CHAPTER VI

EFFECTS OF PLANTING DATE AND CULTIVAR ON GROWTH, STALK YIELD AND ETHANOL PRODUCTION POTENTIAL OF SWEET SORGHUM GROWN AS A PRE-RICE CROP UNDER RAINFED AND IRRIGATED CONDITIONS

Introduction

In the light of rising fossil fuel prices, depleting oils reserves and increasing green house effect related with the use of fossil fuels, biofuels produced from renewable energy sources are gaining importance, particularly ethanol which accounts for 90% of total biofuels production and use worldwide (FAO 2008). However, ethanol production has raised many arguments. Perhaps the most cogent one is a possible increase in food prices due to the diverting of crops from food to bio-fuel feedstock and lands from food crop production to biofuels feedstock production. The introduction of sweet sorghum as a supplement ethanol feedstock into rice-based cropping system would offer opportunities to raise both food and fuel crops. And it could improve the financial well being of small farmers as they gain access to the new markets for agriculturally-based bio-energy systems.

Thailand is the number one rice exporting country in the world, with most arable land planted with rice. This includes both rainfed and irrigated fields. However, in rainfed areas rice is planted as a mono-crop in the mid-rainy season and the land is left fallow for several months. Therefore, the early rains during the dry-wet transition period can be utilized to successfully grow upland crops. Under irrigated areas, farmers usually grow a secondary crop or upland crops after rice. And after harvesting these crops, there is the fallow period between April and late July to early August.

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A double cropping system in rainfed paddy field and the triple cropping system in irrigate paddy field with sweet sorghum would increase land use efficiency and increase additional biofuel feedstock without affecting food crops or traditional crops production. With the high competition of current used biofuel feedstock i.e. cassava and sugarcane molasses, with other well-established industries such as sugar, animal feed and cassava flour industries, the shortage of raw materials causes inefficiency in the industry because factories can be operated only four to six months a year. The production of sweet sorghum might fill the gap during this shortage of feedstock thereby increasing the efficiency of the industry.

However, the success in introducing preceding crops into rice-based cropping systems is not only dependent on market potential of those crops but also the varieties used and crop management. Climatologically factors during pre-rice crop conditions include longer photoperiod, prevailing cloudiness and waterlogging during flowering to maturity. The crops suitable for pre-flood production should be short maturation and be able to tolerate not only drought but also flooding (Lantican 1982). Sweet sorghum appears to meet these criteria (Curt et al. 1995; Mastrorill et al. 1995; FAO 2002; ICRISAT 2004).

Results from our previous experiments showed that sweet sorghum is most susceptible to waterlogging at seedling stage. Fresh stalk yield and juice quality are unaffected by flooding at late reproductive stage. We also found that sweet sorghum possesses some waterlogging tolerant characteristics such as development of aerenchymateous nodal and lateral roots and increased axe and stalk porosity (Promkhambut et al. 2009). Appropriate planting date selection as well as the choice of suitable sweet sorghum cultivars may greatly contribute to yield improvement of sweet sorghum in these areas.

Under normal conditions, yield and quality of sweet sorghum varies with different planting dates and varieties. Higher yield can be obtained at early season, whereas juice quality is controversial (Broadhead 1972; Almodares et al. 1994; Balole 2001; Reddy et al. 2007b; Poornima et al. 2008). However, sweet sorghum production information under rice-based cropping system is scant and cultivation restriction may differ from normal practices. With this in mind, the present experiment aimed to indentify optimum time of sowing and suitable sweet sorghum cultivar/characters for achieving high stalk yield as well as calculated ethanol production grown as a preceding crop under irrigated and rainfed low-land rice fields.

Materials and methods

Location and climatic conditions

Two field experiments were conducted during the 2007 wet season on two farmers' lowland paddy fields in Khon Kaen province, Northeastern of Thailand (16° 26'N, 102° 50'E). These locations were selected because field conditions at Ban Ampawan represent a typical irrigated paddy field and at Ban Moung is a typical natural rainfall paddy. Soils are silt loam in irrigated field and loamy sand in rainfed field. Some other soil characteristics of both locations were given in Table 1. During growing period (April- September), the total rainfall was 1,103 mm and average temperature was 29.27°C in the irrigated field. In the rainfed field, the total rainfall was 1,123 mm and average temperature was 29.17°C (Fig. 1).

Experimental design and treatments

The experimental design for each location was a randomized complete block in a split plot arrangement with four replications. Planting date was the main plot factor and cultivars were assigned to the subplots. Main plot treatments in each location were assigned as early-, mid- and late-plating date, PD1, PD2 and PD3, respectively. In the irrigated field; PD1, PD2 and PD3: seeds were sown on 19 April, 03 May and 24 May and stalks were harvested at the maturity stage of each cultivar (90 days after emergence, DAE, for Wray and Keller and 103 DAE for Bailey) i.e., on 03 Aug, 10 Aug and 11 Sep, respectively. In rainfed field; PD1, PD2 and PD3: seeds were sown on 04 May, 29 May and 15 Jun. Stalks were harvested on 08 Aug, 30 Aug and 17 Sep in 2007, respectively. Cultivars used in both locations were Wray, Keller, as we have some information regarding their high potential for sugar and ethanol production and wide adaptability (Broadhead et al. 1978; Smith et al. 1987) and Bailey, which has been known as a high stalk production cultivar (Guiying et al. 2003).

Field managements

After the first rainfall of the wet season with adequate soil moisture content, during late April 2007, the soil was plowed twice and harrowed. The sub- plots of the experiments, measuring 24 $m^{2,}$ were surrounded by low bunds, were constructed. Shallow furrows were made and additional basal fertilizer grate 15-15-15 of nitrogen, phosphorus and potassium at 47 kg ha^{-1} was applied. Seeds were sown in each planting date in the furrows. The plants' spacing was 0.6 m between row and 0.1 m within row (population density 16.7 plant m^{-2}). The seedlings were thinned out to allow them to stand alone at each point at 10-15 DAE. In the irrigated field, supplemental irrigation was applied during a short rainfall period. In both fields, manual weeding was done twice at 15 and 30 days after emergence. Fungicide (Dithane) and insecticides (Carbofuran and Carbosulphan, Methomyl) were applied several times to control pests and diseases.

Recorded data

During growing period, a PVC tube inserted to 150 cm depth was used for weekly measurements of the groundwater table from the soil surface. Soil water content was measured using gravimetric method made in 0-5 and 25-30 cm from soil surface to monitor soil moisture content each week interval before flooding occurred.

Sections of 0.24 m^2 were hand harvested from each plot to determine dry mater (DM) accumulation on 15 day intervals starting 30 days after emergence (DAE). There were five sampling dates throughout the growing season (30, 45, 60, 75 DAE and harvest). At each sampling date the height of plants from four taxed plants was measure. Leaf, stalk and panicle were separated. Samples were oven-dried at 80° C to a constant weight to determine growth on a dry weight basis. Total top dry matter (TDM) was the sum of all plant parts. Leaf area was measured using a Li- COR 3100 leaf area meter (Lincoln, NE, USA) and leaf area index (LAI) was calculated. At harvest (physiological stage), the center area of 13.8 m^2 per plot was cut at ground level. Stalks were counted. Leaves and leaf sheathes were stripped from the stalks. Panicles were also excluded as a part of stalk weight due to its other additional use as food or feed. These stripped stalks were weighed as a stalk yield. Stalk diameter and Brix were determined in 4 stalk samples from each plot. Brix determinations were made with a hand refractometer obtained from the midpoint of the stalk (Smith et al. 1987).

Sugar yields were calculated from multiplying stalk fresh weight (t ha^{-1}) by total sugar content (%), which calculated from Brix value according to relationship between Brix value and total sugar content (%) of a greenhouse experiment (2006) using the same sweet sorghum cultivars, $y = 0.669X+6.2$. Then the calculated ethanol yield was obtained by dividing total sugar yield (t ha^{-1}) by 5.68, which is equivalent to 12.51 lbs of sugar per gallon of ethanol. The resulting values were then converted to liters by multiplying by 3.78 and multiplying these values by 0.8 because 80% of projection ethanol yield is a more practical figure for large scale processing due to losses associated with extraction of sugar from stem and sugar consumed by growth of bacteria according to Smith et al. (1987).

Data analysis

Pooled analysis of variance was used to evaluate treatment effects between locations. Then an analysis of variance and comparison of means of measured data was performed using the Statistix 8 software (Analytical software 2003) for each location. Levels of significance are indicated by the least significant difference between the means at 5% and 1% of probability.

Results

Ground water table depth and soil moisture content

During growing period of sweet sorghum, water table depth in the irrigated field was relative fluctuated, measured at 3- 123 cm below soil surface and 10 cm above soil surface (Fig. 1A). Recorded soil moisture content at soil surface (0-5 cm) was similar to water table depth, ranging from 2.63-26.67 g 100 g^{-1} whereas at deeper soil layer (25-30 cm) soil moisture content was constant (11.46-20.58 g 100 g^{-1}) (Fig. 2A).

However, in the rainfed field, the water table ranged 55-143 cm below soil surface. Soil moisture content at soil surface was constantly higher than FC throughout measured dates (6-12 g 100 g^{-1}) with higher values found at deeper soil layers, ranging 10-14 g 100 g^{-1} (Fig. 2B). In irrigated fields, periodic flooding about 1 week occurred at 4-5 leaf stage of PD1 with coincided with seedling stage (1-2 leaf stage) of PD2 and at mid-reproductive stage of PD1, late-vegetative of PD2 and vegetative stage of PD3 (see Fig. 1A). In the irrigated field, continuous waterlogging was occurred at the early of August and in ranfed field, the field was completely flooded starting from second week of August (15-25 cm water level above soil surface) or concurring at grain filling stage of PD2 and flowering stage of PD3 in both fields.

Crop growth parameters

The combined analysis showed significantly different between locations of all measured traits except plant no. m^{-2} and Brix value (data not shown). Therefore the analysis of data is presented separately for each location.

Across sampling dates, planting dates had significant effects on plant height in both fields but it was not consistent. Plant height increased at each sampling date and reached maximum at final harvest. At early growth stage, 30 DAE, the highest plants were recorded in late planting date (PD3) in irrigated field in contrast to rainfed field. However, at final harvest, it clearly shows that early planting date (PD1) significantly increased plant height in both fields. Differences were small in irrigated field when planting date was delayed (Fig. 3A), however, in rainfed field PD3 reduced plant height up to 25% and 21% as compared to PD1 and PD2 (Fig. 3B).

Among cultivars significant differences were found at 30 DAE in rainfed field and at 60 DAE in both locations. At 30 DAE, tallest plants were found in Bailey and lowest in Keller. However, at 60 DAE Wray was the tallest cultivar and lowest in Bailey. At final harvest, no significant difference was found among studied cultivars in both fields (Fig. 3C and D).

Significant difference was found in planting date x cultivar interaction, noted at harvest in irrigated field only. Tallest plant was Bailey grown at PD2 (312.5 cm) and shortest plant was Wray grown at PD2 (259.80 cm), whereas plant height in rainfed field ranged from 180-270 cm (data not shown). At final harvest, an average of 15% taller plants were found in irrigated field than rainfed field.

In irrigated field in contrast to rainfed field, LAI was significantly different beginning from 45 DAE onwards and the first two planting dates had similar responses. Plants reached maximum LAI at 60 DAE. PD1 (6.31) and PD2 (6.66) plants had higher LAI than PD3, 30%-53%, particularly at 75 DAE (Fig. 4A). In the rainfed field, early planted plants reached maximum LAI at 45 DAE (5.31), whereas similar responses were noted between PD2 and PD3, reaching maximum LAI at 60 DAE (4.25 and 5.59, respectively). However, at final harvest LAI was highest in PD1 and lowest in PD3 in both fields. PD3 had 70% and 48% lower LAI than PD1 in rainfed field and irrigated field, respectively.

Among cultivars, no significant difference in LAI was noted in both fields at all measured dates except at 30 DAE in the rainfed field. In general, plants reached maximum LAI at 60 DAE with the highest in Bailey and lowest in Keller, particularly at late growth stage (see Fig. 4C and D). However, in the rainfed field, Keller reached maximum LAI earlier (45 DAE) than other cultivars (see Fig. 4D). Interactions between planting date x cultivar were found at 60 DAE and harvest stage in irrigated the field only. At harvest, Wray grown at PD1 and PD2 gave the highest (5.36) and lowest (1.45) LAI, respectively. At all sampling dates, LAI was found higher in the irrigated field than the rainfed field and at harvest it was 61% higher.

In the irrigated field, planting dates had significant effect on TDW (g m^{-2}) at 75 DAE and harvest. PD2 gave the highest TDW and lowest in PD3, resulting in 50% lower at 75 DAE and 40% TDW reduction at harvest compared to TDW at PD2 (Fig. 5A). In rianfed field, significant higher TDW was found in PD1 at 30 DAE to 60 DAE, while at 75 DAE there was no significant difference among planting dates. However, at final harvest PD1 gave the significantly highest TDW (Fig. 5B).

Among cultivars, significant differences were noted at 75 DAE in the irrigated field and 30 DAE in the rainfed field. At 75 DAE, the highest TDW was found in Bailey and lowest in Keller in both fields (see Fig. 5C and D). Highly significant planting date x cultivar interaction was found only in irrigated field due to the highest TDW in Bailey grown at PD2 (31.02 g m^{-2}) and lowest in Wray grown at PD3 (13.18 g m^{-2}). The averaged TDW was found higher in the irrigated field than the rainfed field at all sampling dates both due to the effect of planting date and cultivars being 30% higher at final harvest.

Yield and yield components

Early planting date significantly increased fresh stalk yield in both fields (34.57 t ha^{-1} in irrigated field and 29.01 t ha^{-1} in rainfed field). In the irrigated field, later two planting date had similar stalk yield (23 and 27 t ha^{-1} for, PD2 and PD3, respectively) (Table 2) but late planting date (PD3) (4 t ha^{-1}) in rainfed field gave about three folds stalk yield lower than PD2 (14 t ha^{-1}) (Table 3). The higher fresh stalk yield at early planting date in the irrigated field was influenced by bigger stem diameter and single stalk fresh weight (see Table 2), whereas in the rainfed field it was distributed by higher plant no. m^{-2} and single stalk fresh weight (see Table 3). In contrast to fresh stalk yield, the highest stalk DW was found in PD2 in both fields i.e. 22.67 t ha^{-1} in irrigated field and 17.43 t ha^{1} in the rainfed field. In the irrigated field as in the rainfed field, PD3 gave the lowest stalk DW with significant lowest in the rainfed field (11.33 t ha^{-1}).

All studied cultivars performed similarly in all studied traits in both fields with relative high in Bailey. However, a significantly higher stalk yield was noted in Bailey at irrigated field (31.76 t ha^{-1}), whereas a 50% lower yield was found in rainfed field. Highly significant interaction between planting date x cultivar was observed in the irrigated field for stem diameter, single stalk weight and stalk DW whereas no significant difference was found in the rainfed field except significant at 95% of probability for plant no. m^{-2} (Table 3). Stalk DW in irrigated field were found highest in Bailey grown at PD2 and lowest in Wray grown in PD3 (Table 4). Similar responses were also found for stem diameter and single stalk weight (data not shown). And averaged values across planting dates showed that stem diameter, single stalk fresh weight, stalk DW and fresh stalk yield in irrigated field were higher than that in rainfed field, 16%, 30%, 26% and 45%, respectively.

Sugar yield

In the irrigated field as well as the rainfed field, early planting date increased sugar yield to 6.14 t ha^{-1} and 4.87 t ha^{-1}, respectively. Other two planting dates in irrigated field produced a similar sugar yield (4.16 t ha^{-1}- 4.66 t ha^{-1}). However, delay planting date to PD2 and PD3 in the rainfed field decreased sugar yield to 50% and 87%, respectively; as compared to PD1 (see Table 3). The higher sugar yield was not influenced by Brix value, which means that early planting date did not affect juice quality, particularly in the irrigated field.

Among three cultivars, a significant difference for sugar yield was found in the irrigated field only. The significant highest sugar yield was found in Bailey (5.57 t ha^{-1}), whereas Wray and Keller had similar responses (4.56-4.81 t ha^{-1}). In the rainfed field the relative highest sugar yield was also found in Bailey but it was 50% lower than that in the irrigated field (see Table3). No significant interaction between planting date x cultivar was found in either locations. The significant higher sugar yield was found in the irrigated field compared to the rainfed field (47 %).

Ethanol yield

Calculated ethanol yield was similar to sugar yield. The early planting date gave the significant highest ethanol yield (3269.80 l ha^{-1} in irrigated field and 2601.70 l ha^{-1} in the rainfed field) with no significant difference between PD2 and PD3 in the irrigated field (see Table 2) but enormous differences were found when planting date was delayed in the rianfed field (see Table 3). Cultivars also performed similar to sugar yield. There was no significant difference interaction between planting date and cultivars for calculated ethanol yield but there was a 47% higher calculated ethanol yield in the irrigated field compared to the rainfed field.

Discussion

The effect of planting date on pre-rice sweet sorghum: a supplemental ethanol feedstock

The early planting date significantly increased fresh stalk yield, a direct ethanol feedstock, under both paddy fields. This finding is consistent with previous researchers (Broadhead 1972; Almodares et al. 1994; Balole 2001; Almodares and Darany 2006; Reddy et al. 2007b; Poornima et al. 2008). Fresh stalk obtained, ranging 29-35 t ha^{-1}, at early planting date is similar to that produced in upland areas within the same region during early planting date, February, 30 t ha^{-1}, or close to yield obtained from the most suitable sowing date, March to July, 38-50 t ha^{-1} (Jaisil et al. 2007) or the highest stalk yield grown during July in India, 41 t ha^{-1}, (Reddy et al.

2007b). In terms of sugar yield, it showed that in this study a relative higher sugar yield (5-6 t ha^{-1}) could be obtained as compared to about 3 t ha^{-1}, produced in upland areas in India (Reddy et al. 2007b) and Indonesia (Tsuchihashi and Goto 2004).

The potential yield of ethanol production, 2600-3300 l ha^{-1}, is higher than ethanol production from cassava in Nigeria and Brazil or maize in China (1480-1995 l ha^{-1}) and almost equivalent to maize ethanol production in the United State (3751 l ha^{-1}) (Naylor et al. 2007). Besides Zhao et al. (2009) showed that cellulose and hemicelluloses in baggasses of sweet sorghum can be harvested around 2-6 t ha^{-1} each and yield ethanol around 1796-6591 l ha^{-1} varying with cultivars and harvest time. And additional grain starch yields ethanol potential around 505-1223 l ha^{-1}. These finding confirm that sweet sorghum could be a promising high-energy crop for farmers under conditions of no land and water competition with food crops.

Higher stalk yield at early planting date than at late planting date was distributed by higher LAI indicating the greater solar radiation absorption, particularly during late season, higher biomass and sugar accumulation period, and taller plants as well as bigger stem diameter, especially in irrigated field, which is in agreement with Almodares et al. (1994), Balole (2001) and Almodares and Darany (2006). Delayed planting date significantly decreased plant growth, stalk and ethanol yield, particularly mid-June in the rainfed field. This was due to the short photoperiod sensitive of sweet sorghum. Delayed sowing date resulted in shorter a growth period. Therefore, less assimilates are used for vegetative growth, which is consistent with Balole (2001). In addition, during growing periods in both fields, more cloudiness at late planting dates may result in lower light intensity received by plants. The similar finding is also reported by Hipp et al. (1969). Moreover, as distinguish from upland production, late sowing sweet sorghum suffered from waterlogging or flooding conditions. Even though plants could acclimate to flooding stress by increase in nodal and lateral root development in water, a strong wind and heavy rainfall during mid-rainy season leaded to lodging problem. This is one of the main reasons for plant damage in mid-June planting in the rainfed field. In irrigated areas, planting date had no significant effect on Brix value consistent with the findings of Broadhead (1972), Almodares et al. (1994), Almodares and Darany (2006). However, under rainfed conditions, Brix value was significant highest in PD2. This may distributed by the significantly higher plant growth at PD2, resulting in higher photosynthate accumulation and sugar content. However, it was noted that in present experiment, the relative small difference in Brix value did not affect sugar yield and estimated ethanol yield but stalk yield did. Therefore, with this range of Brix value, increase stalk yield is the strategy to improve sugar yield and ethanol yield.

The preferable sweet sorghum characteristics grown as a pre-rice crop in riceland

Cultivar effects on plant growth parameters across measurement dates and at harvest stage were not constant and less occurred indicating that effects of cultivars is relatively similar, particularly in rainfed field (Table 3). This may be narrow genetic diversity among three sweet sorghum cultivars. However, the higher significant fresh stalk yield, sugar yield and calculated ethanol yield in Bailey (31.76 t ha^{-1}, 5.57 t ha^{-1} and 2974.40 l ha^{-1}, respectively) under irrigated fields and relatively better performance than other cultivars in rainfed fields indicates that with low and high input Bailey could produce the higher yield.

The relative longer growing period and higher LAI, enable greater radiation absorption during dry mater accumulation, may contribute to the greater stalk and ethanol yield of Bailey in this study. Reddy et al. (2007a) also reported that genotypes with tall and long-duration tend to produce more cane yield or higher ethanol yield (Zhao et al. 2009). Furthermore, under greenhouse experiment, it was observed that this cultivar had lower stalk yield reduction than other cultivars under flooding conditions. This was distributed by the ability to produce higher nodal root during flooding period than the other two cultivars (Promkhambut et al. 2009).

Sweet sorghum responses between locations

At harvest, significantly higher plant height, stem diameter, LAI, TDW and single stalk weight were found in the irrigated field compared to the rainfed field (15%, 16%, 61%, 30% and 30%, respectively) and these resulted in higher stalk DW yield, stalk fresh weight yield, Brix value, sugar yield and calculate ethanol yield (26%, 45%, 3%, 47% and 47%, respectively). The contributing factors may be the higher soil fertility of silt loam in irrigated field than loamy sand in the rainfed field and water management in the irrigated field. During short rainfall the field was irrigated giving higher plant growth throughout the growing period and at mid-rainy season excess water could be drained from the field, causing waterlogging rather than high water level of flooding in rainfed field. Therefore, plant growth was not affected by severe flooding such as in the rainfed field. In addition, the higher soil moisture content at rhizosphere than FC in the rainfed field indicates that waterlogging hampered plant growth and yield in the rainfed field throughout the growing period. This was due to an unusual rainfall in the studied year, which resulted in earlier saturated soil at early rainy season in rainfed field. This confirms that sweet sorghum growth and yield varies with location such as reported by Smith and Buxton (1993) and water inputs (Sakellariou-Makrantonaki et al. 2007).

In Northeast Thailand, under irrigation system there is the follow period between April and late July to early August, at the end of harvesting of secondary rice or upland crops after rice to the beginning of new rice growing season, sweet sorghum cultivars recommended would need to be harvested not later than 115 DAE. Sweet sorghum cv. Bailey with 103 DAE and having high stalk yield, 32 t ha^{-1}, is recommended. Cv. Bailey is also recommended in rainfed lowland paddy field, where the first sufficient rainfall is available at mid-late April.

In addition, under the irrigated field, in which farmers normally grow secondary rice and upland crops such as soybean, but plants frequently encounter drought problems because low water reservation in irrigation systems as well as high competition between agricultural use and urbanization. Growing sweet sorghum, having low water requirement (8,000 m^3 over two crops) (Soltani and Almodares 1994) and drought tolerance (FAO 2002) will ensure households' profits while subsidizing the shortage of ethanol production feedstock from sugarcane, which harvest only November- April. With ready- irrigation systems, early planting starting from February will provide opportunity to use the late maturity cultivar and avoid waterlogging problem also will not interfere with main rice production.

Conclusion

Sweet sorghum appears to be a good potential biofuel feedstock to increase the efficiency of existing sugarcane base ethanol factories and farmers' incomes by growing as a pre-rice crop. To maximize stalk yield and ethanol yield, early planting is strongly recommended. In Northeast Thailand, under irrigated lowland paddy fields sweet sorghum could increase land intensify by triple cropping system during follow period between April and late July or early August by planting at mid-April. In rainfed lowland paddy field, planting date as soon as there is available soil moisture is recommended, probably at mid-late April. In addition in irrigated areas, sweet sorghum could substitute the high water requirement of upland crops or secondary rice by an early planting date, properly starting from February would provide opportunity to use the late maturity cultivar, maximize the growing period, while avoid waterlogging condition and lodging problem. Base on plant performance under both locations, Bailey had a potential to provide higher stalk and ethanol yields due to its taller and bigger stem and relative better waterlogging tolerance. However, the experiment should be repeated to confirm plants' performances in both locations. And additional studies are needed to determine the effect of this new cropping system to environment as well as succeeding rice.

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Table 1 Soil physiochemical characteristics of the experimental field.

Soil characteristics	Values	
	Irrigated field	Rainfed field
pH[1]	5.59	4.53
Organic matter (g 100 g^{-1})[2]	1.69	1.08
Total N (g 100 g^{-1})[3]	0.084	0.054
Extractable P (ppm)[4]	14.95	15.6
Exchangeable K (ppm)[5]	128.7	116.70
Soil texture[6]	Silt loam	Loamy sand
Soil classification	Vertisols	Ultisols
Permanent wilting point(g 100 g^{-1})	5.05	1.96
Field capacity(g 100 g^{-1})	15.35	5.09

[1]pH: pH meter (1:1 H_2O), [2]O.M.: Walkley and Black method, [3]Total N: Kjeldahl method, [4]Extractable P: Bray II and Molybdenum-blue method, [5]Exchangeble K: 1N NH4OAc pH7 and Flame photometry method, [6]Texture: Hydrometer method.

Table 2 Means of calculated ethanol yield and factors directly affecting ethanol production as influenced by planting date and cultivar grown in irrigated paddy field at harvest.

Treat-ment	Irrigated field							
	Stem dia. (mm $plant^{-1}$)	Plant no (m^{-2})	Single Stalk fresh weight (g $plant^{-1}$)	Stalk DW (t ha^{-1})	Stalk fresh weight (t ha^{-1})	Brix (degree)	Sugar yield (t ha^{-1})	Calculated ethanol yield (l ha^{-1})
planting	date (PD)							
PD1	17.9 a[1]	9.48 b	498.96 a	19.46	34.57 a	17.23	6.14 a	3269.80 a
PD2	19.7 a	5.35 c	578.33 a	22.67	23.28 b	17.38	4.16 b	2214.20 b
PD3	14.2 b	13.71 a	334.58 b	15.23	26.51 ab	17.00	4.66 b	2479.30 b
Cultivar	(C)							
Bailey	17.9	9.44	532.92	20.64	31.76 a	16.90	5.57 a	2974.40 a
Keller	17.2	9.97	434.58	18.76	27.08 b	17.35	4.81 b	2559.60 b
Wray	16.8	9.13	444.38	17.95	25.52 b	17.37	4.56 b	2429.39 b
F-test								
PD	*	**	*	ns	*	ns	*	*
C	ns	ns	ns	ns	**	ns	*	*
PD x C	**	ns	**	**	ns	ns	ns	ns

*, ** indicate significant at $P \leq 0.05$, 0.01 and ns not significant.

[1] In a column, treatment means followed by the same letter are not significantly different.

Table 3 Means of calculated ethanol yield and factors directly affecting ethanol production as influenced by planting date and cultivar grown in rainfed paddy field at harvest.

	Rainfed field							
Treat-ment	Stem dia. (mm plant^{-1})	Plant no (m-^{2})	Single stalk fresh weight (g plant-1)	Stalk DW (t ha^{-1})	Stalk fresh weight (t ha^{-1})	Brix (degree)	Sugar yield (t ha^{-1})	Calculated ethanol yield (l ha^{-1})
Planting date (PD)								
PD1	14.4	13.75 a	360.42 a	13.92 ab	29.01 a	15.80 b	4.87 a	2601.70 a
PD2	15.2	10.73 a	358.54 a	17.43 a	13.59 b	17.84 a	2.45 b	1303.70 b
PD3	14.2	4.61 b	244.17 b	11.33 b	3.62 c	16.26 b	0.62 c	329.70 c
Cultivar (C)								
Bailey	14.6	9.57	365.63	14.94	16.71	14.96 b	2.83	1507.00
Keller	14.4	9.72	290.83	14.47	14.50	16.87 ab	2.44	1298.10
Wray	14.9	9.79	326.67	13.28	15.00	18.08 a	2.69	1430.00
F-test								
PD	ns	**	**	**	**	*	**	**
C	ns	ns	ns	ns	ns	**	ns	ns
PD x C	ns	*	ns	ns	ns	**	ns	ns

*, ** indicate significant at $P \leq 0.05$, 0.01 and ns not significant.

[1] In a column, treatment means followed by the same letter are not significantly different.

Table 4 Stalk dry weight (tonnes ha^{-1}) responses of three sweet sorghum cultivars grown at three planting dates between irrigated and rainfed paddy fields at harvest.

Location	Planting dates	Cultivars		
		Bailey	Keller	Wray
Irrigated	PD1	15.36 bc	17.39 bc	25.62 a[b1]
	PD2	28.67 a	23.47 abc	15.87 bc
	PD3	17.89 abc	15.44 bc	12.35 c
Rainfed	PD1	13.92	15.55	12.30
	PD2	18.18	18.74	15.37
	PD3	12.71	9.118	12.16

[1]Treatment means followed by the same letter are not significantly different by Least significant different (LSD) at $P \leq 0.01$.

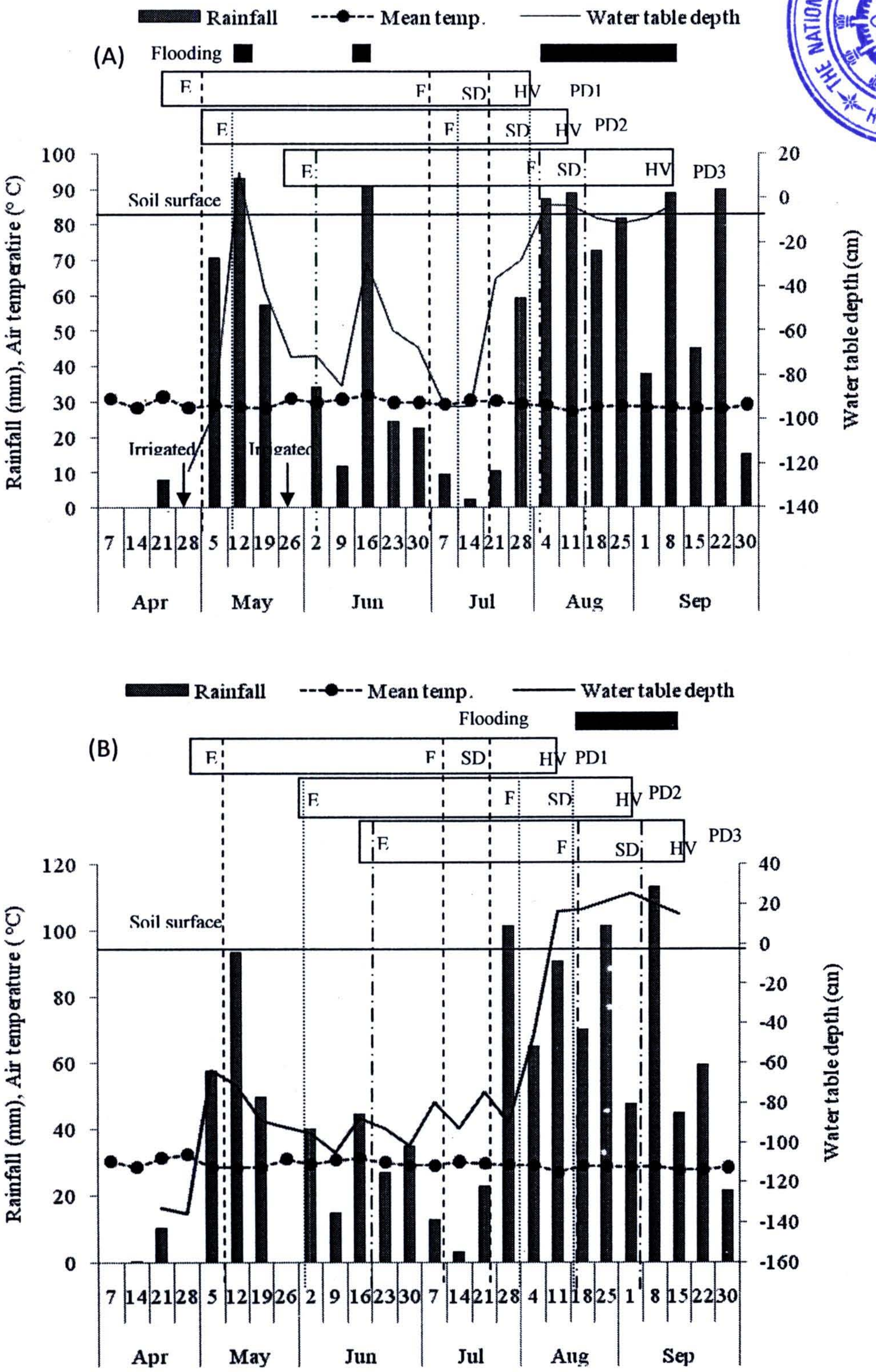
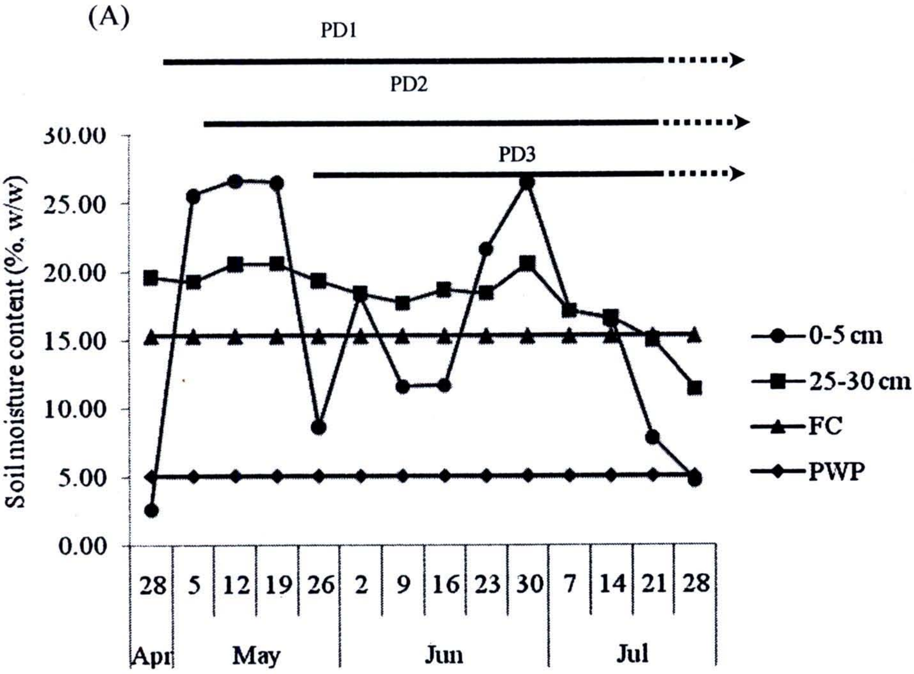


Figure 1 Water table depth, weekly mean temperature and weekly rainfall distribution in (A) irrigated field and (B) in rainfed field. Growing period; planting -harvest dates were different between fields. In irrigated field; PD1: 19 April- 03 Aug, PD2: 03 May-10 Aug and PD3: 24 May-11 Sep and in rainfed field; PD1: 04 May-08 Aug, PD2: 29 May- 30 Aug and PD3: 15 June- 17 Sep in 2007. E= emergence, F= flowering, SD= soft dough and HV= harvest.

(A)



(B)

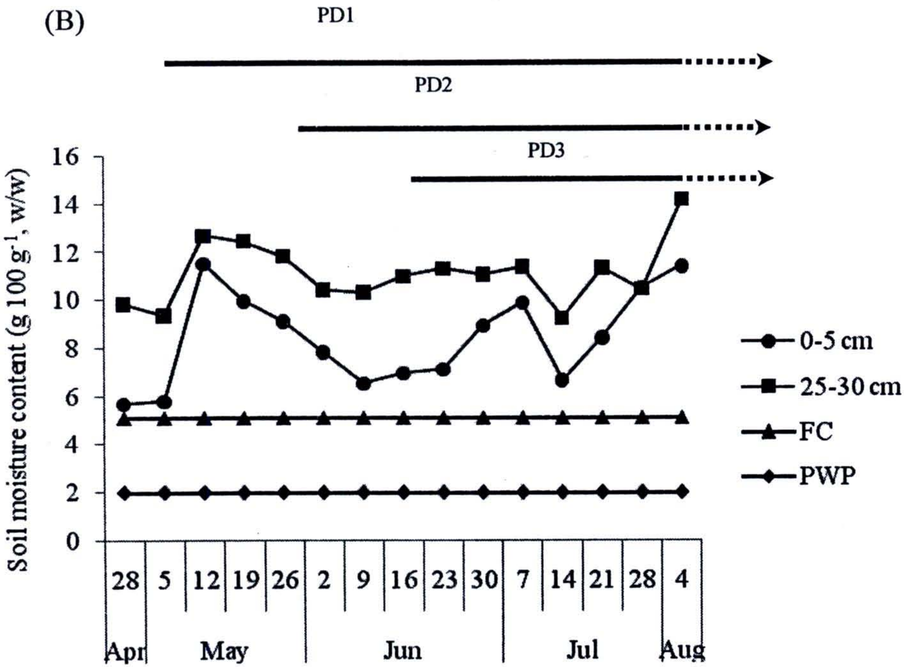


Figure 2 Soil moisture content at 0-15 and 25-30 cm depth during growing season before flooding in filed at A) irrigated paddy field and B) rainfed paddy field.

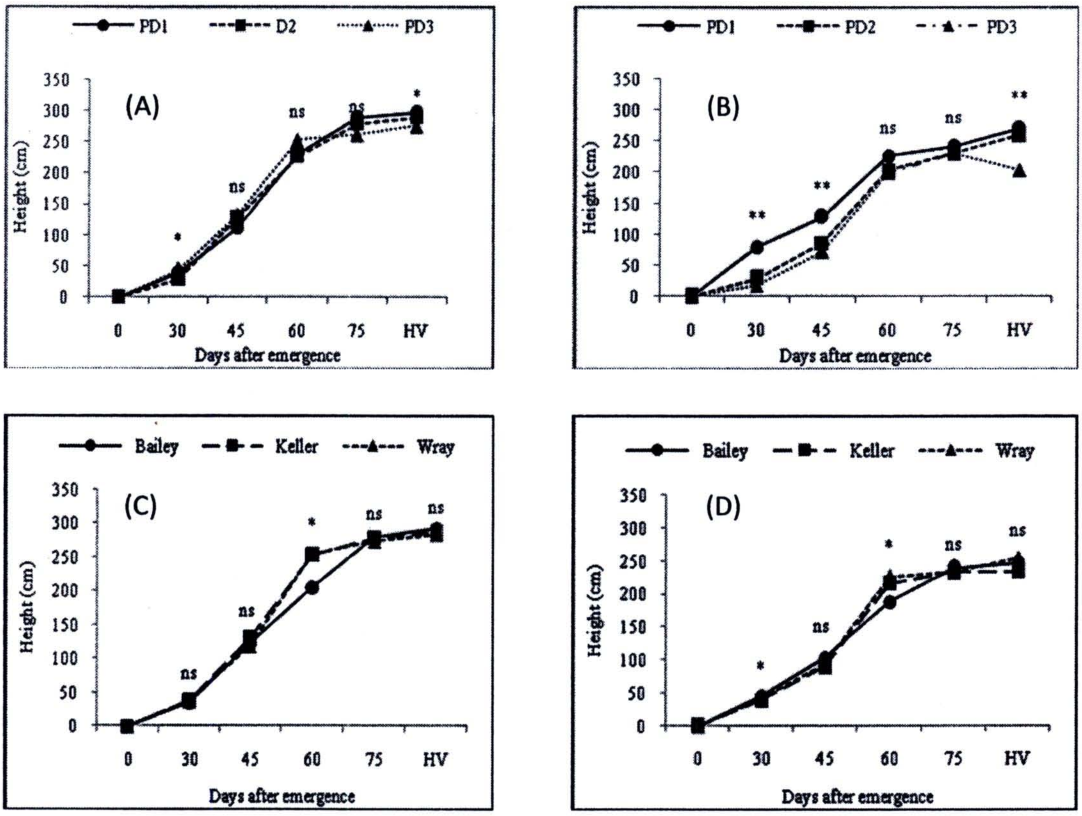


Figure 3 Effects of planting dates and cultivars on plant height of sweet sorghum grown in irrigated field (A and C) and rainfed field (B and D).*, ** indicate significant at P≤ 0.05, 0.01 and ns not significant.

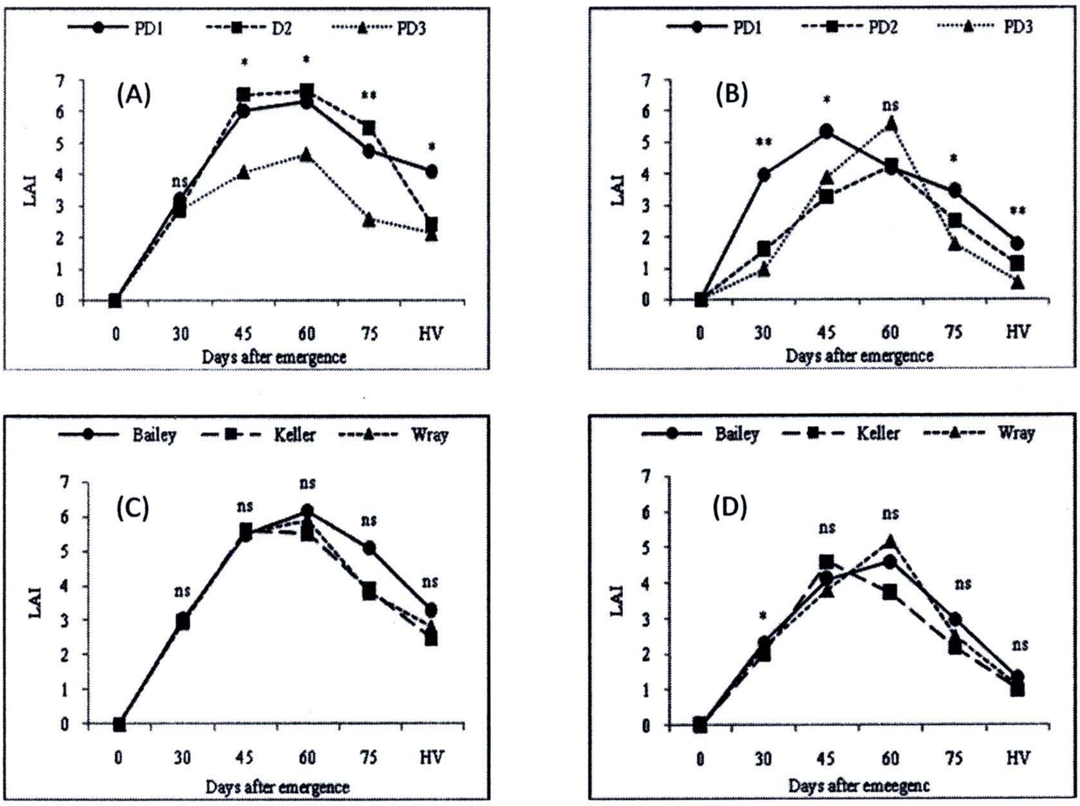


Figure 4 Effects of planting dates and cultivars on LAI of sweet sorghum grown in irrigated field (A and C) and rainfed field (B and D).*, ** indicate significant at P≤ 0.05, 0.01 and ns not significant.

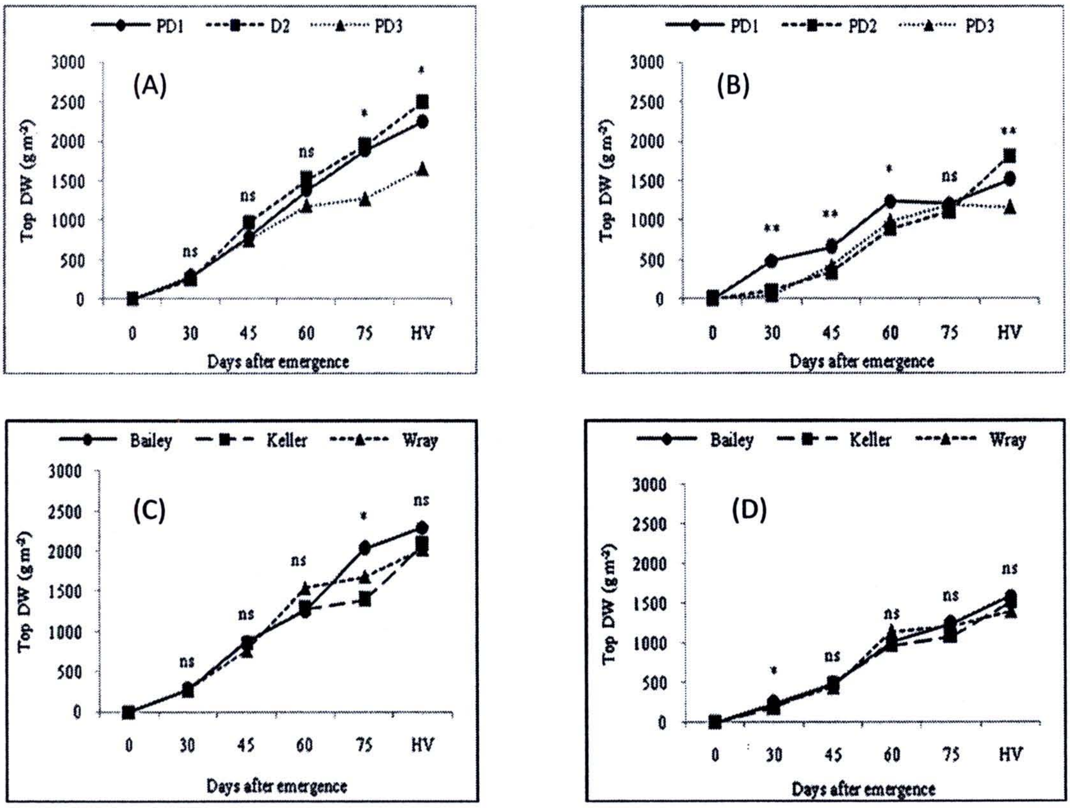


Figure 5 Effects of planting dates and cultivars on total top dry weight of sweet sorghum grown in irrigated field (A and C) and rainfed field (B and D). *, ** indicate significant at $P \leq 0.05$, 0.01 and ns not significant.