Research article

The Application of Deficit Water and Fertilizer upon Yield and Water Footprint in Baby Corn

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Abstract Baby corn (*Zea mays* L.) is one of the most significant and lucrative agricultural products grown in Thailand. Thailand, the largest exporter of baby corn in the world, has an average export income of 33 million dollars each year. However, Thai farmers income levels were lower for baby corn cultivation whereas a result of an increase in production factors. The objective of this study is to assess the appropriate water usage and fertilizer application on clay loam soil, in order to create higher yields of baby corn production. The experiment involved split-plot in randomize complete block design with three replications. Treatments consisted of three main plots of variable irrigation supply 1) 40% allowable depletion content (ADC), 2) 60% ADC, and 3) 80% ADC. Each plot acted in combination with four sub plots: 1) control, 2) 94-31-31 kg/ha (N-P_2O_5-K_2O), 3) 47-16-16, and 4) 47-47-47 kg/ha. The results found 40% ADC irrigation the most favorable to increase pod weight and water usage efficiency. The findings also proved this method to have the least amount of reduction in green, blue, and total water footprint amounts. Past fertilizer applications found that 94-31-31 kg/ha fertilizer enhanced pod weight and length, as well as corn height, and water usage in both amount and efficiency. The fertilizer 47-47-47 kg/ha resulted in decrease of green, blue, and total water footprint amount compared with other sub plots. A 40% ADC irrigation combination with 94-31-31 kg/ha yielded the highest pod weight and water usage efficiency compared with all other treatments. Moreover, the water footprint demonstrated the least amount of decrease in green, blue, and total water footprints compared with other treatments.

Keywords baby corn production, water depletion, water footprint, fertilizer utilization.

INTRODUCTION

Baby corn (*Zea mays* L.) is one of the most significant and lucrative agricultural products grown in Thailand. Thailand, the largest exporter of baby corn in the world, has an average export value of 33 million dollars each year (98% of which is frozen baby corn). The majority areas of baby corn plantation on 4 provinces such as Supanburi, Kanchanaburi, Nakhon-Phatom and Phathum-Thani in central region of Thailand were approximately 75% of all baby corn plantation areas. However, Thai farmers income levels were lower for baby corn cultivation whereas a result of an increase in production factors. While the average yield of baby corn per hectare was relatively low (7,500 to 9,375 kg/ha). Thai farmers struggled to increase production to more profitable levels (12,500 to 15,625 kg/ha). The demand of larger yields, under a reduced budget, required farmers to seek optimal irrigation and fertilization applications for baby corn production (Agriculture Economic Bureau, 2010). The relationship between crop yield and water and fertilizer usage, has been a major focus of agricultural research (Howell, 1990).

The 'water footprint' was introduced as an assessed indicator of water usage in plant production by Kongboon and Sampattagul (2012). Their study of the water footprints for sugarcane and cassava in northern of Thailand found that the water footprint in cassava (509 L/kg) was greater than that of the sugarcane (202 L/kg), as a result of different climates and cultivation areas. The Department of Agriculture (2005) reported that baby corn assimilated macro nutrients, in the order of nitrogen, potassium and phosphorus. The optimal soil properties of baby corn were found to be loam, sandy loam, and clay loam soil texture class sufficient aeration, organic matter of at least 1.5%, and available P of more than 10 mg/kg, and exchangeable K of more than 40 mg/kg. Research of the interaction and effects of plant irrigation requirements and fertilizer applications in baby corn production has become essential.

OBJECTIVE

The objective of this study was to determine the optimum water usage and fertilizer application on clay loam soil for baby corn production.

METHODOLOGY

Climate and Location of Experimental Areas

This study was conducted in 2011 and 2012 on a farm in Phathum Thani province, in the central region of Thailand. The experimental field is located in Alluvial Plain (altitude 4 m, $14^{o}11^{/}$ North and $100^{o}53^{/}$ East) where the climate is moist and tropical. The hot season, February to May; and the rainy season, June to October; are expressed in Fig. 1 (Thai Meteorological Department, 2010).

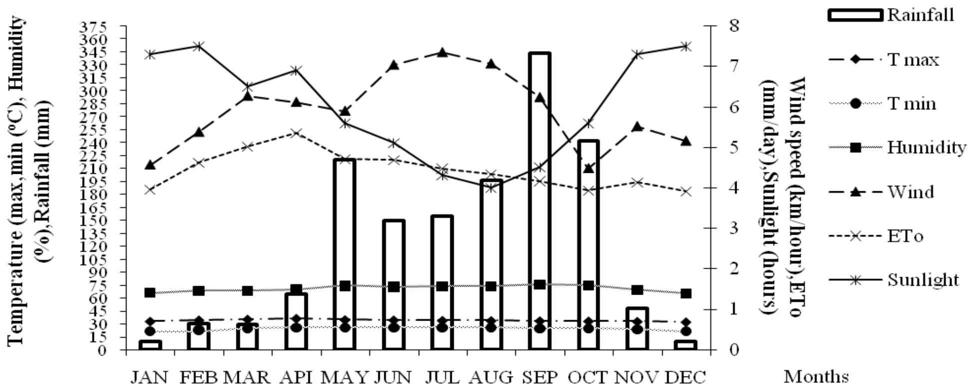

Fig 1. Weather data of 30 years (1980) to (2010) in Pathum Thani province of Thailand

Treatments and Data Collected

Soil samples were collected on the farmer's field at depths of 0-60 cm (Rangsit soil series, Very-fine, mixed, semiactive, acid, isohyperthermic Sulfic Endoaquepts). Soil texture classes were clay loam to clay (sand 27 - 40%, silt 25 - 28%, and clay 35 - 45%), soil bulk density 1.99 to 1.33 g/cm^{-3}, hydraulic conductivity 0.002 to 0.02 cm/hr^{-1}, and available water depth of 9.67 to 10.77 mm. Chemical properties of soil samples were pH 3.87 to 4.19, organic matter 1.60 to 2.42, available P 3.4 to 70.1 mg/kg, exchangeable K 270.7 to 349.0 mg/kg, and exchangeable Ca 634.2 to 1,542.0 mg/kg. The experiment was designed split in RCBD with three replications. Treatments consisted of three main plots: 1) 40% allowable depletion content (ADC), 2) 60% ADC, and 3) 80% ADC. Irrigation treatments were provided through a trickle irrigation system of tape lines; which were spaced to emit 20 cm at the rate of 2 L/hour, in combination with four sub plots: 1) control, 2) 94-31-31 kg/ha (N-P_2O_5-K_2O), 3) 47-16-16, and 4) 47-47-47 kg/ha. In this study, the SG-17 hybrid variety of baby corn was used as the crop material. Each plot consisted of eight rows, ten meters in length. The rows were spaced 50 cm apart, with 50 cm spacing between plants in each row. The seeds were grown between 2 April to 31 May 2011 in the first year; and between 10 February to 9 April 2012 in second year. Baby corn pods were collected from each of the six rows and six plants, from the center of each plot. The data of this experiment were analyzed with analysis of variance (ANOVA) and the means compared by Duncan's multiple rank tests (DMRT), using MSTAT-C statistical software (Cochran and Cox., 1957).

Calculating Plants Water Usage

The amount of irrigation supply was determined by the Penman-Monteith equation, and reference evapotranspiration in the treatments was computed using Eq. (1).

$$\mathrm{ETo} = \frac{0.408\,\Delta(R_n - G) + \gamma(900/(T+273))\,U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

Where ET_o is the reference evapotranspiration (mm/d),Δ slope vapor pressure curve (kPa/^oC), R_n net radiation at the crop surface (MJ/m^2/d), G soil heat flux density (MJ/m^2/d), T mean daily air temperature at 2 m height (^oC), γ psychrometric constant (kPa/^oC), U_2 wind speed at 2 m height (m/s), and e_s-e_a saturation vapor presser deficit (kPa). Actual evapotranspiration was calculated by following Eq. (2), (Allen et al., 1998).

$$ET_{c\ adj} = K_s\,K_c\,ET_o \quad (2)$$

$ET_{c\ adj}$ is actual evapotranspiration (mm/d), Ks water stress coefficient either non soil water stress Ks = 1 or soil water limiting Ks < 1 and Kc crop coefficient; crop coefficient in the initial growth stage 0.65, mid-season growth stage 1.22, and at the end of late growth stage 0.61. Evaluations followed protocol according to the (Irrigation Research Bureau, 2010).

Computing the Water Footprint

Water footprints consist of three components: green, blue, and grey water. The green water footprint, consisting of rainwater, evaporated during crop growth. The blue water footprint refers to surface and ground water usage in plant areas, which also evaporates during crop growth. The grey water footprint is the volume of freshwater for dilution, in which waste water becomes the drinking water quality standard. The computation of green and blue components of crop water usage (CWU) was calculated by summation of the daily evapotranspiration and irrigation supply; by following Eqs. (3) and (4), (Hoekstra et al., 2011).

$$CWU_{green} = 10 \times \sum_{d=1}^{\mathrm{lgp}} ET_{green} \quad (3)$$

$$CWU_{blue} = 10 \times \sum_{d=1}^{\mathrm{lgp}} ET_{blue} \quad (4)$$

CWU is crop water usage (m^3/ha), ET_{green} daily evapotranspiration (mm/d), ET_{blue} irrigation amount (mm/d); lgp denotes the length of growing period (in days), and 10 is the value used to convert units from (mm) into (m^3/ha). Calculations of green and blue water footprints within each period are determined by Eqs. (5) and (6), (Hoekstra et al., 2011).

$$WF_{proc,green} = \frac{CWU_{green}}{Y} \quad (5)$$

$$WF_{proc,blue} = \frac{CWU_{blue}}{Y} \tag{6}$$

Where WF $_{proc}$ is the water footprint (m^3/ton or L/kg), and Y is the economic yield (ton/ha). The grey water footprint is calculated by following Eq. (7)

$$WF_{proc,grey} = \frac{(\alpha \times AR)/(c_{\max} - c_{nat})}{Y} \tag{7}$$

Where α is leaching–run off fraction of nitrogen fertilizer assumed 10%, *AR* perform chemical fertilizer application (kg/ha), C_{max} is the maximum acceptable concentration of nitrate found (drinking water quality standard is 50 mg/l), and C_{nat} the natural concentration for pollutant nitrate from cultivation. The total water footprint of the crop growing process is the sum of green, blue, and grey water footprints, demonstrated in Eq.(8), (Kongboon and Sampattagul, 2012).

$$WF_{proc} = WF_{proc,green} + WF_{proc,blue} + WF_{proc,grey} \tag{8}$$

RESULTS AND DISCUSSION

Yield Components

This results were achieved when 40% allowable depletion content (ADC) increased corn height, pod weight, pod length, and water use efficiency to 188.75 cm, 7.75 ton/ha, 9.61 cm, and 3.26 kg/m^3, respectively. Production of 60% ADC measured 180.61 cm, 7.54 ton/ha, 7.54 cm, and 3.19 kg/m^3. A yield of 184.37 cm, 6.81 ton/ha, 923 cm, and 2.54 kg/m^3 was produced of 80% ADC. Enhancement of the 80% ADC's finest pods showed no significant difference when compared with both the 40% ADC and 60% ADC.

Aydinsakir et al., (2013) reported that sweet corn production, affected by deficit water, reduced corn height, pod diameter, pods length, and seed weight/1,000 seeds. The pod amount, however, was not reduced. Past applications of fertilizer, applied at 94-31-31 kg/ha (N-P_2O_5-K_2O), yielded the highest corn height, pod weight, pod length, amount of pods, and amount and water use efficiency (192.61cm, 8.82 ton/ha, 9.57 cm, 146,234 pods/ha, and 3.59 kg/m^3 , respectively). In comparison, the fertilizer application of 47-47-47 kg/ha yielded 188.82 cm, 8.62 ton/ha, 9.64 cm, 141,111 pods/ha, and 3.50 kg/m^3.The application of 47-16-16 kg/ha yielded 179.20 cm, 6.98 ton/ha, 9.34 cm, 123,889 pods/ha, and 2.84 kg/m^3. Lastly, the control treatment yielded 177.67 cm, 5.03 ton/ha, 9.19 cm, 95,679 pods/ha, 2.06 kg/m^3, and 2.16 kg/m^3 and was considered not significant. Cela et al., (2011) studied 0, 50, 100, 150, 200 and 300 kg N/ha application on sweet corn production in a semi-arid climate in Spain which found that 100 kg N/ha provided the greatest increase in sweet corn production. The interaction of the main plot combined with sub plots having 40% ADC was associated with 94-31-31 kg/ha fertilizer, which had the greatest affect upon pot weight and water efficiency. The exception was corn height, pod length, and pod amount, which proved to be insignificant.

Water Footprint

This study found that the 40% ADC showed the least reduction of green, blue, grey, and total water footprint amounts (490, 340, 16 and 845 L/kg), 60 % ADC yielded 606, 423, 23 and 1,051 L/kg^{-1}; and 80 % ADC at 809, 482, 22, and 1,313 L/kg, respectively. This result corresponded with Jeswani and Azapagic, (2011) who reported that total water footprint within sweet corn production, in each region of the world; ranged from 354 to 2,434 L/kg. In sub plots factors, in which the green, blue, and total water footprints were reduced the most using 47-47-47 kg/ha obtained results of 444, 303 and 763 L/kg.

Table 1 Showed yield and water footprint of Baby corn production

Main plots	Sub plots (N-P_2O_5-K_2O kg ha^{-1})	Corn height (cm)	Pods weight (ton ha^{-1})	Pods length (cm)	Pods amount (pods ha^{-1})	Water use efficiency (kg m^{-3})	Green water footprint (L kg^{-1})	Blue water footprint (L kg^{-1})	Grey water footprint (L kg^{-1})	Total water footprint (L kg^{-1})
40 % ADC	Control	187.80a	5.78a	9.20a	103,899cd	2.45a	721b	487b	3e	1,211b
	94-31-31	190.93a	9.40a	9.57a	147,777a	3.96a	362b	256b	27b	644b
	47-16-16	183.35a	7.36a	9.60a	125,740b	3.10a	490b	342b	18bcd	850b
	47-47-47	192.91a	8.45a	10.07a	126,852b	3.54a	386b	276b	14cde	676b
	Mean	$188.75A^{ns}$	$7.75A^{ns}$	$9.61A^{ns}$	$126,065A^{ns}$	$3.26A^{ns}$	490B*	340B*	$16A^{ns}$	845B*
60 % ADC	Control	173.27a	5.41a	9.33a	97,963de	2.27a	657b	479b	7de	1,143b
	94-31-31	192.18a	8.86a	9.87a	142,037ab	3.77a	565b	385b	41a	991b
	47-16-16	175.35a	7.06a	9.27a	119,630bc	2.99a	661b	454b	24bc	1,139b
	47-47-47	181.65a	8.82a	9.40a	139,074ab	3.73a	541b	372b	20bc	933b
	Mean	180.61A	7.54A	9.47A	124,675A	3.19A	606B	423A	23A	1,051B
80 % ADC	Control	171.93a	3.91a	9.03a	85,185e	1.45a	1,547a	895a	4e	2,447a
	94-31-31	194.73a	8.21a	9.27a	148,889a	3.06a	529b	322b	39a	890b
	47-16-16	178.91a	6.53a	9.17a	126,297b	2.43a	757b	451b	28b	1,237b
	47-47-47	191.89a	8.60a	9.47a	157,407a	3.22a	404b	259b	15cde	679b
	Mean	184.37A	6.81A	9.23A	129,445A	2.54A	809A	482A	22A	1,313A
Mean sub plots	Control	177.67B*	5.03B**	$9.19A^{ns}$	95,679B**	2.06B**	975A**	621A**	5C**	1,600A**
	94-31-31	192.61A	8.82A	9.57A	146,234A	3.59A	485B	321B	36A	842B
	47-16-16	179.20B	6.98A	9.34A	123,889A	2.84A	636AB	416AB	23AB	1,075B
	47-47-47	188.82AB	8.62A	9.64A	141,111A	3.50A	444B	303B	16BC	763B
Interaction main plots x sub plots		ns	ns	ns	*	ns	**	**	*	**
% CV (main plots)		4.56	17.53	4.96	15.38	17.69	24.13	21.36	27.02	22.86
% CV (main plots x sub plots)		5.68	10.60	4.00	8.00	10.46	30.14	25.56	31.55	28.17

*Caution: ns = non significant)P>0.05(, * = significant at)P < 0.05(, ** = significant at)P <0.01(and Different letters indicated significant different by DMRT*

The proved less than the mixture of 94-31-31 kg/ha, which had results of 485, 321, and 842 L/kg; as well as the 47-16-16 kg/ha mixture, with 636, 416, and 1,075 L/kg. Another control treatment found 975, 621 and 1,600 L/kg to be significant. Whereas, the control treatment which held the lowest grey water footprint at 5 L/kg, less than 47-47-47 kg/ha was the 16 L/kg together with 47-16-16 kg/ha, the 23 L/kg and the 94-31-31 kg/ha at 36 L/kg, which were very significant. The interaction of both the irrigation and fertilizer applications, found 40% ADC combined with 94-31-31 kg/ha fertilizer, to produce the greatest decrease in green, blue, and total water footprints with the exception of the grey water footprint.

CONCLUSION

Results indicate that 40% ADC irrigation application yielded the highest corn height, pod weight, and water use efficiency; as well as producing the greatest decrease in green, blue, and total water footprints (compared with both the 60% and 80% ADCs). Past fertilizer applications found 94-31-31 kg/ha enhanced corn height; pod weight, length, and amount as well as water usage efficiency. In contrast, 47-47-47 kg/ha offered the least reduction of green, blue, and total water footprint content compared with other sub plots. The association of 40% ADC with the 94-31-31 kg/ha^{-1} application is recommended for farmers, in the parameters of pod weight, and water usage (including footprint contents) in both clay loam and clay soil. However, economic factors involving profit and budget for unit costs are not considered here.

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