EFFECTS OF DROUGHT STRESS AND POTASSIUM ON THE GROWTH AND YIELD OF LOCALLY PLANTED SWEET CORN

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ABSTRACT

Drought stress is an abiotic factor affecting growth and yields of crop plants globally. The growth and yield performances of Thai Super Sweet (TSS) corn variety treated with drought stress levels (29.00%, 14.50% and 7.25% Soil Moisture Content, SMC) and potassium rates (30, 60 and 90 kg/ha) were investigated in an insect-proof net-house of Faculty of Sustainable Agriculture (FSA), Universiti Malaysia Sabah, Sandakan Campus, Malaysia. Drought treatment was applied at the flowering stage (period of tasseling to complete silk emergence) and lasted for 20 days. Experimental units were arranged factorial completely randomized design with four replications. Parameters of growth, chlorophyll content, proline content and yield were measured and analysed statistically in this study. Plant height, first cob height from the soil surface, fresh cob weight, grain number per cob, 100-grain weight and free proline content showed interaction effects among the drought and potassium treatments while cob length showed significant effect among drought stress treatments and relative chlorophyll content showed significant effect among potassium rates treatments. It may be concluded that 7.25% SMC + 60 kg/ha K was adequate for irrigation and fertilization for the corn plants as there was no significant difference observed when compared to the control treatment, 29.00% SMC + 60 kg/ha K. Corn plants treated with 7.25% SMC + 60 kg/ha K expressed tolerance response through the higher level of proline content which aid in resisting drought stress and hence was able to perform the best overall yield components. The irrigation cost that can be saved is RM722.90 per hectare with 7.25% SMC. Thus, irrigation reduced to 7.25% SMC can be recommended to the farmer to reduce the cost of irrigation and hence to obtain a better yield. Further research should be conducted to study the drought stress and potassium effects on other corn varieties and in the open field trial.

Key words: Corn, drought stress, free proline content, potassium, soil moisture content.

INTRODUCTION

Drought is one of the significant limiting abiotic factors for crop productivity and had become an increasingly severe problem in many regions all over the world, which generally inhibits plant growth through reduced water absorption and nutrient uptake (Aslam *et al.*, 2013). In different parts of the world, more frequent and prolonged drought events are anticipated due to climate changes and global warming, which reduced the growth and final yield in crop plants. Water stress has been found to reduce leaf area, photosynthesis, leaf chlorophyll contents and consequently corn grain yield (Azab, 2016). It reduces evapotranspiration by closing stomata, which results in reduced carbon assimilation rate and declined in biomass production (Demir *et al.*, 2006). Plants that are continuously exposed to drought stress can form reactive oxygen species (ROS), which leads to leaf damage and ultimately, decreases crop yield (Lum *et al.*, 2014).

Maize (*Zea mays* L.), also known as corn, is one of the most important food grain crops throughout the world. Demand for corn in the developing countries will double between now and 2050 as the world will have around 7.7 billion people by 2020 and the figure will be approximately 9.3 billion by 2050 (Sinar Harian, 2016). It is an economically important crop that is often threatened by severe abiotic stresses, of which the most common is drought stress and it is highly susceptible to drought (Valerie and Moses, 2016). Potassium (K) can reduce the adverse effects of drought by inducing various physiological changes such as osmotic adjustment, protein synthesis and reduction in transpiration rate in water-deficient plants (Farooq *et al.*, 2009). K plays a key role in the formation of the osmotic adjustment ability, which acts as one of the most prominent inorganic osmotic in plants under drought conditions (Wang *et al.*, 2013). The exogenous application of K can alleviate drought-induced negative effects on plant growth (Zhang *et al.*, 2014).

Drought tolerance is the single most important constraint to increase productivity for crops worldwide which usually results from complex physiological changes of the plants (Xoconostle-Cázares *et al.*, 2010). Proline content was significantly increased under drought stress conditions (Efeoğlu *et al.*, 2009) and it is readily metabolized upon recovery from drought when the plant is subjected to water stress (Singh *et al.*, 2000). Accumulation of proline in plants under drought stress can protect the plant cell by balancing the osmotic potential of cytosol with that of vacuole and the external environment (Johari-Pireivatlou, 2010).

In Malaysia, some corn production areas are exposed to the threat of low growth and yield reduction during drought seasons. Based on the above review, little is reported in the literature about the interaction effects of drought and potassium for sweet corn production. Hence, this study was carried out to determine the effects of potassium fertilizer rates to achieve higher growth and yield of sweet corn under drought stress. Observation of the corn plants react to drought and the mechanism involved in resisting drought were needed to find out the extent of drought tolerance and water management in achieving higher corn crop productivity. Under the treatment of different levels of drought stress and potassium, we were able to determine the minimum water required to produce potential yield for sweet corn variety. The finding of the optimum rate of potassium fertilizer through this study will fill the relevant knowledge gaps for the benefits of the local farmers and smallholders even under drought stress condition and hence they can determine the best time to plant this variety according to the rainfall pattern of the region.

MATERIALS AND METHODS

PLANTING, DESIGN AND MANAGEMENT OF CROPS

A pot experiment was conducted in an insect-proof net-house of the Faculty of Sustainable Agriculture (FSA), Universiti Malaysia Sabah (UMS) Sandakan campus from August 2017 to November 2017. During this period, intensive care of corn plants was taken from seed sowing to transplanting of the corn seedlings. Thai Super Sweet (TSS) corn variety from Wah Heng Hang Seeds & Co. was used in this study. The factorial experiment was laid out in Completely Randomized Design (CRD) with nine treatments of different drought stress levels using soil moisture content (29.00, 14.50 and 7.25% SMC) and potassium fertilizer rates (30, 60 and 90 kg/ha) (Amanullah *et al.*, 2016) and four replicates for each of the treatments.

The corn seeds were germinated in a germination tray with sand in the laboratory and the healthy seedlings were selected and transplanted in the pot where only one seedling was transplanted into one pot with a depth of 5 cm from the soil surface. The drought stress levels were adjusted by using soil moisture content (SMC). The soil moisture was determined by using FieldScout Soil Sensor Reader (Spectrum Technologies, Inc.) according to the Field Capacity (FC) suggested by Cassel and Nielson (1986). Field capacity was defined as the amount of water held in the soil after the excess water had been drained away (Cassel and Nielson, 1986). A field capacity test was conducted before the study to determine the optimum level of water reserve of the soil at 100% FC. The soil media used in this study (ultisols) was dried and sieved to a uniform size of 2 mm to be tested. The dry weight of soil was recorded before wetting of soil for determination of field capacity. It was then slowly wet to approximately half of its depth from the top by slowly adding water to saturation. The soil was ensured to be fully wet to saturation, however, care was taken not to overwater the soil, which could occur if the rate of water application was too much. The pots were then covered with dark plastic to prevent evaporation occur. The containers were left for 24 hours for the water to drain fully. After 24 hours, the soil was at 100% FC and the weight was recorded as wet weight. Soil Sensor Reader was then used to record the percentage of water content (% WC) in the soil. The field capacity water content in kilogramme was then calculated by using the formula below and converted into a litre of water:

Field capacity water content (L) = Weight of wet soil - Weight of dry soil
*1 kg = 1 L
The drought treatment was applied at the flowering stage which was at the period of tasseling to complete silk emergence and lasted for 20 days (Ji *et al.*, 2012). The irrigation regime before and after the treatment was the same, which is no drought stress applied to the corn plants. The watering operation was done twice a day, which was in the morning and evening period respectively by using a watering can.

Straight fertilizers were used in this study where Urea as a source of nitrogen, Triple Super Phosphate (TSP) as a phosphorus source and Muriate of Potash (MOP) as a potassium source. NPK straight fertilizer with 60 kg/ha N: 60 kg/ha P_2O_5: 60 kg/ha K_2O was acting as the control basal treatment for this study, where 60 kg/ha N and 60 kg/ha P_2O_5 were applied as basal fertilizer with a specific amount of K_2O according to treatments. Topdressing of urea fertilizer was applied at a rate of 130 kg/ha N five weeks after planting. Fertilizer was applied at a depth of 3 cm from the soil surface and 5 cm from the corn plants and then covered by the soil (Leong, 2005).

The four parameters considered in this study were vegetative growth, yield, physiological characteristic and biochemical characteristic. Parameters on corn growth and physiological characteristic were observed and collected weekly whereas the yield and biochemical parameter was taken after the harvesting of corn. Corn cobs were harvested when the silk of cob appeared with dark and little dry silk at 80 days after planting.

GROWTH PARAMETERS

The growth components that were measured are plant height, stem girth, leaf number, leaf length, leaf width, leaf area and first cob height from the soil surface. The height of the plants was measured from the base of the plant to the ligule of the youngest fully developed leaf (second uppermost leaf) by using a measuring tape. The measurement was taken every week. The girth of each stem was also measured with measuring tape every week. The number of leaves was counted by using the leaf over method visually. This method was counted from the lowest leaf (the coleoptile leaf with a rounded tip) up to the last leaf that is arched over (tip is pointing down). The young leaves which are still inside the whorl were not counted.

The data of leaf length and leaf width were collected using a measuring tape. The measurement for leaf length was taken from the ligule to the apex of the leaf which subtends the uppermost ear while the measurement of leaf width was taken at the mid-way along the length of a leaf which subtends the uppermost ear. Leaf length and leaf width measurement were done every week after transplanting until maturity and the data recorded weekly was used to calculate the leaf area. The first cob height from the soil surface was measured from the soil surface to the stalk of the first cob by using measuring tape. Leaf area of individual leaf was calculated by using the formula LA (m^2) = L × W × k; where: LA = Leaf area; L = Leaf length; W = Leaf maximum width and k = Constant (k = 0.75) (Valerie and Moses, 2016).

YIELD AND YIELD COMPONENTS

All the yield attributes were measured upon maturity. The yield attributes taken in this study were cob length, cob diameter, fresh cob weight, cob girth, grain number per cob and 100-grain weight. The length of the cob was measured by using a measuring tape from the base of the cob to the tip of the cob. The diameter of a cob of each plant was measured by placing a ruler in the central part of the uppermost cob horizontally.

The fresh cob weight was measured by using Mettler Toledo AB204-S analytical balance upon harvest. The girth of the cob was measured by placing a measuring tape in the central part of the cob after harvest. The number of grains per cob was counted manually upon harvest. The grains of harvested cobs were threshed and removed manually. The 100-grain weight of corn was measured by using Mettler Toledo AB204-S analytical balance. All the yield data was taken and recorded upon harvest.

RELATIVE CHLOROPHYLL CONTENT

The relative chlorophyll content was measured by using Konica Minolta portable SPAD-502 Plus chlorophyll meter throughout the study. Measurement of relative chlorophyll content was carried out at 11 a.m. due to the sensitivity of the SPAD chlorophyll meter towards sunlight and this is the time where the condition will not be too wet for measurements (Nozulaidi *et al.*, 2016).

FREE PROLINE CONTENT

Free proline concentration (FPC) in fresh leaf samples was estimated following the procedure of Bates *et al.* (1973). The proline concentration was determined using a standard curve and was expressed as micromole per gram of fresh weight (µmole/g FW). It was calculated on a fresh weight basis (Bates *et al.*, 1973) as follow:

$$\text{Proline (µmole/g FW)} = \frac{proline\ (\text{µg/mL})}{115.5\ \text{µg/µmole}} \div \frac{sample\ (g)}{5}$$

STATISTICAL ANALYSIS

Data collected were subjected to Two-way Analysis of Variance (ANOVA) by using the Statistical Analysis Software (SAS) Version 9.4 (SAS Institute Incorporation, 2002) software. The Least Significant Difference (LSD) test at 0.05 level of probability was used to compare between means when ANOVA showed significant treatment effects of this study.

RESULTS AND DISCUSSION

The results showed that there were interaction effects among the drought and potassium treatments for the plant height (Figure 1A), first cob height from the soil surface (Figure 1B), fresh cob weight (Figure 1C), grain number per cob (Figure 1D), 100-grain weight (Figure 1E) and free proline content (Figure 1F). The cob length showed significant effects among drought treatments (Figure 2) whereas the relative chlorophyll content (SPAD unit) showed a significant effect among potassium treatments (Figure 3).

There was an interaction effect among the treatments ($p<0.05$) on the plant height after 20 days of drought treatment. The highest mean plant height was showed by T3K2 (7.25% SMC + 60 kg/ha K) (234.40 cm) (Figure 1A). The highest plant height showed by T3K2 indicated that although the plants treated with 7.25% SMC, the plants managed to alleviate the drought stress effect by applying a recommended rate of 60 kg/ha potassium fertilizer to the corn plants. Similar findings were reported that the exogenous application of potassium can alleviate drought-induced negative effects on plant growth (Fanaei *et al.*, 2012). An adequate amount of potassium can promote the accumulation of a total dry mass of plants under drought stress compared with the plants with lower potassium concentration (Wang *et al.*, 2013). Potassium also aided in the opening and closing of stomata, water use efficiency which also known as resistance to drought and expanding the root growth (Wang *et al.*, 2013).

The first cob height from the soil surface showed an interaction effect among the treatments ($p<0.05$) after 20 days of drought treatment. The ideal first cob height of corn from the soil surface was 100 cm (Gyenes-Hegyi *et al.*, 2002), thus treatment T3K1 (7.25% SMC + 30 kg/ha K) had the favourable first cob height from the soil surface (98 cm) which was nearest to 100 cm compared to other treatments (Figure 1B). The height of the cob is determined by the number and length of the internodes and it is a very important characteristic for breeding (Szőke *et al.*, 2002). The higher the first cob height from the soil surface, the more cobs can develop from the nodes below the corn plants. However, if it is too high, the excessive weight of the cob may bend the stalk or even break it which may cause yield losses. Thus, neither too high nor too low cob height is proved to obtain the optimum yield (Szőke *et al.*, 2002).

There was an interaction effect among the treatments ($p<0.05$) on fresh cob weight after 20 days of drought treatment. Treatment T1K2 (29.00% SMC + 60 kg/ha K; control) showed the highest fresh cob weight (94.15 g) which indicated the best crop performance among the treatments (Figure 1C). Plants applied with the recommended rate of potassium (60 kg/ha K) will produce an optimum yield of crops (Leong, 2005). Treatment T2K1 (14.50% SMC + 30 kg/ha K) showed the least fresh cob weight (46.37 g) among all the treatments (Figure 1C). This indicated that watering the corn plants with 14.50% SMC reduced the fresh cob weight under lower potassium fertilizer application (30 kg/ha K). This happened due to the pernicious effects of drought stress on the anthesis-silking interval, pollination and grain formation in corn crop (Wang *et al.*, 2013) which severely reduce the rate of crop growth and accumulation of biomass. Adequate potassium capable to promote the accumulation of a total dry mass of plants under drought stress compared with the plants with lower potassium concentration (Wang *et al.*, 2013 and Jatav *et al.*, 2014).

There was an interaction effect ($p<0.05$) on the grain number per cob after 20 days of drought treatment. The treatment T1K1 (29.00% SMC + 30 kg/ha K) gave the highest grain number per cob (328 grains) while treatment T2K1 (14.50% SMC + 30 kg/ha K) (151 grains) was the lowest among these treatments (Figure 1D). The differences in grain number might be due to the unsuccessful pollination of the plants during the pollination process (Lauer, 2012). It might also cause by the existence of pests such as ants and spiders that suck the milky kernel, thus causing the kernels cannot to develop fully (Lauer, 2012). Grain number per cob is one of the most vital factors which lead to the final grain yield of the crops (Farooq *et al.*, 2009). The more the grain number per cob, the higher the grains yield (El Sabagh *et al.*, 2015). T1K1 (29.00% SMC + 30 kg/ha K) gave the highest grain number per cob which indicated that by watering the plants with 29.00% SMC, application of 30 kg/ha K is sufficient to produce the highest grain number per cob. Treatments T2K1 and T3K1 were planting with the application of 30 kg/ha potassium fertilizers and watered with 14.50% SMC and 7.25% SMC respectively which were considered under drought condition and both treatments showed less grain number per cob compared to other treatments. Similar findings revealed that drought stress caused reduced in leaf area, photosynthesis, leaf chlorophyll contents and consequently maize grain yield (Azab, 2016 and Nikju *et al.*, 2015).

There was an interaction effect among the treatments ($p<0.05$) on the 100-grain weight after 20 days of drought treatment. The treatment T3K1 (7.25% SMC + 30 kg/ha K) gave the highest 100-grain weight (23.71 g) while treatment T2K3 (14.50% SMC + 90 kg/ha K) (16.07 g) was the lowest among these treatments (Figure 1E). There was a difference of 47.54% between treatments T2K3 and T3K1 on 100-grain weight. The higher the weight of 100 grains, the more vigorous the seed and thus the higher the economic yield of corn (Marschner, 2012). Similarly, findings suggested that the weight of grains was reduced in water deprivation condition (Setter *et al.*, 2001 and Sadeghipour, 2008). The grain fill stage is the last set of stages of the corn growth cycle where the size of kernels is set during this stage (Ghassemi-Golezani and Lotfi, 2012). Drought stress during any grain development stage causes the premature cessation of grain filling which resulting in reduced grain weight (Sadeghipour, 2008). Harmful effects of drought on corn yield were due to reduced crop growth, canopy development, dry matter accumulation, kernel number and kernel weight (Hussain *et al.*, 2013).

The free proline content showed an interaction effect among the treatments ($p<0.05$) after 20 days of drought treatment. Treatment T2K3 (14.50% SMC + 90 kg/ha K) had the highest proline content (270.41 µmole/g FW) (Figure 1F). This indicated that the corn plants watered with 14.50% SMC and treated with 90 kg/ha K tend to accumulate more proline to protect the plant cell by balancing the osmotic potential of cytosol which can aid in resisting drought stress (Fahramand *et al.*, 2014). Accumulation of proline content under drought stress reveals that accumulated proline might act as a compatible solute regulating and reducing water loss from the plant cell during water deficit condition (Lum *et al.*, 2014). The maintenance of leaf turgor was achieved by the osmotic adjustment in response to the accumulation of proline, sucrose, soluble carbohydrates and other solutes in the cytoplasm which improved the water uptake from drying soil (Anjum *et al.*, 2011). Proline which is readily metabolized when a plant subjected to drought also plays an important role in balancing osmosis and supplies energy for survival and growth and can help the plants to tolerate stress condition (Lum *et al.*, 2014).

There was no interaction effect on the cob length of all the treatments ($p>0.05$), however a significant effect ($p<0.05$) was found on the drought stress levels toward the cob length of all plants. The mean cob length for T1 (29.00% SMC) was the highest (14.90 cm) while T2 (14.50%) SMC had the lowest cob length (12.84 cm) (Figure 2). The cob length is one of the vital determinants of the yield and price for marketable purposes. It is controlled by genotypic and environmental factors such as water content and nutrients (Moradi *et al.*, 2012). Soil moisture content controls plant phenological, physiological and morphological, when soil available water decreases, the drought pressure results in a decline in cob length (Khan *et al.*, 2001 and Uwizeyimana *et al.*, 2018). Since the cob of corn contains kernels and it has been reported as an important part of yield, thus, the longer the cob length, the more the kernel numbers which leads to higher yield (Ouattar *et al.*, 1987 and Moradi *et al.*, 2012). As a result of drought stress, the cob length decreased, and the fertilised part of the cob and thus the number of kernels per cob were also substantially reduced (Spitkó *et al.*, 2014 and Wang *et al.*, 2019).

There was no interaction effect among the treatments ($p>0.05$) on the relative chlorophyll content but a significant effect of potassium rates ($p<0.05$) toward the relative chlorophyll content of all plants after the 20-day drought treatment period. The LSD test revealed that treatment 90 kg/ha K had the highest relative chlorophyll content which was 36.80 SPAD unit while the treatment of 30 kg/ha K with a value of 33.75 SPAD unit had the lowest relative chlorophyll content (Figure 3). The results were following studies that identified a decrease of chlorophyll concentration under the condition of potassium deficiency (Zhao *et al.*, 2001; Lu *et al.*, 2016 and Tränkner *et al.*, 2018). The chlorophyll content is an index for evaluation of source; hence a decrease of chlorophyll content can be considered as a non-stomata limiting factor under drought stress condition (Mafakheri *et al.*, 2010). Studies reported that the reduction of chlorophyll content was due to the excessive swelling in lamella vascular, lipid peroxidation and loss of chloroplast membrane (Gill and Tuteja, 2010 and Maisura *et al.*, 2014). Drought not only led to a reduction of plant growth but also reduced the water content and chlorophyll pigments of plants (Efeoğlu *et al.*, 2009 and Yang *et al.*, 2009).

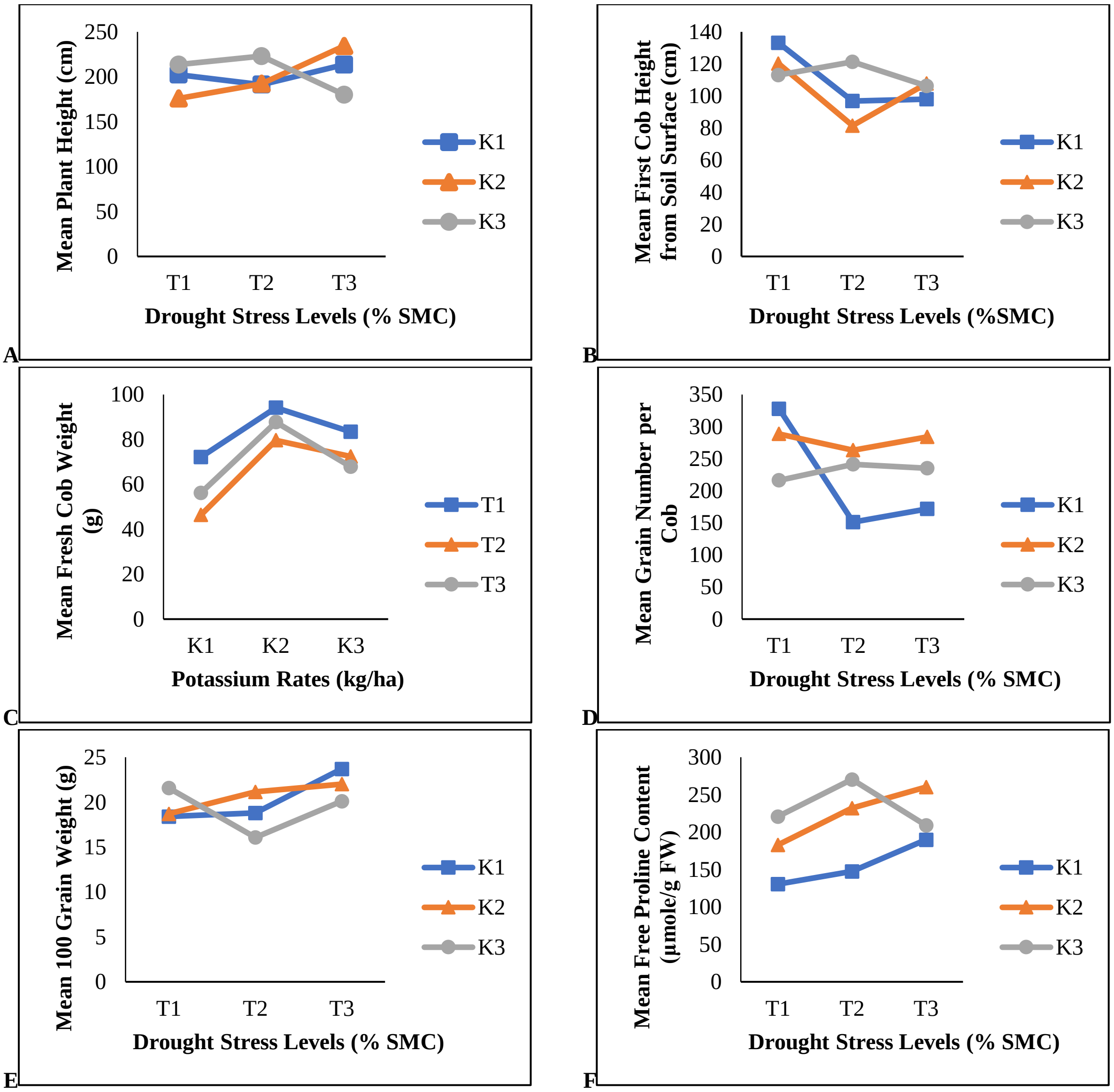


Figure 1. Interaction effects of different drought stress levels and potassium rates of Thai Super Sweet corn variety at 56 Days After Transplanting (DAT). (A) Mean plant height, (B) mean first cob height from the soil surface, (C) mean fresh cob weight, (D) mean grain number per cob, (E) mean 100-grain weight and (F) mean free proline content.

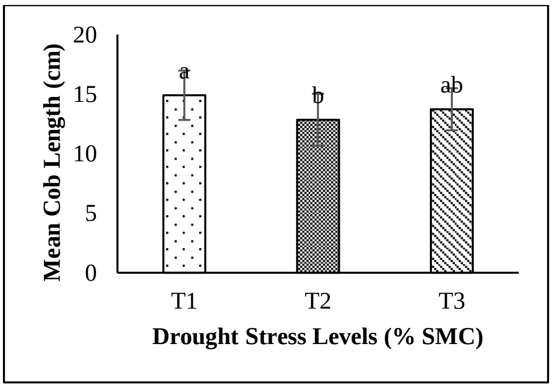


Figure 2. Effects of different drought stress levels on mean cob length of Thai Super Sweet corn variety at 56 DAT.

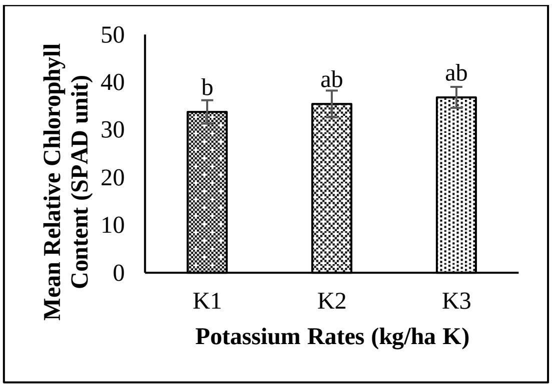


Figure 3. Effects of different potassium rates on mean relative chlorophyll content of Thai Super Sweet corn variety at 56 DAT.

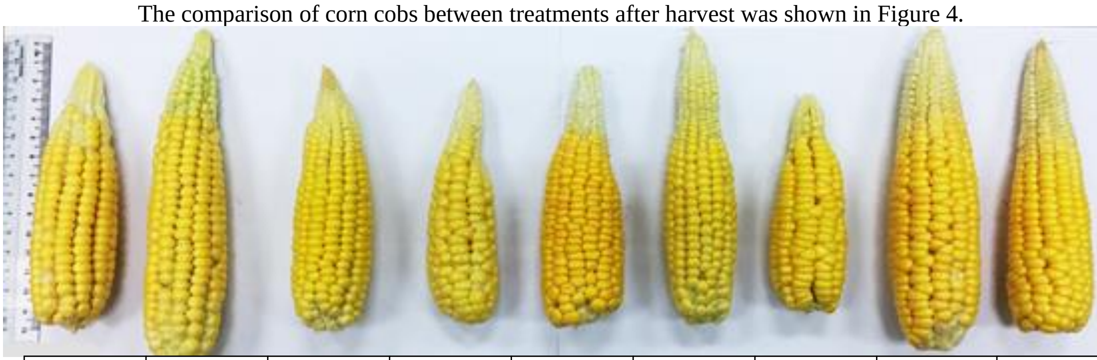
Legends

T1: 29.00% SMC*	K1: 30 kg/ha K
T2: 14.50% SMC	K2: 60 kg/ha K
T3: 7.25% SMC	K3: 90 kg/ha K

*SMC: Soil Moisture Content
*Values are mean of four replications; the bars represent ± standard deviation; different letters are significantly different at $p<0.05$ by the Least Significant Difference test.

Figure 4. Comparison of corn cobs between treatments after harvest

The comparison of corn cobs between treatments after harvest was shown in Figure 4.



T1K1R3	T1K2R1	T1K3R4	T2K1R1	T2K2R2	T2K3R1	T3K1R1	T3K2R4	T3K3R4

Apart from the above parameters, several parameters showed no significant interaction and single effects including the stem girth, leaf number, leaf length, leaf width, leaf area, cob diameter and cob girth of all the treatments (Table 1).

Table 1. Effects of drought stress and potassium on stem girth, leaf number, leaf length, leaf width, leaf area, cob diameter and cob girth at 56 DAT.

Interaction		Stem girth (cm)	Leaf number (cm)	Leaf length (cm)	Leaf width (cm)	Leaf area (cm^2)	Cob diameter (cm)	Cob girth (cm)
Soil Moisture Content (% SMC)	Potassium (kg/ha K)							
29.00	30	5.03±0.24	10.50±0.58	72.95±7.42	6.78±0.38	369.68±29.57	3.53±0.25	11.48±0.62
	60	5.35±0.47	9.50±1.00	75.63±7.81	7.73±0.46	439.13±63.63	3.63±0.43	11.95±0.87
	90	5.33±0.52	10.00±0.82	73.10±8.39	7.35±0.70	403.91±68.49	4.13±0.15	12.03±2.88
14.50	30	5.03±0.31	9.25±0.96	76.53±8.31	7.25±0.54	416.30±55.85	3.05±0.53	9.73±1.01
	60	5.08±0.38	10.50±1.29	71.48±7.92	7.35±0.50	392.35±25.82	3.03±0.97	9.40±3.37
	90	5.08±0.19	10.00±0.82	72.53±5.70	7.13±0.30	386.78±18.98	3.38±0.91	10.95±2.36
7.25	30	4.58±0.56	9.75±0.50	69.53±7.10	7.33±0.40	382.45±50.52	3.40±0.80	10.78±1.93
	60	5.13±0.13	9.75±0.50	77.48±5.53	6.80±0.39	394.63±28.71	3.68±0.43	11.68±1.16
	90	5.00±0.50	10.25±1.26	75.38±6.66	7.13±0.59	402.97±50.06	3.53±0.39	11.33±0.81

*Values are the mean of four replications; the ± represents standard deviation.

CONCLUSION

It was found that 7.25% Soil Moisture Content (SMC) + 60 kg/ha potassium (K) (T3K2) was adequate for irrigation and fertilization for the corn plants as there was no significant difference observed when compared to the control treatment (29.00% SMC with 60 kg/ha K; T1K2) where both treatments had shown a similar yield. Corn plants treated with 7.25% SMC + 60 kg/ha K (T3K2) expressed tolerance response through the higher level of proline content which aid in resisting drought stress and hence was able to perform the best overall yield components. The irrigation cost that can be saved is RM722.90 per hectare with 7.25% SMC. Thus, irrigation reduced to 7.25% SMC can be recommended to the farmers to reduce the cost of irrigation and hence to achieve a better yield. Further research should be conducted to study the drought stress and potassium effects on other corn varieties and to determine the physiological, biochemical responses and yield performance regarding the drought tolerance ability of corn.

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