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Research Article

Efficiency on the Use of Radiation and Corn Yield under Three Densities of Sowing

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Aiming to evaluate sowing densities and efficiency of radiation use, six corn genotypes, three from open pollination ("Amarillo Almoloya," "Cacahuacintle," and "Jiquipilco") and three hybrids ("Z-60," "Condor," and "H-50"), were sown at densities of 6.9, 7.8, and 8.9 plants m^{-2}, under a split plot design, within a factorial arrangement of treatments during three years (2008, 2009, and 2010). Evaluated variables were yield, harvest index, biomass production, attenuation coefficient, and radiation use efficiency. Results indicate that 2008 was the best year because yield, biomass, and radiation use efficiency were 1132.6, 3505 gm^{-2}, and 0.79 g MJ^{-1}, respectively. "Jiquipilco" was the genotype that exhibited the best adaptability to climatic conditions of the zone; thus, it is recommended to be grown on the studied zone.

1. Introduction

The maize (*Zea mays* L.) is of family Gramineae domesticated by indigenous cultures in Mesoamerica region, particularly in the Tehuacan-Cuicatlan Valley in Mexico [1]. It is considered a staple crop on human diet because it supplies carbohydrates needed to obtain metabolic energy. It is also used to grow huitlacoche gall that is used for human consumption [2, 3]. Among environmental factors that affect yield significantly, we may cite solar radiation that interacts with water absorption, nutrients, and temperature [4], influencing the photosynthesis process, which, in turn, determines biomass accumulation on crops; this has been corroborated by [5] who mentioned that solar radiation is a key to determine the plant growth factor. Factors that affect this process are solar light interception and utilization, through crop canopy structure, to transform light in photo assimilates and to transfer carbohydrates to demanding organs [6]. For corn production, dry matter accumulation is one of the more important yield components and this, in turn, is the result of interception and use of the incident solar radiation on the foliage structure of the crop during the growing cycle [7]. To increase grain yield on corn, it is important to increase the amount of intercepted radiation that depends on the variety, sowing density, sowing date, and stage of development [8]. To reach high levels of intercepted radiation, the development of a high leaf area index since early growth stages [9] is needed. An optimum leaf area index (LAI) is the one that allows the maximum dry biomass production, and this is reached when lower canopy leaves maintain a positive balance of carbon; this means when the crop absorbs the whole photosynthetically active radiation (PAR) [10]. Photosynthetically active radiation (PAR) intercepted by the crop is transformed in biomass; thus, the lineal relationship among these variables represents radiation use efficiency (RUE) that is expressed in g of dry matter (DM) per MJ^{-1}

intercepted [11]. Concerning this aspect, [12] mentioned that, in maize, EUR can vary from 2 to 3.4 g per MJ^{-1} depending on the genotype, physiological stage, sowing density, and region. On the other hand, [13] mentions that high population densities on maize intercept higher amounts of radiation increasing significantly biomass production up to 1400 gm^{-2} influencing determinately the final grain yield. Concerning managing practices on the crop, [14] suggests that this have influence on the yield of corn. Population density allows for having anticipated higher canopy in the crop, favoring biomass production. Population density affects efficiency on use of radiation and vegetative and reproductive process of corn growth and directly influences the use of agricultural inputs (water, varieties, and nutrients) [15]. Concerning the final number of grains on ear, it is established that this variable is in close relationship with yield, as it has been demonstrated by the high correlation coefficients between both variables [16]. In this study, six cultivars were evaluated during three years (2008, 2009, and 2010) under three population densities aiming to assess the radiation use efficiency, intercepted radiation, biomass production, and grain yield. Results will help to define the best cultivar for the studied region.

2. Materials and Methods

This study was performed at Toluca, Mexico, 19°24′N, 99°54′W, at 2611 masl. Climate is mild temperate [$Cw_1(w')eg$], with a rain period from June to September and dry winters. Rainfall ranges from 800 to 1250 mm and annual average temperature is 12°C, ranging from 7 to 14°C. The warmest month corresponds to May, before summer solstice [17]. Soil is vertisol type in formation process [pH = 6,6; 0,30 m depth; 2,6% organic matter; initial phosphorous level of 5,8 mg/kg according to Bray and Kurtz method, and cation-exchange capacity (CEC) of 14,5 Cmol(+) kg^{-1} of air-dried soil]. Three open pollinated corn land races ("Amarillo," "Cacahuacintle," and "Jiquipilco") and three hybrids recommended for this region of intermediate growing cycle (90–100 days to male flowering), "Z-60" (single cross hybrid), "Condor" (three-line hybrid), and "H-50" (double cross hybrid) [18], were evaluated. Sowing was performed by hand on April 9, 2008; April 10, 2009; and April 17, 2010. Three seeds were placed per hole. Plants were thinned at the stage of four leaves, leaving one plant per hole. Topological arrangement to get desired density for each treatment (6.9, 7.8, and 8.9 plants m^{-2}) was 18, 16, and 14 cm between plants, respectively. Data analysis was under a factorial design on split plots. Main plots were population densities (6.9, 7.8, and 8.9 plants m^{-2}) and smaller plots were cultivars ("Amarillo," "Cacahuacintle," "Jiquipilco," "Z-60," "Condor," and "H-50"). Treatments were distributed by a randomized blocks design with three replications. Experimental units were five rows 5 m long with 80 cm between rows. Useful plot was integrated by the three central rows. At sowing, fertilizer was applied with the formula 90-90-46 applying urea, calcium triple superphosphate, and potassium chloride, respectively, and other 90 Kg N Ha^{-1} (urea) were applied at hilling, 40 days after sowing. Experiments were established with watering at sowing; crop fulfilled its water requirements with rainfall. Evaluated variables were as follows: (1) For leaf area (LA), on each treatment, 5 plants were removed at male flowering, leaves were measured with a leaf area meter Li-Cor 3100, and average was determined and expressed in cm^{-2}, (2) Leaf area index (LAI) was determined by the formula: (LA)(PD)/SA, where PD is planting density and SA is sown area [19]. (3) For number of grains (NG, m^{-2}), at harvest, measured on 10 ears, grains were counted and an average per ear was obtained. (4) Grain yield (Yield gm^{-2}) is the average weight of grain (14% moisture) from 10 ears. From the weather station of Agricultural Sciences Faculty, Mexico State Autonomous University, located on the studied area, data on maximum, minimum, and average temperature, rainfall, and incident global radiation (IGR) were registered during the experiment period. Intercepted radiation IR expressed in percentage was measured at male flowering on each treatment with a sensor Li-Cor 191. This variable was measured at solar noon at soil level. Radiation use efficiency (RUE) was expressed as g MJ^{-1} and obtained through formula: RUE = (YIELD/PAR)(IR) being YIELD.

3. Results and Discussions

Table 1 shows ANOVA for years, population densities, and cultivars. Highly significant differences were detected for year factor concerning biomass, radiation use efficiency (RUE), and yield, while for LAI and number of grains (NG) only significant differences were detected. In relation to factors population density and cultivars, all variables exhibited highly significant differences except for leaf area index. Concerning the interaction of studied factors, years with densities were highly significant for RUE. For interaction year with cultivar, highly significant differences were detected for K, NG, RUE, and yield. Variation coefficient ranged from 6.4 to 19.1%. Best growing cycle was 2008 with an average yield of 1132.6 g m^{-2}, surpassing years 2009 and 2010 by 14.1 and 16.3%, respectively. This result is attributed to higher average on the variables biomass 3505.9 g m^{-2} and to RUE of 0.79 g MJ^{-1}, having highest values concerning LAI, k, and GN with values of 3.6, 86.1%, and 2824 grains m^{-2}, respectively. During 2008 highest rainfall was registered, compared with other evaluated years and plants exhibited the highest leaf area and, thus, the highest number of grains, but not on dry matter of grain due to higher distribution of photo assimilates to caryopsides. Concerning the grain yield, the highest was for 2008 with 1132.6 g m^{-2}, excelling years 2009 and 2010. This is attributed to the fact that, on these years, due to the low rainfall, plant distributed carbohydrates to the grain. This factor also affected LAI, IR, and K. Concerning the population densities, higher density (8.9 plants m^{-2}) exhibited the highest values for LAI, IR, K, GN biomass, yield, and RUE with 3.82, 88.6%, 0.66, 346.9 g m^{-2}, 3476.6 g m^{-2}, and 0.68 g m^{-2} MJ^{-1}, respectively. These values were expected because, increasing the number of plants per area, the values of studied variables increase. With a higher LAI, more solar radiation is captured, and more biomass

Table 1: Analysis of variance and mean separation densities of three to six maize cultivars evaluated in years 2008, 2009, and 2010.

Factor	LAI	IR (%)	K	GN m^{-2}	Biomass $g\,m^{-2}$	Yield $g\,m^{-2}$	RUE $(g\,MJ^{-1})$	HI
Years (Y)	*	NS	NS	*	***	***	***	NS
2008	3.3^{b}	85.1^{a}	0.64^{a}	2588.1^{b}	3505.9^{a}	1132.6^{a}	0.79^{a}	0.323^{a}
2009	3.6^{a}	86.1^{a}	0.62^{a}	2824^{a}	2784.7^{b}	951.4^{b}	0.51^{c}	0.342^{a}
2010	3.5^{ab}	85.6^{a}	0.63^{a}	2706^{ab}	2909.1^{b}	964.1^{b}	0.54^{b}	0.333^{a}
$DSH_{0.05}$	0.21	3.33	0.033	158.3	233.7	59.1	0.033	0.0439
Density (D)	***	***	***	***	***	***	***	NS
6.9 plants m^2	2.95^{c}	81.83^{b}	0.60^{b}	2382.8^{c}	2687.6^{c}	931.8^{c}	0.54^{c}	0.351^{a}
7.8 plants m^2	3.55^{b}	86.32^{a}	0.62^{b}	2688.4^{b}	3114.6^{b}	992.1^{b}	0.58^{b}	0.333^{a}
8.9 plants m^2	3.82^{a}	88.59^{a}	0.66^{a}	3046.9^{a}	3397.7^{a}	1150.2^{a}	0.68^{a}	0.349^{a}
$DSH_{0.05}$	0.211	3.33	0.032	158.3	233.5	59.1	0.033	0.038
Cultivars (C)	***	**	***	***	***	***	***	NS
"Jiquipilco"	3.8^{a}	86.42^{ab}	0.66^{b}	2768^{ab}	3390.8^{ab}	1156.1^{a}	0.67^{a}	0.341^{a}
"Amarillo Almoloya"	3.12^{c}	85.02^{b}	0.61^{c}	3022^{a}	3003.2^{b}	1052^{ab}	0.62^{ab}	0.361^{a}
"Cacahuacintle"	3.75^{a}	89.2^{a}	0.70^{a}	2139^{c}	3646.8^{a}	964.9^{bc}	0.60^{bc}	0.264^{a}
"Condor"	3.28^{bc}	84.2^{b}	0.59^{cd}	2889^{a}	2947.30^{b}	1021.7^{bc}	0.57^{bc}	0.347^{a}
"H-50"	3.70^{ab}	89.9^{a}	0.61^{cd}	2898^{a}	2980.1^{b}	990.1^{bc}	0.58^{bc}	0.332^{a}
"Z-60"	3.04^{c}	83.5^{b}	0.58^{d}	2518^{b}	2431.9^{c}	936.7^{c}	0.55^{c}	0.389^{a}
$DSH_{0.05}$	0.43	4.70	0.034	346.2	475.3	90.34	0.051	0.521
$Y * D$	ns	ns	ns	ns	ns	ns	***	ns
$Y * C$	ns	ns	**	**	ns	***	***	**
$D * C$	ns	ns	**	ns	**	**	**	ns
$Y * D * C$	ns	ns	ns	ns	*	ns	ns	**
CV%	15.7	6.9	6.41	16.1	19.1	11.2	10.8	18.8

$^{***}P \le 0.001$, $^{**}P \le 0.01$, $^{*}P \le 0.05$, and ns: no significant difference. Columns with the same letter in each study factor are statistically equal ($P \le 0.05$); HSD: honest significant difference; CV: coefficient of variation; LAI: leaf area index; IR: intercepted radiation; K: light attenuation coefficient; GN: grain number; EUR: efficiency in the use of radiation; HI: harvest index.

is produced, increasing the number of grains per area and so yield is increased and also RUE. Regarding the cultivars, "Jiquipilco" exhibited the highest LAI, yield, and RUE with 3.8, 1156.1 $g\,m^{-2}$, and 0.67 $g\,m^{-2}\,MJ^{-1}$, respectively. On the other hand, Z-60 exhibited minimum values for LAI, yield, and RUE. These results indicate that "Jiquipilco" (having higher genetic variability because of its open pollination origin) exhibits more phenotypic resilience. "Jiquipilco" is well adapted to ecological conditions of the studied region; Z-60, on other hand, has been created for Bajio (low lands) Mexican zone, where temperature and rainfall contrast with those of the Mexican high plateau. This response differs from that reported by [20], who mentioned that maize yield under conditions of Kenya to rotate the crop with legumes was 7.0 $t\,ha^{-1}$, 38% lower than those reported in this study may be due to the different areas where the studies were conducted.

Figure 1 shows that higher yield was produced by open pollinated genotypes "Jiquipilco" and "Amarillo" during the three evaluated growing cycles. This is attributed to its higher plasticity to heavy rainfalls, which produce flooding and that, in the case of hybrids, induces chlorosis. Hybrids were affected by soil flooding at both vegetative and reproductive stage [21].

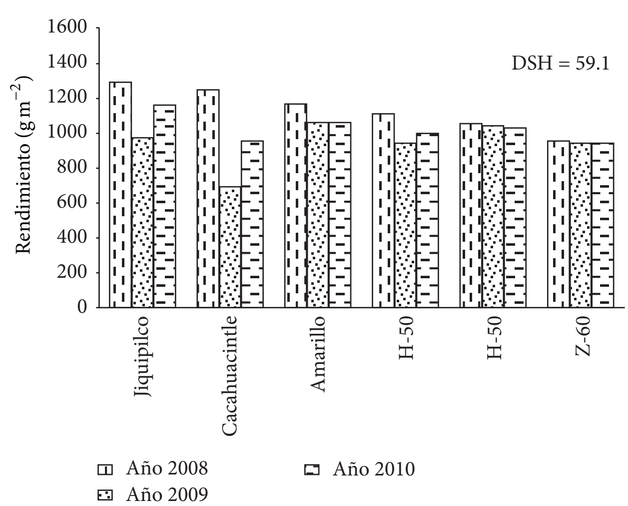

Figure 1: Corn grain yield of six cultivars under three planting densities. El Cerrillo, Toluca México Summer 2008, 2009, and 2010.

"Amarillo" creole was the most homogeneous in three years, exhibiting the following yields (1160 $g\,m^{-2}$ in 2008,

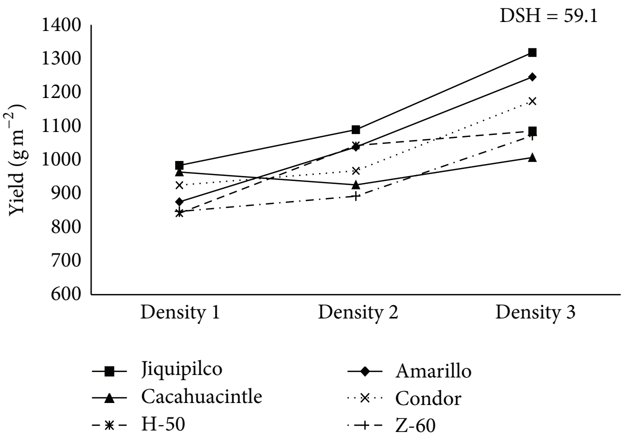

Figure 2: Interaction yield versus plant density evaluated at 2008, 2009, and 2010 summer. El Cerrillo, Toluca Mexico. Densities 1, 2, and 3 = 6.9, 7.8, and 8.9 plants m^{-2}, respectively.

1054.9 $g\,m^{-2}$ in 2009, and 1052 $g\,m^{-2}$ in 2010). Hybrids exhibited a consistent performance outstanding "Condor" with yields of 1049, 1033, and 1021 $g\,m^{-2}$ for 2008, 2009 [22], and 2010, respectively. Similar results are reported by [8].

Figure 2 exhibits interaction population density with yield, showing that the highest yield was for open pollinated cultivars such as "Jiquipilco" and "Yellow." When population density was increased from 2 to 3, yields were increased from 1088 to 1317 $g\,m^{-2}$ for "Jiquipilco," while for "Yellow" increased from 1037 to 1245 $g\,m^{-2}$. Concerning hybrids, "Condor" and "Z-60" exhibited a similar pattern concerning response to population density. "Condor" exhibited an increase from 967 to 1173 $g\,m^{-2}$ while Z-60 increased from 891 to 1071 $g\,m^{-2}$. The aforementioned results indicate that open pollinated genotypes respond well to population density increases and that are well suited to agroecological conditions of studied area; this response is exhibited only for hybrids "Z-60" and "Condor." Higher genetic variability of creoles allows phenotypic plasticity, and, so, yield increases with high population densities, despite the intraspecific competition.

This response has been corroborated by [20]; they mention that creole genotypes, particularly indigenous, exhibit high genetic variability that gives them an inherent capacity of adaptation to variable agroecological conditions of the region, generating good yields and good quality attributes on sweet corn and grain. Hybrids lack those attributes and so their performance is not so good [21–23]. Note that, in hybrids such as H-143C and H-149C, increase in population density affects significantly chemical composition and yield.

4. Conclusions

The best cycle was 2008, which has the highest grain yield, biomass, RUE, LAI, IR, and light attenuation coefficient. Regarding the density factor, the highest density 8.9 plants m^{-2} yielded the highest values for LAI, IR, K, and number of grains. The cultivate "Jiquipilco" presented the highest values of LAI, grain yield and EUR. Of the six cultivars evaluated, it is recommended for use in the study area, which showed a better adaptation with values of population density of 8.9 plants m^{-2}.

Competing Interests

The authors declare that they have no competing interests.

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