DROUGHT TOLERANCE OF TROPICAL MAIZE (*Zea mays* L.) AS AFFECTED BY PRE-ANTHESIS DROUGHT

INTRODUCTION

Global climate is changing now, therefore drought stress is even becoming a more severe problem than ever before for the stability of grain yield of maize (*Zea mays* L.) and other grain crops in dry land tropical and subtropical areas (CYMMYT, 2004). Stress is any environmental factor that reduces plant performance. Drought stress is a most crucial and important factor limiting crop production in many parts of the world by creating a shortage of plant-available water (Conti *et al*., 1994). The losses are expected to increase in the future, since a large proportion of the crop is grown in the drought-prone marginal lands (CIMMYT, 1989). For Thailand drought was reported as a priority constraint in many agro-eco zones except perhaps in the Upper North; the total area affected by drought is on average 0.496 million hectare/year and the loss the money is calculated to be over 298,293,547 million baht /year (Office of Agricultural Economics (OAE), 2005)

Under rain fed agriculture maize is one of the important crop species which are usually affected by drought. It is estimated that about 80% of maize planted in lowland tropical environments suffers with periodic significant yield reductions from drought and drought-related problems (Edmeades *et al*., 1989). A dry spell during flowering attributes to the greatest yield losses (Classen and Shaw, 1970). Denmead and Shaw (1960) reported that a decrease in water potential availability to permanent wilting point during flowering stage reduced grain yield by 50 percent. Nesmith and Retchie (1992) reported that drought affecting the plant at tassel emergence to beginning of grain filling led to a yield reduction of 90 % and to a barrenness of 77 %. Tropical maize hybrids in Thailand had yield losses of 66.6 (Sansern *et al.*, 2004) and of 52.8 percent (Pichet *et al.*, 2004) when drought was affecting the plants at flowering stage. Studies have shown that, when drought stress coincides with flowering, the environment is suitable to select for the harvest index, yield stability and grain yield of lowland tropical maize in a wide range of environments differing in water availability (Bolanos and Edmeades, 1993).

Bruce *et al*. (2002) described the characteristics of the environment required for studies of drought tolerance; the probability of drought stress is high and the time, duration and intensity of the stress can be modulated by irrigation; the environment is similar to that, to which the germplasm under examination will have to adapt. But the level of pre – anthesis drought stress and indicator traits related to stable yields under drought stress are important for improving cultivars for drought tolerance (Blum, 1979; Arboleda-Rivera and Compton, 1974; Quisenberry *et al*., 1982; Rosielle and Hamblin, 1981).

Berchtold Levy and Stamp (2003) reported the following effects of pre-anthesis drought in Thai maize: (a). high grain yield variability of hybrids within the water treatments; (b). yield reductions by moderate stress up to 49% and by severe stress of up to 94% compared to the well watered control. The grain number accounted for the main variation in grain yield. Germplasm of different breeding programs was used in that experiment, the grain yield under moderate stress was reduced by 29 to 49% for the different hybrids. Withholding water for four to five weeks may have been too long, as the aim of this experiment was to identify traits related to early drought tolerance. Abrecht *et al*. (1993) showed with their experiments in Africa, that the grain yield decreased by 18% when drought stress was applied during the vegetative stage and by 49% when the stress was applied during tasseling. The principal effect of pre-flowering drought stress on yield was a decrease in grain mass. As with other crops this occurred primarily through a decrease in grain number (per ground area) (Fischer, 1979)

In Thailand two precipitation peaks are observed, one in May and one in October. The farmers utilize the rainy seasons for agricultural production. If irrigation systems are available, then three maize crops can be grown annually. 67 % of the maize is grown in the first rainy season from late April to June. About 30% of the farmers grow maize during the second rainy season from July to August when precipitation reaches a peak. Only 3% grow maize during the dry season, from December to late March (Office of Agricultural Economics, 2005.). Maize grown in the early season was highly affected by drought on late June-early July.

OBJECTIVES

1. Determine the application of pre – anthesis drought stress treatments that can discriminate hybrids for their tolerance to mild and severe stress.

2. Determine the drought tolerance level to pre – anthesis stress in modern high – yielding Thai hybrids.

3. Test the hypothesis that easy to measure physiological and morphological potential indicator traits exist.

LITERATURE REVIEW

Maize (*Zea mays* L.) is still an important field crop in Thailand, it has become one of the leading economic crops is now the fourth major crop in Thailand. It is important both for export and as an animal foodstuff. In 2004/05 the planted area of about 1.06 million hectares about 98.64 percent planted in rain fed area yielded an average of 3.68 t/ha, resulting in an annual production of around 3.89 million tons a year (Office of Agricultural Economics, 2005); about 95 percent of the area is planted with hybrids. About 67 percent is planted in the early season of April - March, 30 percent in the late season of July-August and 3. percent in the dry season of October-November. In Thailand an estimated 3 to 23 percent of total maize planting area is affected by drought stress every year. The annual yield losses due to drought are thought to be equivalent to 129,000 to 858,000 metric tons of maize grain, worth US$ 12.9 to 85.8 million. Now the planted area is decreasing but the demand of the market is increasing. The problem besides drought is a lower price than that of other crops (Office of Agricultural Economics, 2005)

Maize Plant Development

All normal maize plants follow the same general pattern of development, but the specific time interval between stages and total leaf numbers developed may vary between different hybrids, seasons, dates of planting, and locations. For example:

1. An early maturing hybrid may develop fewer leaves or progress through different stages at a faster rate than indicated here. A late maturing hybrid may develop more leaves or progress more slowly than indicated here.

2. The rate of plant development for any hybrid is directly related to temperature, so the length of time between the different stages will vary as the temperature varies, both between and within growing seasons.

3. Environmental stress such as nutrient or moisture deficiencies may lengthen the time between vegetative stages but shorten the time between reproductive stages.

4. The number of kernels that develop, final kernel size, rate of increase in kernel weight, and length of the reproductive growth period will vary between different hybrids and environmental conditions.

Identifying Stages of Development

Ritchie (1993) identified stages of development of maize into vegetative and reproductive stages. The vegetative (V) stages are designated numerically as V1, V2, V3, etc. through Vn. The (n) represents the last leaf stage before VT. The first and last V stages are designated as VE (emergence) and VT (tasseling). The (n) will fluctuate with hybrid and environmental differences. The six reproductive stages are designated numerically with their common names as R1 (silking) through R6 (physiological maturity). Descriptions of development stages of maize are shown in Table 1.

Table 1 Vegetative and reproductive stages of a maize plant

Stage	Description
Vegetativ*e*	
VE	Emergence. Coleoptile is above the soil surface.
V1	First leaf. The first set (whorl) of nodal roots begins elongation from the first node.
V3	Third leaf. The stem apex (growth point) is still below the soil surface, and that very little stalk (stem) elongation has occurred.
V6	Sixth leaf. The growing point and tassel are above the soil surface and the stalk is beginning a period of greatly increased elongation.
V12	Twelfth leaf. The number of ovule on each ear and the size of the ear are now being determined.
V15	Fifteenth leaf. The beginning of the most crucial period of plant development in term of seed yield determination.
V18	Eighteenth leaf. The upper ear shoot and ear development.
VT	Tasseling. It begins approximately 2-3 days before silk emergence. The maize plant well almost attain it full height and pollen shed begins.
Reproductive	
R1	Silking. Silks are visible outside the husk.
R2	Blister. (10-14 day after silking). Kernels are white on the outside and resemble a blister shape. The cop is dose to or at full size.
R3	Milk (18-22 day after silking). The kernel yellow color on the outside and inner fluid is now milky white.

Table 1 (continued)

Stage	Description
Reproductive	
R4	Dough (24-28 days after silking). Starch accumulation in the endosperm.
R5	Dent (35-42 days after silking). Kernel are dented and the shelled cob is dark red in color.
R6	Physiological Maturity (55-65 days after silking). All kernels on the ear have attained their maximum dry weight or maximum dry matter accumulation. A black or brown abscission layer has formed.

Definition of drought

In the most general sense, drought can be defined as a meteorological phenomenon: a period without rain long enough to cause significant reduction in soil moisture content and plant growth. Drought can be permanent, as in arid regions, or seasonal or even random. The period of time without rainfall actually needed to produce a drought depends mainly on the water holding capacity of the soil and the rate of evapotranspiration by plants (Jones 1992; Larcher, 1995; Kozlowski and Pallardy, 1997).

Plants cope of response with drought

Plant water stress occurs when low plant water potentials develop and cell turgor begins to fall. (Kozlowski and Pallardy, 1997). Plants must be able to cope with and survive drought conditions. Salisbury and Ross (1992); Kozlowski and Pallardy (1997); Gaspar *et al*. (2002.) reported that there are two major strategies:

1. Drought avoidance refers to actions or adaptations which serve to help the plant escape (avoid) the stressful situation. This is primarily limited to short life cycles that finish before drought occurs (this is really only important for desert ephemerals)

2. Drought tolerance refers to actions or adaptations that allow the plant to withstand the stress, with or without a reduction in performance. This includes:

(a) Desiccation avoidance refers to mechanisms by which plants can prevent the initiation of very low tissue water contents despite the presence of drought conditions. Such adaptations may include deep wide-spreading root systems, high internal resistance to water transport and reduction of transpiration through reduced leaf size, leaf abscission, thick cuticles, and good stomatal control

(b) Desiccation tolerance refers to the means by which plants can survive very low tissue water contents. The primary means for this are osmotic adjustment and possession of stiff cell walls (these attributes are possessed almost exclusively by arid region plants; few woody plants can survive desiccation)

Many plants use a combination of both mechanisms (avoidance and tolerance) (Gaspar *et al*., 2002).The term, drought tolerance as it is commonly used, describes mechanisms that tend to maintain survival or productivity during drought (Jones, 1992). Therefore, a more drought tolerant species (or genotype) would be one which survives and produces better than others under drought conditions. In the meaningful target environments severe drought is not a perpetual state, in the target environments plants are faced to droughts of varying intensity, seasonally or periodically. Plants in these situations cannot fully acclimate to one condition or the other, since they must face both. And, frequently, anatomical adaptations which allow plants to be more drought tolerant restrict their productivity under optimal conditions (Ewers *et al*.,2000)

Time scales of response

Plant responses to stresses such as drought involve a variety of temporal scales, from a matter of seconds to evolutionary time scales. Lambers *et al*. (1998) give the following definition:

1. Stress response

The immediate detrimental effect of a stress on a plant process. This usually occurs over a time scale of seconds or days in which the net effect is a decline in plant performance.

2. Acclimation

The morphological and physiological adjustment by plants to compensate for the decline in performance following exposure to stress. Acclimation occurs within the lifetime of the plant, usually within days or weeks of the stress exposure.

3. Adaptation

The evolutionary response that results from genetic changes in populations leading to morphological and physiological compensation. This may be similar to acclimation, but because it requires genetic changes, it must occur over many generations

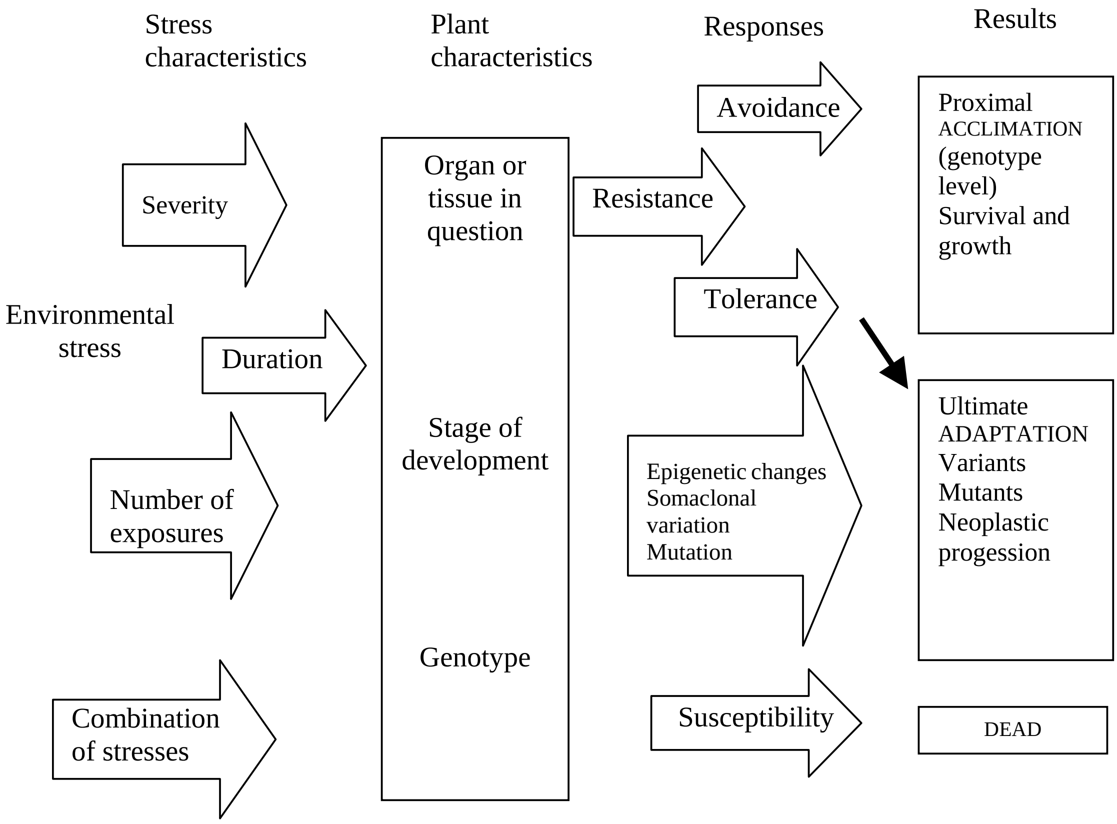

Figure 1. Plant responses to environmental stress in correspondence with stress and plant characteristics

Source: Gaspar *et al*. 2002.

Effects of Drought on Maize Yield.

For the rainy season in Thailand two precipitation peaks are observed, one in May-June and one in October. Maize crops can be grown annually. About 67 percent is planted in the early season of March-June, 30 percent in the late season of July-August and 3 percent in the dry season of October-November. When grown in the early season maize is usually affected by drought on July – August at about V17-R1 growth stage, yield losses can be between 15 to over 50 percent (Office of Agricultural Economics, 2005).

With most maize in the developing world being grown under rain-fed conditions and the proportion of maize grown in marginal areas increasing, breeding for tolerance to drought has become a major focus of CIMMYT's Maize Program. This investment seems justified as annually an estimated 24 million tons of maize are lost to drought, and yield increases in high-potential regions alone are unlikely to meet the projected increase in demand for maize over the next decades (Heisey and Edmeades, 1999). Drought is thought to cause average annual yield losses in maize of about 17% per year in the tropics (Edmeades *et al*., 1992).

Drought stress is a major cause for the instable grain yield of maize (*Zea mays* L.), with yield reductions of 15 to over 50 percent compared with well watered situations. Different Maize yield can be reduced at different levels by drought stress depending on the growth stage that is affected. When a maize crop is affected at the early vegetative state, yield can be reduced by 5-10 percent, at tassel emergence by 10-25 percent, at silk emergence and pollen shedding by 40-50 percent, at blister by 30-40 percent and at dough by 20-30 percent (Classen and Show, 1970).

Denmead and Shaw (1960) reported the following yield reductions by drought stress at different growth stages: Pre-flowering 25 percent, mid-flowering 50 percent, post-flowering 21 percent and NeSmith and Retchie (1992) reported drought at tassel emergence - beginning of grain filling yield reduction 90 percent.

For tropical maize hybrids in Thailand Sansern *et al*. (2004) reported the following maize yield losses in relation to watering every 7 days: withholding water from V.7-8 stage to the beginning of pollen shed yield, 25 percent; withholding water from V.7-8 stage to one week after the beginning of pollen shed, 67 percent. When Pichet *et al*. (2004) withheld water under similar conditions from V.9 stage to two weeks after the mid of pollen shed, the yield decrease was 53 percent.

Bolanos and Edmeades (1996) determined genotypic correlations between a range of secondary traits and grain yield under drought stress for more than 3,500 S_1 progenies from several populations. Traits indicative of reproductive success explained much more of the variation in grain yield than traits indicative of plant water status and water use efficiency.

It is of utmost importance to know the kind of drought stress condition for the study and selection of improved maize drought tolerant varieties; it can determine the extent of drought tolerance and show if physiological and morphological potential indicator traits exist. Genetic correlations (r_g) between grain yield (GY) under severe drought stress and secondary traits, obtained from trials of inbred progenies from maize populations used in the results show a strong dependence of GY on ears per plant (EPP) and grains per ear (GPE), while the correlation between GY and weight per grain was weak. A moderately strong correlation was reported between GY and ASI, while genetic correlations between GY and leaf rolling, stay green, leaf angle, canopy temperature, tassel branch number, leaf chlorophyll concentration, and plant height were generally less than |0.20 | (Bolanos and Edmeades ,1996).

MATERIALS AND METHODS

Experiments were conducted at the National Corn and Sorghum Research Center in the dry seasons of 2005 and 2006.

Materials

Eight single-cross hybrids were used in the study.

Varieties	Source
KSX 4452	National Corn and Sorghum Research Center, Kasetsart University
KSX 4605	National Corn and Sorghum Research Center, Kasetsart University
NSX 012002	Nakhonsawan Research Center, Department of Agriculture
NSX 022027	Nakhonsawan Research Center, Department of Agriculture
DK 888	Cargill Seeds Th. Co. Ltd
Big 949	Monsanto Seeds Th. Co. Ltd
PAC 903	Pacific Seeds Th. Co. Ltd
NT 6621	Syngenta Seeds Th. Co. Ltd

Methods

Experimental design

A split-plot arrangement within a randomized complete block design with four replications was utilized in this experiment. Main-plots consisted of three water regimes as follows: (1) weekly watering every 7 days intervals, from planting to physiological maturity (w1), (2) weekly with only every 2^{nd} row receiving irrigation, reducing such the irrigation amount by half (w2) and(3) withholding water from 7-8 leaf stage to one week after the beginning of pollen shed, otherwise full weekly irrigation (w3). Subplots consisted of eight single cross hybrids.

Trial managements

The experiment covered an area of 73 by 78 m. The water treatments were separated by 4.1 m. In addition, a furrow, 30 cm deep, divided this space as a further measure to impede irrigation water from flowing from one field to the other. The distance between the four replications was 1.5 m. The rows were 75 cm apart and 17 cm of height, thus suitable for furrow irrigation. The ground had an angle of inclination of 2°, which is ideal for this purpose. There were 128 plots, each of which represented an experimental unit and consisted of six rows, 6 m long. A border, several meters wide, surrounds the field. The front border was removed when the grains reached the milky stage.

All the hybrids were sown on 21 November 2003 and 14 November 2004. Pairs of maize seeds were sown manually on the ridges with the jab-planter at a depth of about 5 to 7 cm to ensure that the initial stand was homogeneous. There were 20 cm between two pairs of seeds within a row. Two weeks after sowing one of each pair of plants was left in order to enable equal competition among the plants.

Weeds were controlled initially with pre-emergence herbicides in a mixture of atrazine (active ingredient: 6-chloro-N-ethyl-N'-isopropyl-1,3,5-triazine-2,4-diamine 90%, application: 3.600 kg/ha) and pendimethalin ("Stomp", chemical group: 2,6-dinitroaniline, active ingredient: N-(1-ethylpropyl)-2,6-dinitro-3,4-xylidine 33%, application: 1.320 l/ha).

Water regimes

Just after sowing, the whole experimental field was irrigated with 40 mm of water for three hours by means of a sprinkler system to ensure the initial growth and establishment of the seedlings. It took three more sprinkler irrigation at weekly intervals for a safe crop establishment.

Thereafter different stress treatments were applied and sprinkler irrigation was substituted by furrow irrigation, which allowed the separate watering of blocks. The control treatment was watered each week to ensure a non-limited growth. In the moderate stress treatment, water was withheld from every 2nd row until physiology maturity stage, reducing the water supply during this period to 50% of that of the well watered control. In the severe stress treatment, water was withheld from the 6 - 7 leaf stage to one week before anthesis thereafter the weekly full furrow irrigation was resumed. Field layouts of irrigation management are presented in Fig 2, and Appendix Figure.1-3.

			A		B					C									D
Date	14/11	18/11	25/11	2/12	9/12	16/12	23/12	30/12	6/1	13/1	20/1	27/1	3/2	10/2	17/2	24/2	3/3	10/3	
17/3	24/3																		
Treatment / Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
W1 (control)	S	S	S	F	F	F	F	F	F	F	F	F	F	F	F	F	F		
W2 (mild stress)	S	S	S	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$		
W3 (severe stress)	S	S	S	F	X	X	X	X	X	X	F	F	F	F	F	F	F		

Figure2 Field layout irrigation management of pre- anthesis drought experiment with split plot design in the dry season (November-February) of 2003/2004 and 2004/2005

A = Thinning (V3 stage); S = Sprinkler irrigation; F = Furrow irrigation; X = Withhold water;

B = Side dressing (V7-V8 stages); C = Flowering (67 days); D = Harvesting (130 days)

Data observation

Plant survival

Plant survival is
evaluated twice, right before anthesis of the first flowering plants and at the end of the experiment before the harvest. The first counting is used to determine 50% flowering; the second one represents the actual plant survival. Taking into account that the well-watered plots has the highest potential for plant survival, the average of the four replications of each variety in the control is the reference (100%) for the other water treatments.

50 percent anthesis and 50 percent silking

When flowering started, all the plants in the two centre rows that has reached anthesis or silking were observe every second day. Days to 50% anthesis and 50% silking were recorded when 50% or more of the plants in a plot has reached one of these stages

Anthesis-silking interval (ASI)

The ASI was calculated as the days to 50% silking minus the days to 50% anthesis

Plant height

Various parameters of ten plants per plot were measured to evaluate development:
Tassel height: measurement from ground to tip of tassel.
Ear height: measurement from ground to leaf collar (*ligula*) of ear leaf.

Yields are measured fresh (ear) and grain weight

Fresh weight

All the ears in the two central rows of each plot were harvested. The yield of all plots are compared at 15 % moisture, the harvested area is fixed at 9 m^2 and calculate to Mg^{-1}/ha.

Grain weight

All the ears in the two central rows of each plot are harvested and shelled, grain yield all plot are compare to 15 % moisture, and the harvested area is fixed at 9 m2 and calculated to Mg /ha.

Ears per plot

Total ears per plot were recorded on all the ears in the two central rows of each plot; the recognition as an ear started at one seed set each ear.

Kernels per ear

Total number of grains of each ear with a grain set, based on all ears of each plot.

Kernels per plot

Kernels per plot was calculated from kernels per ear multiplied with the total plants per plot.

Thousand kernel weight

Thousand kernel weight (TKW) of each plot was calculated from the grain dry weight divied by the kernel number and multiplied by 1000.

Harvest index

The HI was calculated by dividing the grain weight by the total shoot biomass of six plants from each plot.

Experimental Site and Duration

Experiments were conducted at the National Corn and Sorghum Research Center, Pakchong, Nakhon Ratchasima, in the dry seasons (November – March) of 2003/2004 and 2004/2005.

Table 2 The general analysis of variance combine in split-plot design

Source of Variation	df	SS
Experiment (expts)	p-1	$(C.F._{1}-C.F._{2})-C.F._{com}$
Reps within expts	p(r-1)	R_1+R_2
Main plot (M_{com})	a-1	$[A^2{}_1+\ldots+A^2{}_a]/pbr-C.F._{com}$
Expts* M_{com}	(p-1)(a-1)	$(M_1+M_2)-M_{com}$
Error a	p(a-1)(r-1)	$E(a)_1+E(a)_2$
Sub plot (S_{com})	b-1	$[B^2{}_1+\ldots B^2{}_b]/par-C.F._{com}$
Expts* S_{com}	(p-1)(b-1)	$(S_1+S_2)-S_{com}$
M_{com} * S_{com} (I_{com})	((a-1)(b-1)	$[(A_1B_1)^2+\ldots+(A_a B_b)2]/pr-C.F._{com}-S_{com}-M_{com}$
Expts* M_{com} * S_{com}	(p-1)(a-1)(b-1)	$(I_1+I_2)-I_{com}$
Error b	pa (b-1)(r-1)	$E(b)_1+E(b)_2$
Total	abpr-1	$[(To_1+C.F._{1})+(To_2+C.F._{2})]-C.F._{com}$

p = number of experiment
r = number of replication
a = number of main plot
b = number of sub plot

RESULTS AND DISCUSSION

Yield and agronomic traits

Table 3, are shown yield and agronomic traits average of eight hybrid affected by tree water condition; yield average were 8.31, 6.16 and 2.74 Ma ha^{-1} under control, mild and severe stress, respectively and percentage yield decrease of 26.5 at mild stress and 67.3 at severe stress, percentage other traits decrease; dry weight per plant of 26.6 at mild stress and 69.8 at severe stress, kernel number per hectare of 21.1 at mild stress and 67.3 at severe stress, kernel number per plant of 19.5 at mild stress and 67.4 at severe stress, plant height of 12.8 at mild stress and 33.8 at severe stress and ear height of 18.2 at mild stress and 38.8 at severe stress.

Days to 50 percentage silking, days to50 percentage tasseling and tasseling-silking interval (ASI) were later than control; days to 50 percentage silking of 2 days at mild stress and 7 days at severe stress, days to 50 percentage tasseling of 1 days at mild stress and 3 days at severe stress and ASI of of 1 days at mild stress and 5 days at severe stress. 1000 kernel dry weight and harvest index were nearly in all three water regimes..

Table 3 Yield and agronomic traits average of eight hybrids in three water treatments full irrigation (control), mild stress and severe stress.

Traits	Control	Mild stress (reduce)	Severe stress (reduce)
Yield (Mg ha^{-1})	8.38	6.16 (26.5%)	2.74 (67.3%)
Dry weight/plant (g)	102.8	75.4 (26.6%)	31.1 (69.8%)
Kernel number/ha^{-1}	23,840	18,816 (21.1%)	7,701 (67.3%)
Kernel number/plant	395	318 (19.5%)	129 (67.4%)
1000 kernel weight (g)	257.0	233.8 -	242.0
Harvest index	0.44	0.46 -	0.31 -
Plant height (cm)	228	199 (12.8%)	151 (33.8%)
Ear height (cm)	121	99 (18.2%)	74 (38.8%)
Days to 50 percentage silking (day)	71	73 (2 days)	78 (7 days)
Days to 50 percentage tasseling (day)	69	70 (1 days)	72 (3 days)

Grain yield at 15 % moisture content

Yields at 15 percent moisture content are presented in Table 4; the corresponding results on the dry weight basis are in the Appendix Table 1. Yield was highly significantly affected by water regime as well as by hybrids; the interactions were significant although they did not change the main effects very much (Appendix Table1). Yield averages were 8.38, 6.16 and 2.74 Mg ha^{-1} under control, mild and severe stress, respectively, with corresponding percentage yield decreases of 27 at mild stress and 67 at severe stress to those achieved under control conditions. Similar results were obtained by Berchtold Levy and Stamp (2003) and Sansern *et al*. (2004); they could show that yields were decreased by 81 and 67% when stress was applied during 7 leaf or 8 leaf stage to pollination stage.

The hybrids PAC 903, NSX 012002 and NSX 022027 had high and stable yields at every water condition relative to the average yields of all hybrids. Their yields were quite similar under control and also showed the smallest yield decreases under stress conditions. KSX 4605 performed medium at control (7.82 Mg ha^{-1}); high at mild stress (6.37 Mg ha^{-1}) and the lowest at severe stress condition (1.6 Mg ha^{-1}), i.e. its decrease was the highest when compared with other hybrids. PAC 903, NSX 012002 and NSX 022007, on the other hand, had still one ton more yield than any other hybrid at the severe stress. The oldest single cross hybrid, DK 888, gave rather inferior yields at every water regime.

In order to discriminate well between genotypes, the type of drought stress must be well chosen; the conditions should be severe enough to uncover weaknesses in grain yield or secondary traits (Bruce *et al*., 2001). This can be done reliably only when well water conditions are integrated for a good check (Beck *et al*., 1997).

Results from this study at severe stress condition (W3) served to discriminate between genotypes differing in tolerance and sensitivity; the first class was represented by NSX 012002, NSX 022027 and PAC 903, the latter by KSX 4605. These consistent degrees of tolerances at drought condition conform well to those of other studies (Edmeades *et al*., 1999 and Bruce *et al*., 2001).

DK 888 is the long-standing popular hybrid of Thailand that has been long time regarded as well tolerant to drought stress. Here it indeed showed less tolerance than is generally accepted for modern hybrids; this new generation has in comparison really made a step forward due to improved maize programs (Bruce *et al*., 2001; Berchtold Levy and Stamp, 2003).

Table 4 Grain yields at 15% moisture content (Mg ha^{-1}) of eight hybrids in three water treatments: full irrigation (control), mild stress and severe stress. The hybrids are ranked according to the yield of the control; the averages of two seasons are presented.

Hybrid variety	Water regime: Control	Mild stress	Severe stress	Average
	---Mg ha^{-1}---			
BIG 949	8.99	6.21	2.63	5.94
PAC 903	8.79	6.33	3.75	6.29
NT 6621	8.60	6.87	2.48	5.98
NSX 012002	8.57	6.58	3.66	6.27
KSX 4452	8.51	5.49	2.01	5.34
NSX 022007	8.36	6.01	3.67	5.91
KSX 4605	7.82	6.37	1.60	5.26
CP 888	7.41	5.40	2.40	5.07
Average	8.38	6.16	2.74	
CV % = 15.4 %				

LSD (0.05) for waters regime of means comparison = 0.76 Mg ha^{-1}
LSD (0.05) for varieties of means comparison = 0.51 Mg ha^{-1}
LSD (0.05) for waters regime x hybrids interaction of means comparison = 0.88 Mg ha^{-1}

Grain dry weight per plant

The grain dry weight per plant differed slightly in rank order of hybrids from the grain yield on an area basis (cf. Table 4) as those had in some cases different plant numbers per area. The yields were decreased 26 and 70 percent under mild and severe stress compared with the control, respectively, slightly larger decreases than at an area basis; this indicates that plant losses were more due to genotype effects than to the water treatments. This can be explained by the fact that no stress was applied until first safe plant establishment.

Pac 903, NSX 012002 and NSX 022027 again had high yields and lowest decreased at severe stress with around 63-59 percent (Table 5) but just Pac 903 still had significantly higher yields at this stress level than the rest of the other hybrids; this indicates that the yield estimate at the area level was more accurate for a judgment of the hybrid performances. KSX 4452 had the highest yields at the control level accompanied by the lowest plant number; its yield decrease was strongest at severe stress again with 81 percent.

Table 5 Grain dry weight per plant (g) of eight hybrids in three water treatments: full irrigation (control), mild stress and severe stress. The hybrids are ranked according to the yield of the control at an area basis, see Table 4; the averages of two seasons are presented.

Hybrid	Water regime			
variety	Control	Mild stress	Severe stress	Average
	---------------------------- g/plant----------------------------			
BIG 949	108.9	70.9	29.9	69.90
PAC 903	105.7	77.4	43.2	75.44
NT 6621	104.0	81.3	28.1	71.14
NSX 012002	101.9	77.5	39.1	72.84
KSX 4452	115.1	80.8	23.0	72.94
NSX 022007	100.6	73.1	37.0	70.23
KSX 4605	94.8	79.2	19.1	64.38
CP 888	91.7	63.4	29.0	61.36
Average	102.8	75.4	31.1	
CV % = 19.1 %				

LSD (0.05) for waters regime of means comparison = 9.54 g.
LSD (0.05) for varieties of means comparison = 7.63 g.
LSD (0.05) for waters regime x hybrids interaction of means comparison = 13.2 g.

Kernel number per hectare and per plant

Results of kernel number per hectare and per plant are presented in Table6 and Table 7. In relation to the control the kernel number per hectare declined due to mild and severe stress by 21and 68 percent; this was in a similar range than for grain yield per hectare, although the impact of severe stress was slightly stronger on kernel number (Table 6). The rank order of hybrids at control was similar to that of grain yield. BIG 949 was the highest at control and mild stress but just medium at severe stress, PAC 903 was high at control and mild stress and the highest at severe stress, NSX 012002 decreased the least at severe stress compared with the control, just by 55 percent. It is interesting to note that at stress conditions PAC 903, NSX 012002 and NSX 022027 again showed the highest stability or tolerance for kernel number, the same as observed for the grain yield per area and per plant. Table 6 shows the results of kernel number per plant. Same as with grain yield per plant these data were influenced by the final number of established plants per harvested plot area. Although the rank order was less conserved at this level of comparison, it was still largely comparable to the data at the area level and the tolerances of hybrids were unchanged.

Table 6 Kernel numbers per hectare (10^4) of eight hybrids in three water treatments: full irrigation (control), mild stress and severe stress. The hybrids are ranked according to the yield of the control at an area basis, see Table 4; the averages of two seasons are presented.

Hybrid variety	Control	Mild stress	Severe stress	Average
	Water regime			
	-----------------kernel numbers/ha ($x10^4$)-----------------			
BIG 949	2.91	2.22	0.81	1.98
PAC 903	2.69	2.03	1.09	1.94
NT 6621	2.34	2.01	0.66	1.67
NSX 012002	2.22	1.80	1.00	1.68
KSX 4452	2.31	1.78	0.55	1.55
NSX 022007	2.21	1.68	0.83	1.57
KSX 4605	2.21	1.91	0.45	1.52
CP 888	2.18	1.62	0.77	1.52
Average	2.38	1.88	0.77	
CV % = 15.5 %				

LSD (0.05) for waters regime of means comparison = 0.212 x 10^4
LSD (0.05) for varieties of means comparison = 0.15 $x10^4$
LSD (0.05) for waters regime x hybrids interaction of means comparison = 0.26 $x10^4$

Table 7 Kernel numbers per plant of eight hybrids in three water treatments: full irrigation (control), mild stress and severe stress. The hybrids are ranked according to the yield of the control at an area basis, see Table 4; the averages of two seasons are presented.

Hybrid	Water regime			
variety	Control	Mild stress	Severe stress	Average
	-------------------kernel numbers/plant--------------------			
BIG 949	485	340	135	320
PAC 903	439	343	182	321
NT 6621	379	331	109	273
NSX 012002	364	299	164	276
KSX 4452	405	342	95	281
NSX 022007	362	285	137	261
KSX 4605	361	326	76	255
CP 888	361	284	133	259
Average	395	318	129	
CV % = 16.6 %				

LSD (0.05) for waters regime of means comparison = 34.6
LSD (0.05) for varieties of means comparison = 26.6
LSD (0.05) for waters regime x hybrids interaction of means comparison = 46

1000 kernels dry weight

1000 kernels dry weight presented a quite heterogeneous picture as they were subject to a strong interaction by all three main factors, hybrids, water regimes and years (Table 8). Generally, the values were more decreased by mild stress than by severe stress, on average 9 percents and 6 percent compared with control values, respectively. In 2004 the values were considerably lower, especially at the control level. In that year half of the hybrids achieved the same or higher values at severe stress than at the control level; this can be seen as a proof that the green leaf area was sufficiently recovered to overcompensate the rather reduced grain set to some extent. At mild stress grain set was seemingly less reduced than the source capacity for carbohydrates; this might explain the more reduced 1000 kernels weight. NSX 022027 alone showed quite stable values in every water regime in both years. Otherwise there were numerous differences of reaction within and between hybrids towards water regimes and years; but despite considerable absolute differences between hybrids at control level no clear reaction pattern of genotypes towards drought stress was visible. From this it can be concluded that the driving force for the stress impact is the ability to set grains, the different hybrids just seem to use free additional assimilate resources after grain set to rectify wrongly adjusted grain number.

Table 8 1000 kernels dry weight (g) of eight hybrids in three water treatments: full irrigation (control), mild stress and severe stress in 2003 and 2004. The hybrids are ranked according to the yield of the control at an area basis, see Table 4.

Hybrid	Water regime					
	2004			2005		
variety	Control	Mild stress	Severe stress	Control	Mild stress	Severe stress
	---------------------------------------g---------------------------------------					
BIG 949	235	221	241	210	187	200
PAC 903	254	225	229	225	222	247
NT 6621	307	257	259	226	234	252
NSX 012002	287	258	237	271	259	239
KSX 4452	261	224	266	279	226	210
NSX 022007	299	284	292	245	219	242
KSX 4605	289	245	250	227	240	268
CP 888	268	223	215	229	216	224
Average	275	242	249	239	226	235
CV % = 8.2 %						

LSD (0.05) for year x waters regime x hybrids interaction of means comparison = 28 g.

Harvest index

The harvest index (HI) was moderately low at control and at mild stress levels with 0.42 to 0.48 (Table 9). Desirably high levels were found for KSX 4605 that had rather low values for grain yield. Although grain yield was considerably decreased by mild stress, all hybrids were still able to maintain normal values of HI, in 2003 even higher ones than at the control level. This can be regarded as a reliable indicator that the plants were able to cope well with this stress intensity by using a relatively larger portion of the shoot dry matter for grain growth. A rather higher intensity of severe stress was indicated by very low values of HI in 2004, 0.26 on average. There was no clear-cut strategy to be seen by which tolerant hybrids could be identified through a more stable HI. But hybrids with a high yield at control levels still had a higher HI at the very severe stress in 2004, with exemptions like KSX 4605, see on Table9.

Table 9 Harvest index (HI) of eight hybrids in three water treatments: full irrigation (control), mild stress and severe stress in 2003 and 2004. The hybrids are ranked according to the yield of the control at an area basis, see Table 4.

Hybrid	Water regime					
	2003			2004		
variety	Control	Mild stress	Severe stress	Control	Mild stress	Severe stress
BIG 949	0.45	0.51	0.34	0.45	0.47	0.33
PAC 903	0.46	0.50	0.45	0.48	0.44	0.24
NT 6621	0.43	0.52	0.33	0.45	0.46	0.36
NSX 012002	0.38	0.46	0.39	0.44	0.43	0.24
KSX 4452	0.36	0.40	0.33	0.45	0.38	0.22
NSX 022007	0.42	0.49	0.36	0.41	0.46	0.27
KSX 4605	0.43	0.50	0.26	0.50	0.50	0.21
CP 888	0.43	0.50	0.39	0.43	0.40	0.19
Average	0.42	0.48	0.35	0.45	0.44	0.26
CV % = 9.7 %						

LSD (0.05) for year x waters regime x hybrids interaction of means comparison = 0.05

Day to 50 percent tasseling and 50 percent silking

Day to 50 percent tasseling was not significant. The values were around 67-74 day (data not shown).

Day to 50 percent silking increased on average three days in mild stress and seven days in severe stress compared with the control (Table 10). These increases were smaller in those hybrids that yielded highest under control level; but this was not a universal rule as it did not explain all cases of the three hybrids with highest yields at severe stress. It was furthermore interesting to note that the lowest yielding and oldest hybrid CP888 had relatively low increases in silking date by stress.

According to Pilar and Johnson (1981) drought appeared to have a greater effect on silk delay than on pollen viability. Drought stress is known to generate early tasseling and stop silk development or increase the silk delay (Jampatong, 2004)

Table 10 Day to 50 percent silking of eight hybrids in three water treatments: full irrigation (control), mild stress and severe stress.

Hybrid	Water regime			
variety	Control	Mild stress	Severe stress	Average
BIG 949	70	72	77	73
PAC 903	72	75	78	75
NT 6621	70	72	78	73
NSX 012002	71	73	77	74
KSX 4452	73	75	80	76
NSX 022007	71	74	78	74
KSX 4605	69	72	78	73
CP 888	74	76	79	76
Average	71.2	73.4	78.0	
CV % = 2.8 %				

LSD (0.05) for waters regime of means comparison = 1.5
LSD (0.05) for varieties of means comparison = 1.2
LSD (0.05) for waters regime x hybrids interaction of means comparison = 2.1

Tasseling – silking interval

The tasseling-silking intervals were extended when water stress was increased (Table 11). The water regime x hybrids interaction was significant. The response of the tasseling-silking interval to the water regime was different depending the stress intensity and on the year. If this parameter is a stress indicator, a slight stress would have been indicated in 2004 even for control plants as their values were higher than those for mild stress in 2003. In 2004 the values were exceedingly high at severe stress with seven days. The three hybrids PAC 903, NSX 012002 and NSX 022027 that had highest and most stable yields at every water condition relative to the average yields of all hybrids, see Table 3. It is interesting to note that there was no common response visible with regard to the change in flowering traits at stress. PAC 903 had rather low increases of silking date and tasseling-silking intervals at severe stress; NSX 012002 had only moderate increases in silking date at stress as well, but maintained relatively stable yields despite extremely high values for tasseling-silking intervals. The third yield consistent hybrid, NSX 022007, had large increases in the silking date but rather stable tasseling-silking intervals at severe stress. The oldest and lowest yielding hybrid in the present trials, CP 888, excelled both by quite stable values for both. The question arises, if this was an artificial fact, due to the late flowering date, or if it has not been achieved by breeders to transfer these traits to modern high yielding hybrids.

Table 11 Tasseling-silking interval of eight hybrids in three water treatments: full irrigation (control), mild stress and severe stress in 2003 and 2004. The hybrids are ranked according to the yield of the control at an area basis, see Table 4.

Hybrid	Water regime					
	2003			2004		
variety	Control	Mild stress	Severe stress	Control	Mild stress	Severe stress
	------------d------------			-----------d-----------		
BIG 949	1.50	3.00	5.75	5.50	4.62	8.50
PAC 903	0.75	0.50	5.50	2.50	3.00	6.50
NT 6621	0.50	1.25	6.76	2.50	3.25	4.25
NSX 012002	1.75	3.50	6.75	3.00	4.00	7.50
KSX 4452	2.50	3.25	9.58	2.50	4.50	7.75
NSX 022007	0.50	2.50	4.00	1.00	2.50	6.00
KSX 4605	1.00	1.50	6.01	2.75	3.00	9.75
CP 888	1.00	3.25	2.50	3.50	3.50	6.25
Average	1.19	2.72	5.86	2.91	3.55	7.06
CV % = 9.7 %						

LSD (0.05) for year x waters regime x hybrids interaction of means comparison = 1.73

Plant height and ear heihgt

Plant height decreased were 13 percent in mild stress and 34 percent in severe stress compared with the control (Table 3). The data are not shown in details as they were not significant.

The error variance for the ear height was very high as well, but some significant differences were observed (Table 12). Ear height was reduced at mild stress and at severe stress by 18 and 38 percent, respectively. Lower yielding hybrids at control level at generally higher ear heights at control, but these differences were not significant. Two hybrids with a good yield consistency at severe stress, PAC 903 and NSX 022007, maintained ear height quite well at severe stress, too, but this was not the case for the third yield consistent hybrid. It is interesting to observe again that CP888 belongs almost to a class of its own, with very high ear heights at control level and extremely severe height reductions at stress. Unluckily, it has to be stated that the plant heights in the present trials showed a too high error variance, making it rather doubtful that they could become of use as secondary indicator traits under the present stress conditions.

Table 12 Ear height (cm) of eight hybrids in three water treatments: full irrigation (control), mild stress and severe stress. .

Hybrid	Water regime			
variety	Control	Mild stress	Severe stress	Average
	---------------------------------cm-------------------------------			
BIG 949	119	92	70	93.81
PAC 903	118	102	78	99.02
NT 6621	112	93	70	92.49
NSX 012002	112	94	72	91.47
KSX 4452	124	96	69	96.60
NSX 022007	129	105	83	105.45
KSX 4605	120	107	80	102.08
CP 888	135	102	74	103.79
Average	121	99	74	
CV % = 8.9 %				

LSD (0.05) for waters regime of means comparison = 11.6
LSD (0.05) for varieties of means comparison = 5.0
LSD (0.05) for waters regime x hybrids interaction of means comparison = 46.1

Correlation Between Giain yield and Other trait

High correlations between grain yield and other traits (Table 13) existed for dry weight per plant (0.98), kernels number per hectare (0.92), kernels number per plant (0.90) and harvest index (0.67). Similar in results were obtained by Bolanos *et al*., (1996), Edmeades *et al*., (1999) and Hugh *et al*., (2003)

Grain dry weight per plant was very closely correlated with kernels number per plant (0.96). Grain dry weight per plant is more closely associated with kernel number at harvest than the single kernel weight; under stress condition it is the decrease in kernel number per plant that determines the decrease in grain dry weight per plant and finally on an area basis as well (Boyer *et al*., 2004)

The kernel number per hectare is strongly correlated with the kernel number per plant (0.99). Similar with results were found by Chapman *et al*. (1999) with a corresponding r of 0.96. According to Maria *et al*. (1981) water deficit decreases kernel number per plant or per area mainly during pollination on maize through the effects of plant water status on male and female floral development; as drought strictly at flowering was avoided in the present experiments the pre-anthesis drought must have had the presumed greater effect on female than on male floral development.

Harvest index was moderately to closely correlated with grain yield (0.67), dry weight per plant (0.72), kernel number per area (0.74) and kernel number per plant (0.72). This could be expected as the harvest index is the ratio between grain to total shoot dry matter (Hugh, 2003).

ASI was negatively correlated with the date of tasseling (-0.76). When drought stress occurs just before to during the flowing period, a consequent delay in silking results in an increase in ASI length (Bolanos *et al*., 1993). This asynchrony has been associated with grain yield decrease under drought (Boyer, 1981 and Edmeades, 2000).

Edmeades *et al*. (2001) made a strong case that genetic progress to drought tolerance in grain yield can be highly heritable to ASI; furthermore it is an inexpensive and quick to measure trait, stable over the measurement period, observed at or before flowering and not associated with yield loss under non stress condition. Under our conditions, however, the relationship of the local germplasm between ASI and grain yield was less high than expected.

Water deficit is known to limit cell elongation and cell divisions and thus to decrease leaf area development and general growth of the plant (Wanlop, 2005); the plant height was negatively correlated with the days to 50% tasseling (-0.81)

Table 13_ Correlation coefficients calculated among traits measured on 8 tropical maize hybrids grown under water stress.

GY	Dw	Dwp	1000kn.	Kn	Kp	HI	AD	SD	ASI	PH	EH
GY-	0.98**	0.98**	0.05ns	0.92**	0.90**	0.67ns	0.13ns	-0.47ns	-0.42ns	0.47ns	0.29ns
Dw-	-	0.99**	0.02ns	0.95**	0.93**	0.67ns	0.05ns	-0.55ns	-0.41ns	0.53ns	0.31ns
Dwp	-	-	0.07ns	0.97**	0.96**	0.72*	0.14ns	-0.46ns	-0.45ns	0.41ns	0.23ns
1000kn.	-	-	-	0.29ns	-0.34ns	-0.23ns	0.06ns	-0.02ns	-0.01ns	0.33ns	0.58ns
Kn-	-	-	-		0.99**	0.74*	0.06ns	-0.50ns	-0.41ns	0.37ns	0.10ns
Kp -	-	-	-		-	0.72*	0.08ns	-0.47ns	-0.42ns	0.34ns	0.09ns
HI -	-	-	-		-	-	0.19ns	-0.35ns	-0.45ns	0.08ns	-0.22ns
AD-	-	-	-		-	-	-	0.51ns	-0.76*	-0.46ns	0.08ns
SD -	-	-	-		-	-	-	-	0.15ns	-0.81*	0.31ns
ASI	-	-	-	-		-	-	-	-	-0.02ns	0.34ns
PH -	-	-	-		-	-	-	-	-		0.61ns

* = Significant at 0.05 level of probability
** = Significant at 0.01 level of probability
Ns = non sisnificant

GY=grain yield; DW=Grain dry weight; DWE= Grain dry weight per ear; 1000kn= 1000 kernels weight; Kn= Kernel number per area;
Kp= Kernel number per plant; HI= Harvest index; AD= 50 % tasseling; SD= 50% silking; ASI= anthesis-silking interval;
PH= plant height; EH= ear height

CONCLUSION

During the early planting season under rain fed agriculture maize cultivation is usually affected by drought. The experiment here were conducted during in dry seasons of 2003 and 2004 in order to study the effect of timings drought stress on growth, development, grain yield and some other agronomic characteristics to grain yield in different genotypes of maize. It was the aim to simulate different intensities of early pre-anthesis stress situations as they can occur due to irregular rainfalls after planting. In order to achieve this aim, drought stress was applied either from V8 stage until 50 % flowering (severe stress), or by a permanently reduced irrigation at a 50 % level of a well watered situation (mild stress) in comparison with a well watered situation (control). The design of the study was a split plot arrangement within a randomized complete block design with four replications. The results can be concluded as follows:

1. Water stress during at V8 to 50 % flowering stage resulted in yield averages of 33 % compared to those achieved under control condition, with an ASI average of 6.4 days. This condition is suitable to discriminate clearly between tolerant and sensitive genotypes; furthermore, it displays an agronomic characteristic correlation with grain yield. Therefore, the W3 condition is a good condition for test the intended drought stress situation.

2. Accordingly, under severe stress condition it was clearly feasible to identify genotypes with a recommendable tolerance like NSX 012002, NSX 022027 (Nakhon Sawan Research Center, Department of Agriculture) and PAC 903 (Pacific seed. Co.th); a strictly sensitive genotype KSX 4605 (National Corn and Sorghum Research Center, Kasetsart University) was found as well.

3. Grain yield was very strongly correlated with dry weight per plant (0.98), kernel number per area (0.92) and kernel number per plant (0.90).

4. The harvest index was less closely but still significantly correlated with dry weight per plant and kernel number.

5. Days to 50 % tasseling was negatively correlated with anthesis-silking interval (ASI)(-0.76); days to 50% silking was negatively correlated with plant height (0.81)

6. It is still too early to comment on the impact under drought of different known genetic features in relation to the phenotype by genetic (G) (P=G+E+GE) situation. But it is noteworthy that is the two tall hybrids NSX 012002 and NSX 022027 were well tolerant, whereas the stay green BIG 949 and the prolific DK 888 were not.

7. However, DK 888 may be a wrong example as modern hybrids were usually more tolerant, like PAC 903 tolerance. This is a fine example that breeders are able to improve their materials with their present tools at an acceptable pace.

8. All in all it could be shown that there exists the genetic scope for drought tolerance that could be transferred to breeding programs for medium maturing hybrids that would be more suitable for being planted in the early rainy season.

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APPENDIX

Appendix Table 1 Analysis of variance for grain yield at 15 % moisture content of 8 hybrids maize

Source of Variation	df	SS	MS	F -Value
Year	1	27.5329	27.5329	7.14 *
Year*Rep	6	36.6750	6.11249	7.77 **
Water [w]	2	1034.73	517.363	134.16 **
Year*Water	2	22.8316	11.4158	14.51 **
Error a	12	46.2774	3.85645	4.90 **
Hybrid [H]	7	37.2268	5.31811	6.76 **
Year*Hybrid	7	11.2091	1.60130	2.03 NS
Water*Hybrid [W x H]	14	26.8258	1.91613	2.43 **
Year*Water*Hybrid	14	17.6640	1.26172	1.60 NS
Error b	126	99.1561	786953	
Total	191	1360.12	7.12107	

* = Significant at 5% level of probability
** = Significant at 1% level of probability
NS = Non-Significant

Appendix Table 2 Analysis of variance for grain dry weigh per plant of 8 hybrids maize

Source of Variation	df	SS	MS	F-Value
Year	1	41458.7	41458.7	67.53 **
Year*Rep	6	2933.46	488.910	2.74 *
Water [w]	2	167956.	83978.0	136.78 **
Year*Water	2	10143.5	5071.73	28.42 **
Error a	12	7367.30	613.942	3.44 **
Hybrid [H]	7	3682.59	526.084	2.95 **
Year*Hybrid	7	2667.21	381.029	2.14 *
Water*Hybrid [W x H]	14	5262.97	375.927	2.11 *
Year*Water*Hybrid	14	2489.09	177.792	1.00 NS
Error b	126	22485.2	178.454	
Total	191	266446.	1395.01	

* = Significant at 5% level of probability
** = Significant at 1% level of probability
NS = Non-Significant

Appendix Table 3 Analysis of variance for kernel number per hectare of 8 hybrids maize

Source of variation	df	SS	MS	F-Value
Year	1	.136283E+10	.136283E+10	47.44 *
Year* Rep	6	.162874E+09	.271457E+08	4.02 **
Water [w]	2	.873007E+10	.436503E+10	151.94 **
Year*Water	2	.160190E+09	.800948E+08	11.85 **
Error a	12	.344741E+09	.287284E+08	4.25 **
Hybrid [H]	7	.559997E+09	.799996E+08	11.84 **
Year*Hybrid	7	.108281E+09	.154687E+08	2.29 *
Water*Hybrid [W x H]	14	.327396E+09	.233854E+08	3.46 **
Year*Water*Hybrid	14	.144770E+09	.103407E+08	1.53 NS
Error b	126	.851516E+09	.675807E+07	
Total	191	.127527E+11	.667679E+08	

* = Significant at 5% level of probability
** = Significant at 1% level of probability
NS = Non-Significant

Appendix Table 4 Analysis of variance for kernel number per plant of 8 hybrids maize

Source of Variation	df	SS	MS	F-Value
Year	1	446755.	446755.	55.52 **
Year*Rep	6	41659.5	6943.25	3.20 **
Water [w]	2	.239330E+07	.119665E+07	148.72 **
Year*Water	2	65550.6	32775.3	15.11 **
Error a	12	96556.2	8046.35	3.71 **
Hybrid [H]	7	115394.	16484.9	7.60 **
Year*Hybrid	7	25372.5	3624.64	1.67 NS
Water*Hybrid [W x H]	14	107052.	7646.56	3.53 **
Year*Water*Hybrid	14	24611.7	1757.98	0.81 NS
Error b	126	273239.	2168.56	
Total	191	.358949E+07	18793.1	

* = Significant at 5% level of probability
** = Significant at 1% level of probability
NS = Non-Significant

Appendix Table 5 Analysis of variance for 1000 kernels dry weight of 8 hybrids maize

Source of Variation	df	SS	MS	F-Value
Year	1	23055.7	23055.7	56.59 **
Year*Rep	6	1875.11	312.518	0.78 NS
Water [w]	2	17741.2	8870.61	21.77 **
Year*Water	2	4857.00	2428.50	6.07 **
Error a	12	4889.25	407.437	1.02 NS
Hybrid [H]	7	46953.8	6707.69	16.75 **
Year*Hybrid	7	14219.2	2031.31	5.07 **
Water*Hybrid [W x H]	14	9902.69	707.335	1.77 *
Year*Water*Hybrid	14	19862.6	1418.76	3.54 **
Error b	126	50449.3	400.392	
Total	191	193806.	1014.69	

* = Significant at 5% level of probability
** = Significant at 1% level of probability
NS = Non-Significant

Appendix Table 6 Analysis of variance for harvest index of 8 hybrids maize

Source of Variation	df	SS	MS	F-Value
Year	1	.602402E-01	.602402E-01	7.40 *
Year*Rep	6	.401725E-01	.669542E-02	4.43 **
Water [w]	2	.897887	.448943	55.15 **
Year*Water	2	.129205	.646027E-01	42.76 **
Error a	12	.976783E-01	.813986E-02	5.39 **
Hybrid [H]	7	.103958	.148511E-01	9.83 **
Year*Hybrid	7	.625528E-01	.893611E-02	5.92 **
Water*Hybrid [W x H]	14	.907694E-01	.648353E-02	4.29 **
Year*Water*Hybrid	14	.767155E-01	.547968E-02	3.63 **
Error b	126	.190355	.151075E-02	
Total	191	1.74953	.915986E-02	

* = Significant at 5% level of probability
** = Significant at 1% level of probability
NS = Non-Significant

Appendix Table 7 Analysis of variance for days to 50 percent tasseling of 8 hybrids maize

Source of Variation	df	SS	MS	F-Value
Year	1	75.0875	75.0875	5.74 *
Year*Rep	6	60.8702	10.1450	5.10 **
Water [w}	2	178.048	89.0239	6.81 **
Year*Water	2	82.3477	41.1739	20.72 **
Error a	12	156.937	13.0780	6.58 **
Hybrid [H]	7 4	35.368	62.1954	31.29 **
Year*Hybrid	7	83.4150	11.9164	6.00 **
Water*Hybrid [W x H]	14	70.4875	5.03482	2.53 **
Year*Water*Hybrid	14	31.6322	2.25944	1.14 NS
Error b	126	250.442	1.98763	
Total	191	1424.63	7.45882	

* = Significant at 5% level of probability
** = Significant at 1% level of probability
NS = Non-Significant

Appendix Table 8 Analysis of variance for days to 50 percent silking of 8 hybrids maize

Source of Variation	df	SS	MS	F -Value
Year	1	4.08625	4.08625	0.24 NS
Year*Rep	6	54.7090	9.11816	3.07 **
Water [w}	2	1523.68	761.839	44.02 **
Year*Water	2	77.9313	38.9656	13.11 **
Error a	12	207.666	17.3055	5.82 **
Hybrid [H]	7	314.872	44.9818	15.13 **
Year*Hybrid	7	83.8075	11.9725	4.03 **
Water*Hybrid [W x H]	14	74.1140	5.29386	1.78 *
Year*Water*Hybrid	14	72.8087	5.20062	1.75 NS
Error b	126	374.609	2.97309	
Total	191	2788.28	14.5983	

* = Significant at 5% level of probability
** = Significant at 1% level of probability
NS = Non-Significant

Appendix Table 9 Analysis of variance for tasseling-silking interval (ASI) of 8 hybrids maize

Source of Variation	df	SS	MS	F-Value
Year	1	74.9625	74.9625	17.85 **
Year*Rep	6	14.5951	2.43252	1.58 NS
Water [w}	2	677.153	338.577	80.62 **
Year*Water	2	6.41148	3.20574	2.09 NS
Error a	12	50.3944	4.19953	2.73 **
Hybrid [H]	7	113.478	16.2111	10.55 **
Year*Hybrid	7	45.5973	6.51391	4.24 **
Water*Hybrid [W x H]	14	74.3525	5.31089	3.46 **
Year*Water*Hybrid	14	64.5635	4.61168	3.00 **
Error b	126	193.580	1.53635	
Total	191	1315.09	6.88528	

* = Significant at 5% level of probability
** = Significant at 1% level of probability
NS = Non-Significant

Appendix Table 10 Analysis of variance for plant height of 8 hybrids maize

Source of Variation	df	SS	MS	F-Value
Year	1	26873.5	26873.5	13.05 **
Year*Rep	6	23866.7	3977.78	24.53 **
Water [w}	2	193318.	96659.2	46.92 **
Year*Water	2	14709.7	7354.86	45.36 **
Error a	12	24719.2	2059.93	12.70 **
Hybrid [H]	7	8725.56	1246.51	7.69 **
Year*Hybrid	7	1958.34	279.763	1.73 NS
Water*Hybrid [W x H]	14	3349.32	239.237	1.48 NS
Year*Water*Hybrid	14	2169.34	154.953	0.96 NS
Error b	126	20430.4	162.146	
Total	191	320121.	1676.02	

* = Significant at 5% level of probability
** = Significant at 1% level of probability
NS = Non-Significant

Appendix Table 11 Analysis of variance for ear high of 8 hybrids maize

Source of Variation	df	SS	MS	F-Value
Year	1	9145.26	9145.26	10.13 **
Year*Rep	6	9670.50	1611.75	20.98 **
Water [w}	2	69567.4	34783.7	38.54 **
Year*Water	2	7959.23	3979.61	51.80 **
Error a	12	10831.0	902.581	11.75 **
Hybrid [H]	7	4782.35	683.192	8.89 **
Year*Hybrid	7	1109.96	158.565	2.06 NS
Water*Hybrid [W x H]	14	2157.18	154.084	2.01 *
Year*Water*Hybrid	14	1580.30	112.878	1.47 NS
Error b	126	9681.04	76.8337	
Total	191	126484.	662.221	

* = Significant at 5% level of probability
** = Significant at 1% level of probability
NS = Non-Significant

	A		B							C									D	D
Date	14/11	18/11	25/11	2/12	9/12	16/12	23/12	30/12	6/1	13/1	20/1	27/1	3/2	10/2	17/2	24/2	3/3	10/3	17/3	24/3
Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
W1 (control)	S		S	S	F	F	F	F	F		F	F	F	F	F	F		F	F	F

Appendix Figure 1 Growth of corn plants which gave irrigation (water) every week interval (W1,Control)

A = Thinning; B = Side dressing; C = Flowering (67 days); D = Harvesting (130 days)
S=Sprinkler irrigation
F=Follow irrigation

	A		B							C									D	D
Date	14/11	18/11	25/11	2/12	9/12	16/12	23/12	30/12	6/1	13/1	20/1	27/1	3/2	10/2	17/2	24/2	3/3	10/3	17/3	24/3
Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
W2	S	S	S		$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$		$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	$F_{1/2}$	

(mild stress)

Appendix Figure 2 Growth of corn plants which reduced water 50 % of the control (W2,mild stress)

A = Thinning; B = Side dressing; C = Flowering (67 days); D = Harvesting (130 days)
S=Sprinkler irrigation
F=Follow irrigation

	A		B							C									D	D
Date	14/11	18/11	25/11	2/12	9/12	16/12	23/12	30/12	6/1	13/1	20/1	27/1	3/2	10/2	17/2	24/2	3/3	10/3	17/3	24/3
Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
W1 (severe stress)	S	S	S	F		X	X	X		X	X	X	F	F	F		F	F	F	F

Appendix figure 3 Growth of corn plants which did not gave water from the 6 - 7 leaf stage until one week before anthesis thereafter the weekly full furrow irrigation was resumed. (W3, severe stress)

A = Thinning; B = Side dressing; C = Flowering (67 days); D = Harvesting (130 days)
S=Sprinkler irrigation
F=Follow irrigation