1), however, indicates differential adaptation to plant density stress. This has relevance if farmers are interested in mechanized planting and/or wider spacing for weed control. Density-stress management can further influence the extent to which potential yield is realized [11]. Earlier work identified plant population as a major determinant of maize growth and ear development [12].

The productivity of maize was greatly affected by the planting geometry under the semi-arid conditions and the range of yields obtained (5.96-10.68 ton ha^{-1}) just proves that. The results are similar to those obtained by Hamoda and Dabbour [3] in maize hybrids where yield differences of 40–60% were obtained under the different spacings; and by Kara et al. [2] who stated that planting geometry needs to be assessed at the plant and area levels. Other experimental evidence supports matching genotype selection with plant density [13]. Field evaluation of maize hybrids under varying densities has likewise demonstrated the importance of local growing conditions [14]. Changes in source–sink balance can also affect dry matter accumulation during grain filling [15].

The high broad sense heritability for plant height (98.94%) and grain yield per plant (62.62%) along with high genetic advance indicated that both the traits were highly influenced by additive gene action. The result agrees with Gonçalves et al. [5] and Zhang et al. [4] who found that direct phenotypic selection is effective in the breeding programs of maize for yield under semi-arid conditions. Quantitative-genetic interpretation follows established approaches to partitioning genetic and environmental variation [8].

Conclusions and Recommendations

The results of this research indicated that maize hybrids behaved differently in response to intra-row spacing under the semi-arid conditions of Mosul, Iraq and therefore selection of appropriate hybrid should be based on the nature of the crop and its adaptation to the system of planting to achieve maximum production. The results indicated that there were no best row spacings for all the hybrids evaluated and that certain planting recommendations should be made for each individual hybrid depending on its growth characteristics and yield.

V1 (SAGUNTO) genotype combined with 20-cm introw proved to be the most productive genotype and distance of rows spacing in the present study and the highest grain yield of 10.68 tons ha^{-1} was reported. However, the V4 (720) genotype yielded 7.23 tons ha^{-1} under 30-cm spacing, indicating it might be appropriate to increase planting distance. These responses, however, need to be assessed in other environments and management systems to ensure their stability.

The findings also indicate that yields per hectare should be the most relevant parameter to assess agronomic productivity and for making practical suggestions relating to planting; other yield parameters (per plant yield, harvest index, plant population, and economics) should be considered afterwards. Moreover, high broad sense heritability estimates and genetic gain for selected traits were available in maize breeding and phenotypic selection benefits could be significant; however, gains from phenotypic selection ought to be evaluated in different environments.

Finally, the study highlights that maize productivity optimization should be evaluated considering the genotype selection and planting geometry. The genotype, V1 (SAGUNTO), performed best with 20-cm spacing between rows. V1 (SAGUNTO) was found to be an appropriate genotype to maize production systems under similar semi-arid conditions, and can be used as a reference genotype to be validated.

Research Limitations and Future Directions

Only one geographic area, and one season, was studied. Further analysis in other environments is needed to assess consistency of these G×S interactions through AMMI or GGE biplot analysis. Moreover, a link between physiological data (radiation use efficiency, root structure and water use efficiency) and detailed economic evaluations will be able to help to fill this separation between potential and actual recommendations for farmers.

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