



Productivity of maize (*Zea mays*) under different crop sequences and irrigation regimes

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ABSTRACT

A two year field experiment was conducted at Research farm of Department of Agronomy, Punjab Agricultural University, Ludhiana during *kharif* 2016 and *kharif* 2017. The experiment was laid out in split-plot design with seven maize (*Zea mays* L.) based crop sequences, viz. maize-wheat, maize-potato-mentha + onion, maize + cowpea (f)-potato-mentha + onion, maize + cowpea (f)-potato-spring maize, maize + cowpea (f)-*gobhi sarson*-summer moong, maize-*toria* + *gobhi sarson*-summer moong and maize + cowpea (f)-*toria* + *gobhi sarson*-summer moong in main plots and four irrigation schedules of 0.75 IW/CPE, 1.0 IW/CPE, 1.25 IW/CPE and recommended schedule in sub plots replicated thrice. Intercropping of cowpea with maize increased the grain yield, crop and water productivity, energy output and net returns of *kharif* maize. The maximum grain yield of maize was recorded under recommended schedule which was statistically at par with 1.25 IW/CPE irrigation regime. Irrigation regime of 1.0 IW/CPE recorded the highest apparent water productivity with 3.00 and 3.07 kg/m³ during 2016 and 2017, respectively. Irrigation regimes of I_{1.25} and I_{Rec} were the most energy efficient and energy productive.

Keywords: Economics, Energetics, Irrigation regimes, Maize, Water productivity

Modern agriculture faces two major challenges. Firstly, to feed the growing world population it is the need of the time to increase the productivity of food sustainably, at the same time, this increase needs to be accomplished under conditions of increasing shortage of water resources (Bouman 2007) and concomitant changing climate. Continuous rice-wheat cropping sequence in Punjab has resulted in number of ecological and other disorders like development of hard pan, low input use efficiency including water, more pests etc. With the large scale production of rice-wheat system in Punjab, the production of food grains has been increased by 65% which has caused over exploitation of the ground water resources. A reduction in the level of water table was reported by the Department of Agriculture, although there were good rains in 2010 (Singh 2011). Water was expected to be the scarce ecological factor and costly input in determining agricultural production as water table in North-Western plains is drastically getting down. Thus, it becomes imperative to sustain the productivity of agricultural systems concomitant with friendly environment and efficient utilization of production resources. There is need to diversify

rice-wheat sequence for higher sustainability of agriculture. Maize (*Zea mays* L.) is a potential *kharif* crop to replace rice. Maize grain is mainly used for feed (63%), food (23%) and industrial purpose (13%) in the country (Parihar *et al.* 2016). To meet the rising demand, a quantum jump in maize production is the need of the hour (Saharawat *et al.* 2010). Water shortage and injudicious use, is the primary factor limiting factor productivity and economic development in semi-arid conditions (Rajanna and Dhindwal 2019). Energy is an important indicator of crop performance and provides financial savings, fossil resource preservation and air pollution reduction (Yadav *et al.* 2017). Availability of sufficient energy and its effective and efficient use are pre-requisites for improved production of agriculture.

MATERIALS AND METHODS

The experimental site is situated at 30° 54'N latitude and 75° 48'E longitude with altitude of 247 m amsl. The weekly mean maximum temperature ranged from 42.1–31.2°C and mean minimum temperature ranged between 29.3–24.6°C during crop season. The mean monthly relative humidity ranged from 65.4–78.5% during crop season. The annual rainfall at Ludhiana is 500-750 mm, most of which is received during the rainy season from July to September due to south-west monsoons. The meteorological data for the crop season obtained from the School of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana during the crop growing seasons (2016

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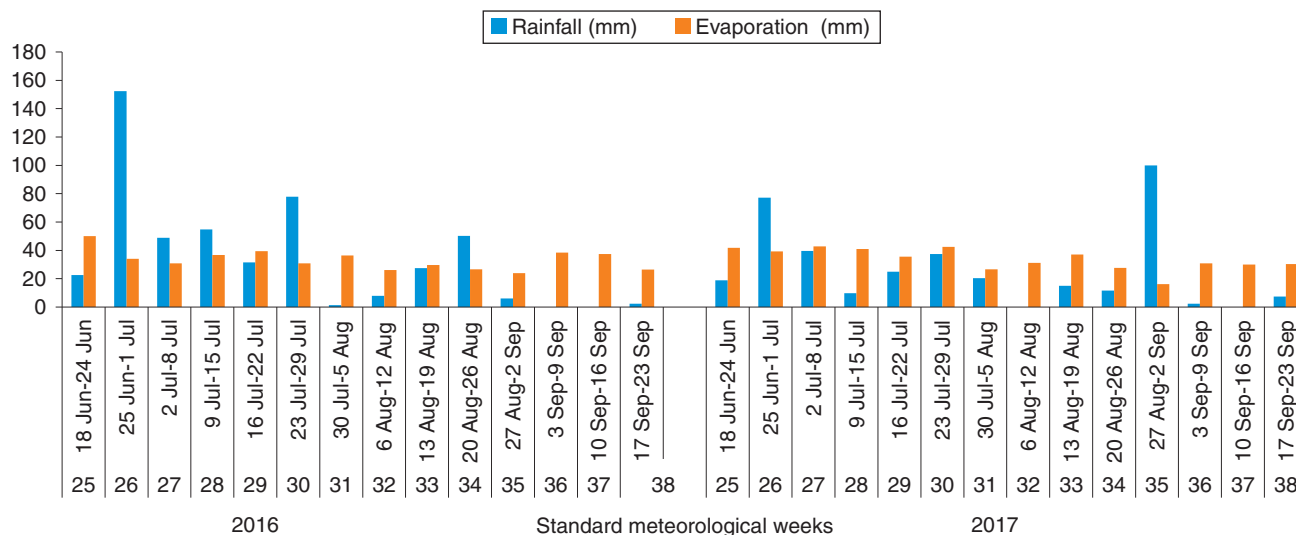


Fig 1 Weekly rainfall and evaporation during *kharif* 2016 and 2017.

and 2017) (Fig 1).

The soil of experimental site was loamy sand in texture. Field capacity (0.3 bar tension value) and permanent wilting point (15 bar tension value) were determined by pressure membrane apparatus (Richard and Weaver 1943). The water storage for 0.3 bar and 15 bar tension values of 0-180 cm rhizosphere were, 37.90 cm and 12.83 cm, respectively. The experiment was laid out in split-plot design with seven crop sequences in main plots, viz. maize (*Zea mays*)-wheat (*Triticum aestivum*), maize-potato (*Solanum tuberosum*)-mentha (*Mentha arvensis*) + onion (*Allium cepa*), maize + cowpea (*Vigna unguiculata*) (f)-potato-mentha + onion, maize + cowpea (f)-potato-spring maize, maize + cowpea (f)-gobhi sarson-summer moong (*Vigna radiata*), maize-toria (*Brassica rapa*) + gobhi sarson (*Brassica napus*)-summer moong and maize + cowpea (f)-toria + gobhi sarson-summer moong and four irrigation schedules in sub plots: 0.75 IW/CPE, 1.0 IW/CPE, 1.25 IW/CPE and recommended schedule with three replications. An irrigation delivery system (PVC pipeline) was constructed to enable delivery of water to every sub plot. A heavy pre-sowing irrigation was given a week before sowing of the crop. The maize variety PMH 1 was sown on 18 and 21 June during 2016 and 2017, respectively, at a spacing of 60 cm × 20 cm with a seed rate of 20 kg/ha. Seeds were treated with Bavistin 50 WP (carbendazim) @ 3 g/kg seed. Total fertilizer application was 125 kg N/ha, 60 kg P₂O₅/ha and 30 kg K₂O/ha. One third of N and entire quantity of P₂O₅ and K₂O were applied at the time of sowing. The remaining N was top dressed as 1/3rd N at knee high stage and 1/3rd at pre-tasseling stage. Pre-emergence herbicide Stomp 30 EC (pendimethalin) was sprayed within 2 days of sowing. Two hand weedings were given to control weeds. Decis 2.8 EC (deltamethrin) was sprayed to control maize borer. Harvesting was done at 19 Sept during both the years by cutting the stalks close to soil surface. The grains obtained after threshing the produce from each experimental unit

were weighed and expressed as yield in q/ha.

IW/CPE approach was used to schedule the irrigation treatments. It is the ratio of amount of irrigation water (IW) applied to cumulative pan evaporation (CPE). The volume of irrigation water applied at each irrigation to each sub plot was determined using a propeller flow meter installed in a straight section of the pipeline downstream from the tubewell outlet. The amount of irrigation water applied (mm) was calculated from the initial and the final flow meter readings divided by the area of the sub plot. Recommended irrigation schedule was applied as given the Package of practices by PAU, Ludhiana. Four irrigations were applied depending on the rainfall. First irrigation was applied before sowing and further irrigations were applied at the pre-tasseling, silking and grain filling stages.

Crop Evapotranspiration (ET_c)

Volumetric soil moisture was measured with Delta-T Devices PR2 soil moisture profile probe (Delta-T Devices, UK) in access tubes down to 100 cm depth. The moisture was measured from six soil depths (0-10, 10-20, 20-30, 30-40, 40-60 and 60-100 cm). Crop evapotranspiration (ET_c) was estimated using soil water balance equation as:

$$ET_c = I + P - R - D \pm \Delta SW$$

where, I, irrigation water applied (mm), P, precipitation (mm), R, surface runoff (mm), D, deep drainage (mm) and $\pm \Delta SW$, the change in soil profile moisture storage (mm). Complete check on runoff was maintained with sufficient dikes. Deep drainage was considered to be zero if soil profile moisture storage remained less than field capacity and when soil moisture storage exceeded the field capacity storage after irrigation or rainfall, then deep drainage was calculated as difference between the field capacity storage and soil moisture storage plus irrigation/rainfall.

Water productivity, energy and economics analysis: Crop and apparent water productivity was calculated in

accordance with Ali and Talukder (2008) and Brar *et al.* (2012). CWP (kg/m^3) is the ratio of grain yield to crop evapotranspiration while AWP (kg/m^3) is the ratio of grain yield to irrigation water applied.

Energy input (MJ/ha)

Inputs counted in the energy analysis were divided into two classes:

Mechanized inputs: These included tractor and equipment usage, and fuel and lubricant consumptions. The energy equivalents for fuel were in accordance with Singh and Mittal (1992) while for tractor hours and farm machinery were in accordance with Panesar and Bhatnagar (1994).

Agronomic inputs: These consisted of crop propagation materials, fertilizers, pesticides and irrigation water, farm yard manure. The energy equivalents for propagation materials, fertilizers and farmyard manure were in accordance with the Singh and Mittal (1992) and for herbicides, insecticides and fungicides were in accordance with Singh *et al.* (2017).

Energy output (MJ/ha): It was calculated by accumulating the main product and by-product produced from different cropping systems.

Energy efficiency: The energy efficiency (EE) was worked out as ratio of energy output (MJ/ha) to the energy input (MJ/ha) as suggested by Demicran *et al.* (2006).

Energy productivity (g grain per MJ energy): The energy productivity (EP) was worked out as ratio of grain yield (g/ha) to the energy input (MJ/ha) as suggested by Demicran *et al.* (2006).

Net returns: Net returns were calculated by subtracting total variable cost from the gross returns.

Benefit cost ratio: Benefit cost ratio was calculated by dividing the net returns with total variable cost under the respective treatment.

Statistical analysis: Statistical analysis of variance (ANOVA) was conducted using SAS version 9.4 for all the parameters and differences were tested using Fisher's protected LSD (least significant difference) test at 5% probability separately for both the years. Similar trends were observed during both the crop seasons therefore, data was pooled to increase the precision of tested treatments.

RESULTS AND DISCUSSION

Yield: The effect of different crop sequences on *kharif* maize grain yield (Table 1) was not significant. The sequences in which cowpea was intercropped with maize recorded numerically higher grain yield as compared to sole maize crop sequences. Maximum grain yield was obtained in maize + cowpea-toria + *gobhi sarson*-summer moong crop sequence while minimum was reported in maize-wheat sequence. Irrigation regimes had significant effect on maize

Table 1 Effect of crop sequences and irrigation regimes on grain yield (q/ha) (pooled), consumptive use of water (mm), crop water productivity (kg/m^3) and apparent water productivity (kg/m^3) of *kharif* maize

Treatment	Grain yield (q/ha)	2016-17				2017-18			
		Irrigation (mm)	Consumptive use (ETc in mm)	CWP (kg/m^3)	AWP (kg/m^3)	Irrigation (mm)	Consumptive use (ETc in mm)	CWP (kg/m^3)	AWP (kg/m^3)
<i>Crop sequence</i>									
M-W	46.86a	206.25	534.20	0.87	2.41	225	536.53	0.88	2.32
M-P-Me+O	47.31a	206.25	534.75	0.87	2.42	225	536.38	0.90	2.35
M+C(f)-P- Me+O	48.5a	206.25	535.0	0.89	2.44	225	538.65	0.93	2.42
M+C(f)-P-SpM	48.83a	206.25	538.28	0.89	2.47	225	537.1	0.93	2.45
M+C(f)-Gs-SuMo	49.19a	206.25	536.98	0.89	2.46	225	541.73	0.94	2.47
M-T+Gs-SuMo	47.04a	206.25	534.58	0.87	2.39	225	538.40	0.89	2.33
M+C(f)-T+Gs-SuMo	49.59a	206.25	537.90	0.89	2.48	225	540.1	0.95	2.49
CD (P=0.05)	NS			NS	NS			NS	NS
<i>Irrigation regime</i>									
I _{0.75}	43.60c	150 (2)*	465.43	0.91	2.81	150 (2)	479.76	0.94	3.01
I _{1.0}	45.49b	150 (2)	507.83	0.89	3.00	150 (2)	506.21	0.91	3.07
I _{1.25}	51.51a	225 (3)	577.59	0.87	2.25	300 (4)	573.71	0.92	1.75
I _{Rec}	52.15a	300 (4)	592.97	0.86	1.70	300 (4)	593.96	0.90	1.78
CD (P=0.05)	1.62			NS	0.12			NS	0.13
Interaction CD (P=0.05)	NS			NS	NS			NS	NS

In case of maize + cowpea (f) maize equivalent yield was taken of maize + cowpea (f) intercropping. M= Maize; C(f)= Cowpea fodder; R=Rice; W= Wheat; P= Potato; Gs= *Gobhi sarson*; T= *Toria*; Me= Mentha; O= Onion; SpM= Spring maize; SuMo= Summer moong I_{0.75}/I_{1.0}/I_{1.25}/I_{Rec} = IW/CPE ratio 0.75/1.0/1.25/recommended schedule. *Figures in parenthesis represent the number of irrigations

grain yield. The maximum grain yield was recorded under recommended irrigation schedule which was statistically at par with 1.25 IW/CPE irrigation regime. The minimum grain yield was recorded in 0.75 IW/CPE ratio. There was 14.64% increase in grain yield under recommended schedule compared to IW/CPE ratio 1.0 while per cent increase was 19.61% compared to 0.75 IW/CPE. Water stress at 0.75 IW/CPE was evident from the lower values of plant height, dry matter accumulation and leaf area index. Increase in senescence of lower leaves under stress conditions might have resulted in decreased dry matter production thereby, reducing the source size for translocation of photosynthates to the developing sink (grains). Singh (2010) also reported increase in grain yield under well watered irrigation regimes.

Water studies: The average consumptive use (ETc) by maize crop was 535.96 and 538.41 mm during the two experimental years, respectively (Table 1). The highest consumptive use of water (592.97 and 593.96 mm) was recorded under recommended irrigation schedule which was 15.38 and 20.25 mm higher compared to $I_{1.25}$, 85.14 and 87.75 mm higher as compared to $I_{1.0}$ and 127.54 and 114.20 mm higher compared to $I_{0.75}$ irrigation regime during 2016-17 and 2017-18, respectively. Higher consumptive use of water under well irrigated regimes was reported by Farre and Faci (2006) as compared to water stressed irrigation regime. There was saving of 75 mm of irrigation water under $I_{1.25}$ producing statistically at par grain yield compared to I_{Rec} during first year of study while the irrigation water applied was same during the second year under both the treatments. There was saving of 150 mm of irrigation water under $I_{1.0}$ but grain yield was significantly reduced compared to recommended schedule. CWP could not reach

the level of significance under different irrigation regimes during both the years. Maximum CWP of 0.91 and 0.94 kg/m³ were obtained with $I_{0.75}$ while the lowest CWP of 0.86 and 0.90 kg/m³ were obtained with I_{Rec} irrigation regime during 2016-17 and 2017-2018, respectively. In case of recommended irrigation schedule, higher consumptive use of water was not able to bring the proportional increase in yield as a result of which CWP decreased. The AWP was significantly the highest under $I_{1.0}$ during both the years but during 2017-18 it was at par with $I_{0.75}$. The highest AWP was 3.00 and 3.07 kg/m³ with $I_{1.0}$ during 2016-17 and 2017-18, respectively, while the lowest was 1.70 kg/m³ with recommended schedule during 2016-17 and 1.75 kg/m³ with 1.25 IW/CPE during 2017-18. Hussaini *et al.* (2002) also reported higher crop water productivity in case of 0.6 IW/CPE over that of 0.8 IW/CPE which in turn recorded higher CWP as compared to 1.0 IW/CPE.

Energetics: Cropping sequences had significant influence on different parameters of energy study (Table 2). Energy input of *kharif* maize increased with addition of cowpea in the crop sequences. Energy output was significantly higher in the sequences in which cowpea was intercropped with maize as compared to sole maize crop sequences. This was due to additional output produced in those sequences. Appropriate and condition-specific irrigation systems and application rates must be identified to optimize energy savings, crop yields and energy efficiency. Irrigation regimes significantly influenced the energy output. Energy output was higher with recommended irrigation schedule being statistically at par with $I_{1.25}$ but produced significantly more energy output compared to $I_{1.0}$ and $I_{0.75}$ during both the years. Higher values of energy efficiency

Table 2 Effect of crop sequences and irrigation regimes on energetics and economics of *kharif* maize

Treatment	Energy input (× 10 ³ MJ/ha)		Energy output (× 10 ³ MJ/ha)		Energy efficiency		Energy productivity (g grain/MJ)		Net returns (× 10 ³ ₹/ha)		B:C ratio	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
<i>Crop sequence</i>												
M-W	14.26	14.38	238.44b	243.19c	16.71a	16.91a	325.74a	328.04a	36.58	40.02	1.06	1.16
M-P-Me+O	14.26	14.38	239.69b	246.85c	16.80a	17.15a	326.21a	333.82a	36.70	41.33	1.06	1.19
M+C(f)-P- Me+O	20.04	20.16	276.77a	297.04ab	13.81b	14.73b	243.27b	256.81b	48.70	55.73	1.29	1.47
M+C(f)-P-SpM	20.04	20.16	280.84a	287.69b	14.01b	14.27b	247.77b	255.22b	49.60	55.18	1.31	1.46
M+C(f)-Gs-SuMo	20.04	20.16	280.66a	294.63ab	14.00b	14.62b	244.99b	261.61b	49.14	57.47	1.30	1.52
M-T+Gs-SuMo	14.26	14.38	241.99b	250.45c	16.96a	17.41a	323.24a	332.78a	36.31	41.39	1.05	1.20
M+C(f)-T+Gs-SuMo	20.04	20.16	284.40a	301.77a	14.19b	14.96b	246.99b	263.26b	50.13	58.09	1.33	1.54
CD (P=0.05)			14.33	12.28	0.89	0.72	27.22	28.23				
<i>Irrigation regime</i>												
$I_{0.75}$	16.80	16.80	242.52c	255.58c	14.70b	15.46b	262.97c	280.85b	36.32	43.33	1.02	1.21
$I_{1.0}$	16.80	16.80	255.76b	266.94b	15.48a	16.10a	279.05b	284.97b	40.46	45.00	1.13	1.26
$I_{1.25}$	17.27	17.74	268.73a	278.11a	15.78a	15.87ab	302.36a	305.61a	47.41	52.83	1.30	1.43
I_{Rec}	17.74	17.74	274.42a	283.61a	15.69a	16.20a	297.26a	310.12a	47.67	53.91	1.29	1.46
CD (P=0.05)			9.09	8.18	0.55	0.49	15.78	15.59				

were obtained under well watered irrigation regimes. Irrigation regimes of $I_{1.25}$ and I_{Rec} were the most energy productive compared to drier irrigation regimes of $I_{1.0}$ and $I_{0.75}$ during both the years.

Economics: The system providing maximum net returns and profitability is considered as economically significant. Inclusion of cowpea with maize increased the cost of cultivation and thus higher net returns due to additional income from the produce of cowpea as compared to sole maize during both the years (Table 2). The highest B: C ratio in maize was also incurred with inclusion of cowpea in the system. Among the irrigation regimes, cost of cultivation was the highest with recommended schedule and 1.25 IW/CPE ratio due to more number of irrigations applied compared to 1.0 IW/CPE and 0.75 IW/CPE during both the years. Net returns and benefit: cost ratio were the highest with recommended schedule and 1.25 IW/CPE. The highest net returns and benefit: cost with recommended schedule and 1.25 IW/CPE was due to higher grain yield in case of higher irrigation regimes as compared to lower irrigation regimes.

Inclusion of cowpea in maize increased the grain yield, crop and water productivity, energy output and net returns of *kharif* maize. The maximum grain yield of maize was recorded with recommended irrigation schedule and it was statistically at par with $I_{1.25}$ but was significantly more as compared to $I_{1.0}$ and $I_{0.75}$.

The maximum apparent water productivity was obtained under $I_{1.0}$ while the minimum was obtained with I_{Rec} and $I_{1.25}$ during 2016 and 2017, respectively. $I_{1.25}$ was statistically at par with I_{Rec} during the second year of study. Irrigation regimes of $I_{1.25}$ and I_{Rec} were more energy efficient during 2016 and 2017, respectively and these two were statistically at par with $I_{1.0}$, I_{Rec} and $I_{1.25}$ and $I_{1.0}$ during 2016 and 2017, respectively. On the basis of energy productivity, the most energy productive irrigation regimes were $I_{1.25}$ and I_{Rec} during 2016 and 2017, respectively and these two were statistically at par with each other. The least energy productive irrigation regime was $I_{0.75}$. Irrigation regimes of I_{Rec} and $I_{1.25}$ recorded the higher net returns and B: C ratio. Based on the data relating to the grain yield, consumptive use of water, energy used and net returns, irrigation regime of $I_{1.25}$ and I_{Rec} have the possibility of adoption in *kharif* maize to get higher water use efficiency and net returns under irrigated conditions of Punjab.

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