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Effect of Summer forage crops and phosphogypsum-enriched urea on soil quality, nitrogen-use efficiency and quality of *Basmati* rice (*Oryza sativa*) and their residual effect on succeeding wheat (*Triticum aestivum*)

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ABSTRACT

A field experiment was conducted during 2007-08 and 2008-09 at New Delhi to study the effect of summer forage crops, pearlmillet [*Pennisetum glaucum* (L.) R. Br. emend. Stuntz] and cowpea [*Vigna unguiculata* (L.) Walp.] and phosphogypsum-enriched urea (PGEU) on soil quality, nitrogen-use efficiency, quality parameters and yield of *Basmati* rice (*Oryza sativa* L.) and their residual effect on succeeding wheat (*Triticum aestivum* L. emend. Fiori & Paol.) productivity under *Basmati* rice–wheat cropping system. Among the 3 forage crops grown during summer, pearlmillet + cowpea mixture recorded significantly higher fodder yields, i e 43.2 and 42.7 tonnes/ha green fodder during 2007 and 2008, respectively compared to pearlmillet sole and cowpea sole. In *Basmati* rice, soil quality, nitrogen-use efficiency, yield and quality parameters of *Basmati* rice were increased significantly due to preceding forage crops. Based on mean of 2 years data, application of 7.5% PGEU significantly increased rice yield (20.5%) and rice kernel quality parameters, viz. protein content (19.9%), hulling (11.4%) and milling (12.5%), head rice recovery (12.5%), rice grain length before (3.5%) and after cooking (6.8%) and rice grain breadth before (8.6%) and after cooking (5.5%) of *Basmati* rice than 0% PGEU. Significantly higher yield, i e 5.33 tonnes/ha and 5.55 tonnes/ha during 2007 and 2008 respectively and better quality parameters, viz. hulling, milling and head rice recovery of *Basmati* rice was obtained when it was grown after the harvest of cowpea than the other treatments. Application of 7.5% PGEU resulted in good quality *Basmati* rice with increased yield. Different summer forage crops and PGEU applied to *Basmati* rice left significant residual effect on succeeding wheat yield under *Basmati* rice–wheat cropping system.

Key words: *Basmati* rice, Phosphogypsum-enriched urea, Productivity, Quality, Soil microbial activity, Summer forage crops, Wheat

Rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) rotation is the most important cropping system in southern and eastern Asia, covering an estimated area of around 21.9 million ha in 7 countries, viz. Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan (Yadav *et al.* 2000). In the Indo–Gangetic Plains (IGP) of India, the farmers' field remains fallow for the period of around two months during summer in the rice–wheat system regions after harvesting of wheat in April till the transplanting of rice in July. In IGP of northern India, there is scarcity of green fodder during extreme summer (May–June) and therefore, farmers can grow summer forage crops like cowpea, pearlmillet or their mixture in addition to rice and wheat during this period. So far no scientific studies and their documentation have been done on this aspect.

Since the inception of 'Green Revolution' in south Asia there has been a race for increasing foodgrain (mainly rice and wheat) production using chemical fertilizers in India. However, cereal production in the country increased only five-fold, while fertilizer consumption increased more than 300 times during the 1950–51 to 2007-08 periods, implying very low fertilizer use efficiency (Prasad 2009). Large scale applications of fertilizer nitrogen (N) have also shown deleterious effects on groundwater quality, especially its nitrate content, which is harmful to health. Furthermore, gaseous losses of N as NH_3 and NOx resulting from N fertilization have adverse effects on the environment (Prasad 2009). Low N use-efficiency (NUE) in rice is a matter of great concern to the farmers as well as researchers. It generally varies from 30 to 50% under lowland situations depending on the climatic, edaphic and management factors. Worldwide, NUE for cereal crops is about only 33% and urea is the dominant form of N fertilizer applied to rice in Asia (Ladha *et al.* 2005), but it is subjected to various forms of losses including nitrification–denitrification (Prasad 2009). The slow release or controlled-release fertilizers are mainly used to reduce leaching of nutrients, especially nitrate–N (NO_3^- N) to groundwater, caused due to application

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of soluble N fertilizers to sandy or sandy loam soils. Bains *et al.* (1971) were the first to report increased NUE due to treating urea with ethanol extract of neem seed. Scientists at Indian Agricultural Research Institute, New Delhi, India have reported the nitrification–inhibiting property of neem (Singh and Shivay 2003, Shivay 2007) and neem cake coated urea (NCU) was developed and found to have higher NUE than prilled urea (Shivay 2007). However, urea–producing plants cannot procure such large amounts of neem oil or cake and thus the technology can be best adopted at cottage industries level. Hence, a field experiment was undertaken to study the effect of summer forage crops and phosphogypsum-enriched urea (PGEU) on soil biological properties, nitrogen-use efficiency, yield and quality parameters of *Basmati* rice and their residual effect on succeeding wheat productivity under *Basmati* rice–wheat cropping system.

MATERIALS AND METHODS

The field experiment was carried out during 2007-08 and 2008-09 at the research farm of the Indian Agricultural Research Institute, New Delhi (28^0 38’23"N, 77^0 09’27"E, 228.61 m above mean sea-level). The soil was sandy clay loam having 51.8% sand, 22.2% silt and 26.4% clay. The experimental soil had organic carbon content 0.54%, available N 140.8 kg/ha, available P 17.0 kg/ha and available K 276.0 kg/ha in the plough layer. The pH of the soil was 7.5 and determined in soil water suspension in the ratio of 1: 2.5 with glass electrode pH meter.

The experiment consisted of 4 summer forage crops treatment, viz. pearlmillet sole, cowpea sole, pearlmillet + cowpea and summer fallow. The summer forage crops, viz. pearlmillet (variety PCB 164) and cowpea (variety V 585) were sown in April. Summer forage crops were raised under randomized block design with 3 replications. For successful growing of summer forage crops, 2 irrigations were given during both the years. The rice field experiment was carried out in split plot design with 3 replications having 4 summer forage crops treatments, viz. pearlmillet sole, cowpea sole, pearlmillet + cowpea mixture (1:1 ratio) and fallow which were assigned to the main plot and 5 phosphogypsum-enriched urea (PGEU) levels, viz. absolute control, 0, 2.5, 5 and 7.5%, to the subplots in *Basmati* rice. The *Basmati* rice variety Pusa Basmati 1121 was used in this field study which is very fine grain variety. The 25-day-old seedlings were transplanted at 20 cm × 10 cm spacing keeping 2 seedlings/hill. Nitrogen @ 120 kg/ha was uniformly applied to all PGEU treatments. Quantity of PGEU was decided based on the N content in the respective PGEU fertilizer materials. The PGEU was applied in 2 equal split – half each at the transplanting and active tillering stages. During the growing season, the *Basmati* rice crop was kept in around 5-6 cm standing water. Wheat crop was raised on residual soil fertility in the same layout which was followed for rice cultivation.

Total Zn, Mn, Fe and Cu were determined in forage crops using a nitric-perchloric acid digest with atomic absorption spectrophotometer as per the procedure described by Prasad *et al.* (2006). Rice grain and straw samples were analyzed for total N using a Kjeldahl digestion unit as per procedures described by Prasad *et al.* (2006). Finally, the nutrient uptake was determined by multiplying dried weight of fodder crops, rice grain and straw with their respective contents.

Hulling (%): Well sun-dried paddy samples of each treatment weighing 100 g from each replication were hulled in a mini “Satake Rice Mill” and weight of brown rice was recorded, hulling percentage was calculated as:

$$\text{Hulling (\%)} = \frac{\text{Weight of brown rice (g)}}{\text{Weight of rough rice (g)}} \times 100$$

Milling (%): To obtain uniformly polished grains, the hulled brown rice was passed through Satake Rice Whitening and Caking Machine for 2 minutes. The polished rice was weighed and milling percentage was worked out as:

$$\text{Milling (\%)} = \frac{\text{Weight of milled rice (g)}}{\text{Weight of rough rice (g)}} \times 100$$

Head rice recovery: The milled produce was sieved with the help of appropriate sieves to separate whole kernels from the broken ones. Small proportion of whole kernels which passed along with broken one was hand separated. Head rice recovery (%) was computed as:

$$\text{Head rice recovery (\%)} = \frac{\text{Weight of whole milled rice (g)}}{\text{Weight of rough rice (g)}} \times 100$$

Ten grains from each replication were selected and were used for measuring their length/breadth on a graph paper using a ‘Photo Enlarger’ with a magnification of 3×. The actual mean of grain length/breadth was expressed in mm.

Ten milled rice kernels from each plot were taken at random and measured on a graph paper for their length and breadth using a ‘Photo Enlarger’ with a magnification of 3×. The actual mean kernel length and breadth was expressed in mm.

A sample of ten kernels before cooking of each replication were taken separately in long labeled test tubes and pre-soaked in 5 ml tap water for 30 min. After that, the tubes were placed in water bath (Thermotech temperature controller TH-013) maintained at boiling temperature for 6-7 min. After cooking, the tubes were taken out and cooled under running water for 2 min. Cooked kernels were taken out of the tubes and excess water was removed with a blotting paper. Length and breadth of cooked kernels were measured as above-mentioned.

Elongation ratio was calculated by dividing the length of cooked kernel by its original length.

Crude protein content in grain was obtained by multiplying N concentration with a coefficient factor 5.95 (Prasad *et al.* 2006).

Soil samples were taken from the experimental plot randomly 60 days after transplanting. Ten soil cores (5 cm diameter, 0–15 cm depth) were taken from each plot. The soil samples were put in polyethylene bags and allowed to dry and taken to the laboratory where they were thoroughly mixed and sieved (2 mm mesh) after that moisture content adjusted to 50% of water-holding capacity and, visible plant material was removed manually. The samples were then stored overnight at 5°C in the dark, and prior to biological analyses they were equilibrated to 22–25°C.

Soil microbial biomass carbon was determined by fumigation extraction method (Vance *et al.* 1987). Three replicate (25 g) soil samples from each treatment were weighed into 100 ml capacity beakers and fumigated with ethanol-free chloroform for 24 hr at 25°C. After fumigant removal, the soils were extracted with 100 ml 0.5 M K_2SO_4 for 30 min. Three replicates each of un-fumigated soil were extracted similarly at the time fumigation commenced. The organic carbon in the soil extracted was measured by dichromate oxidation and soil microbial biomass carbon (MBC) was calculated from: MBC = 2.64 EC, where EC is (organic carbon extracted from fumigated soil) minus (organic carbon extracted from un-fumigated soil). Soil dehydrogenase activity (as a measure of microbial activity) was measured by the method of Casida *et al.* (1964) and alkaline phosphatase activity (representing 'free' enzymes) was measured by Tabatabai and Bremner (1969) method.

The data relating to each character were analyzed as per the procedure of analysis of variance and significance of a randomized block design in forage crops and split plot design in *Basmati* rice was tested by *F*-test (Gomez and Gomez 1984). Standard error of means (SEm±) and critical difference (CD) at 5% level of significance were worked out for each parameter.

RESULTS AND DISCUSSION

Summer forage crop yield

Among the 3 forage crops treatment raised during summer, pearlmillet + cowpea mixture recorded significantly higher green and dry fodder yields compared to pearlmillet sole and cowpea sole (Fig 1). Percentage increase in fresh fodder yield was in the order of 15.3 and 43.4 and 17.1 and 44.7 with pearlmillet + cowpea compared to pearlmillet sole and cowpea sole during 2007 and 2008 respectively. This increase in the fresh and dry forage yields of pearlmillet + cowpea might be owing to synergistic effect of cereal and legume in mixture compared to grown individually. The forage yields in 2007 were slightly higher than that in 2008 because of favourable climatic conditions to summer forage crops in 2007 cropping season.

Micronutrient concentrations and their uptake in summer forage crops

Among the micronutrients, Zn and Mn concentration was recorded significantly higher with pearlmillet + cowpea summer forage crops treatment compared to pearlmillet sole and cowpea sole (Table 1). This might be owing to pearlmillet + cowpea which are the better combination of forage crops and also which contained higher micronutrients concentration compared to individual crop of pearlmillet and cowpea. The significantly higher Fe and Cu concentrations were recorded with summer forage cowpea sole compared to pearlmillet sole and pearlmillet + cowpea summer forage crops during both the years (Table 1). This might be due to the fact that generally legume crops in their vegetative parts contained higher Fe and Cu concentrations compared to cereals/grasses, that is why significantly lower Fe and Cu concentrations were recorded with pearlmillet sole and pearlmillet + cowpea mixture.

The nutrient uptake of any crop is the resultant of multiplication of its concentration and dry-matter accumulation. Therefore, the significantly higher uptake of the micronutrients, viz. Zn, Fe, Mn and Cu was recorded with pearlmillet + cowpea mixture treatment than pearlmillet sole and cowpea sole (Table 2). This was due to significantly higher dry matter accumulation with pearlmillet + cowpea compared to pearlmillet sole and cowpea sole.

Soil biological properties and Basmati rice productivity

Soil microbial biomass C is a small component of soil

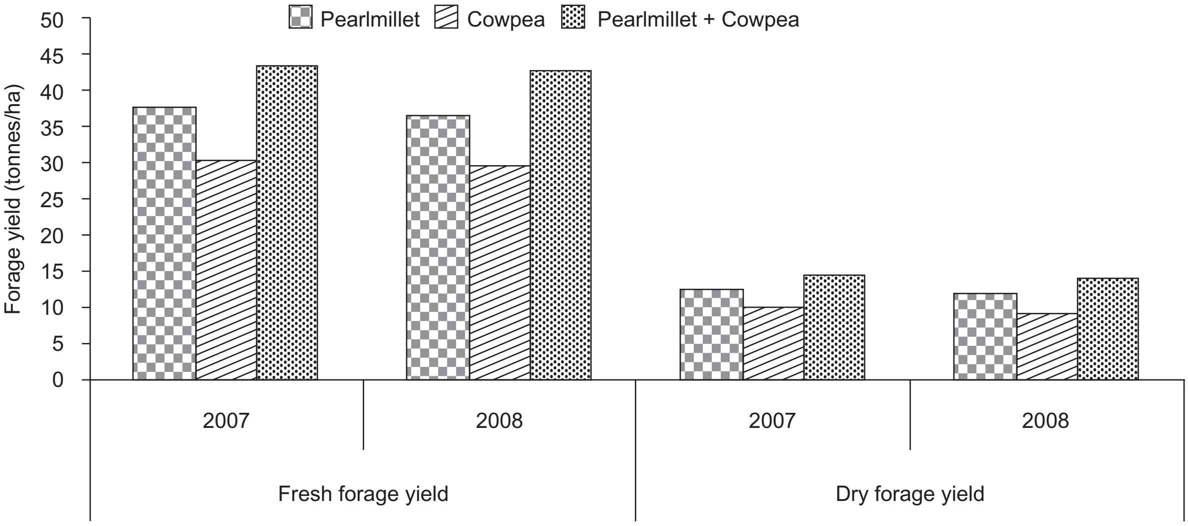

Fig 1 Fresh and dry biomass yield of different summer forage crops

Table 1 Micronutrients concentrations in summer forage crops

Treatment	Zn concentrations (mg/kg DM)		Mn concentrations (mg/kg DM)		Cu concentrations (mg/kg DM)		Fe concentrations (mg/kg DM)	
	2007	2008	2007	2008	2007	2008	2007	2008
Pearlmillet sole	118.7	118.2	29.1	28.9	40.1	39.8	131.6	128.8
Cowpea sole	132.2	131.8	35.2	34.8	44.8	44.2	194.6	193.2
Pearlmillet + Cowpea	136.8	136.8	43.6	43.3	41.9	41.4	162.4	161.0
SEm±	1.86	1.86	1.12	0.91	0.51	0.37	4.76	3.64
CD (*P*=0.05)	6.42	6.42	3.86	3.12	1.75	1.29	16.38	12.46

DM, Dry matter

Table 2 Micronutrients uptake in summer forage crops

Treatment	Zn uptake (g/ha)		Mn uptake (g/ha)		Cu uptake (g/ha)		Fe uptake (g/ha)	
	2007	2008	2007	2008	2007	2008	2007	2008
Pearlmillet sole	1 472.2	1 402.5	359.9	341.3	496.9	472.1	1 633.2	1 533.0
Cowpea sole	1 312.9	1 194.9	349.4	315.6	444.2	400.4	1 933.4	1 744.4
Pearlmillet + Cowpea	1 958.8	1 894.7	624.3	600.1	599.5	573.4	2 328.2	2 234.4
SEm±	89.70	79.87	26.82	23.20	24.20	24.35	136.22	116.34
CD (P=0.05)	309.48	275.55	92.53	80.06	83.48	84.00	469.84	401.52

organic matter and status of soil microbial biomass C and other enzymatic activity is directly related to soil organic matter content (Dhull *et al.* 2004, Jedidi *et al.* 2004). Different summer forage crops and PGEU significantly influenced soil microbial biomass C, dehydrogenase (µg TFT/g/soil/day), alkaline phosphatase (µg/g soil/h) and fluorescein diacetate (µg/g soil/h) enzyme activity. Though highest value of all these microbial activity parameters in *Basmati* rice soils was recorded after cowpea summer forage crop, it was statistically on a par with pearlmillet + cowpea during both the years. Soil microbial biomass C was 217.3 and 220.9 in summer fallow and 238.6 and 239.8 µg/g soil in cowpea sole treatment. The PGEU at 7.5% recorded significantly higher soil microbial biomass C, dehydrogenase, alkaline phosphatase and fluorescein diacetate enzyme activity over absolute control, 0 and 2.5% PGEU but remained on a par with 5% PGEU during both the years (Table 3). The increase in dehydrogenase, alkaline phosphatase and fluorescein diacetate activities with increasing level of coated material as well as summer forage crops is a reflection of organic matter builds up which led to increase in microbial activities. Similar findings are also recorded by Pooniya and Shivay (2011).

Significantly higher grain yield of *Basmati* rice was recorded when *Basmati* rice was grown after preceding cowpea forage crop which was statistically on a par with pearlmillet + cowpea and significantly better than pearlmillet summer forage crop treatment as well as fallow. The increase in grain yield of *Basmati* rice with preceding cowpea summer forage crops was in the order of 6.2 and 5.7%, 3.7 and 3.1%, 9.6 and 8.9% over pearlmillet, pearlmillet + cowpea and fallow during 2007 and 2008 respectively. This might be due to more residual effect of biological N fixed in the root nodules of previous crop of cowpea. The lowest values

Table 3 Effect of preceding summer forage crops and phosphogypsum-enriched urea on soil microbial properties and grain yield of *Basmati* rice

Treatment	Dehydrogenase activity (µg TFT/g soil/day)		Fluorescein diacetate activity (µg /g soil/h)		Grain yield (tonnes/ha)	
	2007	2008	2007	2008	2007	2008
Summer forage crops						
Pearlmillet sole	7.23	7.53	1.59	1.73	4.52	4.73
Cowpea sole	8.08	8.37	1.68	1.98	4.80	5.00
Pearlmillet + cowpea	8.00	8.09	1.64	1.90	4.63	4.85
Fallow	6.67	6.93	1.46	1.62	4.38	4.59
SEm±	0.06	0.08	0.014	0.049	0.05	0.05
CD (P=0.05)	0.22	0.28	0.050	0.169	0.20	0.20
Phosphogypsum-enriched urea						
Control	6.50	6.69	1.15	1.21	3.45	3.65
0% PGEU	7.17	7.24	1.36	1.58	4.41	4.62
2.5% PGEU	7.64	7.85	1.62	1.92	4.72	4.92
5.0% PGEU	7.95	8.28	1.83	2.06	5.01	5.22
7.5% PGEU	8.22	8.59	2.00	2.26	5.33	5.55
SEm±	0.07	0.12	0.031	0.056	0.09	0.09
CD (P=0.05)	0.21	0.36	0.088	0.161	0.26	0.26

PGEU, Phosphogypsum-enriched urea

of yield was recorded when *Basmati* rice was grown after summer fallow (Table 3). The PGEU also had significant effect on grain yield of *Basmati* rice and application of 7.5% PGEU recorded significantly higher grain yield over absolute control, 0, 2.5 and 5% PGEU. The highest grain yield of *Basmati* rice, i e 5.33 and 5.55 tonnes/ha, was recorded with 7.5% PGEU during 2007 and 2008 respectively. The increase in grain yield of *Basmati* rice at 7.5% PGEU was in the order of 54.5 and 52.1%, 20.9 and 20.1%, 12.9 and 12.8%, 6.4 and 6.3% over control, 0, 2.5 and 5% PGEU during 2007 and 2008 respectively (Table 3). This could be attributed to the controlled release of N and longer supply of mineralized N to the plants as recorded in the present study is in accordance with the findings of Bharde *et al.* (2003), Shivay (2007), Meena and Shivay (2010).

Correlation between soil biological properties and grain yield

A significantly high correlation ranging from 0.75 to 0.95 was recorded between grain yield and microbiological parameters such as dehydrogenase activity, microbial biomass carbon, alkaline phosphatase activity and fluorescein diacetate hydrolysis (Fig 2). A positive correlation between microbial parameters such as dehydrogenase activity, soil microbial biomass carbon and other related parameters emphasized further the significant role of microorganisms in nutrient cycling in soil and its interactions with plant health and productivity. Our results indicated that there is a definite improvement in soil organic matter, microbial activities and crop yield of *Basmati* rice which can be attributed to the synergistic effects of summer forage crops and PGEU. Such positive effects of summer forage and coated urea materials can help in maintaining organic matter level and sustain good crop productivity over long period of time without deteriorating soil health.

Nitrogen concentration and its uptake in rice grain and straw

The preceding summer forage crops had significant effect on N concentration in grain and straw of *Basmati* rice (Table 4). The significantly higher N concentration in grain and straw of rice was recorded when *Basmati* rice was grown after preceding cowpea forage crop, which was statistically on a par with pearlmillet + cowpea but significantly better than pearlmillet sole and fallow during both the years in straw. However, in grain N concentration after the preceding pearlmillet + cowpea forage summer crops was significantly higher than pearlmillet sole and fallow but remained statistically on a par with cowpea treatment during both the years of study. The PGEU had significant effect on N concentration in grain and straw of *Basmati* rice. Application of PGEU at 7.5% recorded significantly higher N concentration in grain of *Basmati* rice over absolute control, 0, 2.5 and 5% PGEU. However, in *Basmati* rice straw application of 5% PGEU recorded significantly higher N concentration over control and 0% PGEU and remained on a par with 2.5 and 7.5% PGEU. The highest N concentration in grain and straw of *Basmati* rice, i e 1.29 and 0.62, 1.30 and 0.63% during 2007 and 2008, respectively, were recorded with 7.5% PGEU. Nitrogen concentration in rice grain and straw was influenced

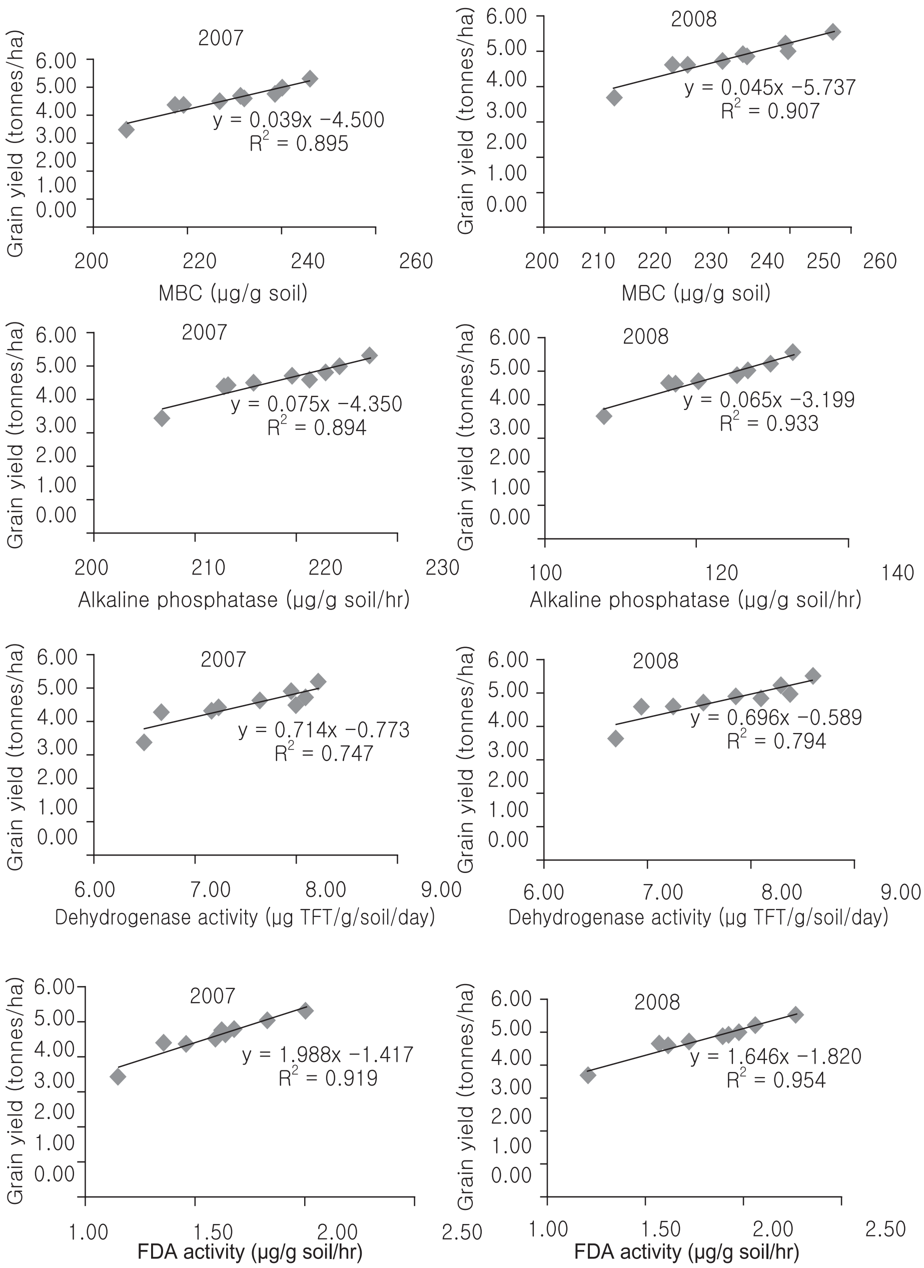

Fig 2 Correlation between soil biological properties and grain yield of *Basmati* rice (FDA, fluorescein diacetate)

Table 4 Effect of preceding summer forage crops and phosphogypsum-enriched urea on N concentration of *Basmati* rice grain, straw and their uptake

Treatment	N content (%) in grain		N content (%) in straw		N uptake by rice grain (kg/ha)		N uptake by rice straw (kg/ha)		N crop recovery efficiency (%)		N harvest index (%)	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
Summer forage crops												
Pearlmillet sole	1.12	1.12	0.56	0.56	51.4	53.8	80.8	85.5	33.4	34.7	38.5	38.2
Cowpea sole	1.18	1.18	0.62	0.63	57.7	60.1	94.8	99.3	39.2	39.8	37.7	37.2
Pearlmillet+ cowpea	1.19	1.19	0.61	0.62	55.9	58.6	89.3	93.7	36.7	37.9	38.0	38.0
Fallow	1.12	1.11	0.57	0.58	49.3	51.5	80.0	84.6	31.9	32.7	37.9	37.6
SEm±	0.019	0.020	0.004	0.003	0.93	1.09	0.70	0.62	1.21	1.22	0.29	0.35
CD (*P*=0.05)	0.066	0.069	0.013	0.011	3.21	3.78	2.42	2.15	4.18	4.21	1.02	NS
Phosphogypsum-enriched urea												
Control	0.97	0.96	0.54	0.54	33.4	35.3	64.1	67.9			34.2	34.2
0% PGEU	1.09	1.08	0.57	0.58	47.9	50.0	80.6	85.2	25.9	26.7	37.3	37.0
2.5% PGEU	1.18	1.18	0.61	0.61	55.7	58.0	90.0	94.1	40.2	40.7	38.3	38.1
5.0% PGEU	1.22	1.22	0.62	0.63	61.7	64.0	95.9	100.8	50.1	51.3	39.1	38.8
7.5% PGEU	1.29	1.30	0.62	0.63	69.3	72.5	100.6	105.9	60.3	62.8	40.8	40.6
SEm±	0.014	0.013	0.005	0.005	1.29	1.38	1.41	1.34	1.98	1.94	0.53	0.58
CD (*P*=0.05)	0.040	0.037	0.014	0.016	3.70	4.00	4.06	3.86	5.70	5.58	1.53	1.67

PGEU, Phosphogypsum-enriched urea

favourably by sources of N. Modified urea materials had beneficial effect on N concentration than prilled urea (Shivay *et al.* 2001, Kumar and Prasad 2004, Shivay 2007).

The preceding summer forage crops had significant effect on uptake of N by *Basmati* rice. The significantly higher N uptake of rice crop was recorded when *Basmati* rice was grown after preceding short duration cowpea summer forage crop (Table 4). The PGEU had significant effect on N uptake of *Basmati* rice. Application of PGEU at 7.5% recorded significantly higher N uptake over absolute control, 0, 2.5 and 5% PGEU. This might be owing to increase in the PGEU levels increased the N concentration proportionately in grain and straw and finally led to increased higher N uptake with highest level of PGEU. Our results confirm the findings of Oo *et al*. (2007), Shivay (2007) and Meena and Shivay (2010).

Nitrogen use indices

The highest crop recovery efficiency of applied nitrogen was recorded when *Basmati* rice was grown after the preceding cowpea summer forage (Table 4). In general the crop recovery efficiency was slightly lower in the first year than that in the second year. The PGEU at 7.5% resulted significantly higher crop recovery efficiency over absolute control, 0, 2.5 and 5% PGEU (Table 4). The highest crop recovery efficiency, i.e. 60.3 and 62.8 during 2007 and 2008, respectively, was recorded with 7.5% PGEU.

The preceding summer forage crops had significant effect on N harvest index of *Basmati* rice during 2007 (Table 4). The highest N harvest index was recorded when *Basmati* rice was grown after pearlmillet sole and it was significantly superior to cowpea sole but remained statistically on a par with pearlmillet + cowpea and fallow treatment. During 2008 however, preceding summer forage crops had nonsignificant effect on N harvest index of *Basmati* rice and no systematic trend was recorded with respect to N harvest index due to the preceding short-duration summer forage crops and fallow treatment. The PGEU had significant effect on N harvest index of *Basmati* rice. With each successive increase in the PGEU level there was significant increase in the N harvest index up to the highest level of PGEU, i e 7.5%. The highest and lowest N harvest index was recorded with 7.5% PGEU and absolute control.

Biochemical quality parameters of Basmati rice grain

The protein content of *Basmati* rice was recorded significantly higher when *Basmati* rice was grown after the harvest of pearlmillet + cowpea and cowpea sole than pearlmillet sole and fallow treatments (Table 5). The PGEU at 7.5% recorded significantly higher protein content over absolute control, 0, 2.5 and 5% PGEU. The highest protein content of *Basmati* rice, i.e. 7.75 and 7.8%, was recorded at 7.5% PGEU during 2007 and 2008 respectively. Oo *et al.* (2007) also reported, increase in protein content owing to ensured supply of nutrients in appropriate quantity supplied at critical growth stages through right sources.

Physical grain quality parameters

Significantly higher hulling and milling percentage was recorded when *Basmati* rice was grown after the harvest of summer forage cowpea compared to fallow. However, different summer forage crops did not affect head rice recovery significantly. With each successive increased in percentage of PGEU, there was a significant increase in hulling percentage up to 7.5% PGEU. The highest hulling and milling percentage and head rice recovery of *Basmati* rice was recorded at 7.5% PGEU (Table 5). The increase in hulling, milling and head rice recovery percentages with

Table 5 Effect of preceding summer forage crops and phosphogypsum-enriched urea on protein content, hulling, milling and head rice recovery of *Basmati* rice

Treatment	Protein content (%)		Hulling (%)		Milling (%)		Head rice recovery (%)	
	2007	2008	2007	2008	2007	2008	2007	2008
Summer forage crops								
Pearlmillet sole	6.71	6.70	65.7	66.4	53.9	54.2	45.8	45.7
Cowpea sole	7.08	7.07	66.4	67.3	55.1	55.3	46.3	46.5
Pearlmillet + cowpea	7.11	7.12	65.4	66.3	53.9	54.2	45.5	45.6
Fallow	6.67	6.64	65.0	65.9	53.6	54.1	45.5	45.6
SEm±	0.12	0.12	0.34	0.34	0.23	0.16	0.19	0.20
CD (*P*=0.05)	0.40	0.41	1.30	1.31	0.90	0.62	NS	NS
Phosphogypsum-enriched urea								
Control	5.80	5.78	60.1	61.6	47.9	48.1	39.5	39.6
0% PGEU	6.50	6.47	63.2	64.1	52.7	53.0	44.3	44.5
2.5% PGEU	7.06	7.04	66.1	66.8	54.6	55.0	46.4	46.4
5.0% PGEU	7.35	7.32	68.5	69.0	56.1	56.5	47.8	47.9
7.5% PGEU	7.75	7.80	70.6	71.2	59.3	59.6	50.9	50.8
SEm±	0.09	0.07	0.46	0.48	0.34	0.29	0.26	0.27
CD (*P*=0.05)	0.25	0.22	1.32	1.39	0.97	0.82	0.75	0.76

PGEU, Phosphogypsum-enriched urea

different levels of PGEU might be due to increase in N concentrations of grain which led to increase in protein content and decreased breakage loss. Rani (2003) and Shivay (2007) also reported that the varieties with higher protein content suffered less breakage and increased hulling, milling and head rice recovery percentages.

Cooking grain quality parameters

The preceding short-duration summer forage crops had significant effect on rice grain length before and after cooking and rice grain breadth after cooking of *Basmati* rice. However, rice grain length expansion ratio, rice grain breadth before cooking, grain breadth expansion ratio did not influence significantly due to summer forage crops (Table 6). This might be due to the fact that most of these parameters of rice cooking quality are very fine in nature and these are generally governed by genetic characters/ hereditary make up of a variety. Similar results were also reported by Rani (2003). Application of 7.5% PGEU was found best treatment in terms of rice grain length before

Table 6 Effect of preceding summer forage crops and phosphogypsum-enriched urea on cooking quality of *Basmati* rice

Treatment	Rice grain length before cooking (mm) L_1		Rice grain length after cooking (mm) L_2		Rice grain length expansion ratio (L_2/L_1)		Rice grain breadth before cooking (mm) B_1		Rice grain breadth after cooking (mm)B_2		Rice grain breadth expansion ratio (B_2/B_1)	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
Summer forage crops												
Pearlmillet sole	7.0	7.0	14.7	14.8	2.10	2.11	1.58	1.60	2.29	2.30	1.45	1.44
Cowpea sole	7.2	7.2	14.9	15.0	2.07	2.08	1.60	1.62	2.33	2.34	1.46	1.44
Pearlmillet + Cowpea	7.1	7.1	14.7	14.8	2.07	2.08	1.59	1.61	2.30	2.31	1.45	1.43
Fallow	7.0	7.0	14.5	14.6	2.07	2.08	1.58	1.59	2.27	2.28	1.44	1.43
SEm±	0.05	0.05	0.08	0.08	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CD (*P*=0.05)	0.19	0.19	0.29	0.30	NS	NS	NS	NS	0.05	0.05	NS	NS
Phosphogypsum-enriched urea												
Control	6.3	6.2	12.8	12.8	2.03	2.06	1.36	1.37	2.07	2.06	1.52	1.50
0% PGEU	7.1	7.1	14.6	14.9	2.06	2.10	1.56	1.58	2.28	2.29	1.46	1.45
2.5% PGEU	7.2	7.2	15.0	15.1	2.08	2.10	1.65	1.66	2.34	2.35	1.42	1.42
5.0% PGEU	7.3	7.3	15.4	15.5	2.11	2.12	1.68	1.70	2.39	2.41	1.42	1.42
7.5% PGEU	7.3	7.4	15.7	15.8	2.15	2.14	1.69	1.72	2.40	2.42	1.42	1.41
SEm±	0.07	0.07	0.14	0.14	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01
CD (*P*=0.05)	0.21	0.21	0.39	0.39	0.06	0.06	0.05	0.05	0.07	0.07	0.04	0.04

PGEU, Phosphogypsum-enriched urea

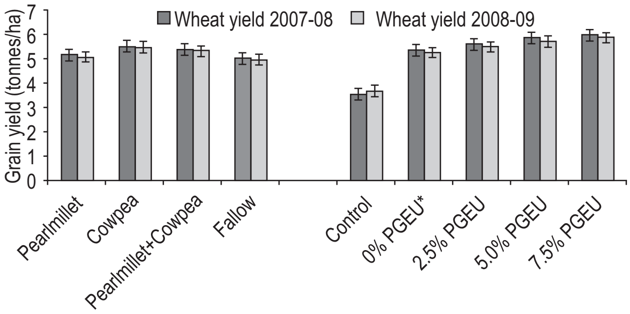

Fig 3 Residual effect of preceding summer forage crops and phosphogypsum-enriched urea on wheat productivity

and after cooking, rice grain breadth before and after cooking, rice grain length expansion ratio and rice grain breadth expansion ratio followed by 5% PGEU (Table 6). These results confirm the findings of Shivay (2007) who also reported that modified urea fertilizers affected the aromatic rice cooking quality parameters.

Residual effect on succeeding wheat

Among the short-duration summer forage crops cowpea sole and pearlmillet + cowpea had significant effect on succeeding wheat (Fig 3). The highest yield was recorded when succeeding wheat was grown after the short-duration summer forage cowpea sole and it was significantly superior compared to summer fallow and pearlmillet sole treatments, however, it remained statistically on a par with pearlmillet + cowpea mixture. The PGEU had also a significant residual effect on yield of succeeding wheat. Each successive increase in the PGEU had significant effect on succeeding wheat yield. These results are in accordance with the findings of Bharde *et al.* (2003) and Pooniya and Shivay (2011).

It can be concluded that among 3 forage crop treatments grown during the summer, pearlmillet + cowpea mixture recorded significantly higher green and dry fodder yields compared to pearlmillet sole and cowpea sole. For enhancing productivity and quality of *Basmati* rice, nitrogen use-efficiency and soil microbial activity, enrichment of urea with 7.5% phophogypsum found beneficial and its significant residual effect was also observed on succeeding wheat. Inclusion of short-duration summer forage crops like, cowpea or pearlmillet + cowpea mixture in conjunction with application of 7.5% PGEU would be sufficient to sustain the productivity of *Basmati* rice-wheat cropping system in the Indo-Gangetic plains. This is also an important finding for increased nutrient recycling and sustaining soil fertility for long term productivity of *Basmati* rice under this intensive cropping system in the south Asia.

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