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IMPACT ASSESSMENT OF PRECISION AGRICULTURE AND OPTIMIZATION OF FERTIGATION FOR CORN GROWTH

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Precision agriculture and optimum fertigation are effective tools to obtain economical crop production. A multi seasonal experiment was conducted on corn at Faisalabad, Pakistan during autumn seasons of 2017 and 2018 to optimize the use of fertilizers and explore the effects of precision agriculture on crop production and fertilizer savings under drip irrigation. Three rates of recommended dose of fertigation (RDF) i.e. 125%, 100% and75% RDF under precise application of fertilizer (PAF) and recommended application of fertilizer (RAF) were evaluated in terms of crop response and fertilizer saving. According to nitrogen (N), phosphorus (P), and potassium (K) concentration in soil, the experimental field was divided into three fertility zones (high, medium and low) using kriging and overlay analysis for fertigation under PAF. Fertilizers under PAF were applied according to soil fertility level, whereas fertilizers under RAF were applied as per recommendations (N:P:K=250:125:125 kg/ha). The results showed 65% irrigation water saving. The results regarding crop parameters showed that the treatments under 125% RDF with RAF produced the highest plant height (176.3 cm), grain yield (8.43 t/ha), crop dry matter (17.97 t/ha) and water productivity (4.79 kg/m^3). Although the treatments under RAF produced better grain yield (7.9 t/ha) as compared to that under PAF (6.73 t/ha) but the treatments under PAF saved urea by 48%, DAP by 39% and SOP by 100% and eventually produced higher benefit cost ratio:BCR (3.17) as compared to that under RAF (2.42). Therefore, it is recommended that precision agriculture should be adopted for economical crop production and environmental protection.
Keywords: Corn, drip irrigation, fertigation rate, precision agriculture, water productivity.

INTRODUCTION

The world's population is growing rapidly at a growth rate of 0.75% per annum and is expected to reach about 9.77billion by 2050 (UN, 2017), posing challenges for meeting sharply growing water and food demand especially in developing countries. This food demand can only be achieved by shifting from conventional to conservation agriculture by improving water use efficiency. Drip irrigation can save 90% of irrigation water (Allen *et al*., 1998) and have special economic and agro-technical advantages over conventional methods of irrigations (El-Hendawy *et al*., 2008; El-Hendawy and Schmidhalter, 2010; Kaur and Brar, 2016; Chauhdary *et al*., 2017; Sinha *et al*., 2017). Along with water savings, drip irrigation has potential to apply fertilizer efficiently for increasing crop yields. Chauhdary (2018) reported that fertigation is an essential factor for crop production.

To increase crop yield and promote vigorous plant growth, use of inorganic fertilizers such as urea, DAP (Diammonium phosphate) and SOP(Sulphate of potash) can play a vital role by supplying basic nutrients (nitrogen, phosphorus and potassium) to crop for its better production(Ayoola and Makinde, 2007; Bokhtiar *et al*., 2008). Excessive use of these fertilizers, however, in crop production leads to accumulation of nitrates and other heavy metals beyond safe limits which is not safe for human health (Musa *et al*., 2010).To avoid excessive use of these fertilizers for environmental safety and reducing crop production cost, there is need to optimize their use and apply fertilizers only where they are needed as typically the soil can be spatially different within a field regarding presence of N , P and K levels. This strategy for fertilizer application is known as precision agriculture. Precision agriculture helps to overcome the variability in the field for lesser use of fertilizers and enhance profitability along with environmental protection (Schimmelpfennig and

Ebel, 2016; Colaço and Molin, 2017). Therefore, present study was designed to save irrigation water and optimize fertigation for corn production and assess economic viability of precision agriculture practices.

MATERIALS AND METHODS

***Study area*:** The study was conducted at experiment area of Water Management Research Centre (WMRC), University of Agriculture, Faisalabad (UAF)on corn under drip irrigation during autumn seasons of 2017 and 2018. The mean annual rainfall in the area is 350 mm and temperature varies from 0 ºC to 50 ºC through out the year. Almost all types of crops including wheat, corn, rice, sugarcane, cotton, bajra and fodder etc. are grown in the study area (GOV, 2018). Soil of study area has medium texture with homogeneous structure.

***Water and Soil sampling and analysis*:** There are two sources of irrigation water at the study area. One is canal water and the other is tubewell water. The water samples were collected from both the water sources to analyze water quality as residual sodium carbonate (RSC), sodium adsorption ratio (SAR), electrical conductivity (EC) and water pH. Three soil samples were taken, prior to crop sowing, at 15 cm depth by core apparatus for determination of bulk density. These samples were further analyzed in "Soil and water quality lab of WMRC, UAF using hydrometer method for texture analysis to find %sand, %silt and %clay for determination of soil type using "USDA soil texture triangle". Again, fifty soil samples were taken at15cm from the whole experimental field to analyze soil fertility in terms of N, P and K as these nutrients play major role in plant growth.

***Development of soil fertility maps*:** The latitude and longitude of sampling points were noted using a GPS receiver (GARMIN 60). These soil samples were analyzed in the laboratory to find N, P and K concentrations (ppm) in the soil. Fertility maps of N, P and K were developed using the technique adopted and suggested by others researchers (Fridgen *et al*., 2004; Damian *et al*., 2016), who developed soil fertility maps using kriging approach in ArcGIS. Binh and They (2008) compared kriging technique for interpolation after compare several interpolation techniques in flat areas.

***Experiment layout and treatments*:** In the current study, three levels of recommended dose of fertigation (RDF) (i.e 125% RDF, 100%RDF and 75% RDF)were evaluated for hybrid corn(Pioneer 30T60) to find their optimum level under precise application of fertilizer (PAF) as well as under recommended applications of fertilizer (RAF). As per recommendations of Punjab Agriculture Department (PAD), Pakistan, the amount of RDF for corn is N:P:K = 250:125:125 kg/ha. The experiment was constituted with six treatments, laid under RCBD arrangement. The treatments included T_1: 125% RDF under PAF; T_2: 100% RDF under PAF; T_3: 75% RDF under PAF;T_4: 125% RDF under RAF;T_5: 100% RDF under RAF;T_6: 75% RDF under RAF. The whole experimental area (60 mx75 m) was divided into eighteen plots (20 mx10 m) for experimental treatments and one control plot (60 mx15 m) for ridge sowing of corn. The layout of the experiment is shown in Fig. 1. Under drip irrigation, corn plants were sown on both sides of drip lateral at 23 cm plant to plant distance. The distance between two consecutive laterals was 90 cm. Under control treatment, corn plants were sown at 17 cm plan to plant distance under ridge furrow system with 37.5 cm wide ridge and 37.5 cm wide furrow.

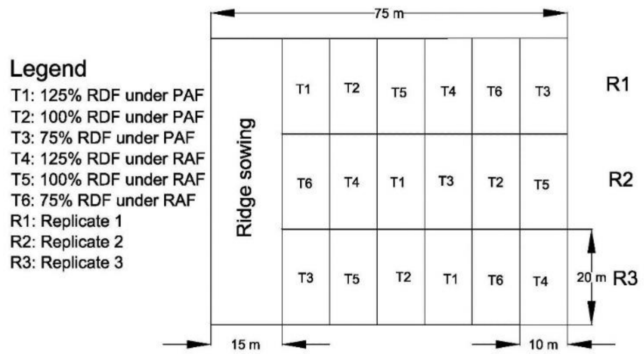

Figure 1. Layout of experimental field

***Irrigation and fertigation*:** The irrigation requirement was calculated by Cropwat 8.0 software using previous ten year climatic data of the study area as used by Chauhdary (2017). The climatic parameters, used in Cropwat software were rainfall (mm), maximum and minimum temperature (^{0}C), humidity (%), wind speed (km/day) and sun shine hours (hrs). Then irrigation was applied with drip irrigation according to that irrigation requirement. For application of N, P and K to crop, urea, DAP (Diammonium phosphate) and SOP (Sulphate of potash) were selected as source compounds (fertilizer) as these fertilizers are being commonly used by the farmers of study area. The N:P:K fraction in urea, DAP and SOP were 46:0:0, 18:46:0 and 0:0:50, respectively. The required amount of fertilizers (urea, DAP and SOP) for crop production was calculated according to the RDF (N:P:K = 250:125:125 kg/ha)and applied to RAF treatments, whereas fertilizers were applied according to fertility of the soil under PAF treatments. All doses of DAP and SOP were applied as basal applications during land preparation as these compounds are not fully soluble in water, and urea was applied with every irrigation through venturi apparatus (drip fertigation). Total number of drip fertigation was 85 for whole season of corn. Total amount of urea for different treatments was divided with number of irrigations to find amount/concentration of urea for each irrigation. Under control treatment; irrigation and fertilizer were applied according to general farm practices of the study area. The corn farm practices were included weekly irrigation and applications of 150 kg urea, 125 kg DAP and 50 kg SOP per acre in each season.

For drip irrigation, cumulative time of irrigation was noted and multiplied with drip emitter's discharge to calculate the irrigation volume. Under control treatment; first discharge was measured using cut-throat flume (8' x 3' size). Then the time of irrigation was multiplied with discharge to calculate volume of irrigation water applied.

***Crop data collection*:** The germination rate was recorded, after completion of corn emergence, by counting the number of plants fallen in one square meter area. The germination rate was measured at three locations (Head, middle and tail) in each plot. For plant height, fifteen plants were tagged along the length of each experimental plot. Plant height of these tagged plants was measured using measuring rod at crop maturity right before harvesting.

At maturity, corn samples were harvested manually from three different locations in each experimental plot along the plot length. The samples were thrashed manually and collected the grains carefully. The weight of these grains was measured after drying in sun light until the moisture content of grains reached to ambient drying conditions. Average weight of these nine samples was considered as grain yields of that particular plot. The water productivity was calculated using eq.1.

$$\mathrm{WaterProductivity}(\mathrm{kg/m^3}) = \frac{\mathrm{Cropyield(kg)}}{\mathrm{irrigationwaterapplied(m^3)}} \quad (1)$$

After separation of grains for determination of corn yield, the stem and the leaves of the plants were chopped and oven dried at 70°C for two days to determine corn dry matter weight (Chauhdary *et al*., 2017; Chauhdary *et al*., 2019; Chauhdary *et al*., 2020).

***Statistical and economic analysis*:** The analysis of variance technique (ANOVA) and least significance difference (LSD) test were used using SAS 9.1 software to analyze the data of corn parameters (Germination rate, plant height, grain yield and crop dry matter)to determine treatment significance difference at 5 percent probability level, as used by Chauhdary (2015) and Bakhsh (2018). The benefit cost ratio (BCR) was calculated for each treatment to economically analyze experimental treatments. The benefit cost ratio (BCR) was calculated for each treatment using eq. 2. The production cost was calculated according to the procedure adopted by Chauhdary (2016a) and total income was calculated from market price of grain yield.

$$\mathrm{BCR} = \frac{\text{Total income}}{\text{Production cost}} \qquad (2)$$

RESULTS AND DISCUSSION

***Water quality analysis*:** According to quality standards for irrigation water, the canal water was ideally fit for irrigation with EC= 0.63 ds/m, pH= 7.7, SAR= 4.7 meq/L and RSC= 1.86 meq/L. The quality of groundwater was also fit for irrigation due to its shallow bore depth and multi-bores (skimming well). The tubewell was installed at 28 m depth from ground surface (7 m deep well, 10 m blind and 11 m screen). The values of EC, pH, SAR and RSC were 1.45 ds/m, 7.8, 11 meq/L and 2.98 meq/L, respectively. These results are also in accordance with the work of others (Chauhdary, 2018; Chauhdary *et al*., 2019), who measured the chemical properties of water at study area and reported similar range of quality parameters. The results of water quality are given in Table 1.

Table 1. Chemical properties of irrigation water

Water source	EC (dS/m)	pH	SAR (meq/L)	RSC (meq/L)
Canal water	0.63	7.7	4.7	1.86
Tubewell water	1.45	7.8	11	2.98

Irrigation water quality standards by WAPDA, Pakistan

- EC (ds/m)=<1.5 (Good), 1.5-2.7 (Marginal), >2.7 (Bad)
- SAR (meq/L)=<10 (Good), 10-18 (Marginal), >18 (Bad)
- RSC (meq/L)=<2.5 (Good), 2.5-5 (Marginal), >5 (Bad)
- pH= 7-8.5 (Acceptable)

***Soil analysis and development of fertility zones*:** The results of soil analysis showed that the soil of the study area was sandy loam (Table 2). The bulk density of upper 15 cm soil layer varied from 1.51 to 1.57 g/cm^3. According to (Meek *et al*., 1992, 1988; Dam *et al*., 2005), the range of bulk density for sandy loam soil was within acceptable range. These researchers also reported same range of results regarding bulk density of the sandy loam soil. The detail results of soil texture and bulk density are given in Table 2.

The results of soil fertility parameters in terms of N, P and K varied from 29.84 to 57.75 ppm, 7.75 to 32.75 ppm and 119.3 to 230.76 ppm, respectively. Based on these results, soil fertility maps of experimental field were developed in ArcGIS using kriging tool and the whole field was divided into to three fertility zones (low, medium and high). The study site is located at experiment research area of Water Management Research Centre, UAF, therefore, different types of experiments in terms of different crops and fertilizer application are conducted by postgraduate students of University of Agriculture, Faisalabad. Execution of different

Table 2. Soil texture and bulk density.

Location	Soil Texture				Soil bulk density		
	Sand (%)	Silt (%)	Clay (%)	Soil type	Soil dry weight (g)	Core volume (cm³)	Bulk density (cm³)
1	58.41	24.12	13.21	Sandy Loam	79	51.5	1.54
2	61.34	23.84	13.64	Sandy Loam	81	51.5	1.57
3	60.41	23.94	13.74	Sandy Loam	78	51.5	1.51

experiments for long time in multi seasons has developed the variability in fertility of the study area within each field. Farid (2016) conducted a study at adjacent land of the current experiment to delineate management zones on the basis of crop yield and soil nitrogen and reported similar trends of variability in soil nitrogen maps. Fridgen (2004) also developed management zones (soil fertility zones) on the basis of crop yields of previous years and soil fertility status of current year. They suggested delineation of management zones for application of crop inputs including pesticides and fertilizers. The field layout and fertility maps were overlaid (layer stacking) on one another to identify the N,P and K availability in each experimental plot as shown in Figure 2-4. Same approach was adopted by Duffera (2007) and Farid (2016), who developed soil fertility maps for major nutrients (NPK) for fertilizer applications, only to meet deficiency of these nutrients in the soil for plant growth.

***Water and fertilizer savings*:** The total volume of irrigation water applied throughout the growing season was lesser in the case of treatments under drip irrigation (1760 m^3/ha) as compared to that under conventional ridge sowing (5120 m^3/ha). Drip irrigation saved 65% of irrigation water. Water saving under drip irrigation has also been reported by many researchers (Ashraf, 2014; Biswas *et al*., 2015; Chauhdary, 2018).

It was observed that treatments under PAF (T_1, T_2 and T_3) saved significant amounts of fertilizer as compared to that under RAF (T_4, T_5 and T_6). The average urea savings was 42%, 46% and 56% for 125%RDF, 100% RDF and 75% RDF, respectively. The urea savings under precision agriculture has also been reported by Chauhdary (2016b).

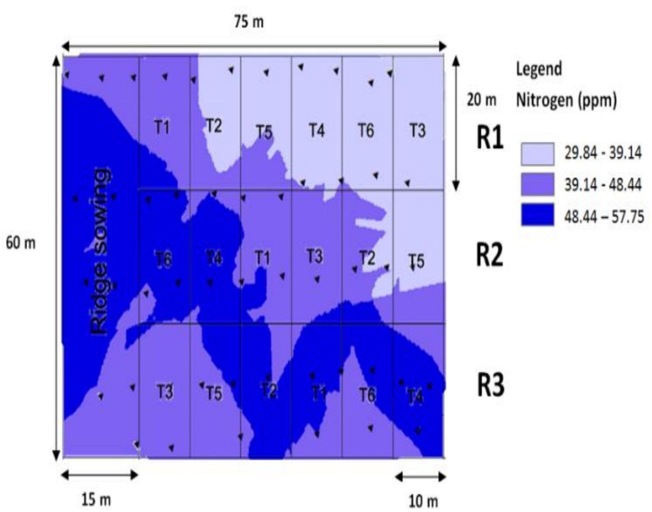

Figure 2. Soil fertility map of nitrogen (N) stacked under field layout.

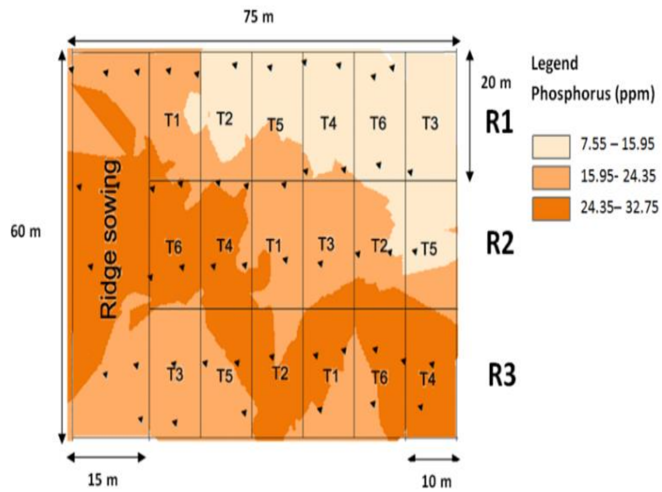

Figure 3. Soil fertility map of phosphorus (P) stacked under field layout.

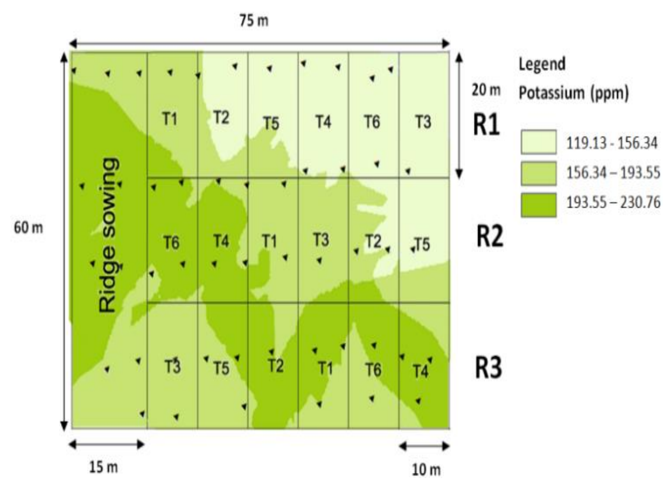

Figure 4. Soil fertility map of potassium (K) stacked under field layout.

Similarly, DAP applications were also reduced under PAF with an average savings of 34%, 38% and 46% for treatments under 125% RDF, 100% RDF and 75% RDF, respectively. Due to adequate presence of K in the soil, the SOP was not applied to the treatments under PAF. Thus, the SOP saving for all the treatments under PAF was 100% as compared to that under RAF. Rahim (Rahim *et al*., 2011) conducted a survey and reported that adequate potassium is present in the upper soil layers of different agro-ecological zones of Pakistan. Ndlovu(2014)conducted a study to analyze the productivity and efficiency of corn under precision agriculture and reported similar results regarding basic nutrient savings and efficiency. The detailed results of urea, DAP and SOP savings are given in Table 3, Table 4 and Table 5, respectively.

Table 3. **Urea savings under PAF.**

Treatment under PAF	Replicate	Available nitrogen (N) a (ppm)	Available urea b (kg/ha)	Crop urea requirement c (kg/ha)	Available urea in applied DAP d=k*0.18 (kg/ha)	Net crop urea requirement e=c-(b+d). If –ve than zero (kg/ha)	Urea savings f (%)	Average urea savings g (%)
T1*	R1	48.44	246	680	43	391	42	42
	R2	48.44	246	680	39	395	42	
	R3	48.44	246	680	39	395	42	
T2**	R1	39.14	199	544	34	311	43	46
	R2	43.80	222	544	31	291	46	
	R3	48.44	246	544	27	271	50	
T3***	R1	34.49	175	408	27	206	49	56
	R2	43.79	222	408	15	171	58	
	R3	43.79	222	408	19	167	59	
					Average Urea savings under PAF (%)			48

*T_1: 125% RDF under PAF (precise applications of fertilizer); **T_2: 100% RDF under PAF (precise applications of fertilizer); ***T_3: 75% RDF under PAF (precise applications of fertilizer)

Table 4. **DAP savings under PAF.**

Treatment under PAF	Replicate	Available Phosphorus (P) h (ppm)	Available DAP i (kg/ha)	Crop DAP Requirement j (kg/ha)	Net Crop DAP Requirement K=j–i, if –ve than zero (kg/ha)	DAP Savings L (%)	Average DAP savings m (%)
T1*	R1	20.15	102	340	238	30	34
	R2	24.35	124	340	216	36	
	R3	24.35	124	340	216	36	
T2**	R1	15.95	81	272	191	30	38
	R2	20.15	102	272	170	38	
	R3	24.35	124	272	148	45	
T3***	R1	11.75	60	208	148	29	46
	R2	24.35	124	208	84	59	
	R3	20.15	102	208	106	49	
					Average DAP savings under PAF (%)		39

*T_1: 125% RDF under PAF (precise applications of fertilizer); **T_2: 100% RDF under PAF (precise applications of fertilizer); ***T_3: 75% RDF under PAF (precise applications of fertilizer)

Table 5. SOP savings under PAF.

Treatment	Replicate	Available Potassium (K) n (ppm)	Available SOP o (kg/ha)	Crop SOP Requirement p (kg/ha)	Net Crop SOP Requirement Q=p–o, if –ve than zero (kg/ha)	SOP Savings r (%)	Average SOP savings s (%)
T1*	R1	193.55	904	313	0	100	100
	R2	193.55	904	313	0	100	
	R3	193.55	904	313	0	100	
T2**	R1	156.34	730	250	0	100	100
	R2	174.95	817	250	0	100	
	R3	193.55	904	250	0	100	
T3***	R1	137.74	643	188	0	100	100
	R2	174.95	817	188	0	100	
	R3	174.95	817	188	0	100	
					Average SOP savings under PAF (%)		100

*T_1: 125% RDF under PAF (precise applications of fertilizer); **T_2: 100% RDF under PAF (precise applications of fertilizer); ***T_3: 75% RDF under PAF (precise applications of fertilizer)

***Germination rate*:** Germination rate for corn was measured after complete emergence in each experimental plot. It was observed that the treatments regarding different fertigation rates and fertilizer applications methods only affected germination time but did not show any effect on the final results. The germination rate varied from 11.67 to 11 Nos./m^2 under different treatments. The results are shown in Table 6. According to Yasmin (1994), the basel applications of urea, DAP and SOP (Sulphate of potash) can delay germination for 1-2 days but it did not affect the final crop count. Nagy and Nádasy(2011) reported that nitrogen fertilizer delayed germination whereas potassium stimulated crop germination to achieve the normal germination, nitrogen fertilizer should be used with potassium fertilizer.

Table 6. Results of crop parameters under different treatments.

Treatments	Germination rate (No./m^2)	Plant height (cm)	Grain yield (t/ha)	Dry matter (t/ha)
Fertilizer application method				
PAF[a]	11.67a	170.28b	6.73b	14.33b
RAF[b]	11.33a	172.91a	7.90a	16.82a
LSD $_{(0.05)}$	0.52	1.01	0.19	0.43
Fertigation rate				
125 % RDF[c]	11.33a	175.23a	7.85a	16.73a
100% RDF	11.50a	172.82b	7.37b	15.68b
75% RDF	11.67a	166.73c	6.73c	14.32c
LSD $_{(0.05)}$	0.63	1.24	0.23	0.52
Interaction (Fertilizer application method* Fertigation rate)				
T_1:125% RDF under PAF	11.67a	174.17b	7.27c	15.50c
T_2:100% RDF under PAF	11.67a	171.43c	6.77d	14.40d
T_3:75% RDF under PAF	11.67a	165.23e	6.16e	13.10e
T_4:125% RDF under RAF	11.00a	176.30a	8.43a	17.97a
T_5:100% RDF under RAF	11.33a	174.20b	7.96b	16.97b
T_6:75% RDF under RAF	11.67a	168.23d	7.30c	15.53c
Control	11.33a	163.70f	4.24f	9.03f
LSD $_{(0.05)}$	0.94	1.85	0.34	0.77

[a]PAF= Precise applications of fertilizer; [b]RAF= Recommended applications of fertigation; [c]RDF= Recommended dose of fertigation; Treatment mean with different letters are significantly different (p=0.05)

***Plant height*:** It was observed that average plant height was significantly higher under RAF (172.91 cm) than that under PAF (170.28 cm). It was due to less fertilizer applications under PAF as compared to RAF. The fertigation rates also affected the plant height, as 150% RDF produced significantly the highest plant height (175.23 cm) than that under 100% RDF (172.82 cm) and 75% RDF (166.73 cm), respectively. Better results regarding plant height under optimum fertigation have also been reported by (Chauhdary, 2018; Hammad *et al*., 2011; Inamullah *et al*., 2011). The interaction of fertigation rate and fertilizer application methods showed that significantly the highest plant height was obtained under T_4: 125% RDF under RAF(176.3 cm) which was 7.7% higher than control treatment (163.7 cm). The detail results regarding plant heights given in Table 6.

***Grain yield*:** Treatments under RAF (7.9 t/ha) gave significantly better yield than that under PAF treatments (6.73 t/ha). This improvement in yield may be due to higher application of fertilizer. This trend was being reflected by the results under different rates of fertigation. Treatments under 125% RDF, 100% RDF and 75% produced (7.85 t/ha), (7.37 t/ha) and (6.73 t/ha), respectively. According to Stone (Stone *et al*., 2010) and Musa (Musa *et al*., 2010), corn performed in a better way in terms of grain yield under higher rates of fertigation. Chauhdary (2017) also conducted a study on different fertigation rates and reported that 100% RDF fertigation performed better than that under lower fertigation rates. Statistically worse grain yield was obtained under control treatment (4.24 t/ha) which was 85% lower than that under 125% RDF. The detail of results regarding grain yield is given in Table 6.

***Crop dry matter*:** The highest dry matter was produced under T_4: 125%RAF (17.97 t/ha) which was significantly higher than that under T_5: 100%RAF (16.97 t/ha), T_6: 75%RAF (15.53 t/ha), T_1: 125%PAF (15.50 t/ha), T_2: 100%PAF (14.40 t/ha), T_3: 75%PAF (13.10 t/ha) and control treatment (9.03 t/ha). All treatments produced significantly different crop dry matter except T_5: 75%RAF and T_1: 125%PAF, which produced statistically similar, crop dry matter (Table 6).

Results regarding different fertilizer rates showed that treatments under 125% RDF produced significantly better results (16.73 t/ha) than these under 100% RDF (15.68 t/ha) and 75% RDF (14.32 t/ha). Moreover, dry matter produced under 100% RDF was statistically better than that produced under 75%RDF. Similar to grain yield, treatments under RAF produced significantly higher crop dry matter (16.82 t/ha), than that under PAF (14.33 t/ha). Similar trend of corn response regarding crop dry matter under different fertigation rates have been reported by other scientists (Muhammad *et al*., 2002; Fridgen *et al*., 2004; Inamullah *et al*., 2011).

***Water productivity*:** The results regarding water productivity of corn under different treatments are show in Fig. 5. The overall water productivity was higher in case of treatments under RAF (4.49 kg/m^3) than that under PAF (3.83 kg/m^3). This trend was due to higher corn yield under RAF (7.9 t/ha) in comparison to that under PAF (6.73 t/ha) and the applied water was same for all treatments under drip irrigation. The graphical representation of results showed that the highest water productivity was produced for the treatment under RAF fertilized with 125% RDF (4.52 kg/m^3) and lowest water productivity was produced by control (0.83kg/m^3) under flood irrigation. Higher water productivity was also been reported by many researchers (Chauhdary *et al*., 2017; Chauhdary *et al*., 2019).

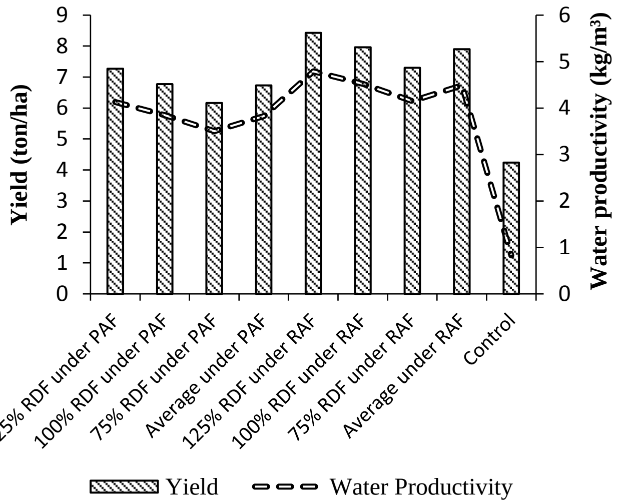

Figure 5. **Crop yield and water productivity.**

Economic analysis**:** For economic analysis, total production cost and total income were calculated separately. Total production cost of corn was divided into two components (management cost and fertilizer cost). The management cost was taken as same for all treatments and it included the cost of tillage practices, seed, sowing, irrigation and intercultural practices (Table 7). The fertilizer cost was calculated according to amount of fertilizer applications under RAF and PAF treatments separately and treatments with different RDF (i.e. 125% RDF, 100%RDF and 75% RDF). The highest fertilizer cost was recorded for 125% RDF under RAF treatment due to the highest amount of applied fertilizer, and lowest fertilizer cost was recorded for 75% RDF under PAF treatment due to 75%RDF application with precise fertilizer applications. The details of treatment wise fertilizer costs are given in Table 8. Total income was calculated as market price of grain yield regarding each treatment. Total production cost and total income were calculated regarding each treatment and depicted in Table 8.

Table 7. **Calculation of management cost for corn (Rs[a]. /ha).**

Operation/Input		Cost/ha (Rs[a])
Tillage cost: Disk Harrow (one operation), Planking (one operation)		5550
Seed cost: 25kg/ha		15000
Sowing cost (Manual)		2000
Irrigation	Drip irrigation	15000
	Control	12000
Pesticides/weedicides: Dualgold (2 liter/ha), Proclaim(500 ml), Furadan (20 kg/ha)		5545
Total management cost (Drip irrigation)		43095
Total management cost (Control)		40095

[a]US$=139.7 Pak Rupee; Note: Crop biomass was paid against the labor cost for harvesting and post harvesting process. Therefore, these costs are not included in management cost.

Table 8. **Benefit cost ratio of different treatments.**

Treatment	Fertilizer amount (kg/ha)		Fertilizer cost (Rs[a]/ha)	Production cost[e] (Rs./ha)	Total income[f] (Rs./ha)	Benefit cost ratio (BCR)	
T_1: 125% RDF under PAF	Urea[b]	394	13790	69373	218100	3.14	3.17
	DAP[c]	223	12488				
	SOP[d]	--	--				
T_2: 100% RDF under PAF	Urea	291	10185	62800	203100	3.23	
	DAP	170	9520				
	SOP	--	--				
T_3: 75% RDF under PAF	Urea	181	6335	55758	184800	3.13	
	DAP	113	6328				
	SOP	--	--				
T_4: 125% RDF under RAF	Urea	680	23800	112227	252900	2.25	2.42
	DAP	340	19040				
	SOP	313	26292				
T_5: 100% RDF under RAF	Urea	544	19040	98367	238800	2.43	
	DAP	272	15232				
	SOP	250	21000				
T_6: 75% RDF under RAF	Urea	408	14280	84815	219000	2.58	
	DAP	208	11648				
	SOP	188	15792				
Control	Urea	544	19040	95367	127200	1.33	1.33
	DAP	272	15232				
	SOP	250	21000				

[a]US$= 139.7 Pak Rupee[b] Urea @ Rs.35/kg; [c]DAP @ Rs.56/kg; [d]SOP @ Rs.84/kg; [e]Production cost was taken as management cost+ fertilizer cost; [f]Total Income was calculated as Rs. 30000/ton of corn grain.

The data regarding benefit cost ratio (BCR) revealed that highest BCR was produced by 75% RDF under PAF (3.37) followed by 100% RDF under PAF (3.05), 75% RDF under RAF (3.03), 125%RDF under PAF (2.80), 100% RDF under RAF (2.78), 125% RDF under RAF (2.53) and control treatment (1.48), respectively. The treatments under PAF (3.07) showed better results regarding BCR as compared to that under RAF (2.78) and control (1.48) due to less input cost (fertilizer cost). The input cost savings and profitability under precision agriculture were also reported by (Griffin and Lowenberg-DeBoer, 2005; Schimmelpfennig and Ebel, 2016). The results regarding BCR are shown in Fig. 6 and Table 8.

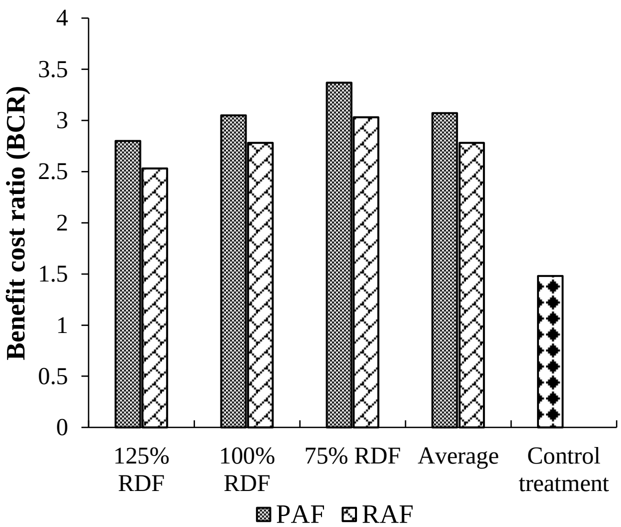

Figure 6. Benefit cost ratio of different treatments

***Conclusions*:** Drip irrigation saved 65% of irrigation water as compared to conventional ridge sowing (control treatment). Treatment under 125% RDF produced higher plant height (172.91 cm), grain yield (7.85 t/ha) and crop dry matter (16.73 t/ha) as compared to that under 100%RDF and 75%RDF.

Although the treatments under RAF produced higher grain yields (7.9 t/ha) and yield components as compared to that under PAF but the treatments under PAF saved urea by 48%, DAP by 39% and SOP by 100% and eventually produced higher BCR of 3.17 as compared to that under RAF (BCR: 2.42), that proved the economic viability of precision agriculture. Therefore, it is recommended that fertigation should be applied at 125% RDF according to the soil fertility only to fulfill the deficiency of nutrients in soil for corn production in the areas similar to study area with spatially varied soil fertility.

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