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Residue Mulching and Foliar Application of Potassium Enhances Yield and Water Productivity of Wheat Under Restricted Irrigated Conditions in Saline Soil

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Abstract

Wheat is the second most important crop in India and the world. Among many difficulties faced in the wheat growing regions, salinity and declining water table and water quality are most affecting factors. This study was conducted to test the hypothesis that whether the use of rice residue as mulch with reduced amount of irrigation water and foliar application of K could maintain wheat yield under salinity conditions. *Ex-situ* rice residue mulching @ 4 Mg ha^{-1} significantly enhanced the tillers m^{-2} (307.1), grain yield (5.10 Mg ha^{-1}), net returns (INR 80.3×10^3 ha^{-1}) and water productivity (2.04 kg m^{-3}) over no residue mulching. Residue mulching significantly enhanced grain yield and net returns at all the irrigation levels. Irrigation at all critical stages (ICS) and residue mulching gave significantly maximum grain yield of 5.69 Mg ha^{-1} and net returns of INR 91.1×10^3 ha^{-1}. Further, restricting irrigations to CRI+BS+MS stages along with residue retention also resulted in statistically similar wheat grain yield (5.38 Mg ha^{-1}) and Net returns (INR 84.1×10^3 ha^{-1}) that obtained with ICS without residue retention, showed advantage of residue mulching in saving of irrigation water. Residue mulching significantly improved the water productivity at all irrigation levels. Foliar application of K:N (2% K + Nitrogen 0.5%) significantly improved tillers m^{-2}, grains $spike^{-1}$ (GPS), grain yield (5.14 Mg ha^{-1}), straw yield (11.29 Mg ha^{-1}), net returns (INR 82.2×10^3 ha^{-1}), benefit cost ratio (2.32) and water productivity of wheat (2.05 kg m^{-3}) compared to control.

Key words: Residue mulching, Foliar application, Potassium, Productivity, Salinity, Net return

Introduction

Wheat is the most important cereal crop growing during winter season in semi-arid region of North-Western India where it is being grown under irrigated conditions which is being sourced from either canal or groundwater. In semi-arid regions, water deficit during crop growth period, light textured and low moisture holding capacity of soil, low soil organic carbon are the common constraints in enhancing productivity (Meena *et al.*, 2019). Besides these, soil and irrigation water salinity further adds to another abiotic stresses limiting crop productivity in majority of semi-arid areas. Although, wheat is classified as moderately salt tolerant crop (Qureshi and Barrett-Lenard, 1998), however higher salinity stress reduces wheat yield considerably.

For assured crop production in semi-arid regions conservation of moisture for reducing the irrigation demand and escaping the salinity stress through agronomic and physiological approaches can minimize the productivity loss. Retention of crop residues as mulch on soil surface reduces the moisture loss through evaporation, maintains the moisture for longer period (Meena *et al.*, 2020; Jat *et al.*, 2018; Kumar *et al.,* 2008; Rathore *et al.,* 2010) moderated soil temperature (Hariram *et al.,* 2012) and also prevents the salts to build up in crop root zone (Prajapat *et al.*, 2019; Dagar and Yadav, 2017). *Ex-situ* application of crop residues adds organic matter which on decomposition, improves the quality of the soil and increases water infiltration and retention capacity of the soil, buffers the pH of the soil and facilitates the availability of nutrients, feeds the carbon cycle of the soil, captures the rainfall and thus increases the soil moisture content (Bhale and Wanjari, 2009) and overall soil quality.

Foliar feeding of nutrients, especially potassium is reported to alleviate the effect of salt and moisture stress on plant by influencing physiological mechanisms (Hasanuzzaman *et al.*, 2018; Ahmad *et al.*, 2019; Meena *et al.*, 2020). Therefore, the objective of this study was to test hypothesis that the use of rice residue as mulch, foliar application of K under restricted irrigated conditions would maintain the grain yield of wheat in semi-arid environments of North Western Plain Zone of India where annual evaporation is nearly double the annual precipitation. Further, aim of the study was to determine the effect of reduced amount of irrigation water on yield components and water use efficiency (WUE) of wheat.

Materials and Methods

Present study was carried out consecutively for two years (2015-16 and 2016-17) during winter (November to April) seasons at Seed and Research Farm, Hisar (Haryana) under ICAR-Indian Institute of Wheat and Barley Research. The experimental site located at 29°10′ N, 75°40′ E and 211 m MASL. The expérimental site represents a semi-arid climate with mean annual rainfall of around ~429 mm mostly occur during July to October months. The mean monthly weather parameters recorded during the cropping months at CCS Hisar Agricultural University, Hisar are depicted in Fig. 1. The soil of experimental site (0-15 cm depth) was sandy loam in texture (73% sand, 17.1% silt and 9.9% clay), slightly alkaline in pH_2 (8.0-8.3), moderately saline (EC_e 6.0-7.5 dS m^{-1}), medium in organic carbon (0.44%) and low in available P (7.5 kg ha^{-1}) and high in available N (705 kg ha^{-1}) and available K (325 kg ha^{-1}) in the beginning of experiment. The higher status of available nitrogen in soil may be due to use of city waste water and organic manure in previous years for leaching the salts.

The experiment was conducted in split-split plot design with three replications. Two treatments of *ex-situ* rice residue mulching (No residue and residue mulching @ 4.0 Mg ha^{-1}) were allotted in main plots; four levels of irrigation *viz.* one irrigation at crown root initiation stage (CRI), two irrigations at CRI and flowering stage (CRI+FS), three irrigations at CRI, booting stage (BS) and milking stage (CRI+BS+MS) and irrigations at all critical stages (ICS) were arranged in sub-plots and three levels of foliar applications of K *viz.* control (only water spray), foliar spray of K along with N in 4:1 ratio (K:N) and only K spray @ 2% were imposed in sub-sub-plots. After field preparation and pre-sowing irrigation, wheat *cv.* HD-2967 was sown (26-11-2015 and 29-11-2016) in all the plots. After seedling emergence, rice residues of previous crop were applied @ 4.0 Mg ha^{-1} as mulch in respective plots. Irrigation (60 mm

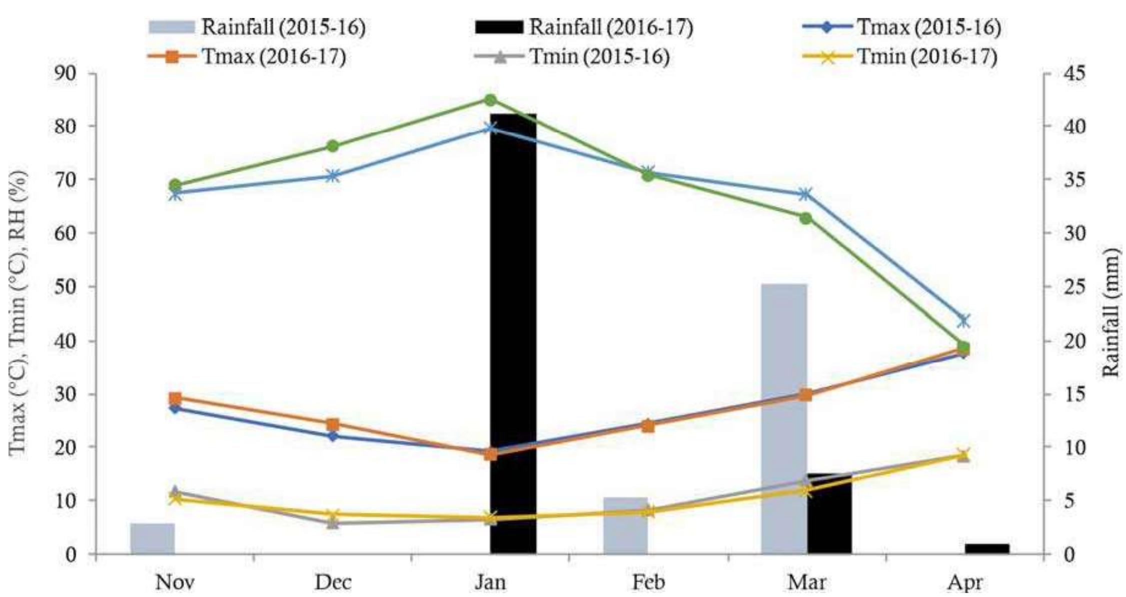

Fig. 1 Monthly weather parameters during the study years

water per irrigation) was applied with canal water at pre-defined stages as per treatments. Total amount of average water applied including rainfall and pre-sowing irrigation under CRI, CRI+FS, CRI+FS+MS and ICS irrigation treatments was 161.6, 221.6 and 431.6 mm, respectively. Foliar spray of 2% K was done through K_2SO_4 at maximum tillering, flowering and grain filling stages of crop using 400 liters spray volume of water. Under K: N treatment, N @ 0.5% through urea was also tank mixed with 2% K. Only water was sprayed in control treatment at all above stages. Wheat crop was fertilized with 25% less recommended N (110 kg ha^{-1}, as the soil had high N content), and recommended dose of P (40 kg P_2O_5 ha^{-1}) was applied as basal dose at the time of sowing of crop. In CRI irrigation treatment, 50% N was applied as basal and remaining 50% N was top dressed at the time of irrigation at CRI stage. In all other irrigation treatments, N was applied in three splits, 1/3rd as basal, 1/3rd at first irrigation and 1/3rd at second irrigation. Crop was grown with recommended package of practices recommended for North Western Plain Zone and harvested at maturity stages from the net plot area (2.0 m × 4.5 m).

To avoid border effects, side rows and 0.5m from each end of the plot was harvested. The remaining net plot of 9.0 m^2 (2.0 m× 4.5 m) was harvested for recording above ground biomass (AGBM) and yield. The crop was hand harvested by cutting at ground level when grains matured, and the straw had turned yellow. Data on biological yield were recorded after sun drying of the harvested crop. The sun-dried bundles were threshed and winnowed, and the grains so obtained were weighed and yield for different treatments was adjusted at 14% moisture for appropriate comparison. Harvest Index (HI) was calculated as the ratio of the grain weight to the total AGBM. Grain samples were randomly collected for thousand grains weight (TGW) and counted by using Contador seed counter and weighed to record TGW. Tillers per square meter (TPM) were counted at physiological maturity from each plot. Grain yield (GY) and straw yield (SY) were multiplied by respective market price to obtain gross returns and net returns (NR) were calculated by deducting the gross returns from the total cost of cultivation under respective treatments.

Water productivity (WP) (water use efficiency) is the physical accounting of water with yield or economic output so as to assess how much value is being obtained from the use of per unit water. For this analysis, water use efficiency was calculated as;

$$\text{Water Use Efficiency (WUE)} = \text{Output}/Q$$

where, WUE is the productivity of water in kg m^{-3}; Output is the productivity of wheat in kg ha^{-1} and Q is the amount of water used by the crop in m^3 ha^{-1}.

Data obtained in the study were subjected to Analysis of Variance (ANOVA) was to test the statistical significance between treatment means and their interaction in split split-plot design. Least significant difference at $p \leq 0.05$ level of significance was used to compare the treatment means and ranking of treatments. Statistical analysis of experimental data was performed online on Indian NARS Statistical Computing Portal (http://stat.iasri.res.in/sscnarsportal) using General Linear Model (GLM) procedure in SAS (SAS Institute Inc.).

Results and Discussion

Effect of residue mulching

Rice residue retention for mulching in wheat significantly influenced the yield parameters, yield, economics and water productivity of wheat (Table 1). Mulched plots had significantly higher tillers per m^2 (TPMS) (307.1) and grain yield (5.10 Mg ha^{-1}) over no mulching. Economics analysis showed that mulching with crop residues resulted in significantly higher net returns (NR) *i.e.* INR 80.3×10^3 ha^{-1} compared to non-mulched treatments (INR 74.3×10^3 ha^{-1}). The benefit-cost ratio (BCR) was not varied significantly due to residue mulching. Significant improvement in water productivity of wheat was recorded in rice residue retention treatments (2.04 kg m^{-3}) than no residue retention (1.85 kg m^{-3}). Straw mulching on soil surfaces conserve the soil moisture directly through reduction in evaporation from soil, reduction in weed growth thereby reducing

Table 1. Effect of residues, irrigation and potassium spray on yield, economics and water productivity of wheat (mean of two years)

Treatment	TPM	GPS	TGW (g)	GY (Mg ha^{-1})	SY (Mg ha^{-1})	HI	NR (INR×10^{3}ha^{-1})	BC-ratio	WP (kg m^{-3})
Residue mulching									
No residue	294.8^{B}	42.10^{A}	38.29^{A}	4.69^{B}	10.37^{A}	44.94^{A}	74.3^{B}	2.24^{A}	1.85^{B}
Residue mulching	307.1^{A}	42.69^{A}	39.38^{A}	5.10^{A}	11.11^{A}	45.41^{A}	80.3^{A}	2.22^{A}	2.04^{A}
Irrigation									
CRI	285.1^{B}	40.01^{C}	36.94^{C}	3.94^{D}	9.68^{C}	42.49^{A}	60.1^{D}	1.81^{C}	2.44^{A}
CRI+FS	294.8^{B}	42.38^{B}	38.35^{BC}	4.84^{C}	10.63^{B}	45.27^{A}	76.7^{C}	2.26^{B}	2.19^{B}
CRI+BS+MS	307.3^{A}	42.56^{B}	39.70^{AB}	5.25^{B}	10.83^{B}	46.26^{A}	82.9^{B}	2.38^{A}	1.86^{C}
ICS	316.7^{A}	44.61^{A}	40.36^{A}	5.55^{A}	11.83^{A}	46.69^{A}	89.4^{A}	2.47^{A}	1.29^{D}
Foliar application of K									
Control	292.4^{B}	40.86^{B}	38.15^{A}	4.52^{C}	10.03^{B}	44.77^{A}	70.5^{C}	2.12^{C}	1.77^{B}
K:N	310.3^{A}	44.22^{A}	39.23^{A}	5.14^{A}	11.29^{A}	45.16^{A}	82.2^{A}	2.32^{A}	2.05^{A}
K	300.1^{AB}	42.09^{B}	39.13^{A}	5.02^{B}	10.89^{A}	45.61^{A}	79.1^{B}	2.24^{B}	2.00^{A}
p-Values									
Residue (R)	0.0188	0.1877	0.3218	0.0243	0.0929	0.7031	0.0247	0.6557	0.0056
Irrigation (I)	0.0002	0.0019	0.0042	<.0001	<.0001	0.3489	<.0001	<.0001	<.0001
R×I	0.1688	0.1193	0.5016	0.0319	0.1793	0.8857	0.0109	0.0043	<.0001
Potassium (K)	0.0206	0.0010	0.1609	<.0001	0.0001	0.8416	<.0001	<.0001	<.0001
R×K	0.9763	0.1152	0.3035	0.9099	0.0059	0.6489	0.0212	0.0429	0.6169
I×K	0.9001	0.6161	0.9725	0.1299	0.2789	0.9748	0.0154	0.0065	<.0001
R×I×K	0.9532	0.0702	0.9954	0.5647	0.0003	0.8886	0.0174	0.0457	0.6272

CRI: irrigation at crown root initiation stage, CRI+FS: irrigations at CRI and flowering stages, CRI+BS+MS: irrigations at CRI, booting and milking stages, ICS-irrigations at all critical stages, Control (only water spray), K:N: foliar spray of 2% K + 0.5% N and K: 2% K application.

TPM: Tillers m^{-2}, GPS: grains spike^{-1}, TGW: 1000-grains weight, GY: grain yield, SY: straw yield, HI: harvest index, NR: net returns and WP: water productivity.

Means with different capital letters within same column are significantly different at 5% level ($p \leq 0.05$) of significance using LSD.

evapotranspiration by weeds which provides plants more moisture for growth and development and in long run decomposition of straw mulch also adds soil organic matter which supply plant nutrition. Reduction in evaporation from surface soil due to surface mulch also prevents soil salts to upward movement through capillary rise which prevents the crop root zone from higher salt build up (Prajapat *et al.*, 2018). All these factors contribute towards better growth, yield and water productivity. The beneficial effect of rice residue retention on improving water status in soil, plant growth, yield and water use efficiency has also reported by Meena *et al.* (2020), Balwinder-Singh *et al.* (2011) and Chakraborty *et al.* (2010) in wheat crop.

Effect of irrigation levels

Data in Table 1 revealed that increase in number of irrigation brought significant changes in yield parameters, yields, economics and water productivity of wheat. The tillers m^{-2} and 1000-grain weight increased significantly when three irrigations were applied at CRI, booting and milking stages than only at CRI and remained statistically similar with irrigation at all critical stages (ICS). Benefit-cost ratio was remained on par between irrigation at CRI, BS, MS and at ICS. The result revealed that, rice residue retention minimizes the use of irrigation water and with three and five irrigations, equal yield was obtained. Water productivity of wheat showed significant decrement with each level of irrigation, lowest at ICS. The decrement in WP with increasing number of irrigations was due to less proportionate increase in grain yield with increase in water use under higher number of irrigations. Similar results have also been reported earlier by Ram *et al.* (2013) and Maurya and Singh (2008) in wheat crop.

Effect of foliar application of K

Foliar application of K had significant positive effect on yield parameters, yield, economics and water productivity of wheat as compared to control except TGW and HI (Table 1). Foliar application of K:N (K @ 2%) + Nitrogen @ 0.5%) resulted in significantly highest TPM, GPS, GY, SY, NR (INR 82.2×10^3 ha^{-1}), BC-ratio (2.32) and WP (2.05 kg m^{-3}) compared to control and foliar spray of K alone. K supplementation increases the leaf K concentration and maintained favourable K/Na ratio in leaves which may be involved in reducing the damage associated with salt stress (Hasanuzzaman *et al.*, 2018). The K fertilization also improves the ability of plant to tolerate osmotic stress and water deficit stress through minimizing its negative effects on plant and enhancing the uptake and translocation of water (Amjad *et al.*, 2016; Adhikari *et al.*, 2019). Therefore, K fertilization through foliar application helped plants to mitigate the effect of the water and salt stress and improved yield and water use efficiency of wheat.

Interaction effect of residue mulching and irrigation

Interaction effect of residue mulching and irrigation was found significant on grain yield, net returns, BC-ratio and water productivity of wheat (Table 1 and Fig. 2). It is revealed from interaction between irrigation and residues that irrigation at ICS and residue mulching gave significantly maximum GY of 5.69 Mg ha^{-1} and NR of INR 91.1×10^3 ha^{-1}. Three Irrigations at CRI, BS, MS growth stages along with rice residue retention as mulch also found statistically similar in terms of GY and NR that of obtained under irrigation at all critical stages without rice residue retention. This revealed benefit of mulching in case of deficit irrigation, which saves huge amount of water. BC-ratio was found maximum with ICS with no residue being on par with ICS with residue retention. Residue retention improved water productivity of wheat in all soil moisture scenarios. Under limited soil moisture conditions, improvement in water use efficiency due to residue retention have also been reported by Meena *et al.*

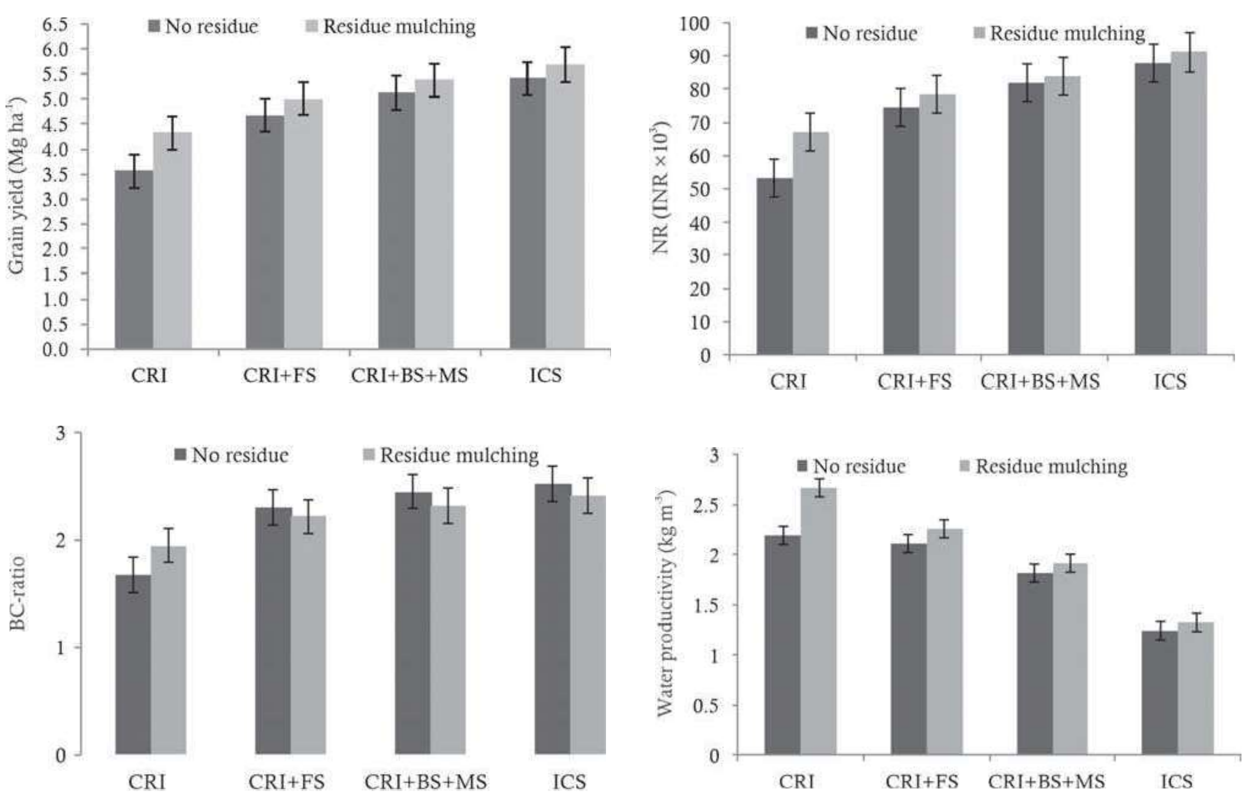

Fig. 2. Interaction effect of irrigation and residues on grain yield, economics and water productivity of wheat
Vertical bars represent LSD value (p≤0.05)

Table 2. Pearson Correlation Matrix between various parameters of study

Variables	TPM	GRNS	TGW	GY	SY	NR	BCR
TPM	1						
GRNS	0.413**	1					
TGW	0.278*	0.458**	1				
GY	0.536**	0.508**	0.742**	1			
SY	0.572**	0.151^{NS}	0.327**	0.598**	1		
NR	0.543**	0.447**	0.700**	0.974**	0.728**	1	
BCR	0.412**	0.365**	0.664**	0.900**	0.653**	0.948**	1
WP	-0.381**	-0.310**	-0.260*	-0.453**	-0.284*	-0.457**	-0.456**

**significant at p≤0.001 *significant at p≤0.005; NS: non-significant.
TPM: Tillers m^{-2}, GPS: grains $spike^{-1}$, TGW: 1000-grains weight, GY: grain yield, SY: straw yield, NR: net returns, BCR: BC-ratio and WP: water productivity.

(2020), Ram *et al*. (2013) and Balwinder-Singh *et al*. (2011).

Correlation among studied parameters

To find inter relations between the studied variables (TPM, GRNS, TGW, SY, NR, BCR), Pearson's correlation analysis was estimated (Table 2). It was observed that GY was positively and significantly (p=0.01) correlated with TPM (r = 0.536), GRNS (r = 0.508), TGW (r = 0.453), SY (r = 0.598), NR (r = 0.974) and BCR (r = 0.900). Whereas, there was significant (p=0.01) negative (r = –0.453) correlation of GY with WP of wheat.

Conclusions

Results of this study revealed that rice residue retention for mulching had positive effect on productivity, profitability and water productivity of wheat and can compensate the yield loss due to moisture deficit under limited availability of water for irrigation. Foliar spay of K also found beneficial in terms of increasing productivity and water productivity under salinity and moisture stress conditions. Therefore, from the present investigation it may be concluded that rice residue retention and foliar application of K is a feasible strategy to mitigate water and salinity stress in wheat.

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