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Crop performance and nitrogen use-efficiency in maize under conservation agriculture coupled with sub-surface drip fertigation

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ABSTRACT

A field experiment was conducted in maize under medium-term conservation agriculture (CA) based maize-wheat system at BISA-CIMMYT, Ladhowal, Punjab during *kharif* 2019 to assess the effect of CA+ practices (CA with sub-surface drip irrigation) with variable N doses on maize. The CA+ treatments were residue retained (WR) permanent bed (PB) with sub-surface drip fertigation (PB-SSD): without N (N0), 120 kg N/ha,150 kg N/ha applied in 4-equal (Eq) and differential splits (Df); CA alone treatment includ PB furrow irrigation with 120 kg N/ha (PBWR-Furrow-N120); conventional tillage (CT) involved furrow irrigation with 120 kg N/ha (CTWOR-Furrow-N120) and other treatments were residue removed (WOR) PB: PBWOR-without N (N0), with 120 kg N/ha, and 150 kg N/ha applied in four Eq-splits and Df-splits. The findings of the present experiment showed that the numerical value of yield attributing characters were higher under CA+ plots as compared to CA alone (PBWR-Furrow-N120) and CT (CTWOR-Furrow-N120). Biological yield of maize was significantly higher in all CA+ plots as compared to CA alone and CT plots. Highest biological yield was recorded under PBWR-SSD-N150 Df (23.45 t/ha). Highest no. of cobs (72800/ha), no. of grains/cob (605) and cob length (22.61cm) along with dry matter resulted highest biological yield in PBWR-SSD-N150 plots. The grain N content remained statistically similar across all the N management plots, but in case of total N uptake, PBWR-SSD-N150 Df (CA+) plots dominated due to higher biomass. Besides, CA+ based PBWR-SSD-N120 (average of Df and Eq) registered 23-24% higher total N uptake than CA alone (PBWR-Furrow-N120) and conventional (CTWOR-Furrow-N120) plots. Improved agronomic N use-efficiency was also recorded under CA+ plots as compared to CA alone (36.4 kg/kg N) and CT (36.7 kg/kg N) plots.

Keywords: Biological yield, Nitrogen uptake, Permanent bed, Yield attributes

Maize-wheat (MW) system is third most important cropping system (~1.86 Mha) and has potential to expand in the Indo-Gangetic Plains (IGP) (Jat *et al.* 2019). MW system with conservation based (CA) based practices have twin benefits of superior food and fodder supply as well as enhanced soil health (Parihar *et al.* 2016). Precise water management through micro-irrigation/drip irrigation has shown numerous benefits in terms of irrigation water savings, increase in yield and quality, and nutrient use-efficiency in horticulture and vegetable crops (Mohammad 2015). To address the water scarcity problem, nowadays surface drip irrigation has been evaluated as a viable option for the wide spaced cereals like maize (Lamm *et al.* 1997), rice and wheat (Sharda *et al.* 2017). To deal with this bottleneck and better farmers' ease for acceptance of drip irrigation in cereal-based systems, sub-surface drip irrigation (SSDI) can be a way forward. In contrast to surface drip irrigation, SSDI system restricts further evaporation losses from the soil surface, facilitate the delivery of water and nutrients directly to the root zone that leads to efficient water use, reduces weed emergence, labor cost, and allows seeding with CA-based no-tillage practices (Sidhu *et al.* 2019).

Along with efficient water management, precise nitrogen (N) application directly to the crop root zone through SSDI may open a new avenue for N management in the context of CA in crops like maize over conventional broadcasting, as large amount of split applied broadcasted N remains over crop residues thereby it undergoes losses particularly through volatilization and microbial immobilization. Fertigation through SSDI system reduces the losses of N through volatilization and leaching thereby enhances the nutrient use-efficiency Hagin *et al.* (2003). But information on optimization of rate and time of N application through sub-surface drip fertigation (SSDF) and their impact on

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N use-efficiency in maize under CA-based MW system is lacking in India. Therefore, keeping above facts in mind the present study was planned and carried out to evaluate the effects of residue management and sub-surface drip fertigation on crop performance and N use-efficiency of maize under CA-based MW system.

MATERIALS AND METHODS

Site characteristics: The field experiment was conducted during *kharif* 2019 at BISA-CIMMYT, Ladhowal (30.99°N latitude, 75.44°E longitude, 229 m ASL), Punjab, India. The region is characterized by a sub-tropical and semi-arid climate with annual rainfall of 734 mm. The total amount of rainfall acived during the crop growing season (20th June, 2019 to 13th October, 2019) was 488.22 mm. The soils of this region basically are of alluvial in origin, flat and well drained sandy loam soil.

Installation of sub-surface drip irrigation system: Polythene made laterals with 16 mm inner diameter were laid parallel to crop rows at 20 cm soil depth. Laterals consist of line-source emitters spaced at 30 cm interval with 2 litres/hour discharge capacity (at 135 kPa pressure). The laterals were spaced at 67.5 cm and each of them supplied water for one row of maize crop. The system was fitted with hydro-cyclone filter and screen filter (100-micron mesh size) for filtration of groundwater. Venturi injectors were used for fertigation and the required suction was developed by using upstream and downstream pressure.

Crop establishment and treatments: The permanent beds (PB) were prepared using a bed planter and were kept undisturbed year after year with only a reshaping (once in a year). The mid-furrow to mid-furrow width of all PB plots was 67.5 cm along with 37 cm wide flat tops, and depth of furrow was 15 cm. In CT plots, initially soil was inverted by one deep tillage followed by 2-ploughings with cultivator and thus the final fresh beds were prepared with the help of bed maker. After harvesting of maize and wheat lach year, 50% and 25% of residues of both crops, respectively were kept on the soil surface in all the CA-based PB plots (PBWR), while in case of CT and without residue retained PB (PBWOR) plots residues of both crops were removed. Maize hybrid (P3396) was sown using maize plants with a seed rate of 20 kg/ha on 20th June, 2019 and was harvested on 13th October, 2019. The experiment was framed in randomized complete block design (RCBD) with 12-treatments and replicated thrice.

In total 12 treatments were selected in this experiment. CA+ treatments were residue retained (WR) permanent bed (PB) with sub-surface drip fertigation (PB-SSD): PBWR-SSD-N0, PBWR-SSD-N120Eq, PBWR-SSD-N120Df, PBWR-SSD-N150 Eq and PBWR-SSD-N150 Df. CA alone treatment included PB furrow irrigation with 120 kg N/ha (PBWR-Furrow-N120); CT treatment (without residue WoR) involved; furrow irrigation with 120 kg N/ha (CTWOR-Furrow-N120) and other treatments were residue removed (WOR) PB: PBWOR-without N (N0), with 120 and 150 kg N/ha applied in four equal (Eq) splits and differential (Df) splits (25% extra N at knee high stage). A common dose of 60 kg/ha P_2O_5 + 30 kg/ha K_2O was applied to all plots as basal. Except N0 (no nitrogen) treatments, all other treatments received 23.5 kg N fertilizer along with the common basal dose of P and K. Rest 96.5 kg and 126.5 kg N was allotted for SSD-N120 Eq (both PBWOR and PBWR) and SSD-N150 Eq (both PBWOR and PBWR) plots, respectively and was fertigated in four equal splits at 15 days interval starting from 21 days after sowing (DAS). Whereas, in PBWOR-SSD-N120 Df, PBWR-SSD-N120 Df and PBWOR-N150 Df, PBWR-N150 Df plots 25% extra N i.e. 30.2 kg and 39.5 kg N, respectively were applied at knee high stage (~21 DAS). The rest amount of N was applied into 3-equal (Eq) splits at 15 days interval. In furrow irrigated plots (CTWOR-furrow-N120, PBWR-furrow-N120) the remaining N (96.5 kg) was top dressed in two equal splits at knee-high stage (~21 DAS) and at pre tasselling stage (~45 DAS).

Yield attributes and yield: Yield attributes, yields and harvest index of maize were measured as per the standard procedure described by Parihar *et al.* (2018) and Nayak *et al.* (2019).

Plant nitrogen analysis and N-use efficiency: N content in stover and grain was determined by CHNS analyser. The N uptake in grain and stover were computed by multiplying N content with maize yields.

Nitrogen use-efficiency was calculated as;

Agronomic N use-efficiency (ANUE) (kg grain yield increase/kg N applied) = (Grain yield (kg) in fertilized plot−Grain yield (kg) in control plot)/kg of N applied.

Statistical analysis: Analysis of variance was performed using the GLM procedures of the statistical analysis system (SAS Institute, Cary, NC) for Randomized Complete Block Design (RCBD) (Gomez and Gomez 1984). The differences between treatment means were performed by least significant difference (LSD) test at $P<0.05$.

RESULTS AND DISCUSSION

Yield attributes and biological yield: Highest number of cobs/ha was observed in PBWR-SSD-N150 Df (72,800) treatment followed by PBWR-SSD-N150Eq (72,460). On an average the CA-based SSDF N120 PB treatments (CA+) had 1829 and 2029 nos. of more cobs per hectare than the CA alone furrow irrigated N120 PB (PBWR-Furrow-N120) and conventional treatment (CTWOR-Furrow-N120), respectively (Table 1). Similarly, there were 1412 more cobs recorded in SSD-N150 Eq treatments (average of both residue retained and residue removed plots) over the SSD-N120 Eq plots. The number of cobs were higher by 1429 in SSD-N150 Df treatment compared to SSD-N120 Df treatment plots. Cob length was also significantly ($P<0.05$) affected by contrasting tillage, residue and N management methods (Table 1). Highest cob length (22.61 cm) was recorded in PBWR-SSD-N150 Df plots which were statistically at par with other SSDF treatment except PBWOR-SSD-N120 Eq. Application of 120 kg N/ha through SSDF in residue retained PB plots (CA+)

Table 1 Yield attributing characters, yield and harvest index of maize as affected by tillage, residue, nitrogen and irrigation management practices

Treatment	Cobs ('000 /ha)	Cob length (cm)	Cob girth (cm)	Grains/ row	Grains/ cob	Biological yield (t/ha)	Harvest index (%)
PBWOR-SSD-N0	51.73	12.12	10.69	17	186	4.29	37.2
PBWR-SSD-N0	52.60	13.71	10.73	18	207	4.78	37.9
PBWOR-SSD-N120 Eq	70.38	20.30	14.71	34	530	18.16	37.8
PBWR-SSD-N120 Eq	71.13	20.78	14.79	35	555	19.71	37.6
PBWOR-SSD-N120 Df	70.91	20.66	14.87	35	542	19.20	38.1
PBWR-SSD-N120 Df	71.27	21.00	14.88	35	561	19.98	38.6
PBWOR-SSD-N150 Eq	71.87	21.79	14.81	35	561	20.48	38.1
PBWR-SSD-N150 Eq	72.46	22.10	14.72	36	595	22.45	36.6
PBWOR-SSD-N150 Df	72.24	21.88	14.67	35	576	21.90	36.4
PBWR-SSD-N150 Df	72.80	22.61	14.77	36	605	23.45	36.0
CTWOR-Furrow -N120	69.17	19.48	14.59	33	510	15.59	38.5
PBWR- Furrow-N120	69.37	20.14	14.39	34	525	16.18	38.0
SEm±	2.20	0.74	0.40	1.2	25.9	0.74	1.27
LSD (P=0.05)	6.46	2.17	1.18	3.7	76.0	2.16	NS

(PBWR-SSD-N120 Eq and PBWR-SSD-N120 Df) did not increase cob length significantly over CA alone PBWR-Furrow-N120 treatment. However, PBWR-SSD-N150 Df treatment (CA+) resulted 2.47 cm and 3.13 cm increase in cob length over PBWR-Furrow-N120 (CA alone) and CTWOR-Furrow-N120 (conventional) plots, respectively. Treatment PBWR-SSD-N150 of and PBWR-SSD-N150 Eq had highest number of granis per row (36). Contrasting tillage practices, N and irrigation management methods also significantly ($P<0.05$) affected the number of grains per cob. Highest number of grains per cob (605) was recorded in PBWR-SSD-N150 Df treatment, although it was at par with other SSDF treatments. The effect of 120 kg N/ha application through SSDF and surface broadcasting (furrow irrigated plots) were also at par with respect to number of grains per cob. On an average the CA-based sub-surface drip fertigated N120 PB plots (CA+) had 33 and 48 more grains per cob than the CA alone and conventional treatment, respectively (Table 1).

The yield attributing characters of maize, i.e., cob length, girth ($P<0.05$) and number of grains per row ($P<0.05$) were significantly correlated with maize grain yield (Fig 1A). The degree of correlation between grains per cob and grain yield was more prominent in differential N application (Df) (25% extra during knee high stage) treatments than the equal split treatments (Fig 1B). Yield attributing characters of maize i.e. cob length and grains per cob were more strongly correlated with grain yield of SSDF-N150 plots than SSDF-120 plots (data not presented). All SSDF treatments had significantly higher biological yield as compared to furrow irrigated (CTWOR-Furrow-N120 and PBWR-Furrow-N120) treatments (Table 1). Although, PBWR-SSD-N150 Df treatment plots resulted highest biological yield (23.45 t/ha), the value was statistically at par with PBWOR-SSD-N150 Df (21.90 t/ha), PBWR-SSD-N150 Eq (22.5 t/ha). The significant biological yield difference between CA+ based PBWR-SSD-N120 (both Eq and Df) plots and PBWR-Furrow-N120 (CA alone) was mainly due to adoption of SSDF technology over furrow irrigated and surface broadcasted of N fertilizer. In this experiment we have estimated a decrease in biological yield of CT plots by about 16% over PBWOR-SSD-N120 (average of both Eq and Df treatments) (Table 1). The magnitude of yield gap could be higher if the comparison was drawn among CTWOR-Furrow-N120 and other SSDF treatments. Result of the study showed that there was a positive effect of residue retention and differential N application (through SSDF) on biological yield of maize (Table 1) which may in turn increased N availability and thereby biological yield. Similar results were also observed by Jat *et al.* (2018) and Parihar *et al.* (2018).

Frequent irrigation and adequate N application through SSDF may have increased number of filled grains per cob, cob length and biomass accumulation which can be again correlated to higher biological yield in SSDF plots as compared to furrow irrigated CA and CT plots. These findings were similar with the result of O'Neill *et al.* (2008) and Bai *et al.* (2009). Martinez-Hernandez *et al.* (1991) also reported greater ear diameter, ear dry matter production, plant height and total dry matter production of maize under SSDF. Higher number of cobs/ha in SSDF plots also indicated that synchronous water and N management is crucial in order to reduce inter-plant competition (Wu *et al.* 2019). Precision water and nutrient management (application of N @120 and 150 kg/ha) through sub-surface drip irrigation technology may have resulted in accumulation of more photosynthates in SSDF plots than furrow irrigated plots.

Nitrogen content, uptake pattern, nitrogen use-efficiency (NUE): In present study among the imposed treatments the

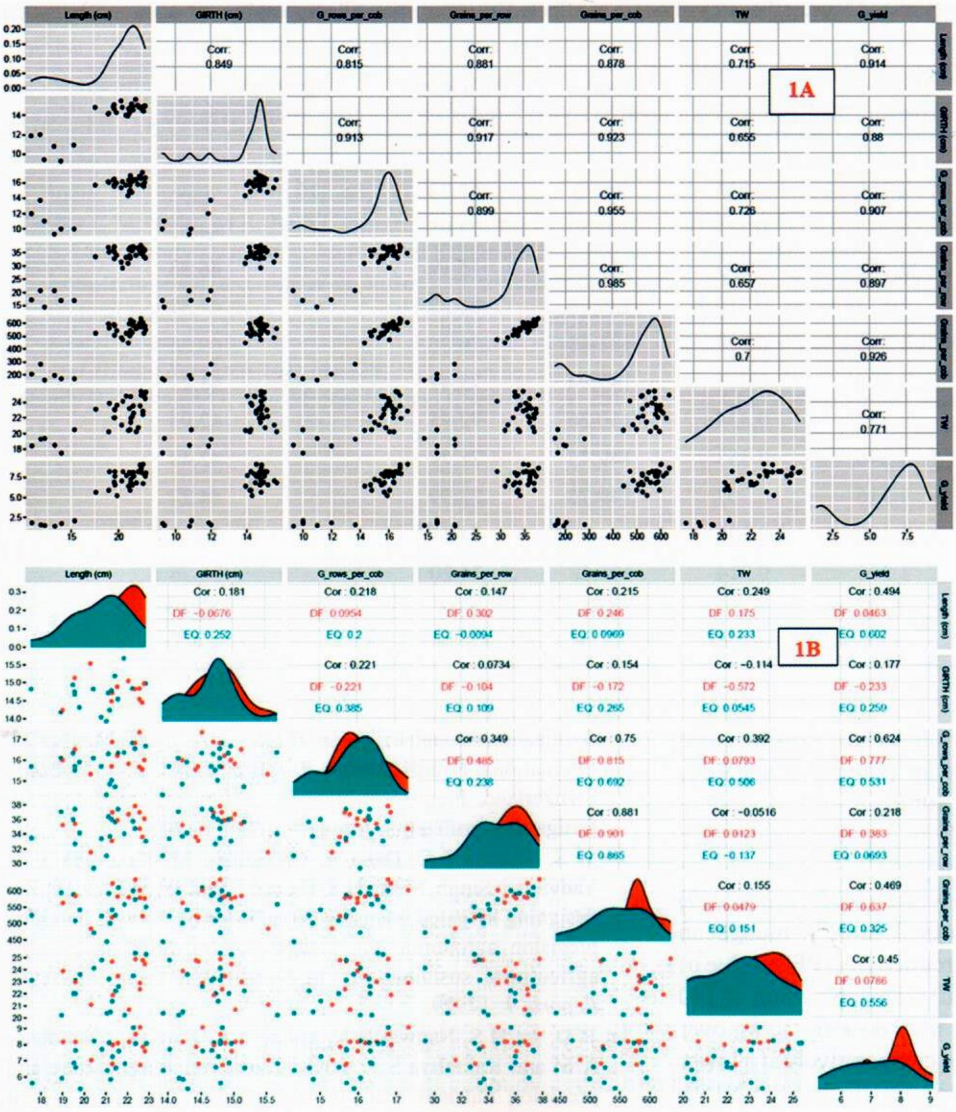

Fig 1 Pearson correlation between yield attributing characters and grain yield of maize (A and B) asaffected by contrasting tillage, residue, N and irrigation management practices (Supporting Information).

highest total N uptake was recorded from PBWR-SSD-N150 Eq (150.26 kg/ha) treatment which was statistically at par with other N150 plots (Table 2). Total N uptake in CTWOR-Furrow-N120 and CA-based PBWR-Furrow-N120 treatments were significantly lower than all the SSDF treatments (both CA+ and non-CA+). CA+ based PBWR-SSD-N120 (average of both Df and Eq) plot registered 23 and 24% higher total N uptake than furrow irrigated CA alone and conventional treatments, respectively. On average N uptake was increased by 21.3 kg/ha with application of additional 30 kg N (in N150 plots) over SSDF N120 treatments. The N harvest index ranged from 67.62% (PBWOR-SSD-N0) to 76.20% (PBWR-SSD-N120 Df) (Table 2). NHI of all the N fertilized (both SSDF and surface broadcasted) treatments were statistically similar. Furthermore, the PBWOR-SSD-N150 Df and PBWR-SSD-N150 Eq treatments also remained statistically at par with N0 plots in terms of NHI. The mineral N availability was higher when N was directly applied to the root zone through SSDF. Wu *et al.* (2019) also observed higher amount of available NO_3-N for plants in the root zone when supplied through fertigation compared to conventional method. The higher N uptake under SSDF as compared to CA-alone (PBWR-Furrow-N120) and CT plots (CTWOR-Furrow-N120) may be justified with the above facts. Grain N content was statistically similar in all treatments whereas stover N content differed. Higher straw N (%) content was recorded under no nitrogen condition (N0). Under no nitrogen condition initiation of physiological maturity was not uniform and there was considerable overlap between vegetative and reproductive phases in existing population. Plants in these plots may have accumulated soil inherent N in excess, but at the same time incapable to remobilize considerable amount of N into grains as the sink development was poor (Uribelarrea *et al.* 2007). Comparatively lower stover N% was recorded in residue retained plots than its counterpart (residue removal). More vegetative N remobilization into grain under residue retained condition may be a reason behind low stover N content in residue retained plots. Ultimate N content in grain is a combined effect of both remobilized pre-anthesis N and N absorbed during grain filling process. Highest ANUE (49.4 kg/kg N) was recorded under PBWR-SSD-N120 Df which remained statistically at par with other SSDF treatments except PBWOR-SSD-N150 Eq (Table 2).

Among the N fertilized treatments (both SSDF and surface broadcasted) comparatively lower ANUE was recorded under furrow irrigated CT (36.7 kg/kg N) and CA alone (PBWR-Furrow-N120) (36.4 kg/kg N) plots. The average ANUE of CA+ N120 treatments (PBWR-SSD-N120 Eq and PBWR-SSD-N120 Df) were11.6 and 11.2% higher than furrow irrigated CT and CA alone treatments, respectively. With reduction in losses of applied N due to direct sub-surface application (spoon feeding) of N fertilizer, the ANUE found to be increased in all SSDF

Table 2 Nitrogen content, uptake pattern and N use-efficiency of maize as affected by contrasting tillage, residue, nitrogen and irrigation management practices

Treatment	Grain N content (%)	Stover N content (%)	Total N uptake (kg/ha)	N Harvest index (%)	Agronomic N use efficiency (kg grain increase/kg N applied)
PBWOR-SSD-N0	1.321	0.436	31.22	67.62	----
PBWR-SSD-N0	1.292	0.423	34.23	67.73	----
PBWOR-SSD-N120 Eq	1.315	0.325	122.67	73.95	44.03
PBWR-SSD-N120 Eq	1.305	0.303	128.28	75.19	46.53
PBWOR-SSD-N120 Df	1.314	0.319	129.46	74.28	47.58
PBWR-SSD-N120 Df	1.302	0.297	131.68	76.20	49.36
PBWOR-SSD-N150 Eq	1.394	0.365	147.94	73.49	41.29
PBWR-SSD-N150 Eq	1.327	0.334	150.26	72.75	42.93
PBWOR-SSD-N150 Df	1.346	0.353	149.45	71.79	42.49
PBWR-SSD-N150 Df	1.316	0.307	149.76	73.99	44.27
CTWOR-Furrow -N120	1.300	0.320	104.89	74.41	36.72
PBWR- Furrow-N120	1.276	0.314	105.68	74.20	36.36
SEm±	0.03	0.01	6.01	1.75	2.38
LSD (P=0.05)	0.09	0.02	17.62	5.15	6.97

plots. ANUE was higher under sub-surface drip irrigated condition due to higher yield per kg of applied N (Wu *et al.* 2019). Lamm *et al.* (2004) in silt loam soils of western Kansas registered 53 kg/kg ANUE in maize when the crop was supplied with 180 kg N/ha using SSDF. Recently, under a CA-based system study in north-west India, Jat *et al* (2019) reported that CA+ practice adopted in MW-mungbean system recorded a partial factor productivity (PFP) value of 53.4 (kg maize grain/kg N applied) with application of 140 kg N/ha through SSDF. Increase in N dose by 30 kg over 120 kg increased the crop yield but comparatively at a lower rate which led to slight reduction of ANUEs in SSD-N150. In conclusion the results of our study suggest adoption of SSDF as a means of increasing crop productivity, saving of precious irrigation water, increasing NUE in CA-based maize grown in MW sequence.

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REFERENCES

Bai X L, Sun S X, Yang G H, Liu M, Zhang Z P and Hua Q I. 2009. Effect of water stress on maize yield during different growing stages. *Journal of Maize Science* **17**: 60–63.

Gomez K A and Gomez A A. 1984. *Statistical Procedures for Agricultural Research*. 2nd edn, pp. 680. John Wiley and Sons, NewYork.

Hagin J, Sneh M and Lowengart-Aycicegi A. 2003. Fertigation-fertilization through irrigation. *IPI Research Topics Number* **23**. International Potash Institute P.O. Box 1609 CH -4001 Basel, Switzerland. Preprint at https://www.ipipotash.org/udocs/39-fertigation-fertilization-through-irrigation.pdf.

Jat H S, Sharma P C, Datta A, Choudhary M, Kakraliya S K, Yadvinder-Singh, Sidhu H S, Gerard B and Jat M L. 2019. Re-designing irrigated intensive cereal systems through bundling precision agronomic innovations for transitioning towards agricultural sustainability in North-West India. *Scientific Reports* **9**: 17929.

Jat R D, Jat H S, Nanwal R K, Yadav A K, Bana A, Choudhary K M and Kakraliya S K. 2018. Conservation agriculture and precision nutrient management practices in maize-wheat system: Effects on crop and water productivity and economic profitability. *Field Crops Research* **222**: 111–20.

Lamm F R, Schlegel A J and Clark G A. 2004. Development of a best management practice for nitrogen fertigation of corn using SDI. *Applied Engineering in Agriculture* **20**(2): 211–20.

Lamm F R, Stone L R, Manges H L and O'Brien D M. 1997. Optimum lateral spacing for subsurface drip-irrigated corn. *Transactions of the ASAE* **40**(4): 1021–27.

Martinez-Hernandez J J, Bar-Yosef B and Kafkafi U. 1991. Effect of surface and subsurface drip fertigation on sweet corn rooting, uptake, dry matter production and yield. *Irrigation Science* **12**: 153–59.

Mohammad A Z. 2015. Effects of trickle irrigation system from southern Iran district Chabahar free zone. *Irrigation and Drainage Systems Engineering* **4**(3): 152.

Nayak H S, Parihar C M, Jat S L, Nain L, Mandal B N, Singh V K, Garnaik S, Muduli L and Sahu S. 2019. Effect of nitrogen point placement on energetic and soil enzymatic activities on long-term conservation agriculture-based maize (*Zea mays*)–wheat (*Triticum aestivum*) system of western Indo-Gangetic Plains. *Indian Journal of Agricultural Sciences* **89**(12): 2102–08.

O'Neill C J, Humphreys E, Louis J and Katupitiya A. 2008. Maize productivity in southern New South Wales under furrow and pressurised irrigation. *Australian Journal of Experimental*

Agriculture **48**(3): 285–95.

Parihar C M, Yadav M R, Jat S L, Singh A K, Kumar B, Pooniya V, Pradhan S, Verma R K, Jat M L, Jat R K, Parihar M D, Nayak, H S and Saharawat Y S. 2018. Long-term conservation agriculture and intensified cropping systems: Effects on growth, yield, water and energy-use efficiency of maize in north-western India. *Pedosphere* **28**(6): 952–63.

Parihar C M, Yadav M R, Jat S L, Singh A K, Kumar B, Pradhan S, Chakraborty D, Jat M L, Jat R K and Saharawat Y S. 2016. Long term effect of conservation agriculture in maize rotations on total organic carbon, physical and biological properties of a sandy loam soil in north-western Indo-Gangetic Plains. *Soil and Tillage Research* **161**: 116–28.

Sharda R, Mahajan G, Siag M, Singh A and Chauhan B S. 2017. Performance of drip irrigated dry-seeded rice (*Oryza sativa* L.) in South Asia. *Paddy and Water Environment* **15**: 93–100.

Sidhu H S, Jat M L, Singh Y, Sidhu R K, Gupta N, Singh P, Singh P, Jat H S and Gerard B. 2019. Sub-surface drip fertigation with conservation agriculture in a rice-wheat system: a breakthrough for addressing water and nitrogen use efficiency. *Agricultural Water Management* **216**: 273–83.

Uribelarrea M, Moose S P and Below F E. 2007. Divergent selection for grain protein affects nitrogen use in maize hybrids. *Field Crops Research* **100**(1): 82–90.

Wu D L, Xu X X, Chen Y L, Shao H, Sokolowski E and Mi G H. 2019. Effect of different drip fertigation methods on maize yield, nutrient and water productivity in two-soils in Northeast China. *Agricultural Water Management* **213**: 200–11.