Improving yield and quality of maize by different drip-fertigation rates of N, P and K fertilizers

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[Received: January 20, 2020 Accepted: April 02, 2020 Published Online: April 11, 2020]

Abstract

Lower fertilizer use efficiency coupled with conventional irrigation methods has been the issue of agricultural production system in Pakistan contributing to lower crop yields. In this backdrop, an experiment was conducted to investigate the impact of drip-fertigation using different rates of N, P and K fertilizers i.e., F_{100} (100% of recommended), F_{75} (75% of recommended), F_{50} (50% of recommended) and F_{25} (25% of recommended) on hybrid maize in autumn and spring growing season. Results suggested that number of final harvested plants ha^{-1} decreased by 4.9% in autumn and 5.85% in spring season as fertilizer rates decreased from F_{100} to F_{25} while decrease in ears ha^{-1} was 5.9% and 6.05%, respectively. Plant and ear height remained stable with decrease in fertilizer rate from F_{100} to F_{50} . On average with F_{25} , crop reached maturity 2 days earlier in both autumn and spring seasons, respectively, against F_{100} . Ear length and number of grains row^{-1} showed an increasing trend with increasing fertigation rate. Number of rows ear^{-1} showed significant response only in one growing instance out of four. In both seasons, crop produced or sustained highest fresh ear weight and grain yield ($kg\ ha^{-1}$) at F_{75} indicating that a further increment of 25% nutrients (F_{100}) would be an excessive rate. Protein and oil % were also higher at F_{75} treatment in both seasons. Partial factor productivity (PFP) showed a negative relation with increasing fertigation rate however higher PFP values at lower fertilizer rates were economically ineffective. In conclusion, application of 75% of the recommended N, P and K fertilizers through drip fertigation optimized the grain yield and quality of maize in Punjab.

Keywords: NPK, partial factor productivity, protein%, fresh ear weight, quality, oil contents

Introduction

Pakistan is a dry country in the warm temperate zone where precipitation (except in the northern highlands) averages to less than 250 mm annually, that decreases from north to south. The Indus basin system is the main source of fresh water in the upper and lower Indus plains. Approximately 170 billion cubic meter (BCM) enters the basin out of which 75% diverted for irrigation purpose to the canals leaving rest to fall in the sea (GoP, 2014). About 93% of the total fresh water available in the country is used by agriculture (Qureshi *et al.* 2009). Due to high temperature, fusty irrigation designs and practices and poor crop management have resulted in 30-40% delivery

efficiency of water from canals to the root zone. Adding to this, Pakistan is the 7th worst hit country by climate change (Eckstein *et al.*, 2019). Rise in temperature is projected in the country that will increase the evaporative demand of the crops further exacerbating the misery of water shortage. Alike, another major key issue in sustainable agricultural production in Pakistan is lower fertilizer use efficiency (<20%) owing to low organic matter (<1%), fusty fertilizer application techniques, less interest in improving soil health through green manuring etc. (Afzal and Ahmad, 2009). Iqbal *et al.* (2013) has identified that effective and efficient fertilizer use would be an important strategy to address the problem of intensive agriculture. Therefore, improved and efficient techniques of irrigation and fertilizer application

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are indispensable for judicious resource utilization and sustaining the agricultural production system.

According to the 6th population and housing census of Pakistan in 2017, country's population is increasing at 2.4% annually. To meet the dietary needs of rapidly growing population, crop yield per unit of land has to be increased. This increase can only be achieved through efficient use and management of limited agricultural resources. Of these resources, water and fertilizers are the most important that contribute towards crop yield yet mismanaged at farm level.

Maize has become a very important cereal crop in Punjab after wheat and rice. During 2018-19 maize was cultivated on 899.7 thousand hectares (574.5 autumn and 325.2 spring). In Punjab about 92% of the total maize is sown under irrigated conditions. Punjab shares 59% in the total maize cultivated area while 81.42% of the country's total production. Average yield of maize in Pakistan is 4.31 t ha⁻¹ which is quite low comparing to other countries that are using their resources efficiently.

Drip irrigation is one of the most efficient irrigation methods that reduces crop water requirement, improves yield and decreases the fertilizer application requirements (Lekakis *et al.* 2011) and is accepted for crop production in areas of water scarcity (Fanish *et al.*, 2011). Drip irrigation allows the efficient application of fertilizers (drip-fertigation) and other agro-chemicals (Pablo *et al.*, 2007). Higher crop yields are achieved by precise irrigation management that generates radial distribution pattern and effective utilization of nutrients (Qureshi *et al.*, 2015). Synchronous application of irrigation with fertilizer reduces inter-plant competition, improves and optimizes the growth and subsequent yield of the crop (Prihar *et al.*, 2000; Wu *et al.*, 2019). Highly localized application of plant nutrients makes the nutrients available for substantial part of the roots. Furthermore, frequent application of nutrients in several little doses makes their optimum utilization, which ensures higher yield. Currently, in Pakistan use of drip irrigation is limited in orchards and lawns however row crops specially cotton, and maize can successfully be grown

Table 1: Average soil characteristic of experimental site

Soil depth	Ec (ms/cm)	pH	OM (%)	Avail. P (ppm)	Avail. K (ppm)	Saturation	Texture
Autumn							
0-15cm	1.1	8.2	0.62	12	210	41	Loam
5-30cm	1.4	8.4	0.48	9	196	38	Loam
Spring							
0-15cm	1.3	8.2	0.71	14	212	40	Loam
5-30cm	1.5	8.3	0.53	9	197	39	Loam

Table-2: Average monthly maximum and minimum temperature (°C), relative humidity (%) and rainfall (mm) during the experimental period

Climatic parameter	Autumn season									
	August		September		October		November		December	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Daily maximum temperature (°C)	39.67	26.48	38.43	34.56	37.52	40.26	27.51	42	27.45	43.3
Daily minimum temperature (°C)	27.93	8.89	23.76	16.29	19.77	20.26	12.88	23.45	7.21	27.1
RH % at 8 a.m.	62.45	84.62	66.8	79.35	71.39	61.02	84.36	44.06	82.97	45.54
RH % at 5 p.m.	43.25	77.03	48.23	62.35	35.45	34.03	50.13	36.45	65.23	41.5
Rainfall (mm)	9		74	16.8	-	3.5	2.2	4	7.6	
Climatic parameter	Spring Season									
	February		March		April		May		June	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Daily maximum temperature (°C)	26.48	19.11	34.54	28.03	40.26	36.6	42	40.64	40.63	44.03
Daily minimum temperature (°C)	8.89	8.17	16.29	13.45	20.56	20.4	23.45	22.29	26.60	25.76
RH % at 8 a.m.	84.62	83.85	79.35	73.03	61.23	55.1	44.06	50.41	49.2	46.33
RH % at 5 p.m.	77.03	77.57	62.35	47.03	34.03	32.9	36.45	31.38	42.53	36.3
Rainfall (mm)	0	41.3	16.8	5.5	3.5	31.6	4	31.2	64.1	1

under drip irrigation system (Ünlüt *et al.*, 2011; Wan *et al.*, 2012; Wu *et al.* 2019).

The concept of fertigation in Punjab is mostly limited to application of urea dissolved in a drum placed at water course from where it trickles in the flowing irrigation water into the field. To achieve the food security while protecting the environment, a fertigation should be optimally used in any irrigation system (Azad *et al.*, 2018). Though myriad of research has investigated the impact of different levels of fertilizers especially N applied through drip-fertigation on maize yield and quality under different soil types (Fanish *et al.*, 2011; Sampathkumar and Pandian, 2011; Azad *et al.*, 2018; Wu *et al.*, 2019). However, no such study has been conducted in Pakistan, though chunk of the maize crop is cultivated under irrigated conditions.

In the present study, two year field experiments were conducted to find out the effect of simultaneous application of nitrogen, phosphorus and potassium fertilizers with different rates through drip-fertigation on grain yield, quality and partial factor productivity of maize.

Materials and Methods

Location and Soil

Experiments were conducted at Water Management Research Farm, Renala Khurd, District Okara that is one of the six major maize growing districts of Punjab province

(30.53°N, 73.36°E, 170 m above sea level). Experiments were carried out in two distinct maize growing seasons i.e., autumn (July-November) and Spring (February-June) for two years (autumn 2017, 2018 and spring 2018, 2019). Weather conditions during the study period are depicted in table 1.

The soil type of the experimental site was loam. To estimate different physico-chemical attributes soil samples were collected from top 0-15 cm and 15-30 cm depth separately and analyzed. The average characteristics of pre-sowing soil analysis are given in table 2.

Field layout

Treatments were laid out in randomized complete block design with four replications. Sowing was done on 1.05 m center-to-center wide beds. One seed was planted on pre-marked spacing of 22.5 cm on both sides of the beds to achieve 33000 plants acre⁻¹. Gross plot size for each treatment was 12.6m × 5m while a net plot size of 3.15m × 4m from center of each plot was allocated for data recording. Specifications of drip irrigation system were a main line 60 mm and sub-main 37 mm diameter. Drip laterals of 16 mm diameter with 40 cm dripper spacing were placed at the center of the bed top while distal end of the lateral was tied and crimped over. Water was supplied with 2.5 to 3.0 bar with a discharge rate of 4 liters h⁻¹.

Table 3: Schedule of nitrogen, phosphorus and potassium fertilizer management according to the treatment

Crop growth stage	Nutrients kg/ha/day			Fertilizer kg/ha/day		
	N	P ₂ O ₅	K ₂ O	Urea	MAP	SOP
100%						
Vegetative Phase	1.77	1.36	0.78	3.27	2.23	1.57
Flowering Phase	2.66	1.36	1.57	5.20	2.23	3.14
Ear Development Phase	1.77	0.00	3.14	3.85	0.00	6.27
Grain Development Phase	0.89	0.00	1.57	1.93	0.00	3.14
75%						
Vegetative Phase	1.33	1.03	0.59	2.46	1.69	1.18
Flowering Phase	2.00	1.03	1.18	3.90	1.69	2.36
Ear Development Phase	1.33	0.00	2.36	2.90	0.00	4.71
Grain Development Phase	0.67	0.00	1.18	1.45	0.00	2.36
50%						
Vegetative Phase	0.89	0.68	0.39	1.65	1.11	0.79
Flowering Phase	1.34	0.68	0.79	2.62	1.11	1.58
Ear Development Phase	0.89	0.00	1.58	1.94	0.00	3.16
Grain Development Phase	0.45	0.00	0.79	0.97	0.00	1.58
25%						
Vegetative Phase	0.45	0.34	0.20	0.82	0.56	0.39
Flowering Phase	0.67	0.34	0.39	1.31	0.56	0.79
Ear Development Phase	0.45	0.00	0.79	0.97	0.00	1.58
Grain Development Phase	0.22	0.00	0.39	0.48	0.00	0.79

Treatments and Crop husbandry

Crop water requirement and irrigation scheduling was determined by CropWat 8 model, a decision support tool developed by FAO that helps in calculating the potential Evapotranspiration (based on Penman-Monteith method), in an area taking into account various climatic factors including humidity, wind speed, sunshine hours, and temperature (FAO, 2017).

Seeds were provided with proper moisture up to germination and treatments were applied thereafter. Treatments consist of simultaneous application of four different levels of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) fertilizers viz. 100% (F_{100}), 75% (F_{75}), 50% (F_{50}) and 25% (F_{25}) of recommended rate (205-82-205 N- P_2O_5 - K_2O kg ha⁻¹). Detail of treatments is given in Table 3. In autumn maize hybrid 31R88 of Pioneer was planted on 21st and 09th August in 2017 and 2018 while in spring season maize hybrid DK6789 of Bayer Crop Sciences was planted on 12th February and 1st March in 2018 and 2019,

Partial fertilizer productivity (PFP)

Partial factor productivity (PFP) that is the crop production per unit of nutrient applied describes how a system is productive in relation to its nutrient input (Van Cleemput 2000) was determined by;

$PFP \text{ (kg grain kg}^{-1} \text{ of fertilizer)} = \frac{\text{Grain Yield}}{\text{Nutrient Input}}$
Nutrient input includes N+ P_2O_5 + K_2O in kg ha⁻¹.

Statistical analysis was done by subjecting the data to ANOVA using SAS statistical Package Program. Separation of means of significantly affected characters was done by Fisher's LSD Test at 5% probability (Steel and Torrie, 1980).

Results and Discussion

Harvested plants ha⁻¹ in both the seasons were affected by drip-fertigation levels ($p < 0.05$). Across the seasons and years, decrease in fertigation level generally lowered the final stand count (Table 4). In spring, harvested plants only decreased to significant level until drip-fertigation rate was

Table 4: Effect of drip-fertigation of different rates of N, P and K fertilizer on harvested plants ha⁻¹ and number of ear ha⁻¹

Treatments	Harvested plants ha ⁻¹				No. of ears ha ⁻¹			
	Autumn		Spring		Autumn		Spring	
	2017	2018	2018	2019	2017	2018	2018	2019
F_{100}	61560 a	77579 a	85506 a	84524 a	50833 a	73810 a	82639	90278 a
F_{75}	61905 a	75198 ab	85843 a	83333 a	50496 a	73214 a	84494	89087 ab
F_{50}	59048 b	74008 b	86181 a	82341 a	47619 b	72817 ab	84325	86905 b
F_{25}	58774 b	73413 b	81627 b	78373 b	47012 b	70635 b	81458	82540 c
LSD_{0.05}	1424	2505	2645	3450	1074	2539	ns	2969

Means sharing similar letter are not significantly different from each other ($p > 0.05$ ANOVA followed by Fisher's LSD Test).

respectively. Weeds and insects were controlled by applying proper herbicides and insecticides.

Time of the harvest was determined by appearance of symptoms that include development of black layer at the kernel tip. Number of harvested plants and ears ha⁻¹ were determined by counting the ear bearing plants and ears from net plot and then calculated for hectare. Yield and yield components were determined by harvesting net plot from every treatment and ears were separated and weighed afterward. Grain moisture was determined by Agratonic™ MT-16 grain moisture tester and subsequently grain yield was expressed at 14% grain moisture. Ten ears randomly were selected from each plot to determine the ear length, number of rows ear⁻¹, number of grains row⁻¹. Grain starch, oil and protein content percentages were determined by 'Inframatic 9200', a whole grain near infra-red (NIR) analyzer.

decreased beyond F_{50} in both years however in autumn count remained stable up to F_{75} and thereafter decreased. Decrease in harvested plants ha⁻¹ from F_{100} to F_{25} fertilizer level was 4.94% and 6.32% in autumn and spring, respectively. Increasing rate of N, P and K fertilizers helped to lower the competition among maize plants and sustained more number of plants to be productive (Wu *et al.*, 2019) while poor stand count in treatments with lower rate of drip-fertigation reflects the insufficient nutrients availability for normal plant growth.

Treatment effect on number of ears ha⁻¹ was significant ($p < 0.05$) on three instances out of four (Table-4). In these seasons, ear number is linearly related with decreasing fertigation rate. From F_{100} to F_{25} , decrease in ear number was 5.9% across seasons and years however difference between F_{100} and F_{75} was not significant ($p > 0.05$). Ear density is a function of number of plants per unit land and crop management during growth season. Improvement in

water and nutrient management through drip-fertigation minimized the competition among plants (Wu *et al.*, 2019) therefore treatment with higher fertilizer rates sustained more number of plants hence number of ears.

Plant and ear height are important plant traits linked with production potential of the maize crop. Both the traits were significantly affected by treatments under study ($p < 0.05$). Higher rates of fertilizers increased the plant and ear height (Table-5) though fertigation rates (F_{100} , F_{75} and

the fertilizer rate increased from F_{25} to F_{100} across the seasons. These results can be explained by availability of sufficient nutrients for plants to grow vigorously that delayed the plant phenology (Dolan *et al.*, 2006 and Khaliq *et al.*, 2008). Plants from F_{25} reached silking 2.2 and 1.75 days earlier compared to F_{100} in autumn and spring, respectively, that reflects more profound impact of fertigation rate on crop growth in autumn compared to spring.

Table 5: Effect of drip-fertigation of different rates of N, P and K fertilizer on plant height (cm) and cob height (cm)

Treatment	Plant height (cm)				Cob height (cm)			
	Autumn		Spring		Autumn		Spring	
	2017	2018	2018	2019	2017	2018	2018	2019
F_{100}	195 a	254 a	247 a	252 a	86b	114 a	112 a	124 a
F_{75}	198a	259 a	247 a	254 a	88 ab	120 a	109 ab	121 a
F_{50}	197 a	264 b	242 a	250 a	91a	118 a	115 a	120 a
F_{25}	190 b	249 c	221 b	224 b	81c	101 b	101 b	99 b
LSD_{0.05}	3.5	5.03	9.97	12.5	3.4	8.8	9.4	11.8

Means sharing similar letter are not significantly different from each other ($p > 0.05$ ANOVA followed by Fisher's LSD Test).

Table 6: Effect of drip-fertigation of different rates of N, P and K fertilizers on days to 50% silking and cob length (cm)

Treatment	No. of days to 50% Silking				Ear length (cm)			
	Autumn		Spring		Autumn		Spring	
	2017	2018	2018	2019	2017	2018	2018	2019
F_{100}	54.7 a	55.0 a	72	68.5 a	17.5 ab	18.8 a	16.1 a	16.2a
F_{75}	54.5 ab	54.0 b	72	68.5 a	17.6 ab	18.4 a	15.5 b	16.3a
F_{50}	53.8 b	54.0 b	72	67.75 b	18.1 a	18.2 a	15.1 b	15.8 b
F_{25}	52.8 a	52.5 c	71	66.75 c	16.9 b	16.4 b	13.9 c	14.7 c
LSD_{0.05}	0.93	0.65	ns	.60	0.72	1.31	0.43	0.49

Means sharing similar letter are not significantly different from each other ($p > 0.05$ ANOVA followed by Fisher's LSD Test).

F_{50}) did not differ significantly ($p > 0.05$) in both the seasons. Similar results have also been reported by Rop *et al.* (2019) and Law-Ogbomo *et al.* (2009). Availability of sufficient nutrients especially nitrogen prolonged vegetative growth period hence increased production of photosynthates and its partitioning to stem that might have increased the plant height (Abera, 2013) and position of main ear on stem as both varietal traits are closely correlated (Gyenes-Hegyi *et al.*, 2002). Significantly lower plant and ear height at F_{25} across seasons and years suggested nutrient deficiency in this treatment that negatively affected the plant growth.

In both experimental years, plants supplied with F_{25} fertigation rate reached 50% silking stage earlier ($p < 0.05$) (Table 6). Crop reached 50% silking in 54 and 69 days in autumn and spring, respectively, and the difference can largely be attributed to different type of hybrid and weather conditions in both seasons. Days to 50% silking increased as

Ear length decreased ($P < 0.05$) as fertigation rate decreased but, in autumn, impact was not significant until rate was lowered beyond F_{50} (Table 7). However, in autumn 2017 longest ears were observed at F_{50} . On average, ear length was 17.73 cm and 15.45 cm in autumn and spring, respectively. No. of rows ear⁻¹ though decreased with decrease in fertilizer rates however difference was not significant ($p > 0.05$) except in spring 2018 where difference reached a significant level (Table 7). This result is usual as number of grain rows ear⁻¹ are strongly governed by genetics of the hybrid while environment and growing conditions have a lesser impact on it (Nielsen, 2003). Higher grains row⁻¹ were recorded at higher fertigation rate. Greater uptake of N, P and K (Wu *et al.*, 2019), higher assimilate partitioning to the seeds coupled with longer vegetative growth period in response to higher drip-fertigation rates might have resulted in higher number of grains (Dawadi and

Sah, 2012; Sharifi and Namvar, 2016). In autumn 2018 and spring 2019 F₇₅ produced higher grains row⁻¹ than F₁₀₀ that reflects F₇₅ to be the optimized combination of nutrient and moisture availability.

Fresh ear weight ha⁻¹ and grain yield (kg ha⁻¹) was significantly affected ($p < 0.05$) by drip-fertigation rates (Table 8). In autumn 2017, disease incidence and termite

attack resulted in substantially lower fresh ear and grain yield. In autumn 2018 fresh ear weight varied between 18066 kg ha⁻¹ for F₇₅ and 15187 kg ha⁻¹ for F₂₅ while variation for next season (spring 2019) was from 18849 kg ha⁻¹ to 12778 kg ha⁻¹. Across the season and years, grain yield at F₇₅ was statistically similar to that produced at F₁₀₀ indicating that 25% incremental nutrients from F₇₅ to F₁₀₀ were an excessive supply (Jiang *et al.* 2019). Application of

Table 7: Effect of drip-fertigation of different rates of N, P and K fertilizer on No. of rows ear⁻¹ and No. of grains row⁻¹

Treatment	No. of rows ear ⁻¹				No. of grains row ⁻¹			
	Autumn		Spring		Autumn		Spring	
	2017	2018	2018	2019	2017	2018	2018	2019
F ₁₀₀	16.2	14.4	17.9 a	19	32.8	37.0 a	29.3 a	32.97 a
F ₇₅	16.3	14.3	17.3 ab	18.83	33.2	37.1 a	27.9 a	35.53 a
F ₅₀	16.3	14.3	16.5 bc	18.66	33.9	36.5 a	27.5 b	32.02 b
F ₂₅	16.0	14.3	15.9 c	18	31.6	33.9 b	22.7 c	28.2 b
LSD _{0.05}	ns	ns	1.03	ns	ns	2.74	1.50	2.60

Means sharing similar letter are not significantly different from each other ($p > 0.05$ ANOVA followed by Fisher's LSD Test).

Table 8: Effect of drip-fertigation of different rates of N, P and K fertilizer on fresh ear weight (kg ha⁻¹) and grain yield (kg ha⁻¹)

Treatment	Fresh ear weight (kg ha ⁻¹)				Grain yield (kg ha ⁻¹)			
	Autumn		Spring		Autumn		Spring	
	2017	2018	2018	2019	2017	2018	2018	2019
F ₁₀₀	8845 a	16428 b	18480 a	18373 a	6035 a	10530 b	12735 a	13367 a
F ₇₅	8739 a	18066 a	18275 a	18849 a	5988 a	11483 a	12177 a	13646 a
F ₅₀	8339 b	17950 a	15494 b	15933 b	5567 b	11384 a	10103 b	11812 b
F ₂₅	8214 b	15187 c	14058 b	12778 c	5451 b	9597 c	8905 c	9507 c
LSD _{0.05}	280	594	1457	1333	205	582	826	1011

Means sharing similar letter are not significantly different from each other ($p > 0.05$ ANOVA followed by Fisher's LSD Test).

Table 9: Response of grain oil, protein and starch contents (%) to different drip-fertigation rates of N, P and K fertilizers

Treatment	Oil %				Protein %				Starch %			
	Autumn		Spring		Autumn		Spring		Autumn		Spring	
	2017	2018	2018	2019	2017	2018	2018	2019	2017	2018	2018	2019
F ₁₀₀	4.1 a	4.55	4.5 a	4.3 a	11.1 a	12.7 a	11.7 ab	11.8 a	53.4	48.6 b	52.2 A	51.9 a
F ₇₅	4.0 ab	4.35	4.6 a	4.4 a	10.6 b	13.0 a	12.2 a	12.1 a	53.9	48.7 b	50.2 B	51.6 a
F ₅₀	4.0 ab	4.35	4.1 b	4.3 a	10.3 bc	12.7 a	11.2 b	12.0 a	54.1	50.8 a	50.4 B	51.1 a
F ₂₅	3.9 b	4.38	4.1 b	4.0 b	10.1 c	11.3 b	11.6 b	11.0 b	53.0	51.3 a	48.7 C	49.4 b
LSD _{0.05}	0.16	ns	0.32	0.26	0.33	0.61	0.54	0.73	ns	1.67	1.45	1.50

Means sharing similar letter are not significantly different from each other ($p > 0.05$ ANOVA followed by Fisher's LSD Test).

Table 10: Effect of different rate of N, P and K fertilizer on Partial Factor Productivity

Treatment	Total nutrient applied (N+K ₂ O+P ₂ O ₅) (kg ha ⁻¹)	Partial Factor Productivity (PFP)			
		Autumn		Spring	
		2017	2018	2018	2019
F ₁₀₀	492	12.3	21.4	25.9	27.2
F ₇₅	369	16.2	31.2	33.0	37.0
F ₅₀	246	22.7	46.3	41.1	48.1
F ₂₅	123	44.4	78.1	72.5	77.3

nutrients and water at the same time in drip-fertigation improved the water and fertilizer use efficiency and minimized nutrient losses (Wu *et al.*, 2019) resulting in realization of higher yield at lower than recommended fertilizer rate. Results are in agreement with Jiang *et al.* (2019), Yan *et al.* (2014) and Seggewiss and Jungk (1988) who reported that yield increased efficiently in response to increase in N, P or K up to an optimal rate and after that, the rate of yield increase slowed down before reaching a plateau. It is also remarkable to note that, on average, yield reduced by 16% and 30.1% in autumn and spring, respectively, as fertilizer rate decreased from 100% recommended to mere 25% of recommended N, P and K nutrient rates. More profound impact in spring season may largely be attributed to longer growth period in spring than autumn that required more nutrients to produce higher yield.

Grain quality

Data regarding grain quality parameters is presented in Table 9. In autumn 2017, oil contents remained stable for F₁₀₀, F₇₅ and F₅₀ and decreased ($p < 0.05$) for F₂₅ while impact in autumn 2018 was non-significant. Sinha *et al.* (2017) also found non-significant impact of different drip-fertigation levels (100%, 80% and 60% of recommended dose) on oil contents in sunflower. While in spring, higher oil contents were greatest at F₇₅ that decreased on both directions. In all four instances of experiment, F₂₅ produced lowest oil contents. Results are in agreement to Wang and Frei (2011) who concluded that oil contents in crops decrease in response to abiotic stresses. Protein contents were significantly affected ($P < 0.05$) by fertilizer rates. Higher protein contents were recorded from F₇₅ except in autumn-2017 where F₁₀₀ produced highest protein contents. In autumn 2018 and spring 2019, protein contents were maintained even at F₅₀ but decreased significantly afterward in all four growing seasons. Incremental increase of fertilizer especially N for plant growth increased the protein contents in grain (Sharifi and Namvar, 2016). Starch contents responded to drip-fertigation significantly ($p < 0.05$) in three growing instances while remained unaffected in autumn 2017. In autumn 2018, highest starch contents were recorded at F₂₅ that decreased with increase in fertilizer rate. While in spring season, starch contents decreased with decrease in drip-fertigation rate and least amount of starch were produced by F₂₅ in both years.

Partial factor productivity (PFP)

Data regarding PFP is depicted in Table 10. It revealed that PFP decreased as the nutrient application (fertilizer rate) increased. Results are in agreement to those previously reported by Darwish *et al.* (2006), Fontes *et al.* (2010) and

Ierna *et al.* (2011). PFP was lower in autumn-2107 due to incidence of stalk rot and termite attack (data not included) that resulted in substantially lower yield. In all the four seasons, highest PFP was recorded at 25% of the recommended fertilizer doses though higher fertilizer use efficiencies at lower application rates are not necessarily economically effective (Roberts, 2008). Decline in fertilizer productivity in autumn was steeper (30.5% and 27.5%) compared to spring season (21.5% and 24.5%) with decrease in fertilizer rate from F₇₅ to F₅₀ and F₅₀ to F₂₅, respectively. This might have been due to the difference in prevailing climate conditions in both the seasons and its impact on plant growth resulting in differential nutrient requirements and uptake rate.

Conclusion

In current study, impact of different drip-fertigation rates of N, P and K fertilizers was evaluated on maize yield and quality. Results suggested that yield and yield contribution attributes improved by incremental application of NPK fertilizers. Different attributes i.e. number of ears ha⁻¹, cob length, number of grains row⁻¹ remained higher at F₇₅ most of the instances. Similarly, fresh ear weight and grain yield (kg ha⁻¹) at F₇₅ were also higher or similar to that produced by F₁₀₀ clearly indicating that additional 25% N, P and K fertilizers were excessive that can be saved successfully without compromising yield and quality. Judicious and efficient application of NPK improved the grain quality in terms of oil, protein and starch contents (%) even at lower application rate. Summarizing the results, under drip-fertigation system, higher grain yield of better quality can be achieved by applying 75% of the recommended fertilizers in area of study.

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