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Full Length Article

Improving Resource Use Efficiencies of Sugarcane at Farmer Field under Arid Environment

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Abstract

Improving resource use efficiency of arable crops is necessary to meet increasing demands for food for burgeoning population. A two- years (2017 and 2018) field study was conducted under arid environment to explore the effect of diverse planting dates, irrigation regimes and nitrogen (N) levels on resource use efficiencies (radiation-use-efficiency, RUE; water-use-efficiency, WUE; and nitrogen-use-efficiency, NUE) of ponda sugarcane. Ponda sugarcane was sown under six sowing dates from April 05 to May 25 with 10 days' interval (experiment 1), six irrigation regimes *i.e.*, 0, 4, 8, 12, 16 and 20 irrigations (experiment 2) and six N levels *i.e.*, 0, 57, 114, 171, 228 and 285 kg N ha^{-1} (experiment 3). Maximum biomass, cane yield, RUE_{TDM} and RUE_{CY} were recorded for sugarcane planted on 25th May in both years. Likewise, maximum biomass, cane yield, RUE_{TDM}, RUE_{CY}, WUE_{TDM} and WUE_{CY} were observed with 16 irrigations significantly similar with 20 irrigations. Moreover, optimum rate of N application was 228 kg ha^{-1} to get higher biomass, cane yield, RUE_{TDM}, RUE_{CY}, NUE_{TDM} and NUE_{CY} and WUE in both years. Nonetheless, biomass and cane yield, RUE_{TDM}, RUE_{CY}, WUE_{TDM}, WUE_{CY} and NUE_{TDM} and NUE_{CY} were slightly higher during 1st year of study. In summary, ponda sugarcane planted on May 25 with optimal inputs may be a viable option to get higher resource use efficiencies and cane yield under irrigated arid environmental conditions. © 2020 Friends Science Publishers

Keywords: Radiation-use-efficiency; Water-use-efficiency; Nitrogen-use-efficiency; Biomass; Cane yield; Leaf area index

Introduction

Sugarcane shares 3.2% in value addition in agriculture and 0.5% in gross domestic product (GDP) of Pakistan (GOP 2019). Sugarcane is an imperative crop as it is used for making sugar as well as bioenergy. It provides almost 76% of sugar production for the human-being consumption in world. It is one of the world's main C_4 sugar producing crops, which are mostly grown in the tropical and subtropical regions (Farooq and Gheewala 2019; Waqas *et al*. 2019).

Ponda sugarcane (*Saccharum officinarum* L.) is one of the utmost imperative agronomic crops in the Punjab, Pakistan. Ponda term is used for chewing sugarcane cultivar because it is best for chewing due to high sugar and juice contents (Ullah *et al*. 2013).

Optimization of management practices like sowing dates, irrigation regimes and nitrogen (N) levels is crucial to improve resource use efficiencies of ponda sugarcane. Radiation use efficiency (RUE) is a valuable parameter to relate canopy photosynthesis to crop production (Silva *et al*. 2013; López-Pereira *et al*. 2020; Abbas *et al*. 2020a). It is an imperative quantifier for cane and sugar yield in relation to photosynthesis process; as it combines both the quantity of solar radiations capturing and its efficiency to produce biomass, presumptuous other factors are not restrictive (Anderson *et al*. 2015; Schwerz *et al*. 2018). Measurement of RUE of various management systems involve the collections of biomass, cane and sugar yield, and the accumulations of intercepted photoactive radiations through the canopy over the life cycle of the crop (Olivier *et al*. 2016; Ahmad *et al*. 2017). Canopy architecture would be

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one path toward enhancing crop yield, which might emphasis on more efficiently conversion of available photoactive radiations into dry matter or cane yield and straightway associated to factors contributing to improve RUE (Silva and Costa 2012; Ehsanipour *et al*. 2019; Abbas *et al*. 2020b). Optimal planted crop capture more solar radiations by leaves; resultantly more photo assimilates are produced leading to higher RUE for biomass and cane yield. Shukla and Singh (2011) reported higher cane productivity in summer planting dates while Hoy *et al.* (2006) reported sizable decrease in cane productivity in case of early and late planting. However, Ahmad *et al*. (1991) concluded more autumn sugarcane productivity in case of August planting than September sown crop.

Water use efficiency (WUE) plays a vital role in improving cane yield over unit water use (Hurst *et al*. 2004). Water is one of the most important restraining factors of ponda sugarcane productivity; and sugarcane productivity can be enhanced by ensuring necessary irrigations during its whole growing season (Silva *et al*. 2013). Various research studies report specified that water influence on ponda sugarcane production due to its effect on yield parameters (Singh *et al*. 2018). In relationship to improvement of WUE, optimum irrigations are necessary to gain maximum cane length, cane diameter, plant height and ultimately more fresh cane yield (Singh *et al*. 2007; Olivier and Singels 2015). Silva *et al*. (2007) reported positive correlation amid variables and productivity that increased with irrigation quantity which causes direct rise in cane yield. Bekheet (2006) found that irrigation regimes significantly affected cane length and diameter.

Nitrogen use efficiency (NUE) can be improved by applying optimum amount of N under irrigated arid environment for sugarcane crop (Snyman *et al*. 2015). Nitrogen plays an imperative role for attaining maximum fresh cane yield and its components (Otto *et al*. 2016; Hoang *et al*. 2019). It is involved in several critical processes for example sugarcane growth and development, enlargement of green leaves, and tillers or sucrose contents, particularly in the formation of plant protein, which is vital for the photosynthesis process components like PEPCase or Rubisco enzymes (Suman *et al*. 2008; Nurhidayati and Basit 2015). The growth and yield of sugarcane cane be enhanced by improving NUE, because excess amount of N can lead to extended vegetative growth period and decreased sugarcane production (Ali *et al*. 2000; Whan *et al*. 2010). For instance, increase N uptake and NUE in ponda sugarcane contributed to the increase in fresh cane and sugar yield (Hajari *et al*. 2017; Thorburn *et al*. 2017). Sime (2013) reported relationship amid growth along with N application and concluded that higher N level resulted in greater plant height. Rizk *et al.* (2002) concluded that sugarcane productivity enhanced with increased N levels. Sogheir and Ferweez (2009) noticed that N increase up to 240 t ha^{-1} augmented millable canes along with productivity; the cane productivity was increased up to 51% with 138 kg N ha^{-1}. Mengistu (2013) reported at high N doses (252 and 336 kg ha^{-1}) positively increased cane-length, millable and stripped-cane-yields and compared to lower rate of 168 kg ha^{-1}. Greater N application increased cane productivity besides sugar contents (Azzazy and El-Geddawy 2003). The results showed that increasing N dose up to 200 improved cane productivity during two seasons (Shahrzad *et al*. 2014).

In view of aforementioned discussion, it is imperative to optimize management practices like sowing dates, irrigation regimes and N levels to improve resource use efficiencies. However, to best of our knowledge, resources use efficiency for ponda sugarcane has not reported in scientific literature. Therefore, this two-years field study was designed to optimize the best sowing date, irrigation regime and N rate to maximize cane yield and resource use efficiencies *i.e*., RUE, WUE and NUE of ponda sugarcane under irrigated arid environment.

Materials and Methods

Trials were carried out at Vehari (Longitude: 72°34′ E, Latitude: 30°12′ N, Elevation: 134 m, Climate: irrigated arid conditions), Punjab, Pakistan for two years 2017 and 2018. Soil analysis showed soil of clay loam texture, calcareous and alkaline in nature. It had bulk density of 1.2 g cm^{-3}, pH 8.3, total nitrogen 0.03%, available phosphorus 7.3 mg kg^{-1} and available potash 80.5 mg kg^{-1}. The weather trends for two years of experimental site are presented in Fig. 1.

Experimental treatments and designs are given in Table 1. Seedbed preparation was uniform for each field trial during both years. Pre-soaking irrigation of 10 cm depth was applied before seed bed preparation. At workable moisture level, seedbed was prepared by tractor mounted cultivar by tilling the soil two times to a depth of 10–12 cm followed by planking plus two times sub-soiling and again planking. Ponda variety was planted in all field experiments using seed rate of 74100 double budded setts ha^{-1}. Planting of sugarcane was done according to sowing dates treatments during both years in experiment 1. Moreover, sugarcane was planted on April 05 during both study years in experiment 2 and 3. Ponda sugarcane was sown in 120 cm spaced double row furrows with plant to plant distance of 22.5 cm. The detailed husbandry practices used to grow ponda sugarcane are given in Table 1. Nitrogen in the form of urea was applied at 228 kg ha^{-1}, phosphorus and potassium were applied at 120 and 145 kg ha^{-1}, respectively using di-ammonium phosphate (DAP) and sulphate of potash (SOP) as sources in each experiment. Weeds were controlled using S-Metolachlor, insects' pests were controlled using Fipronil (Carbofuran) and for disease management Thiophanate methyl was used at recommended rates during both years.

Data recorded

At harvesting, central two ridges from each plot were cut from base to determine total biomass and fresh cane yields. The samples were oven dried at 70°C for two days for determination of dry weight and yield is given as kg ha^{-1}. Sampling for leaf area and biomass was started at 30 days after planting (DAP) to harvesting of crop with 15-days interval to record leaf area. Leaves were separated, to measure leaf area using leaf area meter (Licor Model-3100). Leaf area index (LAI) was calculated as a ratio of leaf area to ground area. Maximum LAI was recorded at peak tillering stage. Harvested plants, including leaves, were chopped and dried in an oven till constant weight to record dry weight.

Fraction of intercepted PAR

The fraction of PAR (F_i) of sugarcane was valued from leaf area index employing Monteith and Elston (1983) equation.

$$F_i = 1 - \exp(-k \times LAI)$$

'k' a extinction co-efficient suggested by Monteith (1977). F_i and S_i multiply gave intercepted radiation (Sa).

$$\text{Sa} = F_i \times S_i$$

Radiation use efficiency (RUE)

RUEs for sugarcane for TDM & cane yields by employing equations.

$$\text{RUE}_{\text{TDM}} = \frac{TDM}{\sum Sa}$$

$$\text{RUE}_{\text{CY}} = \frac{Cane\ yield}{\sum Sa}$$

Water use efficiency (WUE)

WUE for sugarcane for TDM & cane yields by employing equations.

$$\text{WUE}_{\text{TDM}} = \frac{TDM}{\sum ET}$$

$$\text{WUE}_{\text{cane yield}} = \frac{Cane\ yield}{\sum ET}$$

Nitrogen use efficiency (NUE)

NUE (kg kg^{-1}) of sugarcane for total biomass and cane yields by employing Nyborg *et al*. (1995) formula

$$\text{ANUE}_{\langle \text{TDM} \rangle} = \frac{N_x \langle TDM \rangle - N_c \langle TDM \rangle}{N\ application\ rate}$$

$$\text{ANUE}_{\langle \text{CY} \rangle} = \frac{N_x \langle CY \rangle - N_c \langle CY \rangle}{N\ application\ rate}$$

Here N_x represent to grain yield with N application and N_c is represent grain yield without N application.

Statistical analysis

Data were statistically analyzed using one-way ANOVA for all three experiment using Statistics 8.1 and least significant difference (LSD) test was employed for mean separation at probability level 0.05 (Steel *et al*. 1997).

Results

Planting dates

Results revealed that planting dates had significant effect on biomass, can yield, RUE_{CY} and RUE_{TDM} during both years (Table 2). During both years, crop planted on 25th May resulted in significantly higher total biomass and cane while earlier planted crop (April 05) resulted lesser biomass and cane yield. Likewise, late planting (May 25) resulted significantly higher RUE_{TDM} and RUE_{CY} while earlier planted crop (April 05) resulted lesser RUE_{TDM} and RUE_{CY}, respectively during both years (Table 2).

Irrigation regimes

Results showed that effect of irrigation regimes had significant influence on total dry matter, cane yield, RUE_{TDM}, RUE_{CY}, WUE_{TDM}, WUE_{CY} (Table 3). During both years, highest number of irrigations applications resulted in significantly higher total biomass and cane yield, while at control, when no irrigation application resulted lesser biomass and cane yield as compared to other irrigation treatments. However, highest irrigations application was statistically at par with irrigation regime of 16 irrigations. Likewise, highest number of irrigations applications resulted significantly higher RUE_{TDM} and RUE_{CY} while at control, when no irrigation application resulted lesser RUE_{TDM} and RUE_{CY}, respectively during both years Likewise, 20 number of irrigations applications resulted significantly higher WUE_{TDM} and WUE_{CY}. However, highest irrigations applications were statistically at par with irrigation regime of 16 irrigations while at control, when no irrigation application resulted lesser WUE_{TDM} and WUE_{CY}, respectively during both years. The relationship between RUE and WUE for ponda sugarcane for pooled data has been presented in Fig. 2a. WUE is enhanced with increasing RUE. There was a strong positive correlation between WUE and RUE. More water productivity was gained with more RUE.

Nitrogen levels

The impact of N levels on total dry matter, cane yield, RUE_{TDM}, RUE_{CY}, NUE_{TDM}, NUE_{CY} was significant (Table 4). During both years, application of 285 kg N ha^{-1} resulted significantly higher total biomass and cane yield, however, it was statistically at par with of 228 N kg ha^{-1} (Table 4).

Table 1: Experimental details regarding *ponda* sugarcane at farmer field Vehari

Experimental details	Experiment 1 (Planting dates)	Experiment 2 (Irrigation regimes)	Experiment 3 (Nitrogen levels)
Experimental years	2017 & 2018	2017 & 2018	2017 & 2018
Treatments	PD_1=05[th] April; PD_2 = 15[th] April; PD_3=25[th] April; PD_4=05[th] May;PD_5=15[th] May;PD_6=25[th] May	I_0 = No Irrigations; I_1 = 4 Irrigations; I_2 = 8 Irrigations; I_3 = 12 Irrigations; I_4 = 16 Irrigations; I_5 = 20 Irrigations	N_0 = 0 kg ha^{-1}; N_1 = 57 kg ha^{-1}; N_2 = 114 kg ha^{-1}. N_3 = 171 kg ha^{-1}; N_4 = 228 kg ha^{-1}; N_5 = 285 kg ha^{-1}
Irrigations	16 Irrigations	As above	16 Irrigations
Planting date	As above	April 05	April 05
Nitrogen	228 kg ha^{-1}	228 kg ha^{-1}	As above
Phosphorus	120 kg ha^{-1}	120 kg ha^{-1}	120 kg ha^{-1}
Potassium	145 kg ha^{-1}	145 kg ha^{-1}	145 kg ha^{-1}
Experimental design	RCBD	RCBD	RCBD
Harvest dates	15 November	11 November	12 November

RCBD: Randomized complete block design

Table 2: Effect of different planting dates on total dry matter, cane yield and RUEs for total dry matter and cane yield of sugarcane

Planting dates	Total dry matter (kg ha^{-1})		Cane yield (t ha^{-1})		RUE_{TDM} (g MJ^{-1})		RUE_{CY} (g MJ^{-1})	
	2017	2018	2017	2018	2017	2018	2017	2018
April 05	31112f	29818f	72.89f	69.86f	2.39f	2.27f	2.03f	1.93f
April 15	36299e	34849e	85.04e	81.64e	2.79e	2.66e	2.37e	2.26e
April 25	40036d	38393d	93.79d	89.94d	3.08d	2.93d	2.62d	2.49d
May 05	43387c	42301c	101.65c	99.10c	3.34c	3.23c	2.84c	2.74 c
May 15	46582b	44781b	109.13b	104.91b	3.59b	3.42b	3.05b	2.90b
May 25	49768a	47732a	116.59a	111.82a	3.83a	3.64a	3.26a	3.10a
LSD value at 5%	1377.0	1489.0	3.22	3.48	0.10	0.11	0.09	0.09

Means sharing different letters in a column differ significantly at $P \leq 0.05$
RUE = Radiation use efficiency

Table 3: Effect of different irrigation regimes on total dry matter, cane yield and RUEs for total dry matter and cane yield of sugarcane

Irrigation regimes	Total dry matter (kg ha^{-1})		Cane yield (t ha^{-1})		RUE_{TDM} (g MJ^{-1})		RUE_{CY} (g MJ^{-1})		WUE_{TDM} (kg ha^{-1} mm^{-1})		WUE_{CY} (kg ha^{-1} mm^{-1})	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Control	16177e	15251e	37.90e	35.73e	1.24e	1.16e	1.06e	0.99e	-	-	-	-
4 Irrigations	26746d	25677d	62.66d	60.15d	2.06d	1.96d	1.75d	1.67d	18.63d	16.19d	16.25d	14.28d
8 Irrigations	33462c	32250c	78.39c	75.55c	2.58c	2.46c	2.19c	2.09c	28.05c	25.35c	24.92c	23.41c
12 Irrigations	39429b	38431b	92.37b	90.03b	3.04b	2.93b	2.58b	2.49b	39.42b	36.08b	35.14b	32.65b
16 Irrigations	46967a	45613a	110.03a	106.86a	3.62a	3.48a	3.07a	2.96a	51.41a	48.21a	46.03a	43.89a
20 Irrigations	48111a	46756a	112.71a	109.54a	3.70a	3.57a	3.15a	3.036a	54.28a	49.54a	48.59a	44.25a
LSD value at 5%	1591.1	1720.9	3.72	4.03	0.12	0.13	0.10	0.11	8.34	8.46	7.29	7.65

Means sharing different letters in a column differ significantly at $P \leq 0.05$
RUE = Radiation use efficiency; WUE = Water use efficiency

Table 4: Effect of different nitrogen levels on total dry matter, cane yield, RUE and NUE for total dry matter and cane yield of sugarcane

Nitrogen levels (kg ha^{-1})	Total dry matter (kg ha^{-1})		Cane yield (t ha^{-1})		RUE_{TDM} (g MJ^{-1})		RUE_{CY} (g MJ^{-1})		NUE_{TDM} (kg kg^{-1})		NUE_{CY} (kg kg^{-1})	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
0	12649e	12364e	29.63e	28.96e	0.97e	0.94e	0.89e	0.80e	-	-	-	-
57	24339d	21985d	57.02d	51.50d	1.88d	1.68d	1.59d	1.42d	180.24d	157.19d	165.35d	144.22d
114	30451c	27609c	71.34c	64.68c	2.35c	2.11c	1.99c	1.79c	225.50c	197.41c	206.85c	181.11c
171	35880b	32893b	84.06b	77.06b	2.76b	2.51b	2.35b	2.13b	265.71b	235.19b	243.77b	215.64b
228	42740a	39055a	100.13a	91.49a	3.29a	2.98a	2.80a	2.53a	316.51a	279.25a	290.36a	256.19a
285	43781a	39958a	102.57a	93.61a	3.37a	3.05a	2.86a	2.59a	324.21a	285.70a	297.44a	262.11a
LSD value at 5%	1513.7	1424.0	3.54	3.33	0.11	0.10	0.09	0.09	17.29	20.41	15.85	18.71

Means sharing different letters in a column differ significantly at $P \leq 0.05$
RUE = Radiation use efficiency; NUE = Nitrogen use efficiency

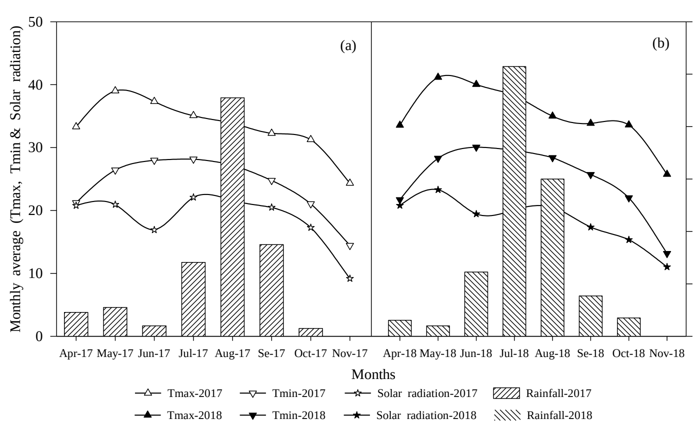

Fig. 1: Mean monthly maximum and minimum temperatures, solar radiation and total monthly rainfall at study site during 2017 and 2018

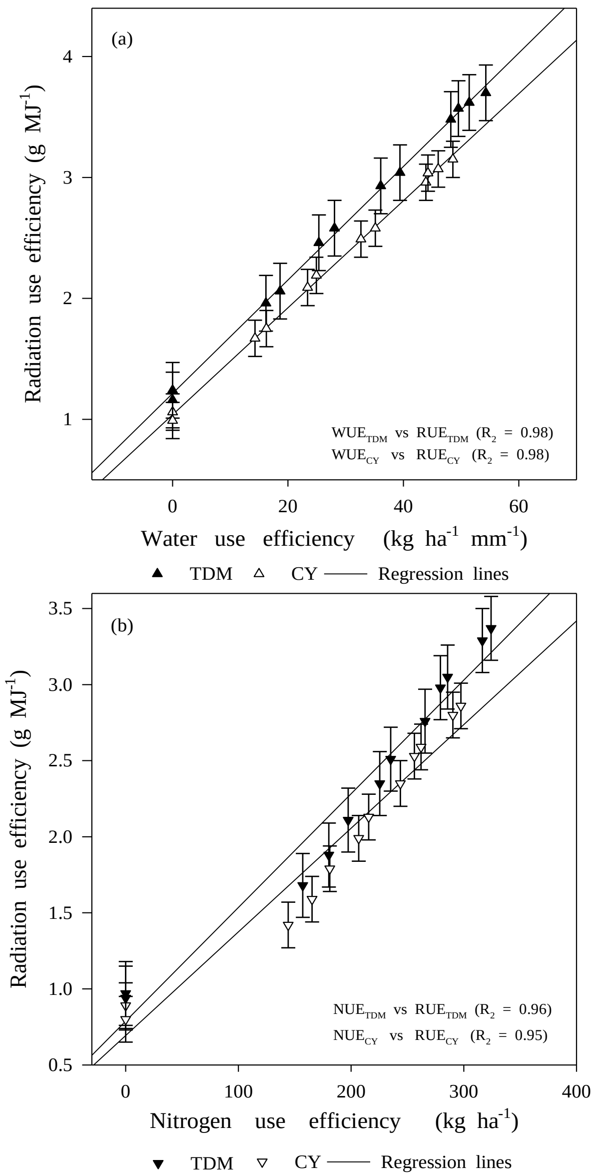

Fig. 2: Relationships between radiation use efficiency and water use efficiency (**a**) and nitrogen use efficiency (**b**) for *ponda* sugarcane for pooled data

However, lesser biomass and cane yield were observed for control withut N application. Similarly, 285 kg N ha^{-1} resulted significantly higher RUE_{TDM} and RUE_{CY} while control, with no N, resulted lesser RUE_{TDM} and RUE_{CY}, respectively during both years of study (Table 4). Likewise, application of N 285 kg ha^{-2} resulted significantly higher NUE_{TDM} and NUE_{CY}; however, it was statistically at par with 228 kg N ha^{-1}. Moreover, control, where no N was applied, resulted in lesser NUE_{TDM} and NUE_{CY}, respectively during both years of study (Table 4). The relationship between RUE and NUE for *ponda* sugarcane for pooled data has been presented in Fig. 2b. NUE is enhanced with increasing RUE. There was a strong positive correlation between NUE and RUE. More NUE was attained with more RUE (Fig. 2b).

Discussion

The RUE was affected significantly by diverse planting dates and management practices. Maximum RUE was gained at planting date 25 May, application of 16 irrigations and N level of 228 kg N ha^{-1} during both years. The main reason behind the higher RUE_{CY} and RUE_{TDM} of ponda sugarcane in all experiments was the more accretion of biomass and cane yield recorded at respective treatments in both years (Tables 2–4).

Environmental factors that influence sugar and cane productivity are capturing of more solar radiations that interrelates with uptake of water, nutrients, as well as temperature affecting photosynthesis process; which regulates dry matter accumulation of ponda sugarcane. Ponda sugarcane for best performing treatments during entire life cycle enjoyed favorable temperature for germination and growth, and optimum water and nutrients supply which enabled it to produce more biomass and cane yield leading to higher RUE (Anderson *et al.* 2015; Schwerz *et al.* 2018). Factors that influence on photosynthesis process are interception of solar radiations as well as its exploitation with the help of crop canopy configuration, to transformation of light into photo-assimilates and ultimately to translocation of sucrose contents toward sinking organ parts of sugarcane plant (Silva and Costa 2012; Ehsanipour *et al.* 2019). For the enhancement of resources use efficiency on ponda sugarcane crop, it is vital to upsurge the quantity of intercepted radiations that depend on the cultivar response, optimum planting date, irrigations, and nitrogen amount application (Ahmad *et al.* 2017). To capture higher amount of intercepted solar radiations, development of a higher LAI during earlier stages of growth and phases is desired. Optimal LAI is the one that permits the highest total biomass productivity, and this can be attained when whole canopy leaves sustain an optimistic steadiness of carbon; when sugarcane plant captivates whole PAR (Anderson *et al.* 2015; Ehsanipour *et al.* 2019). Photosynthetically active radiations captured by the ponda sugarcane crop are converted into dry biomass, therefore, the linear relationship among irrigations, N levels and planting dates treatments characterized variations in RUE. Best performing treatments resulted in maximum RUE (Silva *et al.* 2013; López-Pereira *et al.* 2020). With increasing irrigation regimes, adequate water and nutrient supply was maintained resulting in better canopy development (as evident with LAI) to capture more solar radiation to prepare more photo-assimilates (Jangpromma *et al.* 2012) which resulted in better RUE.

Maximum NUE was gained under best performing N application. At highest level of N application, NUE was decreased which might be due to losses of N during both years. It is proven fact that an optimum N availability, NUE of ponda sugarcane is improved, through greater height, LAI, intercepted light, along with development of canopy (Hajari *et al*. 2017; Thorburn *et al*. 2017). Like inclinations of NUE against N applied in sugarcane crop showed that NUE might be better on total dry matter basis under appropriate N level (Ali *et al.* 2000; Whan *et al*. 2010). Ponda sugarcane displayed additional N assimilation at higher N level as compared lower N levels. Optimum N application for ponda sugarcane crop increases productivity in the form of sugar and fresh cane yield, and then likewise enhanced NUE. Optimum N supply enhanced cane length, cane diameter, internodal length and plant height; which leads to higher cane yield and ultimately improved NUE (Suman *et al*. 2008; Nurhidayati and Basit 2015).

The WUE is a good indicator to determine efficient utilization of scare water resources for any crop under optimal and less than optimal conditions (Farooq *et al*. 2019). In this study both WUE_{CY} and WUE_{TDM} were increased with increasing irrigation regimes and reached to maximum at 16 irrigations (Singh *et al*. 2007; Olivier and Singels 2015; Table 3). Higher WUE of sugarcane at higher irrigations might be due to its C4 photosynthesis system; as C4 plants efficiently utilize water and nutrients to accumulate more biomass and may result in higher WUE at higher irrigations (Table 3). With increasing irrigation regimes, adequate water and nutrient supply was maintained resulting in better canopy development as evident with LAI to capture more solar radiation to prepare more photo-assimilates (Jangpromma *et al*. 2012).

Conclusion

Results suggest that productivity and resource use efficiency of ponda sugarcane can be achieved through integrated approaches at farmers' fields. Higher biomass, cane yield and resource use efficiencies like RUE, WUE and NUE of ponda sugarcane can be achieved by optimizing planting time, irrigation regimes and nitrogen levels under irrigated arid environmental conditions.

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Author Contributions

The experiment was designed by GA, ZF, and MAK and performed by MNK. Literature was reviewed by PI, AK, and IZ. Data were analyzed by AM. The paper was written by MH and MA. Overall study was supervised by SA. All the authors read paper before submission.

References

Abbas G, S Ahmad, M Hussain, Z Fatima, S Hussain, P Iqbal, M Ahmed, M Farooq (2020a). Sowing date and hybrid choice matters production of maize–maize system. *Intl J Plant Prod* 93:1–13

Abbas G, Z Fatima, M Hussain, S Hussain, N Sarwar, M Ahmed, S Ahmad (2020b). Nitrogen rate and hybrid selection matters productivity of maize–maize cropping system under irrigated arid environment of Southern Punjab, Pakistan. *Intl J Plant Prod* 14:309–320

Ahmad R, M Hussain, MB Gill (1991). Effect of different planting dates on the yield and quality of sugarcane. *Pak J Agric Sci* 28:388–391

Ahmad S, M Nadeem, G Abbas, Z Fatima, RJ Khan, M Ahmed, A Ahmad, G Rasul, MA Khan (2017). Quantification of the effects of climate warming and crop management on sugarcane phenology. *Clim Res* 71:47–61

Ali FG, MA Iqbal, AA Chattha, A Shahid (2000). Fertilizer-use efficiency and cane yield under different nitrogen levels and weed management practices in spring planted sugarcane. *Pak Sugar J* 15:22–26

Anderson RG, R Tirado-Corbalá, D Wang, JE Ayars (2015). Long-rotation sugarcane in Hawaii sustains high carbon accumulation and radiation use efficiency in 2nd year of growth. *Agric Ecosyst Environ* 199:216–224

Azzazy NB, IH El-Geddawy (2003). Effect of nitrogen fertilization on yield and quality of some sugar cane varieties under develop surface irrigation system. *Egypt J Agric Res* 81:1137–1148

Bekheet MA (2006). Effect of irrigation and potassium fertilization on yield and quality of two sugarcane varieties. *Assiut J Agric Sci* 37:1–19

Ehsanipour A, H Abbasdokht, M Gholipour, ARA Mashhadi (2019). Evaluation of radiation use efficiency and weed control in intercropping of sugarcane (*Saccharum officinarum* L.) and legumes. *Iran J Crop Sci* 21:67–79

Farooq M, M Hussain, S Ul-Allah, KHM Siddique (2019). Physiological and agronomic approaches for improving water-use efficiency in crop plants. *Agric Water Manage* 219:95–108

Farooq N, SH Gheewala (2019). Water use and deprivation potential for sugarcane cultivation in Pakistan. *J Sustain Ener Environ* 10:33–39

GOP (Government of Pakistan) (2019). *Economic Survey of Pakistan 2018–2019, Finance Division, Economic Advisory Wing*, pp:19–24. Islamabad, Pakistan

Hajari E, SJ Snyman, MP Watt (2017). The effect of form and level of inorganic N on nitrogen use efficiency of sugarcane grown in pots. *J Plant Nutr* 40:248–257

Hoang DT, T Hiroo, K Yoshinobu (2019). Nitrogen use efficiency and drought tolerant ability of various sugarcane varieties under drought stress at early growth stage. *Plant Prod Sci* 22:250–261

Hoy JW, AE Arceneaux, CF Savario (2006). Effects of date and rate of billet planting on sugar-cane yield. *Amer Soc Sugar Cane Technol* 26:116–124

Hurst CA, PJ Thorburn, D Lockington, KL Bristow (2004). Sugarcane water use from shallow water tables: Implications for improving irrigation water use efficiency. *Agric Water Manage* 65:1–19

Jangpromma N, S Thammasirirak, P Jaisil, P Songsri (2012). Effects of drought and recovery from drought stress on above ground and root growth, and water use efficiency in sugarcane (*Saccharum officinarum* L.). *Aust J Crop Sci* 6:1298–1304

López-Pereira M, DJ Connor, AJ Hall (2020). Intercepted radiation and radiation-use efficiency in sunflower crops grown at conventional and wide inter-row spacings: Measurements and modeled estimates of intercepted radiation. *Field Crops Res* 246; Article 107684

Mengistu S (2013). Effect of different nitrogen rates and time of application in improving yield and quality of seed cane of sugarcane (*Saccharum* spp. L.) variety B41/227. *Intl J Sci Res* 3:36–51

Monteith JL (1977). Climate and efficiency of crop production in Britain. *Phil Trans Roy Soc Lond B* 281:277–294

Monteith JL, JF Elston (1983). Performance and productivity of foliage in the field. *In: The Growth and Functioning of Leaves*, pp:499–518. Dale JE, FL Milthorpe (Eds.). Cambridge University Press, Butterworths, London

Nurhidayati N, A Basit (2015). Improvement of nitrogen use efficiency derived from ammonium sulfate substitute fertilizer in sugarcane cultivation through the addition of organic amendment. *Intl J Plant Soil Sci* 6:341–349

Nyborg M, ED Solberg, RC Izaurralde, SS Malhi, M Molina-Ayala (1995). Influence of long-term tillage, straw and N fertilizer on barley yield, Plant-N uptake and Soil-N balance. *Soil Till Res* 36:165–174

Olivier FC, A Singels (2015). Increasing water use efficiency of irrigated sugarcane production in South Africa through better agronomic practices. *Field Crops Res* 176:87–98

Olivier FC, A Singels, AB Eksteen (2016). Water and radiation use efficiency of sugarcane for bioethanol production in South Africa, benchmarked against other selected crops. *S Afr J Plant Soil* 33:1–11

Otto R, SAQ Castro, E Mariano, SGQ Castro, HCJ Franco, PCO Trivelin (2016). Nitrogen use efficiency for sugarcane-biofuel production: What is next? *Bioener Res* 9:1272–1289

Rizk NS, EAY Bashbishy, ME Rasian (2002). Effect of macro and micro-nutrients and farmyard manure on sugar cane. *Ann Agric Sci Moshtohor* 40:2311–2316

Schwerz F, SL Medeiros, EF Elli, E Eloy, J Sgarbossa, BO Caron (2018). Plant growth, radiation use efficiency and yield of sugarcane cultivated in agroforestry systems: An alternative for threatened ecosystems. *Anais Acad Bras Ciênc* 90:3265–3283

Shahrzad MM, N Kamla, AE Hak (2014). Effect of irrigation regime and nitrogen fertilization levels on sugarcane yield and its component. *Alexandr Sci Exch J* 35:288–293

Shukla SK, I Singh (2011). Tillering pattern, growth and yield of three promising genotypes of sugarcane under three fertility levels in subtropical India. *Ind J Sugar Cane Technol* 26:10–13

Silva ALCD, WAJMD Costa (2012). Growth and radiation use efficiency of sugarcane under irrigated and rain-fed conditions in Sri Lanka. *Sugar Technol* 14:247–254

Silva MDA, JL Jifon, CMD Santos, CJ Jadoski, JAGD Silva (2013). Photosynthetic capacity and water use efficiency in sugarcane genotypes subject to water deficit during early growth phase. *Braz Arch Biol Technol* 56:735–748

Silva MDA, JL Jifon, JAG Silva, V Sharma (2007). Use of physiological parameters as fast tools to screen for drought tolerance in sugarcane. *Braz J Plant Physiol* 19:193–201

Sime M (2013). Effect of different nitrogen rates and time of application in improving yield and quality of seed cane of sugarcane (*Saccharum spp*. L.) variety B41/227. *Intl J Sci Res* 3:1–7

Singh I, RP Verma, TK Srivastava (2018). Growth, yield, irrigation water use efficiency, juice quality and economics of sugarcane in pusa hydrogel application under different irrigation scheduling. *Sugar Technol* 20:29–35

Singh PN, SK Shukla, VK Bhatnagar (2007). Optimizing soil moisture regime to increase water use efficiency of sugarcane (*Saccharum* spp. hybrid complex) in subtropical India. *Agric Water Manage* 90:95–100

Snyman SJ, E Hajari, MP Watt, Y Lu, JC Kridl (2015). Improved nitrogen use efficiency in transgenic sugarcane: Phenotypic assessment in a pot trial under low nitrogen conditions. *Plant Cell Rep* 34:667–669

Sogheir KSE, H Ferweez (2009). Optimum harvesting age of some promising sugar cane genotypes grown under different nitrogen fertilizer levels. *Egypt J Appl Sci* 24:195–214

Steel RG, JH Torrie, DA Dickey (1997). *Principles and Procedures of Statistics, A Biometrical Approach*, pp:172–177, 3rd edn. McGraw Hill Book Co., Inc., New York, USA

Suman A, AK Shrivastava, A Gaur, P Singh, J Singh, RL Yadav (2008). Nitrogen use efficiency of sugarcane in relation to its BNF potential and population of endophytic diazotrophs at different N levels. *Plant Growth Regul* 54:1–11

Thorburn PJ, JS Biggs, J Palmer, EA Meier, K Verburg, DM Skocaj (2017). Prioritizing crop management to increase nitrogen use efficiency in Australian sugarcane crops. *Front Plant Sci* 8; Article 1504

Ullah SMS, M Hossain, S Barman, MH Sohag, SH Prodhan (2013). Genetic diversity analysis of chewing sugarcane (*Saccharum officinarum* L.) varieties by using RAPD markers. *J BioSci Biotechnol* 2:34–45

Waqas MM, SHH Shah, UK Awan, M Arshad, R Ahmad (2019). Impact of climate change on groundwater fluctuation, root zone salinity and water productivity of sugarcane: A case study in Lower Chenab Canal System of Pakistan. *Pak J Agric Sci* 56:26–39

Whan A, N Robinson, P Lakshmanan, S Schmidt, K Aitken (2010). A quantitative genetics approach to nitrogen use efficiency in sugarcane. *Funct Plant Biol* 37:448–454