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Effect of Potassium and Crop Residue Levels on Potassium Solubilizers and Crop Yield under Maize-Wheat Rotation

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A B S T R A C T

To study the effect of different levels (0, 2, 4 and 6 t ha^{-1}) of wheat and maize crop residues (CR), potassium (K) doses [50, 100, 150% recommended K and 50% RDK+K solubilising bacteria (KSB)] and a combination of CR+K doses on maize and wheat crop yield and KSB population, a field experiment was conducted during 2014-15 and 2015-16, following split plot design. The biological yield and KSB population in soil under both the test crops responded positively to CR and K management practices. Wheat and maize CR retention of 4 t ha^{-1} recorded significantly higher biological yield of maize and wheat, compared to their un-amended controls (11.88 and 12.04 t ha^{-1} in maize and 12.09 and 12.77 in wheat during 2014-15 and 2015-16, respectively). The viable population of KSB in inoculated soil under maize increased to 24.1 and 26.3 $x10^4$ cfu g^{-1} soil at 60 days after sowing (DAS) and 25.7, 27.9 $x10^4$ cfu g^{-1} soil in wheat compared to their 30 DAS values of 15.5, 16.3 x 10^4 cfu g^{-1} in maize, 15.8, 16.8 $x10^4$ cfu g^{-1} in wheat during test years of 2014-15 and 2015-16. Statistically insignificant difference in yield and KSB population was observed with KSB+ CR at 4 and 6 t ha^{-1}. Application of 50 % RDK+KSB resulted in highest biological yield (13.32, 14.46 t ha^{-1} in maize and 13.51, 14.34 t ha^{-1} in wheat). A positive correlation between biological yield of maize and wheat, yield components and KSB population was recorded at harvest stage.

Introduction

Crop residues are plant parts, left behind after the harvesting and threshing of crops. These are the waste material that need effective disposal. Over the years, their value as important nutrient resources is being realized. India produces about 500 Million tonne (Mt) of crop residue every year, of which cereal crops (rice, wheat, maize, millets) residue's share is about 70 %. Generation of cereal residues is highest in Uttar Pradesh (53 Mt) followed by Punjab (44 Mt) and West Bengal (33 Mt). The total surplus crop residue in

India amounts to 84-141 Mt yr^{-1} whereas cereals contribute 23 % (MNRE, 2009). Intensive cultivation has caused the mining of soil for major nutrients leading to net negative balance and multi-nutrient deficiencies in crops and that being one of the reasons for the yield decline in the Indo Gangetic Plain (IGP) region. Farmers usually dispose of the cereal crop residue through open field burning. This leads not only to emission of harmful gases such as carbon dioxide, carbon monoxide, methane, nitrous oxide, sulphur dioxide and harmful air pollutants into the atmosphere, (Gadde *et al.*, 2009), but also causes loss of nutrients. To minimize this problem, recycling of nutrients (N, P and K) through crop residue incorporation is one of the desired options that may lead to effective disposal and help overcome the deficiencies of other nutrients, *viz.*, S, Zn and B deficiencies, which are widespread in the IGP region (Prasad, 2005).

Potassium (K) is the third macro-nutrient required by the crop plants (Bagyalakshmi *et al.*, 2012) and plays a significant role in growth, yield and activation of several metabolic processes including protein synthesis, photosynthesis, enzymes, besides providing resistance to diseases and insects etc (Rehm and Schmitt, 2002). The sustainable nutrient management practices have mainly been focussed on supply of N and P while the issue of sustainable management of K in soil has partly been ignored. As available soil K levels have dropped, the desired requirement of the nutrient is met through chemical fertilizer. There are no reserves of K-bearing minerals in India for production of commercial K-fertilizers and the whole consumption of K-fertilizers are imported in the form of muriate of potash (KCl) and sulphate of potash (K_2SO_4) which involves huge amount of foreign exchange. This necessitates the need to find an alternate K source that can meet the plant's K needs and maintain K status in soils for sustaining crop production. Potassium applied though chemical fertilization, only 1-2 % is available to the plants and the rest gets bound with other minerals. Under such circumstances, biological extraction of K holds good promise. Potassium solubilising microorganisms have the potential to solubilise 'micas, illite and orthoclase, by excreting organic acids (Bennett *et al.*, 1998; Barker *et al.*, 1998). KSB have been reported to increase K availability in soils and result in its increased uptake by crop plants (Sheng *et al.*, 2003). However, the performance of KSB depends upon their establishment in soil niche and may vary with type of strain, crop management practices and test crops and thus needs to be investigated. Keeping in mind the effective disposal of crop residues and importance of K in crop growth and its sustainable management, present investigation was undertaken with the following objectives (i) to optimize the dose of wheat and maize crop residues for enhancing the maize and wheat yield respectively. Enumeration of KSB in the crop residue and potassium amended rhizosphere soil of maize and wheat under zero till agriculture.

Materials and Methods

Crop residue

Maize and wheat crop residue was collected from the experimental farm located at Indian Agricultural Research Institute, New Delhi, India after the respective crop harvest. The residue was chopped to small size (6-7 cm) pieces before their incorporation in soil as mulch.

Potassium solubilising bacterial strain

K solubilising liquid bio-fertilizer (*Bacillus decolorationis*) was obtained from bio-fertilizer unit of Microbiology Division, ICAR- Indian Agricultural Research Institute, New Delhi, India and kept in refrigerator till further use. Wheat and maize seed inoculation was done with KSB applied @ 125 ml ha^{-1} seed using 5% sugar solution as a sticker during both years of study.

Experimental site and climatic conditions

The field experiment was conducted during *kharif* and *rabi* seasons of 2014-15 and 2015-16 at the research farm of the ICAR-Indian Agricultural Research Institute, New Delhi, India located at 28.35°N latitude and 77.12°E longitude and 228.6 m above mean sea level (MSL). Delhi falls under the agro-climatic zone 'Trans-Gangetic Plains'. During wet season of 2014 and 2015, when maize was grown, total rainfall received was 395.4 and 633.10 mm. However, during dry season of wheat cultivation (2014-15 and 2015-16) total rain fall had wide variation and it was 315.80 and 19.80 mm in respective seasons. The mean maximum and mean minimum temperature during maize growth was (34.27, 33.47 ^{o} C), and (22.83, 22.13 ^{o} C) respectively during 2014 and 2015. For wheat the recorded mean maximum and minimum temperature was (24.27, 26.81^{o}C), and (10.36, 9.77 ^{o} C), respectively during 2014-15 and 2015-16. The soil of the experimental site was sandy loam (Bouyoucos, 1962). It had a bulk density of 1.52 Mg/m^3 (Piper, 1950), organic carbon of 0.43% (Walkley and Balck, 1934), $KMnO_4$ oxidizable N-143 kg ha^{-1} (Subbiah and Asija, 1956), $NaHCO_3$ extractable P-13.45 kg ha^{-1} (Olsen *et al.,* 1954), exchangeable K- 245 kg ha-^{1} (Hanwey and Heidel, 1952), pH 8.33 and EC 0.37 dS m^{-1} $^{(}$Jackson, 1973) at the start of experiment.

Experimental details

The experiment was laid out in split plot design in twenty treatment combinations. Four levels of wheat crop residue (CR) added for maize cultivation and maize crop residue for wheat cultivation (CR) included (No CR, 2 t, 4 t and 6 t ha^{-1}) in main plot and five potassium levels (No K, 50% RDK (Recommended dose of Potassium), 100% RDK, 150% RDK and 50% RDK+KSB (Potassium solubilising bacteria) in sub plots and replicated thrice. Maize (cv-PMH 4, seed rate 20 Kg ha^{-1}) was sown at row spacing of 60 x 30 cm and wheat (cv- HD CSW 18, seed rate 100 Kg ha^{-1}) was sown at row to row distance of 20 cm, respectively with the help of zero seed drill. Recommended dose of chemical fertilizer for maize (150:80:60 kg N, P_2O_5 and K_2O ha^{-1}) and wheat (120:80:60 kg N, P_2O_5 and K_2O ha^{-1}) was placed below the seed zone while sowing as per treatment schedule given in Table 1. In maize and wheat crops full dose of P and K and half of the dose of N were applied as basal at sowing. The remaining N in wheat was top dressed in two equal splits after the first and second irrigation. In maize remaining N was top dressed at 35 days after sowing. Seeds of both maize and wheat crops were treated with potassium solubilising bacteria (KSB) @ 50 ml/ acre as per treatment. Sun dried and chopped residues of the wheat and maize crops of previous season were applied at cited levels to maize and wheat crops respectively by retaining it on the soil surface as mulch in all treatments except control after sowing of crops. Depth of irrigation water was kept at 6-7 cm and number of irrigation applied in maize and wheat were 4 and 5 during 2014-15 and 3 and 6 during 2015-16, respectively. To provide an ideal weed free environment to maize crop the Pendimethalin @ 1.00 kg a.i. ha^{-1} along with Atrazine (@ 0.75 kg a.i ha^{-1} was sprayed as pre-emergence at 1-2 days after sowing. To manage weeds in wheat, Isoproturon @ 0.75 kg a.i. ha^{-1}) along with 2, 4D @ 0.25 kg a.i. ha $^{-1}$ was applied as post emergence at 30 days after sowing.

Maize and wheat crop were harvested manually from the central net plot area for biological yield assessment. The potassium solubilising bacterial population in rhizospheric soil was determined by dilution and pour plate method using Aleksandrov medium (Hu *et al.,* 2006). The yield data obtained from two cycles of maize and wheat crops were statistically analysed using the F-test as per the procedure given by Gomez and Gomez (1984).

Results and Discussion

Yield components and biological yield

The yield components and biological yield of maize and wheat were significantly influenced with residue retention and K fertilization (Table 1). The application of 4 t ha^{-1} of crop residue (CR), being at par with 6 ha^{-1} that recorded the highest yield components viz., cob length (15.6, 16.4 cm), cob girth (14.8, 16 cm), single cob weight (152, 166 g) and biological yield (13.09, 14.17 t/ha) in maize. However, in wheat, maximum spike length of 11.1 and 10.9cm, spiklets per spike (22.2, 24.9) and biological yield (13.27, 14.05 t ha^{-1}) was recorded during both crop cycles.

Similarly 50% RDK+KSB registered statistically higher value of yield attributes with cob length (16.4, 18.0 cm), cob girth (15.3, 16.7 cm), single cob weight (154.7, 169.4 g) and biological yield (13.32, 14.46 t ha^{-1}) in maize and spike length (10.9, 12.1 cm), spiklets per spike (23.3, 26.3) and biological yield (13.51, 14.34 t/ha) in wheat during both years of study. The values were at par with 100% RDK and 150% RDK.

KSB population dynamics

The application of crop residue and K to soil exerted significant effect on potassium solubilising bacterial population (Table 2). It was observed that KSB population was more during vegetative to flowering stage and thereafter declined as the crop matured. The crop residue application at 6 t ha^{-1} resulted in significantly higher population of KSB at 30 days after sowing (15.5, 16.3 x 10^4 cfu g^{-1} in maize, 15.8, 16.8 x10^4 cfu g^{-1} in wheat) compared to 60 DAS (24.1, 26.3 x10^4 cfu g^{-1} in maize, 25.7, 27.9 x10^4 cfu g^{-1} in wheat) and at harvest (19.8, 21.2 x10^4 cfu g^{-1} in maize, 19.6, 22.4 x10^4 cfu g^{-1} in wheat). Though, the values were at par with 4 t ha^{-1} in both the crop and both the crop cycles.

The treatment 50% RDK+KSB has reported significantly maximum potassium solubilising bacterial population at 30 DAS (15.8, 16.9 x10^4 cfu g^{-1} in maize and 16.2, 17.2 x10^4 cfu g^{-1} in wheat), 60 DAS (23.8, 25.9 x10^4 cfu g^{-1} in maize and 25.7, 27.6 x10^4 cfu g^{-1} in wheat) and at harvest (20.0, 21.5 x10^4 cfu g^{-1} in maize and 20.1, 23.1 x10^4 cfu g^{-1} in wheat) over No K and 50% RDK and which was on par with 100% RDK and 150% RDK in both years of experimentation.

Correlation and regression study

Correlation estimation (mean of two years data) was accomplished at phenotypic level and the results obtained are presented in Table 3. The values of correlation denoted that biological yield (t ha^{-1}) of maize and wheat respectively showed highly significant positive correlation with cob length (cm) (r =0.9974**), cob girth (cm) (r =0.98803**), single cob weight (g) (r =0.99245**), in maize and spike length (cm) (r =0.94783**), spiklets per spike (r =0.9881**) in wheat. In addition, these characters were also inter-related among themselves.

A strong and positive correlation coefficient (r^2) value was observed in potassium solubilising bacterial population and biological yield of maize (0.948, 0.932) and wheat (0.980, 0.965) in both the year of experimentation (Fig. 1).

Table.1 Effect of crop residue and potassium management practices on yield attributes and yield of maize and wheat in conservation agriculture based maize-wheat cropping system

Treatment	Maize								Wheat					
	Cob length (cm)		Cob girth (cm)		Single cob weight (g)		Biological yield (t ha^{-1})		Spike length (cm)		Spiklets/spike		Biological yield (t ha^{-1})	
	2014	2015	2014	2015	2014	2015	2014	2015	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Crop residue management practices (CRM)														
No CR	10.9	11.8	12.3	12.8	138.0	147.7	11.88	12.84	8.9	9.5	17.2	19.9	12.09	12.77
2 t/ha CR	13.2	14.8	13.3	13.5	141.0	152.5	12.46	13.51	9.8	10.2	18.9	21.6	12.65	13.35
4 t/ha CR	15.6	16.4	14.8	16.0	152.0	166.1	13.09	14.17	11.1	12.2	22.2	24.9	13.27	14.05
6 t/ha CR	15.1	16.0	14.3	15.2	149.4	163.6	13.05	14.08	10.9	12.0	21.1	23.9	13.21	13.98
SEm±	0.3	0.2	0.2	0.3	0.8	1.4	0.15	0.16	0.3	0.2	0.4	0.4	0.14	0.15
LSD (P=0.05)	1.0	0.8	0.7	1.1	2.9	4.8	0.52	0.54	0.9	0.6	1.3	1.4	0.48	0.53
Potassium management practices (PM)														
No K	8.6	7.6	11.0	9.8	125.3	132.6	10.95	11.78	8.7	9.1	14.0	15.7	11.20	11.72
50% RDK	12.7	13.4	12.9	13.3	141.3	152.5	12.35	13.35	9.6	10.2	18.5	21.5	12.46	13.09
100% RDK	15.5	17.5	14.8	16.4	152.3	167.1	13.27	14.36	10.9	11.8	22.1	25.1	13.47	14.30
150% RDK	15.4	17.2	14.4	15.8	151.8	165.9	13.22	14.29	10.7	11.7	21.3	24.3	13.38	14.24
50% RDK+KSB	16.4	18.0	15.3	16.7	154.7	169.4	13.32	14.46	10.9	12.1	23.3	26.3	13.51	14.34
SEm±	0.4	0.4	0.3	0.4	1.4	1.6	0.10	0.14	0.2	0.2	0.7	0.7	0.12	0.13
LSD (P=0.05)	1.0	1.1	0.9	1.3	4.0	4.7	0.28	0.39	0.7	0.6	2.1	2.1	0.34	0.39
CRM x PM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

CR: Crop residue, RDK: Recommended dose of potassium, KSB: Potassium solubilising bacteria, DAS: Days after sowing, NS: Non Significant

Table.2 Effect of potassium and crop residue management practices on potassium solubilising bacterial population dynamics in rhizospheric soil of maize and wheat in conservation agriculture based cropping system

Treatment	Potassium solubilising bacteria (x10^4cfu g^{-1})											
	Maize						Wheat					
	2014			2015			2014-15			2015-16		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
Crop residue management practices (CRM)												
No CR	11.0	17.2	14.7	11.4	18.6	15.5	12.0	19.4	16.0	12.6	20.7	18.2
2 t/ha CR	13.4	20.9	17.3	13.9	22.6	18.2	13.7	22.9	17.4	14.3	24.4	19.7
4 t/ha CR	14.7	23.5	19.1	15.7	25.4	20.3	14.9	25.1	18.9	15.6	26.7	21.8
6 t/ha CR	15.5	24.1	19.8	16.3	26.3	21.2	15.8	25.7	19.6	16.8	27.9	22.4
SEm±	0.34	0.57	0.47	0.40	0.52	0.52	0.33	0.49	0.34	0.39	0.55	0.30
LSD (P=0.05)	1.19	1.96	1.62	1.38	1.80	1.81	1.14	1.71	1.19	1.37	1.89	1.02
Potassium management practices (PM)												
No K	10.1	16.7	13.4	10.5	18.1	14.2	8.5	18.3	14.0	8.9	19.6	16.1
50% RDK	11.9	20.2	16.8	12.4	21.8	17.8	14.2	22.0	16.8	14.9	23.5	19.0
100% RDK	15.4	23.4	19.5	16.2	25.5	20.7	16.1	25.3	19.8	16.8	27.3	22.7
150% RDK	15.0	23.0	18.8	15.7	24.8	19.9	15.6	24.8	19.3	16.3	26.6	21.8
50% RDK+KSB	15.8	23.8	20.0	16.9	25.9	21.5	16.2	25.7	20.1	17.2	27.6	23.1
SEm±	0.47	0.59	0.58	0.54	0.61	0.60	0.42	0.35	0.45	0.45	0.41	0.53
LSD (P=0.05)	1.36	1.69	1.68	1.56	1.76	1.71	1.22	1.02	1.29	1.31	1.19	1.52
CRM x PM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

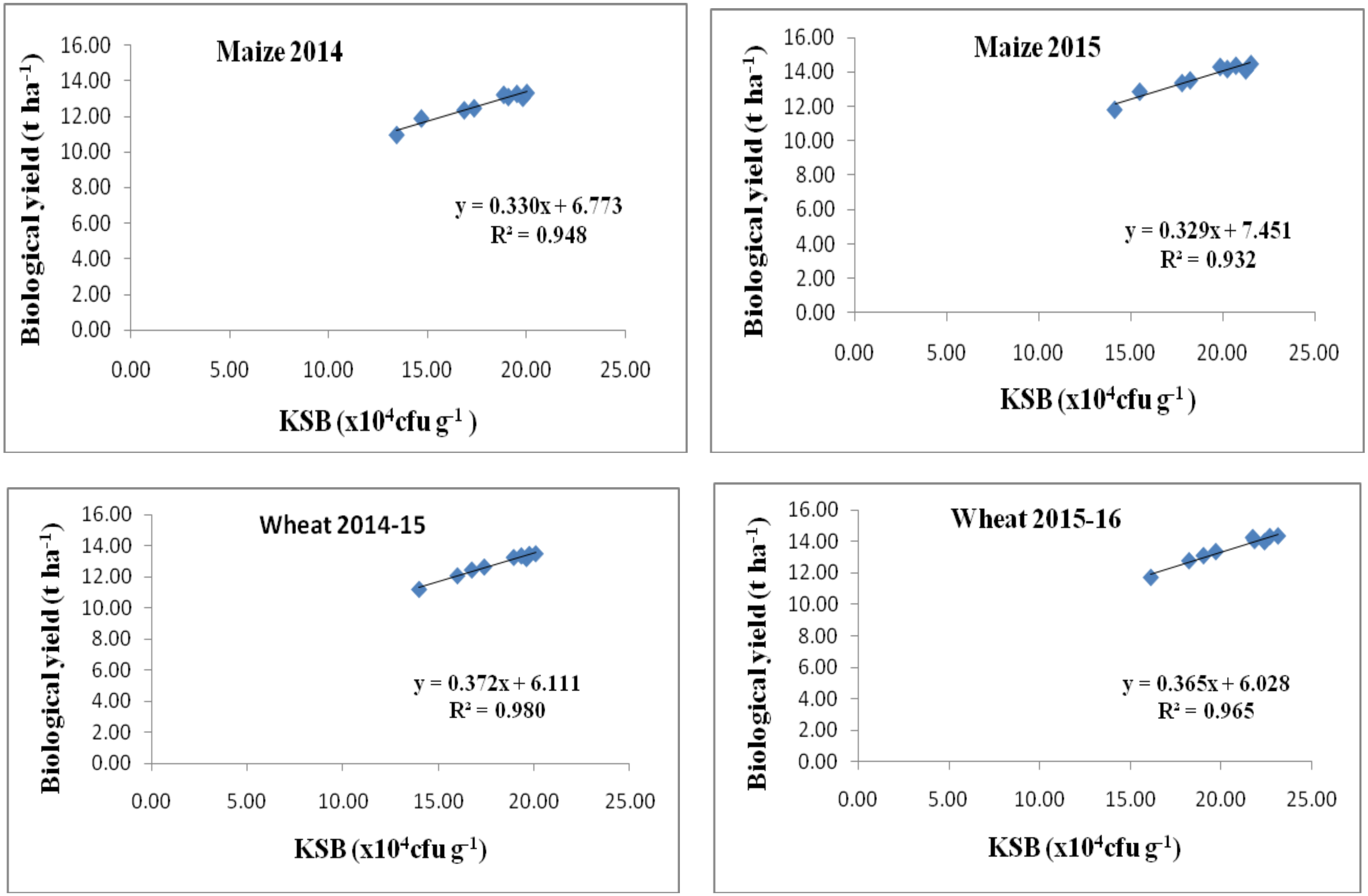
Initial KSB: 8.5 x 10^4cfu g^{-1}

Table.3 Pearson correlation (r-values) among different yield components and biological yield (two years mean data) of maize and wheat under conservation agriculture based maize-wheat cropping system

	Maize cob length (cm)	Maize cob girth (cm)	Maize single cob weight (g)	Wheat spike length (cm)	Wheat spiklets/spike	Maize biological yield (t ha^{-1})	Wheat biological yield (t ha^{-1})
Maize cob length (cm)	1	0.99134**	0.98996**	0.94924**	0.99134**	0.9974**	0.99657**
Maize cob girth (cm)	0.99134**	1	0.99482**	0.95604**	0.99827**	0.98803**	0.99124**
Maize single cob weight (g)	0.98996**	0.99482**	1	0.947**	0.99424**	0.99245**	0.99331**
Wheat spike length (cm)	0.94924**	0.95604**	0.947**	1	0.94791**	0.94351**	0.94783**
Wheat spiklets /spike	0.99134**	0.99827**	0.99424**	0.94791**	1	0.98722**	0.9881**
Maize biological yield (t ha^{-1})	0.9974**	0.98803**	0.99245**	0.94351**	0.98722**	1	0.99882**
Wheat biological yield (t ha^{-1})	0.99657**	0.99124**	0.99331**	0.94783**	0.9881**	0.99882**	1

**Significant at 0.01% level of significance

Fig.1 Simple regression between potassium solubilising bacterial population at harvest and biological yield of maize and wheat under conservation agriculture based maize-wheat cropping system



All the yield components and biological yield of maize and wheat crops were significantly influenced by crop residue, K application and seed inoculation of plant-growth-promoting rhizobacteria (KSB), with the highest yield components observed in 4 t/ha and 6 t/ha crop residue plot, the increased yield components and biological with crop residue application might be due to no-tillage management, in conjunction with application of large quantities of straw mulch on the soil surface maintain good and favourable soil moisture, moderate soil temperature, and improved soil water and nutrient conditions, increased saturated and unsaturated hydraulic conductivities, earthworm population, soil water retention, total soil porosity, and macro-porosity (Blanco-Canqui and Lal, 2006), might have been the reasons. Sharma *et al.,* (2009), Jat (2010) and Saad *et al.,* (2015) also reported the higher values of yield attribute and biological yield under residue application. The application of 50% RDK in conjunction with seed inoculation of plant-growth-promoting rhizobacteria (KSB) has significantly improved all the yield attributes and biomass yield of both the crops under zero till condition were mainly due to the mobilization of K from soil because of secretion of organic acids, protons, siderophores, exopolysaccharides and organic ligands by bacterial strain, which in turn increased availability of both essential macro and micro nutrients for crop uptake in soil by maintaining good health of soil. These findings are also conformity with Muralikaman (1996), Basak and Biswas (2009) and Basavesha *et al.,* (2016). The increased yield with K fertilization might be due to increased availability, absorption and translocation of K nutrient. As the K is essential for grain development, the favourable effect of high doses of K on growth and yield attributes was mainly responsible for higher biological yield. Significant effects of K application in sesame, mustard, groundnut, maize wheat were reported by Yadav *et al.,* (2012) and Jat *et al.,* (2014). Potassium solubilising bacterial population was significantly improved with crop residue retention in soil and their population changed from 30 DAS to at crop harvest might be due to crop residues had a stronger impact on soil microbial activity interns of residue decomposition and higher root activity upto 60 DAS there after it decreases and also micro-climate created by zero tillage with residue, availability of substrate provided by crop residues and micro-organism density as earlier reported by Balota *et al.,* (1998), Valpassos *et al.,* (2001) and Chaitanya *et al.,* (2013). K solubilising bacterial population activity was increased markedly by K- mineral fertilization along with seed inoculation of KSB in both crops and variability of microbial population in the present study might have been resulted from growth hormone production and release of organic acid by KSB inoculants with seed in soil. This result is also comparable with Basavesh (2013) and fertilizer directly improve the plant root growth and development and root exuded provide the required nutrients for microbes it intern enhance microbial growth and may affect the composition of microbial communities and similar result was also reported by (Khonje *et al.,* 1989; Naher *et al.,* 2013).

The highly significant correlation was found between different yield attributes and biological yield of maize and wheat. Yield formation in cereals is a complex coordinated process that involves the build-up and subsequent re-assimilation of yield components. These processes are under genetic control and strongly affected by environmental conditions and other management practices. Similar correlation trend was also reported by Inamullah *et al.,* (2011) in maize and Limon *et al.,* (2000) and Nasri *et al.,* (2014) in wheat.

The findings of this experimental trial suggest that crop residues can partially (if not fully) compensate for the low fertility status of the agricultural soils caused due to high cost of chemical fertilizer. A combination of chemical K-fertilizer and crop residues can be termed as an ideal technique to maintain the fertility of soil in both short and long terms. Although chemical K-fertilizer resulted in best results, it seems logical to conclude that a combination of crop residues with it will have more benefits in the long run due to slow decomposition of residues which will enhance biological (KSB) activity, improve nutrients availability and biological yield of maize and wheat under zero till environment in the following years.

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