

Influence of Crop Establishment Techniques, Fertilization and Microbial Consortia on Potassium Nutrition of Wheat

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Abstract

A field experiment was conducted for 2 years (2013-14 and 2014-15) during winter (*Rabi*) season at Research Farm of ICAR-Indian Agricultural Research Institute, New Delhi, India with an objective to study the significance of two microbial consortia inoculations, zinc (Zn) fertilization (5 kg Zn ha⁻¹ through ZnSO₄·7H₂O soil application in each crop at sowing) and three rates of nitrogen (N) and phosphorus (P) fertilization on potassium (K) concentration, uptake and as well as ammonium acetate (NH₄OAC)-extractable K content in soil at different growth stages in wheat. The microbial consortia used were *Anabaena* sp. (CR1) + *Providencia* sp. (PR3) and *Anabaena-Pseudomonas* biofilmed bio-fertilizer; while rate of fertilization were 0, 75% and 100% of recommended rate of nutrients (RDN) (120 kg N ha⁻¹ and 25.8 kg P ha⁻¹). The concentration and uptake of K was significantly higher in zero tillage wheat (ZTW) than conventional drill-sown wheat (CDW) and system of wheat intensification (SWI) at all observations except at 30 days after sowing. The application of 100% RDN and Zn fertilization have significant and positive effect on K uptake. The microbial consortia increase K concentration and uptake by 0.09-0.12 mg kg⁻¹ and 9.9-12.7 kg ha⁻¹ in straw and 0.08-0.11 mg kg⁻¹ and 3.8-5.6 kg ha⁻¹ in grain. The soil ammonium acetate (NH₄OAC)-extractable K decreased by 87-108 kg ha⁻¹ and 19-44 kg ha⁻¹ in first and second year, respectively over initial soil K even after application of recommended rate of K (49.8 kg ha⁻¹). Our study concludes the significant increase in K uptake due to ZTW and use of microbial consortia and there is the need for redeciding K fertilization in wheat for sustained productivity.

Keywords: *Anabaena-Pseudomonas* biofilmed formulation, potassium, system of wheat intensification, wheat, zero tillage

1. Introduction

Wheat (*Triticum aestivum* L.) is second most important crop of India grown on 29.1 million ha area out of which 9.20 to 10 million ha area is under intensive cereal based rice-wheat cropping system (Timsina & Connor, 2001). The wheat account 10.4% K (0.3 million tonnes K₂O or 0.25 million tonnes K) used out of total nutrient consumption in India with nutrient application ratio of 11.7 N: 4.9 P₂O₅: 1 K₂O (Fertilizer Association of India, 2017). The nutrient uptake per tonne of wheat grain produced was 25.0, 3.93 and 27.5 kg N, P, and K (Tandon, 2013); while uptake of K ranging from 75 to 143 kg ha⁻¹ with mean values of 100 kg ha⁻¹ and generalized recommended rate of K application to wheat was 33 kg K ha⁻¹ (Dwivedi et al., 2017). The major factors which decide the potassium application in wheat includes soil available K content, contribution of soil non-exchangeable K to plant K uptake, wheat response to K application, application rate of primary nutrients (nitrogen and phosphorus), distribution of K in plant parts and economics of K fertilization. In plants, potassium though not present as a component of biochemical compound (Havlin et al., 2010), it is required for activation on 60 different enzymes involved in plant growth (Sekhon, 1999) and regulation such as osmotic adjustment, turgor generation, cell expansion, regulation of membrane electric potential and pH homeostasis (Ragel et al., 2019). The distribution of K in plant is uneven with most part remain in the straw (Sharma et al., 2012).

The K is third largest plant mineral nutrient in earth crust after iron and calcium and present in soil in four different forms viz. primary mineral (structural form), non-exchangeable or fixed, exchangeable and solution

(Zorb et al., 2014). Among these four forms, except primary mineral form all other are actively involved in plant K nutrition. The range of total potassium from Indian soil varies from 0.35 to 4.65% (Sekhon, 1999); while 13% soils are low and 37% soils are medium in available K content in India (Tandon, 2013). The decreasing soil available K in Indian soil was also reported by Pathak et al. (2010). This decreasing status of soil K is again aggravated by low rate of K application (Dwivedi et al., 2017). Even though the presence of mica and feldspar as well as smectites clay minerals in soils provide an abundant *in-situ* source of potassium (Sanyal et al., 2014), their presence in soil as well as release and fixation rate of K across soil (Simonsson et al., 2007) also needs to be considered. This soil K status and capacity of soil mineral to supply K to crop are the two important reasons for lower crop response to K fertilization than N and P as well as for lower K application rate. National Academy of Agricultural Sciences (NAAS, 2009) reported low response to K application than both N and P; while low rate of K application was also mentioned (Dwivedi et al., 2017) in trans and upper Indo-Gangetic plain where rice-wheat cropping system is main factor.

Considering K uptake of 33 kg K tonne⁻¹ by wheat grain, total K removal in wheat is 2.71 million tonnes; while considering K application rate of 100 kg ha⁻¹ (Dwivedi et al., 2017); total K uptake by wheat will be 2.91 million tonnes. If the amount of K applied was calculated based on the recommended rate of 33 kg K ha⁻¹, 0.96 million tonnes of K is applied. This showed the mining of K from soil reserve if all crop dry matter removed from the field. Along with rate of fertilization, uptake varies with application of other primary nutrients (Mosaad & Fouda, 2016). The imbalance use of primary nutrient leading to mining of K (Y. Singh & B. Singh, 2001) was also reported.

The change in crop establishment techniques (CET) from conventional drill sown wheat to zero tillage wheat and system of wheat intensification leads to change in soil tillage practices and their influence on soil physical and chemical properties (Gathala et al., 2011; Bera et al., 2018). Singh et al. (2018) reported that change in crop establishment methods in rice, wheat and maize showed significant variation in K uptake. Among the crop establishment methods, drill-sowing of wheat is conventionally followed on large area with two major difficulties viz., short turn around period after rice harvest and disposal of rice straw. The alternative CET such as zero tillage wheat (ZTW) getting popularity due to its ability to deals with above mentioned problems and save energy thereby reducing cost of cultivation (Erenstein et al., 2008; Kumar et al., 2013). Along with ZTW, another CET followed and getting attention is system of wheat intensification (SWI) (Kumar et al., 2013; Shiva et al., 2016) which involves application of principles of system of rice intensification to wheat with necessary modification. At the same time, application of different microbial inoculations showed variation in K concentration and uptake (Singh et al., 2010) which also need to be investigated under different techniques of wheat establishments under field condition. The goal of this field experiment was to generate valuable information by analysing variation in K concentration and uptake at different growth stages due to above-mentioned factors, and therefore the present study was executed.

2. Materials and Methods

2.1 Description of Study Area

A field experiment was conducted consecutively for two years (2013-14 and 2014-15) during winter season at Research Farm of Indian Council of Agricultural Research (ICAR)-Indian Agricultural Research Institute; New Delhi, India (Latitude of 28°38' N, longitude of 77°10' E and altitude of 228.6 m above the mean sea level). During the year of experiment, 147.6 mm and 308.6 mm rainfall was received during first and second growing season of wheat; with evaporation losses of 542.5 mm and 580.5 mm, respectively. The properties of soil of the experiment field are mentioned in Table 1.

Table 1. Initial soil properties of the experimental field

Sl. No.	Soil properties	Value	Reference
1.	Texture	Sandy clay loam	Bouyoucos (1962)
2.	Organic carbon	5.4 g kg ⁻¹	Walkley & Black (1934)
3.	Nitrogen (Alkaline permanganate oxidizable)	200.3 kg ha ⁻¹	Subbiah & Asija (1956)
4.	Phosphorus (NaHCO ₃ -extractable)	23.3 kg ha ⁻¹	Olsen et al. (1954)
5.	Potassium [1 N ammonium acetate extractable (NH ₄ OAC-extractable)]	283.1 to 287.7 kg ha ⁻¹	Hanway & Heidel (1952)
6.	Zinc (DTPA-extractable)	0.87 mg kg ⁻¹	Lindsay & Norvell (1978)
7.	pH (1:2.5 soil and water ratio)	7.6	Prasad et al. (2006)

2.2 Experimental Details and Material Studied

The experiment was conducted in split plot design involving three crop establishment techniques (CETs) viz. conventional drill-sown wheat (CDW), system of wheat intensification (SWI) and zero tillage wheat (ZTW) as main plots and in each main plot, nine subplot treatments were applied (Table 2). All the treatments were replicated three times. The wheat (*Triticum aestivum*) variety ‘HD 2967’ was grown in this experiment during both years.

Table 2. Subplot treatment details applied in all CETs

Treatment	Details
T1	Absolute control (no fertilizer application)
T2	100% recommended dose of nitrogen and phosphorus (RDN) (120 kg nitrogen ha ⁻¹ and 25.8 kg phosphorus ha ⁻¹)
T3	100% RDN + Zinc (5 kg Zn ha ⁻¹ through ZnSO ₄ ·7H ₂ O)
T4	75% RDN (90 kg nitrogen ha ⁻¹ and 19.4 kg phosphorus ha ⁻¹)
T5	75% RDN + Zinc (5 kg Zn ha ⁻¹ through ZnSO ₄ ·7H ₂ O)
T6	75% RDN + <i>Anabaena</i> sp. (CR1) + <i>Providencia</i> sp. (PR3) consortium (MC1)
T7	75% RDN + <i>Anabaena</i> sp. (CR1) + <i>Providencia</i> sp. (PR3) consortium (MC1) + Zinc (5 kg Zn ha ⁻¹ through ZnSO ₄ ·7H ₂ O)
T8	75% RDN + <i>Anabaena-Pseudomonas</i> biofilm formulation
T9	75% RDN + <i>Anabaena-Pseudomonas</i> biofilm formulation + Zinc (5 kg Zn ha ⁻¹ through ZnSO ₄ ·7H ₂ O)

2.3 Methods and Techniques

2.3.1 Crop Establishment and Management

In order to have same crop growth duration in all three CETs, sowing was done on same date. For ZTW, sowing of seeds (120 kg ha⁻¹) was done with spacing of 20 cm between two rows using seed-drill. In SWI, 1-2 seeds were dibbled per spot at a spacing of 20 cm × 20 cm. In CDW, sowing was done with seed drill with seed rate of 100 kg ha⁻¹ with a spacing of 22.5 cm between two rows. In our study, microbial inoculations was selected from the study conducted by Prasanna et al. (2011) for development and evaluation of cyanobacteria based bioformulation for their plat growth promoting traits; while the *Anabaena* sp. (CR1) + *Providencia* sp. (PR3) consortia was selected from the 51 combinations compared for their significance on rice yield and carbon and nitrogen sequestration (Prasanna et al., 2012). For application of inculcations, a thick paste of respective culture was made in carboxy methyl cellulose (CMC) (1%) and seeds were treated with this thick paste and dried in shade before sowing. The details of management, input addition and treatment application is given in Table 3.

Table 3. Details of crop management and input addition in present investigation

Sl. No.	Particular	Crop establishment techniques (CETs)		
		CDW	SWI	ZTW
1.	Field preparation	One ploughing followed by one harrowing and planking	One ploughing followed by one harrowing and planking	No tillage operation except reshaping of bunds
2.	Seed and sowing	Seed rate: 100 kg ha ⁻¹ Spacing: 22.5 cm (row to row) Sowing method: Drilling	Seed rate: 30 kg ha ⁻¹ Spacing: 20 cm × 20 cm Sowing method: Dibbling (1-2 seeds at each spot)	Seed rate: 120 kg ha ⁻¹ Spacing: 20 cm (row to row) Sowing method: Drilling
3.	Water management	Critical crop growth stage approach were followed in all CETs; Irrigation was given at six critical crop growth stages viz., crown root initiation, tillering, late jointing, flowering, milking and grain hardening stages		
4.	Weed management	Two hand weeding at 20-25 and 40-45 DAS was done in all CETs		
5.	Nutrient management	(1) Sources of nutrient application: Urea for nitrogen; single super phosphate for phosphorus and muraita of potash for potassium. (2) Rate of application: as per the treatment details (Table 2). (3) Methods and timing of application: Drilling of 1/3 rd N, complete dose of P, K and Zn below the seed at the time of sowing; top dressing of 1/3 rd N each at 30 and 60 DAS in all CETs		

2.3.2 Dry Matter Accumulation and Potassium Determination in Plants & Soil Samples

For measurement of the above ground shoot dry matter accumulation, representative plant samples were taken at different growth stages from each plot and same samples were used to determine K concentration in plant after

recording weight of dry matter accumulation. For determination of K concentration in straw and grain, representative samples from each plot were taken at harvesting. The potassium content was determined by using flame photometer method. The potassium uptake was computed by multiplying the potassium concentration with plant dry biomass and expressed as potassium uptake in kg ha^{-1} . For determination of NH_4OAC -extractable K in soil, flame photometric method was used as described by Prasad et al. (2006). In this method, 1 N ammonium acetate solution was used to extract the K from soil. Reading was taken for soil extract against the standard solutions and expressed in terms of kg K ha^{-1} .

2.4 Data Analysis

The statistical significance among applied treatments were studied using the F-test and least significant difference (LSD) values ($P = 0.05$) (K. A. Gomez & A. A. Gomez, 1984).

3. Results

3.1 Potassium Concentration

The K concentration decreased as crop turns towards maturity. The variation in K concentration across the growth stages was higher during 60 to 90 DAS and lowest during 90 DAS to harvest (Table 4). The K concentration in straw was ranged between 1.21 to 1.83%; while for grain it ranged between 0.21 to 0.43%. The ZTW found significantly superior at all observations and contribution of ZTW to increase in grain and straw concentration was 0.11-0.12% and 0.13-0.15% over other CETs; while the CDW and SWI remained on par to each other at all observations recorded. The contribution of ZTW over CDW and SWI to increase in K concentration over the duration was highest at 60 DAS (0.15-0.16%) and decreased thereafter; while lowest contribution was at 30 DAS (0.04%). The highest K concentration was recorded with RDN + Zn which remained on par with RDN and found statistically superior over 75% RDN. The application of microbial consortia with 75% RDN had significantly higher concentration than 75% RDN and remained on par with RDN.

Table 4. Effect of crop establishment techniques and nutrient management options on potassium concentration (%) in wheat

Treatment	2013-14					2014-15				
	30 DAS	60 DAS	90 DAS	Grain	Straw	30 DAS	60 DAS	90 DAS	Grain	Straw
<i>Crop establishment techniques</i>										
Conventional drill-sown wheat (CDW)	3.68	3.25	2.18	0.31	1.68	3.63	3.22	2.17	0.30	1.63
System of wheat intensification (SWI)	3.68	3.26	2.19	0.32	1.68	3.65	3.22	2.17	0.30	1.62
Zero tillage wheat (ZTW)	3.72	3.41	2.33	0.43	1.81	3.68	3.39	2.30	0.42	1.77
Mean	3.69	3.31	2.23	0.35	1.72	3.65	3.28	2.21	0.34	1.67
LSD ($p = 0.05$)	0.09	0.03	0.016	0.013	0.012	0.08	0.02	0.013	0.012	0.011
Significance	NS	*	*	*	*	NS	*	*	*	*
<i>Nutrient management options</i>										
Control ($\text{N}_0\text{P}_0\text{Zn}_0$)	3.25	2.85	1.75	0.21	1.24	3.21	2.81	1.70	0.21	1.21
RDN*	3.77	3.41	2.32	0.40	1.81	3.72	3.36	2.31	0.38	1.75
RDN + Zn**	3.80	3.43	2.37	0.42	1.83	3.76	3.40	2.34	0.39	1.78
75% RDN	3.70	3.24	2.17	0.28	1.68	3.67	3.23	2.18	0.28	1.64
75% RDN + Zn	3.71	3.25	2.21	0.30	1.71	3.68	3.25	2.20	0.29	1.65
75% RDN + MC1	3.73	3.37	2.30	0.38	1.79	3.68	3.34	2.29	0.36	1.73
75% RDN + MC1 + Zn	3.77	3.41	2.34	0.41	1.82	3.73	3.38	2.31	0.38	1.77
75% RDN + MC2	3.74	3.38	2.31	0.39	1.80	3.70	3.35	2.29	0.37	1.74
75% RDN + MC2 + Zn	3.79	3.43	2.34	0.41	1.83	3.74	3.39	2.32	0.38	1.78
Mean	3.70	3.31	2.23	0.36	1.72	3.65	3.28	2.22	0.34	1.67
LSD ($p = 0.05$)	0.11	0.08	0.07	0.05	0.06	0.11	0.08	0.06	0.05	0.05
Significance	NS	*	*	*	*	NS	*	*	*	*
Interaction	NS	*	*	*	*	NS	*	*	*	*

Note. NS: Non-significant; *: Significant at $p = 0.05$; RDN*: Recommended dose of nutrients 120 kg N ha^{-1} and $25.8 \text{ kg P ha}^{-1}$; Zn**: Soil applied 5 kg Zn ha^{-1} through zinc sulphate heptahydrate; MC1: (*Anabaena* sp. (CR1) + *Providencia* sp. (PR3) consortia; MC2: *Anabaena-Pseudomonas* biofilmed formulations and DAS: Days after sowing.

3.2 Dry Matter Accumulation and K Uptake

The above ground dry matter accumulation varied between 27.7-31, 197.4-242 and 601.1-716.8 g m⁻² at 30, 60 and 90 DAS; while for straw and grain it varied between 565-669.5 and 375-468 g m⁻², respectively (Table 5). The highest dry matter was found in ZTW at all growth stages and was significantly superior over CDW and SWI; while both CDW and SWI remained on par to each other. The dry matter with application of RDN + Zn was highest which remained on par with 75% RDN + MC1 + Zn and 75% RDN + MC2 + Zn.

Table 5. Effect of crop establishment techniques and nutrient management options on dry matter accumulation (g m⁻²)

Treatment	2013-14					2014-15				
	30 DAS	60 DAS	90 DAS	Straw	Grains	30 DAS	60 DAS	90 DAS	Straw	Grains
<i>Crop establishment techniques</i>										
Conventional drill-sown wheat (CDW)	30.7	233.1	691.5	610.2	436.5	29.9	219.0	665.4	636.9	429.2
System of wheat intensification (SWI)	30.7	233.0	691.4	607.5	434.5	29.9	218.9	665.3	634.1	427.1
Zero tillage wheat (ZTW)	31.1	238.2	707.0	644.7	461.1	30.2	223.5	678.8	670.6	451.7
Mean	30.8	234.8	696.6	620.8	444.0	30.0	220.5	669.8	647.2	436.0
LSD ($p = 0.05$)	0.23	2.12	6.15	13.1	8.9	0.19	1.96	5.29	11.7	7.5
Significance	*	*	*	*	*	*	*	*	*	*
<i>Nutrient management options</i>										
Control (N ₀ P ₀ Zn ₀)	28.0	205.0	608.0	557.0	381.2	27.3	189.7	594.1	573.0	369.3
RDN*	31.3	238.1	713.0	632.6	454.5	30.4	224.3	682.4	656.5	444.5
RDN + Zn**	31.4	249.8	732.9	657.7	474.3	30.6	234.1	700.6	681.2	462.4
75% RDN	30.7	224.4	665.8	592.0	424.2	30.0	211.1	644.8	624.2	421.2
75% RDN + Zn	30.8	227.5	674.4	599.2	429.3	30.0	214.0	652.2	631.8	426.3
75% RDN + MC1	31.2	236.2	708.3	619.5	444.7	30.4	222.2	680.1	650.3	440.1
75% RDN + MC1 + Zn	31.3	247.5	727.4	652.1	469.3	30.5	232.7	696.1	676.3	458.2
75% RDN + MC2	31.2	236.4	710.4	623.9	448.1	30.4	222.7	681.0	654.7	443.2
75% RDN + MC2 + Zn	31.4	247.8	729.5	653.1	470.6	30.5	233.1	697.1	676.6	458.8
Mean	30.8	234.7	696.6	620.8	444.0	30.0	220.4	669.8	647.2	436.0
LSD ($p = 0.05$)	0.31	2.71	7.87	18.0	12.3	0.26	2.52	6.83	16.3	10.5
Significance	*	*	*	*	*	*	*	*	*	*
Interaction	NS	NS	NS	*	*	NS	NS	NS	*	*

Note. NS: Non-significant; *: Significant at $p = 0.05$; RDN*: Recommended dose of nutrients 120 kg N ha⁻¹ and 25.8 kg P ha⁻¹; Zn**: Soil applied 5 kg Zn ha⁻¹ through zinc sulphate heptahydrate; MC1: (*Anabaena* sp. (CR1) + *Providencia* sp. (PR3) consortia; MC2: *Anabaena-Pseudomonas* biofilmed formulations and DAS: Days after sowing.

The uptake of K was increased as crop progressed toward maturity even though concentration decreased towards maturity (Table 6). At the same time, positive correlation between dry matter accumulations in straw with K uptake (Figures 1 and 2) was also showed the role played by applied treatment in enhancing K uptake through their contribution to increase in dry matter. The CETs significantly increased K uptake from 60 days onwards with significantly higher K uptake in ZTW over CDW and SWI. The increase in K uptake in ZTW was 5.2-5.6 and 11.7-14.3 kg ha⁻¹ at 60 and 90 DAS and 14.1-15.9 and 5.9-6.2 kg ha⁻¹ in straw and grain, respectively during first year and such increase were also observed during second year. This increase in K uptake was very less (8-10%, 4-5% and 2-3% of the dry matter accumulation respectively at 90 DAS and in straw and grain) compared with increase in dry matter accumulation over same duration. Among nutrient management treatments, application of RDN + Zn had the highest uptake and remained on par with 75% RDN + MC1 + Zn and 75% RDN + MC2 + Zn. The effect of applied treatments on the total K uptake was remained same as that of straw and grain K uptake in both years.

Table 6. Effect of crop establishment techniques and nutrient management options on potassium uptake (kg ha^{-1}) by wheat

Treatment	2013-14					2014-15				
	30 DAS	60 DAS	90 DAS	Grain	Straw	30 DAS	60 DAS	90 DAS	Grain	Straw
<i>Crop establishment techniques</i>										
Conventional drill-sown wheat (CDW)	11.3	75.9	151.2	13.9	103.1	10.9	70.7	145.2	12.9	104.5
System of wheat intensification (SWI)	11.3	76.3	152.3	14.2	102.3	10.9	70.8	144.9	12.8	103.2
Zero tillage wheat (ZTW)	11.6	81.5	165.5	20.1	117.2	11.1	76.1	156.9	18.9	119.1
Mean	11.4	77.9	156.3	16.1	107.5	11.0	72.5	149.0	14.9	108.9
LSD ($p = 0.05$)	0.26	0.94	1.92	0.64	0.80	0.28	0.85	1.67	0.53	0.82
Significance	*	*	*	*	*	NS	*	*	*	*
<i>Nutrient management options</i>										
Control ($\text{N}_0\text{P}_0\text{Zn}_0$)	9.1	58.4	106.2	8.3	69.3	8.8	53.3	101.1	7.9	69.8
RDN*	11.8	81.2	165.8	18.3	114.6	11.3	75.3	157.6	16.9	115.1
RDN + Zn**	11.9	85.8	173.8	19.9	120.2	11.5	79.7	163.7	17.9	121.3
75% RDN	11.4	72.7	144.3	12.1	99.7	11.0	68.2	140.7	11.9	102.7
75% RDN + Zn	11.4	74.0	148.9	13.1	102.7	11.0	69.6	143.6	12.5	104.6
75% RDN + MC1	11.6	79.5	163.1	16.9	110.8	11.2	74.1	155.6	15.7	112.6
75% RDN + MC1 + Zn	11.8	84.5	170.4	19.2	118.5	11.4	78.8	160.6	17.2	119.7
75% RDN + MC2	11.7	79.9	163.8	17.7	112.4	11.2	74.6	156.0	16.4	114.2
75% RDN + MC2 + Zn	11.9	85.1	170.6	19.1	119.8	11.4	79.1	162.0	17.6	120.2
Mean	11.4	77.9	156.3	16.1	107.6	11.0	72.5	149.0	14.9	108.9
LSD ($p = 0.05$)	0.33	1.94	4.78	2.38	4.20	0.33	1.76	4.22	2.17	4.09
Significance	NS	*	*	*	*	NS	*	*	*	*
Interaction	NS	*	*	*	*	NS	*	*	*	*

Note. NS: Non-significant; *: Significant at $p = 0.05$; RDN*: Recommended dose of nutrients 120 kg N ha^{-1} and $25.8 \text{ kg P ha}^{-1}$; Zn**: Soil applied 5 kg Zn ha^{-1} through zinc sulphate heptahydrate; MC1: (*Anabaena* sp. (CR1) + *Providencia* sp. (PR3) consortia; MC2: *Anabaena-Pseudomonas* biofilmed formulations and DAS: Days after sowing.

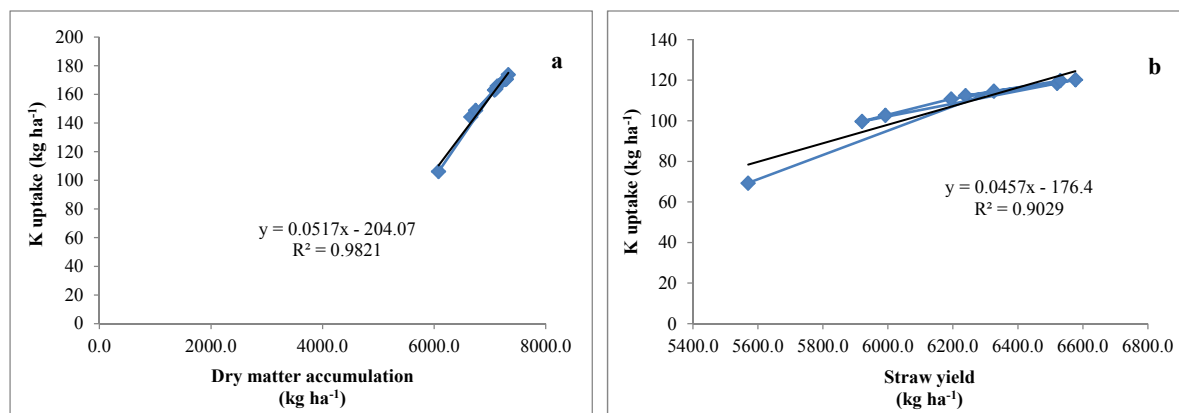


Figure 1. Correlation of potassium uptake and dry matter production at 90 DAS (a) and in straw (b) during first year of study (Compared across nutrient management treatments)

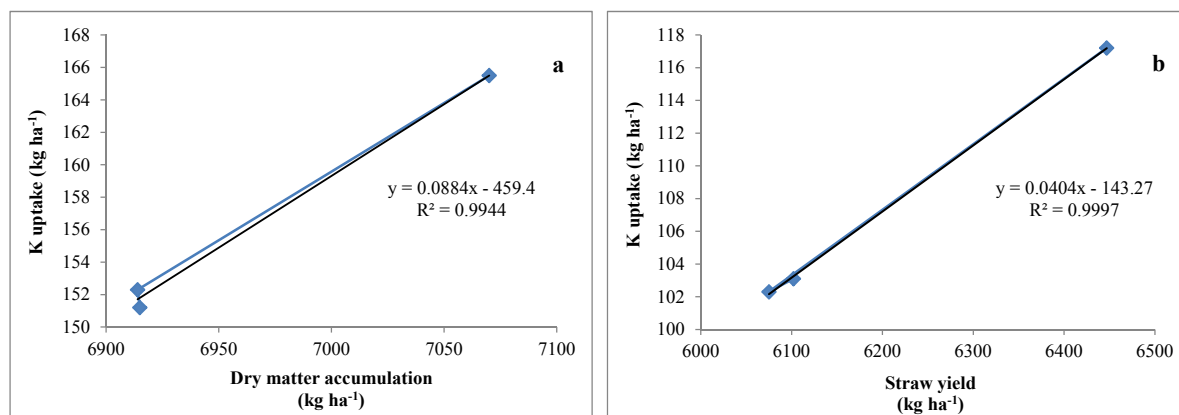


Figure 2. Correlation of potassium uptake and dry matter production at 90 DAS (a) and in straw (b) during first year of study (Compared across crop establishment techniques)

3.3 Soil NH_4OAC -Extractable K at Different Growth Stages and Potassium Balance in Soil

The ZTW had significantly lower soil K over other CETs at all observations recorded in both years (except initial and 30 DAS in first year) (Table 7). Three treatments viz. control, 75% RDN and 75% RDN + Zn had significantly higher soil K than rest of the treatments at almost all observations in both years. This variation signifies that, along with K fertilization, other components of nutrient management plays significant role in soil K status and ultimately potassium nutrition of wheat. The soil K was significantly lower in RDN + Zn and RDN than 75% RDN at all observations; similarly application of MC1 and MC2 with 75% RDN also found inferior than 75% RDN.

Table 7. Effect of crop establishment techniques and nutrient management options on soil potassium ($kg\ ha^{-1}$) in wheat field at different growth stages

Treatment	2013-14					2014-15				
	Initial	30 DAS	60 DAS	90 DAS	At harvest	Initial	30 DAS	60 DAS	90 DAS	At harvest
<i>Crop establishment techniques</i>										
Conventional drill-sown wheat (CDW)	283.1	313.8	242.7	161.0	195.2	188.8	243.2	198.8	139.8	167.6
System of wheat intensification (SWI)	283.2	313.8	242.4	160.0	195.7	189.0	243.4	199.1	140.5	169.4
Zero tillage wheat (ZTW)	287.7	317.9	241.4	150.9	179.1	180.4	233.8	183.6	117.5	136.4
Mean	284.7	315.2	242.2	157.3	190.0	186.1	240.1	193.8	132.6	157.8
LSD ($p = 0.05$)	1.79	1.82	1.96	2.45	1.76	3.61	3.63	3.47	3.56	4.32
Significance	*	*	NS	*	*	*	*	*	*	*
<i>Nutrient management options</i>										
Control ($N_0P_0Zn_0$)	289.4	327.2	276.3	227.1	255.6	226.2	274.0	236.2	195.2	218.7
RDN*	282.2	311.8	235.4	143.7	176.6	173.9	228.0	179.7	113.0	138.6
RDN + Zn**	278.3	307.8	227.1	132.1	165.8	153.4	205.5	151.1	80.9	105.5
75% RDN	294.5	324.1	255.3	176.3	208.8	225.1	284.2	247.2	194.9	221.1
75% RDN + Zn	291.0	320.7	250.9	168.6	201.7	214.6	272.6	233.4	178.7	205.2
75% RDN + MC1	283.9	313.5	238.6	147.9	183.3	184.5	239.7	193.4	128.6	155.8
75% RDN + MC1 + Zn	280.7	310.3	230.6	137.8	170.4	160.6	213.5	160.6	93.2	116.9
75% RDN + MC2	283.7	313.3	238.0	147.0	180.7	180.1	234.8	187.7	122.5	147.8
75% RDN + MC2 + Zn	278.2	307.8	227.7	135.2	166.9	156.4	208.9	155.3	86.5	110.6
Mean	284.7	315.2	242.2	157.3	190.0	186.1	240.1	193.8	132.6	157.8
LSD ($p = 0.05$)	3.67	3.66	4.17	6.10	7.37	10.15	10.82	12.25	14.84	17.24
Significance	*	*	*	*	*	*	*	*	*	*
Interaction	NS	NS	NS	*	*	NS	NS	NS	*	*

Note. NS: Non-significant; *: Significant at $p = 0.05$; RDN*: Recommended dose of nutrients $120\ kg\ N\ ha^{-1}$ and $25.8\ kg\ P\ ha^{-1}$; Zn**: Soil applied $5\ kg\ Zn\ ha^{-1}$ through zinc sulphate heptahydrate; MC1: (*Anabaena* sp. (CR1) + *Providencia* sp. (PR3) consortia; MC2: *Anabaena-Pseudomonas* biofilmed formulations and DAS: Days after sowing.

The soil NH_4OAC -extractable K (soil available K + K applied through fertilizer) at the start of first year wheat crop varied between 328.1 to 344.3 kg ha^{-1} (Table 8). The variation in soil K across nutrient management treatments at the start of first season wheat crop was 16.3 kg ha^{-1} and this variation increased to 72.8 kg ha^{-1} in second year. The initial soil K in first year was significantly higher in ZTW during first year; while it had significantly lower soil K than CDW and SWI at the start of second season wheat crop. The uptake of K in wheat of first season and rice planted after wheat is an important factor affecting initial soil K status in second season wheat crop. The calculated balance and actual soil K at harvest of both wheat crops was significantly higher in CDW and SWI than ZTW in both years. The actual K present after harvest in first wheat crop was lower than calculated balance by 20-21 kg ha^{-1} and in second year, actual K was higher by 44 to 46 kg ha^{-1} than calculated balance. The calculated balance as well as actual available K at harvest was significantly higher in control, 75% RDN and 75% RDN + Zn than rest of the treatment which is due to less uptake in these three treatments.

Table 8. Effect of crop establishment techniques and nutrient management options on potassium (kg ha^{-1}) balance in soil

Treatment	Initial soil potassium		Potassium applied through fertilizer		Expected potassium present in soil after addition of fertilizers		Total potassium uptake		Balance		Actual potassium present in soil after harvest	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
<i>Crop establishment techniques</i>												
Conventional drill-sown wheat (CDW)	283.1	188.8	49.8	49.8	332.9	238.6	117.0	117.4	215.9	121.2	195.2	167.6
System of wheat intensification (SWI)	283.2	189.0	49.8	49.8	333.0	238.8	116.6	116.0	216.4	122.8	195.7	169.4
Zero tillage wheat (ZTW)	287.7	180.4	49.8	49.8	337.5	230.2	137.3	138.0	200.2	92.2	179.1	136.4
Mean	284.7	186.1	49.8	49.8	334.5	235.9	123.6	123.8	210.8	112.1	190.0	157.8
LSD ($p = 0.05$)	1.79	3.61	-	-	1.79	3.61	0.83	0.94	1.80	3.99	1.76	4.32
Significance	*	*	-	-	*	*	*	*	*	*	*	*
<i>Nutrient management options</i>												
Control ($\text{N}_0\text{P}_0\text{Zn}_0$)	289.4	226.2	49.8	49.8	339.2	276.0	77.6	77.7	261.6	198.3	255.6	218.7
RDN*	282.2	173.9	49.8	49.8	332.0	223.7	132.9	132.0	199.2	91.7	176.6	138.6
RDN + Zn**	278.3	153.4	49.8	49.8	328.1	203.2	140.1	139.1	188.0	64.1	165.8	105.5
75% RDN	294.5	225.1	49.8	49.8	344.3	274.9	111.8	114.6	232.5	160.3	208.8	221.1
75% RDN + Zn	291.0	214.6	49.8	49.8	340.8	264.4	115.8	117.1	225.1	147.3	201.7	205.2
75% RDN + MC1	283.9	184.5	49.8	49.8	333.7	234.3	127.7	128.3	206.0	106.0	183.3	155.8
75% RDN + MC1 + Zn	280.7	160.6	49.8	49.8	330.5	210.4	137.7	136.9	192.8	73.5	170.4	116.9
75% RDN + MC2	283.7	180.1	49.8	49.8	333.5	229.9	130.1	130.6	203.4	99.2	180.7	147.8
75% RDN + MC2 + Zn	278.2	156.4	49.8	49.8	328.0	206.2	138.9	137.8	189.1	68.4	166.9	110.6
Mean	284.7	186.1	49.8	49.8	334.5	235.9	123.6	123.8	210.9	112.1	190.0	157.8
LSD ($p = 0.05$)	3.67	10.15	-	-	3.67	10.15	6.42	6.13	7.43	15.46	7.37	17.24
Significance	*	*	-	-	*	*	*	*	*	*	*	*
Interaction	NS	NS	-	-	NS	NS	*	*	*	*	*	*

Note. NS: Non-significant; *: Significant at $p = 0.05$; RDN*: Recommended dose of nutrients 120 kg N ha^{-1} and 25.8 kg P ha^{-1} ; Zn**: Soil applied 5 kg Zn ha^{-1} through zinc sulphate heptahydrate; MC1: (*Anabaena* sp. (CR1) + *Providencia* sp. (PR3) consortia; MC2: *Anabaena-Pseudomonas* biofilmed formulations and DAS: Days after sowing.

4. Discussion

4.1 Potassium Concentration

In present study, the K concentration was significantly affected due to CETs, rate of N and P application and microbial inoculation at 60 and 90 DAS and in grain and straw even though rate of K application was same for all treatments; while Zn fertilization had no significant effect on K concentration across different growth stages (Table 4). The growth variations might be due to applied treatments, positive interaction of N and P with K, residual effect of previous season rice crop and variation in K release and fixation across CETs are the important reasons for this variation in K concentration in wheat. The variations in K concentration across CETs were also

reported by Singh et al. (2018). The performance of nutrient management options differed significantly across CETs which has been shown by significant interaction effect. Guo et al. (2019) reported that application of N through NO_3^- had positive effect on K concentration in wheat plant; while it was negative with NH_4^+ form. The increase in K concentration due to Zn fertilization was reported by Shivay et al. (2015); while the role of microbial inoculation in solubilizing mineral K was also reported by Leungvutiviroj et al. (2010).

4.2 Dry matter Accumulation and Potassium Uptake

The higher shoot dry matter accumulation in ZTW was due to higher seed rate used, better growth stand establishment and residual effect (soil nutrient status) of previous season rice crop. The variation in growth and yielding ability of wheat across CETs were also reported by Saharawat et al. (2010). The order of significance of applied treatments in present study in enhancing dry matter was rate of N and P application > CETs > microbial consortia > Zn fertilization; while their contribution to increase in dry matter was 64-154.5, 58-63, 46.5-54.5 and 43-50.5 g m⁻², respectively (Table 5).

The significant variation observed in dry matter accumulation among nutrient management treatments is one of the important reasons for having various K uptakes among applied treatments (Table 6). The positive effect of dry matter accumulation was reflected in to increases in uptake which indicates that, dry matter accumulation dominate over concentration in deciding K uptake. There might be possibility that increase in dry matter accumulation was also responsible for dilution of nutrient concentration and also reduction in total K uptake; while in present study K uptake was also found significantly higher in same treatment having higher dry matter accumulation (Tables 5 and 6). Out of the total K uptake 85.8-89.8% remained in straw and therefore retention and/or incorporation (Singh et al., 2018) of residue in rapidly spreading tillage system such as conservation tillage bring economy in K fertilization.

The variation in K uptake by applied treatments, fixation of applied K and release of fixed K due to concentration gradient between plant roots and soil fixed K are the important factors affecting variation in soil NH_4OAC -extractable K. Among applied treatments, CETs and rate of N and P application significantly affect the soil K at initial and at 30 DAS; while all factors (CETs, rate of N and P application, microbial inoculation and Zn fertilization) statistically differed in soil K at 60 and 90 DAS and at harvest in first year. In second year, all applied treatment variables significantly affected the soil K at all observations recorded. The rate of N and P application and Zn fertilization has respectively the highest and lowest effect on soil K content.

4.3 Soil NH_4OAC -Extractable K and Potassium Balance in Soil

The variation in soil K status due to applied nutrient management treatment showed the relation between K uptake and soil available K (NH_4OAC -extractable). Zhang et al. (2017) also showed the relationship between soil available K and K uptake by wheat. At the same time the soil available K was decreased even after fertilizing the soil with recommended rate of K. This signifies the role of soil inherent K over K applied through fertilizer in meeting K need of wheat and this was the reason for negative balance of K in soil (Sanyal et al., 2014). Singh et al. (2019) also showed the decrease in soil exchangeable K even after addition of recommended dose of potassium (33 kg K ha⁻¹ crop⁻¹) in rice-wheat cropping system.

5. Conclusions

The present study showed that, application of recommended rate of N and P (120 kg N ha⁻¹ and 25.8 kg P ha⁻¹) enhanced the potassium uptake in wheat in all three CETs as compared to 75% recommended rate of N and P (sub-optimal fertilization). Supplying 25% of nitrogen and phosphorus through microbial consortia (MC) have same level of K uptake as that observed with application of all nutrients through chemical fertilizers. The uptake of K was found higher in zero tillage wheat and with application of RDN + Zn. The calculated as well as actual balance of NH_4OAC -extractable K in soil decreased over initial soil K status and this signifies the need of K fertilization.

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