Yield of tropical Asian maize (*Zea mays* L) at alternating row irrigation and at severe drought

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Abstract

Drought is a major reason for inconsistent grain yield of maize in lowland tropical and subtropical areas. In bimodal rainy seasons with unequal amounts of rainfall, the shorter season requires germplasm with sufficient residual yields at various situations of low water availability. Thus farmers will avoid the risk of cultivation failure. The respective adaptation of eight Thai hybrids was tested in two dry seasons from late November 2003 to April 2005. Furrow irrigation of 40 mm was applied at seven days intervals from planting to physiological maturity (control, W1); 50% less water supply than W1 from the sixth week onwards by alternating irrigation of one of two rows (W2); withholding water from 5 weeks after planting to the beginning of anthesis (W3). At W3, three hybrids excelled with yields above 350 g m^{-2}, i.e. residual yields of more than two of them performed very well at W2 too, with more than 650 g m^{-2}, a residual yield of about 80%. This genetic range is encouraging to breed for earlier hybrids that can be cultivated in the minor rainy season with a reduced risk of failure.

Keywords: maize, Thai hybrids, alternate row irrigation, drought

Introduction

During a FAO meeting the question was raised by how much the land, water and crop yields need to be raised to feed the world in 2050 (Bruinsma, 2009). The clear answer is that the focus will be on increasing the yield per area. Time is running short to achieve the goal (Fischer and Edmeades, 2010); the main road to go is an acceleration of breeding in general and a utilization of all main and niche environments to increase yields per season and year (Stamp and Visser, 2012). As about 80% of maize planted in all lowland tropical environments is subject to periodic drought and drought-related problems, the demand on breeding research is strong, see “What the world eats: Maize, a sustainable strategy for food security”, a present CIMMYT mission. For advancing drought tolerant germplasm, already decades ago the right degree of preanthesis stress had been identified as main avenue for selecting tolerant cultivars (Blum, 1979; Quisenberry et al, 1982; Rosielle and Hamblin, 1981). For niche production chances, adaptation potential to specific types of early stress gain in importance as risk-avoiding farmers must be convinced to get better benefit from bimodal monsoon rains with a minor and major peak. Right now , productive new hybrids are cultivated just once a year mostly at later planting dates, i.e. without using both parts of the rainy season with two subsequent crops. Modern hybrids are bred for a long rainy season and an accordingly high yield level. According to Tollenaar and Aguilera (1992) the ongoing gain in yield could be partly due to improved radiation use efficiency, an increasingly important feature for future yield increase (Fischer and Edmeades, 2010). As preanthesis stress is the main problem for yield inconsistency across the tropics, little attention has been given to permanent low water availability throughout the season. Such situations can be best tested when the growing environment is similar to the one the germplasm under examination is adapted to (Bruce et al, 2002). Fitting conditions exist at the National Corn and Sorghum Research Center, Farm Suwan, in the hilly region of Thailand.

The objectives were to assess variability in high yielding tropical hybrids to severe preanthesis water lack in comparison to permanent moderate lack of water.

Materials and Methods

The experiments were conducted at the National Corn and Sorghum Research Center, Suwan Farm, Thailand, (14.5°N, 101°E, 360 m above sea level) on a Rhodic Kandiustox Oxisol (USDA taxonomy) in the dry seasons of 2003/4 and 2004/5. During the stress periods there was no rainfall, with maximum temperatures around 30°C, minimum temperatures around 19.5°C, and average daily water evaporation from the soil surface about 7 mm.

Seven modern single cross hybrids of medium maturity time were used, KSX 4452, KSX 4605, NSX 012002, NSX 022027, Big 949, PAC 903, and NT 6621; DK 888 was included as check, a long-term leading hybrid, released in 1991. The breeders were Kasetsart University (KSX), Department of Agricul-

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ture (NSX), Monsanto Seeds (Big, DK), Pacific Seeds (PAC), and Syngenta Seeds (NT).

Split plot experiments were arranged in a randomized complete block design with five replications. Main-plots were water regimes; single cross hybrids were assigned to subplots. The water regimes were: W1 - weekly irrigation from planting to physiological maturity with a total amount of irrigation water of 680 mm; W2- alternating weekly irrigation of every second row from BBCH 18 onwards, with a total amount of 360 mm; W3 - no irrigation between the BBCH 18 and BBCH 65, end of pollen shed but otherwise full weekly irrigation with a total amount 400 mm.

Main plots were 4.1 m apart from each other and separated by a 30 cm deep furrow that prevented irrigation water from flowing between them. The ground had an angle of inclination of 2°, which is ideal for furrow irrigation. A subplot consisted of six rows, 6 m long.

Sowing dates were 21 November 2003 and 14 November 2004. Two seeds per hill were sown manually on the ridges with a jab-planter at a depth of 5 to 7 cm and a distance of 20 cm within rows, which were 17 cm high and 75 cm apart. Two weeks after sowing, the plants were thinned to a density of 4.44 m^{-2}. Prior to sowing, 55 kg N ha^{-1} and 30 kg P ha^{-1} were applied; 145 kg N ha^{-1} was applied one month after sowing. Weeds were controlled with pre-emergence herbicides in a mixture of atrazine (3.6 kg ha^{-1}) and pendimethalin (1.32 l ha^{-1}).

The soil water potential was measured in 2004 by placing Watermark® soil moisture sensors at 30, 60, and 90 cm depth at one position both in W1 and W3. Time to anthesis and silking were recorded as the number of days from sowing to the day when at least 50% of the plants in the two center rows had extruded anthers or silks; the anthesis silking interval, ASI, was calculated as the difference between the time to silking and to anthesis (Bolaños and Edmeades, 1996).

In the two central rows all ears were hand-harvested and shelled; the grains were weighed then, and subsamples of 100 g fresh grains per plot were dried in the sun for three days. Thereafter, they were dried at 105°C for 24 hours and weighed. Dry grain yield (GY), harvest index (HI), kernel number (KNO) per m^2, and thousand kernel weight (TKW) were calculated from the primary data.

Analysis of variance was carried out with the statistic program Statistix. The experimental years were characterized by rather uniform temperature patterns as no rainfall with low pressure had occurred that could have lowered the temperatures for at least several days. Interactions of years with water supply or hybrids were not significant.

Results and Discussion

The yield level was high in all modern hybrids under optimum conditions (W1), the former top-ranking DK 888 was lower yielding and less drought tolerant than most modern hybrids (Table 1). The new generation had really made a step forward, a nice example that breeders are able to improve their materials even with their present tools at a respectable pace. Maybe a consequence, too, of close contact to CIMMYT research progress and germplasm (Bruce et al, 2002). Big 949, a stay green hybrid, was the top yielder at W1.

At the end of the stress period in 2004 the soil water potential at severe preanthesis (W3) was -199, -121, and -46 kPa at 30, 60, and 90 cm soil depth, respectively, indicating that a desired severe level of drought stress had been achieved. This resulted in a decrease of grain yield by 67% compared to W1, At W3, the hybrids PAC 903, NSX 002 and NSX 027 excelled with yields above 35 g m^{-2}, i.e. residual yields of more than 40%, whereas residual yields of the other hybrids were about 30% or lower.

Alternate weekly furrow irrigation (W2) simulated a season of permanent suboptimal but rather evenly distributed rainfalls from plant establishment onwards, i.e. repeated drying out of soil patches. The yield decrease was much lower under W2 with just 27% than at severe stress. It has been recommended as water saving way of cultivating irrigated maize (Kang et al, 2000). Partial lack of water in soil compartments improves indeed root exploration of the soil (Weerathaworn et al, 1992a). With almost 50% less water than under well watered conditions, about 75% of the maximum yield could be achieved, whereas severe preanthesis stress with more water available in the total season reduced the yield by 66%.

Two of the aforementioned hybrids, PAC903 and NSX 002, performed very well at W2, too, with more than 650 g m^{-2}, a residual yield of about 80%. A few other hybrids did similarly well at an absolute or relative level but PAC903 and NSX 002 may serve as a model that breeding can achieve both, a very water efficient genotype at permanent water deficiency throughout the season as well as a high stress tolerance at severe preanthesis stress followed by full water supply afterwards. Averaged across the three water levels they had the highest yield with a 5% plus in comparison to other well performing hybrids. The kernel number declined at W2 and W3 by 21 and 68%, respectively in comparison to W1. The data are not shown as the rank order between hybrids was similar to that for grain yield per area, although the impact of severe stress was slightly stronger on kernel number than on grain yield, indicating recovery potential in single kernel growth after stress. A much tighter relationship between grain dry weight per plant with kernel number than with thousand kernel weight under stress condition is well documented from from studies of Bolaños and Edemeades (1996) and Edmeades et al, (1999).

The anthesis silking interval, ASI, was 1.25, 3.25

Table 1 - Grain yield (GY) of eight hybrids in three water treatments: full irrigation (W1), mild stress (W2) and severe stress (W3). The hybrids are ranked according to the yield in W1. Trait values with the same letter are not significantly different (P≥0.05).

Varieties	GY(W1) [g m-2]	GY(W2) [g m-2]	GY(W2)/GY(W1) [%]	GY(W3) [g m-2]	GY(W3)/GY(W1) [%]
BIG949	899 A	621 B	69	263 B	29
PAC903	879 AB	633 AB	72	375 A	42
NT 6621	860 AB	687 A	80	248 BC	29
NSX002	857 AB	658 AB	77	366 A	42
KSX452	851 B	549 C	65	201 C	24
NSX027	836 BC	601 B	72	367 A	44
KSX605	782 C	637 AB	81	160 C	20
CP 888	741 CD	540 C	73	240 BC	32
Average	838	616	74	274	33

CV = 15.4 %
LSD (0.05) for waters regime x hybrids interaction of means comparison = 88 g m^{-2}

and 6.75 days on average in W1, W2 and W3; at W3 hybrid values ranged from 4.0 to 9.5. As no correlation was identified with yield at any water supply level, detailed data are not shown. The low and insignificant relationship between ASI and grain yield confirmed earlier data on drought effects in South-East Asian germplasm (Weerathaworn et al, 1992b; Moser et al, 2006).

Conclusively, there exists the genetic scope for improved tolerance to quite different drought situations like severe preanthesis stress (W3) or a permanent moderate lack of water throughout the whole growing season (W3) that could be utilized to breed early maturing robust hybrids. Such adapted hybrids that would be better accepted by farmers because of higher yield consistency in the early rainy season.

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