Nutrient Uptake and Related Efficiencies in a Fodder Sorghum (*Sorghum bicolor* L.) – Mustard (*Brassica juncea* L.) Cropping Sequence as Influenced by Nitrogen, Phosphorus and Bio-inoculant inputs

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Abstract

The productivity of mustard in North West India is low especially when it is preceded by crops like fodder sorghum and is mainly due to improper or imbalanced use of nutrient inputs. An experiment involving fodder sorghum-mustard sequence was carried out during 2003-04 and 2004-05 at the Research farm of Agronomy Division, Indian Agricultural Research Institute, New Delhi, India. The objective of experiment was to study the effect of N, P and biofertilizers [Azotobacter and phosphate solubilizing bacteria (PSB)] on the productivity, nutrient dynamics and economic viability of a fodder sorghum – mustard sequential system. It was observed that the fodder yield of sorghum with recommended dose of fertilizers (RDF, 60 kg N + 12.9 kg P ha^{-1}) and half RDF + biofertilizers on fresh as well as dry weight basis was statistically similar and superior to half RDF and control. Observations on succeeding crop of mustard showed that the seed yield was highest due to applied RDF (residual or direct) was on par with that of half RDF + biofertilizers. The mustard seed equivalent yield had similar trend as seed yield of mustard. Agronomic efficiency and apparent recovery efficiency of N in mustard and also b:c ratio of fodder sorghum-mustard sequence were highest with directly applied half RDF + biofertilizers treatment.

1. Introduction

Oilseed, *Brassicas* provide almost 15% of world's edible vegetable oil. Rapeseed – mustard are the premier winter oilseed crops in India. These crops occupied 6.33 million hectares with a total production of 6.69 million tonnes (Banga and Banga, 2009). It is the third most important oilseed crop next to groundnut and soybean in India. Maximum area by rapeseed-mustard is occupied in North Western India. Though, 68 % of the cropped area is raised under irrigated conditions, the productivity levels are still low (1056 kg ha^{-1}) accounting for only 56% of the world's average mustard productivity (1889 kg ha^{-1}). Imbalanced use of organic and inorganic fertilizers and poor adoption of improved agronomic practices besides other factors are mainly responsible for low productivity of mustard. Mustard being an exhaustive and energy rich crop, responds well to nutrients application, especially under irrigated conditions. Increases in biomass production and yield in response to N supply have been observed in mustard (Bilsborrow *et al*., 1993; Wright *et al*., 1988). Variable linear response of mustard to N fertilization in multi-location experiments have been reported by Singh *et al*. (1998) upto 80 kg ha^{-1}, 100 kg ha^{-1} by Aulakh and Pasricha (1998) and 120 kg ha^{-1} by Patil *et al*. (1996). Response of mustard to P varied from 30 to 60 kg ha^{-1} (Narang *et al*., 1993) depending on the soil moisture and available P supply. Due to it's ability to produce more with less water, mustard can be a potential crop in double cropping sequences vis-à-vis maize-mustard, mung/urd-mustard, sorghum-mustard and rice–mustard.

In recent times, demand for fodder has increased in North West India due to growth in dairy sector which in turn is driven by increased purchasing power. *Kharif* (monsoonal rainy season) fodder sorghum accounts for more than 60 % of fodder supply in North West India. Fodder sorghum due to its ability to withstand drought, water logging, rejuvenation capacity, quick growth, high yielding ability, palatability and wider adaptability makes it an ideal forage crop. Being a heavy feeder due to high plant population, it exhausts soil fertility and inhibits succeeding crop growth and productivity. Unless

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the nutrients exhausted by preceding sorghum are replenished, high productivity from succeeding mustard crop may not be feasible (Mishra, 2003).

Though, more than 50% enhancement in yield over the years has been attributed to inorganic fertilizers, its continuous usage, affects long-term soil fertility and in turn crop productivity, while threatening environmental safety. Crops grown in a definite sequence may require differential application of nutrients through organic, inorganic and biofertilizers (Solaippan, 2002). Judicious mix of organics and inorganics is highly essential to sustain the productivity of a given cropping system (Singh and Yadav, 1992). Considering the problems and challenges, bio-inoculants or biofertilizers like *Azotobacter* and phosphate solubilizing bacteria (PSB) have been suggested to economise on N and P fertilizers, besides attaining social, economical and environmental benefits. They not only supply N and P, respectively but also improve the nutrient use efficiency. The objective of this study was to investigate the direct and residual effect of N, P and bio inoculants on fodder sorghum-mustard cropping system in terms of production potential, nutrient dynamics and economic viability.

2. Materials and Methods

Field experiments were conducted at the Research farm of Division of Agronomy, Indian Agricultural Research Institute, New Delhi, India during 2003-04 and 2004-05 under irrigated conditions. The experimental site was sandy loam in texture having 63.7 % sand, 19.7% silt and 16.6% clay content. Soil chemical analysis for nutrients was conducted by using the Subbiah and Asija (1956) procedure for determination of available N, Olsen's method for available P (Olsen et al., 1954), 1 N ammonium acetate method for available K (Hanway and Heidel, 1952) and the chromic acid oxidation method for organic carbon (Walkey and Black, 1934). The experimental soil was tested low in available N (135.5 kg N ha^{-1}), medium in available P (18.5 kg P ha^{-1}) and K (225.5 kg K ha^{-1}) and low in organic carbon content (0.43 %), while the pH of soil was 7.1. The average maximum and minimum temperatures during fodder sorghum growing season (last week of June to first week of September) were 34.5 ^{o}C and 26.6 ^{o}C, respectively and during mustard growing season (October to March), it was 25.4 ^{o}C and 11.6 ^{o}C, respectively. The average (2003-04 and 2004-05) rainfall received during fodder sorghum and mustard growing seasons was 320.4 mm and 88.9 mm.

The experiment for fodder sorghum was laid out in randomized block design (RBD) replicated thrice with four treatments viz., control, half of the recommended dose of fertilizer (RDF) i.e., 30 kg N + 6.45 kg P ha^{-1}, RDF (60 kg N + 12.9 kg P ha^{-1}) and half RDF + biofertilizers (*Azotobacter* + PSB). Six treatments namely ontrol, 40 kg N ha^{-1}, 80 kg N ha^{-1}, half RDF, RDF (80 kg N + 17.2 kg P ha^{-1}) and half RDF + biofertilizers (*Azotobacter* + PSB) replicated thrice in split plot design (SPD) was followed in mustard (post rainy season) . The bio-inoculants *Azotobacter chroococcum* and *Pseudomonas striata* (PSB) were used for treating fodder sorghum and mustard seeds @ 600 g ha^{-1} just before sowing. N and P in the form of urea and single super phosphate, respectively were applied as per the treatments. In both the crops, half dose of nitrogen and full dose of phosphorus were applied just before sowing. The remaining half dose of N was applied as top dressing at 30 days after sowing (DAS) in sorghum and after the first irrigation (53 DAS) in mustard during both the years of experimentation.

Pusa Chari-9, a single cut fodder sorghum cultivar was sown at 30 x 10 cm^2 during the *kharif* season. It is a medium thick stemmed, no-sweety and pithy with the potentiality of producing green fodder upto 42.5 t ha^{-1}. Mustard variety *Pusa Jagannath* was grown at a spacing of 45x10 cm^2 during *rabi* (post-rainy) season matures in 125 days yielding 2.9 t ha^{-1}. Growth and yield parameters observered and samples were analysed for total N using micro-Kjeldahl method, while total P was determined using sulphuric-nitric-perchloric tri-acid digest as per procedure suggested by Prasad (1998). Data obtained from fodder sorghum and mustard for consecutive years were statistically analysed following Gomez and Gomez (1984).

The indices of N use viz. agronomic efficiency, apparent recovery efficiency of N and nitrogen use efficiency (NUE) were calculated by using the formulae given below:

$$\text{Agronomic efficiency (kg grain kg}^{-1}\text{ N applied)} = \frac{\text{Grain yield in fertilized crop - Grain yield in unfertilized crop (in kg ha}^{-1})}{\text{Quantity of N applied (kg ha}^{-1})}$$

$$\text{Apparent recovery efficiency of N (kg N uptake kg N applied}^{-1}) = \frac{\text{Grain yield in fertilized crop - Grain yield in unfertilized crop kg ha}^{-1})}{\text{Quantity of N applied (kg ha}^{-1})}$$

(Crasswell and Godwin, 1984)

$$\text{Partial factor productivity} = \frac{\text{Yield in N applied plot (kg ha}^{-1})}{\text{Quantity of N applied (kg ha}^{-1})}$$

Baligar et al., 2001

3. Results and Discussion

3.1. Fodder sorghum

3.1.1. Yield and nutrient uptake

A perusal of data in table 1 indicated that green and dry fodder yields of sorghum were highest when the crop received recommended dose of fertilizer (RDF) i.e., 60 kg N + 12.9 kg

P ha^{-1}. However, green and dry fodder yields obtained with half RDF + biofertilizers was statistically on par with that of RDF. Application of RDF and half RDF + biofertilizers enhanced sorghum dry fodder yield by 45.8 and 41.2 % over control. On the contrary, the crude protein concentration and yield (table 1) of fodder sorghum were significantly higher due to application of RDF (60 kg N + 12.9 kg P ha^{-1}). The better performance of fodder sorghum with RDF was mainly due to the availability of N and P nutrients in adequate amounts and the comparable performance of half RDF + biofertilizers might be due to utilization of N and P supplied through inorganic fertilizers in the initial stages and N and P fixed and mobilized by *Azotobacter* and PSB, respectively, in the later phases of crop development (Kumar and Sharma, 1999). Application of half RDF + biofertilizers not only saves half the dose of N and P but also improves soil health by producing growth hormones, antifungal substances and vitamins which can contribute to sustained crop productivity.

3.1.2. Residual effect of nutrients applied in mustard (post-rainy season, 2003-04) on fodder yield of sorghum in succeeding rainy season, 2004

The green fodder yield of sorghum grown after mustard supplied with RDF (80 kg N + 17.2 kg P ha^{-1}) was significantly higher than that of other residual treatments except residual half RDF + biofertilizers. Residual RDF and half RDF + biofertilizers enhanced the dry fodder yield of sorghum by 31.6 and 27.0%, respectively over control (table 2).

3.2. Residual effect on succeeding mustard

3.2.1. Growth parameters

The residual effect of treatments imposed in fodder sorghum and also directly applied nutrients to mustard had significant effect on total biomass accumulation, number of branches plant^{-1} and leaf area index but had no significant influence on plant height of mustard (Table 3). The residual or direct effect of application of RDF resulted in significantly more leaf area index and number of branches plant^{-1}. However, RDF and half RDF + biofertilizers (previously or directly applied) were on par in case of number of branches plant^{-1}.

3.2.2. Yield attributes and seed yield of mustard

The nutrient management practices followed in fodder sorghum and mustard exerted marked and significant variation in yield attributes, seed and stover yield and total biomass accumulation in mustard plant (table 3). Residual RDF (60 kg N + 12.9 kg P ha^{-1}) (1.69 t ha^{-1}) enhanced the mean seed yield of mustard by 19% over residual control and 11% over half RDF, however, at par with residual half RDF + biofertilizers (1.66 t ha^{-1}). Stover yield and total biomass accumulation of mustard crop followed similar trend of seed yield (Table 3).

In respect of direct effect, seed, stover and total biomass accumulation of mustard were lowest in unfertilized control. These parameters started increasing with increase in N dose up to 80 kg N ha^{-1}. Application of half the doses of N and P had out yielded the 40 or 80 kg N ha^{-1}. Application of RDF to mustard resulted in 43.0, 21.6, 17.6 and 9.0% increase in seed yield over control, 40 kg N ha^{-1}, 80 kg N ha^{-1}, half RDF. However, RDF and half RDF + biofertilizers significantly out yielded other treatments in the experiment.

Residual RDF (60 kg N + 12.9 kg P ha^{-1}) resulted in significantly higher seed yield of mustard (1.69 t ha^{-1}) than that of other residual treatments barring residual half RDF + biofertilizers (1.66 t ha^{-1}). It was mainly due to significantly higher dry matter production, photosynthetic leaf area, number of branches plant^{-1}, number of siliquae and seed weight plant^{-1}. In Mustard crop, highest seed yield (1.80 t ha^{-1}) was obtained when the crop was fertilized with RDF (80 kg N + 17.2 kg P ha^{-1}). This could be ascribed to many reasons like 1. Adequate supply of N and P brought out significant improvement in total biomass production (table 3). 2. This finally resulted in better transformation of photosynthates into yield attributes from source. 3. Ultimately better transformation of yield attributes into higher economic yield (Singh and Brar, 1999 and Singh, 2003). RDF significantly out yielded all other treatments and gave 4.05, 11.1, 17.6, 21.6 and 42.9 % more seed yield than that of half RDF + biofertilizers, half RDF, 80 and 40 kg N ha^{-1}

Table 1: Effect of N, P and bio-inoculants on fodder, crude protein yield and returns of fodder sorghum

Treatments	Green fodder yield (t ha^{-1})		Dry fodder yield (t ha^{-1})		Agronomic efficiency (avg. over two years)	Crude protein concentration (%)		Crude protein yield (kg ha^{-1})	
	2003-04	2004-05	2003-04	2004-05		2003-04	2004-05	2003-04	2004-05
Control	20.0	21.6	4.00	4.30	-	5.7	5.0	228	215
Half RDF	25.2	23.7	5.00	4.70	23	6.2	5.2	310	244
RDF	30.7	30.5	6.10	6.00	32	7.1	6.0	433	360
Half RDF + biofert	28.9	29.9	5.80	5.90	57	6.4	5.7	371	336
LSD (p=0.05)	4.2	2.1	0.80	0.48	-	0.6	0.3	-	-

RDF: 60 kg N + 12.9 kg P ha^{-1}; Biofert: *Azotobacter* + PSB

Table 2: Residual effect of nutrients applied to mustard (post-rainy season 2003-04) crop on yield of fodder sorghum in the succeeding season (rainy season, 2004)

Treatments	Fodder yield (t ha^{-1})	
	Green	Dry
Control	23.3	4.50
40 kg N ha^{-1}	24.9	4.98
80 kg N ha^{-1}	25.7	5.10
Half RDF	26.8	5.40
RDF	29.6	5.92
Half RDF + Biofert	28.5	5.73
LSD (*p*=0.05)	1.1	0.22

RDF (mustard): 80 kg N + 17.2 kg P ha^{-1};
Biofert: *Azotobacter* + PSB

and control, respectively. However, the seed yield of mustard obtained due to RDF was found to be at par with that of half RDF + biofertilizers. The phenomenon of similar performance of half RDF + biofertilizers with that of RDF could be deduced that *Azotobacter* and PSB , which were cheaper sources of N and P, respectively were efficient in improving the growth, yield attributes and nutrient utilization by mustard crop.

3.2.3. Quality parameters

Residual treatments did not show any significant effect on oil content of mustard seeds. However, mustard seed oil content was significantly influenced by directly applied nutrients during first year (table 4). Data clearly showed that unfertilized control in mustard gave higher oil content (38.5%), which was suppressed with increase in N dose up to 80 kg ha^{-1}. There after, it started improving with the supply of P and reached highest level with RDF and half RDF + biofertilizers. This phenomenon could be attributed to degradation of carbohydrates to acetyl CO-A in tricarboxylic acid (TCA) cycle by N (Mahler and Cardes, 1971) and also increase in protein content (table 4), thus suppression of oil synthesis. This result was in accordance with the studies of Joshi et al., (1998).

Table 3: Effect of N, P and bio-inoculants on growth parameters of mustard

Treatments	Plant height (m)		LAI at 135 DAS		No. of branches $plant^{-1}$		No. of Siliquae $plant^{-1}$		Seed weight $plant^{-1}$		Seed yield (t ha^{-1})		Stover yield (t ha^{-1})		Total biomass (t ha^{-1})	
	1st yr	2nd yr	1st yr	2nd yr	1st yr	2nd yr	1st yr	2nd yr	1st yr	2nd yr	1st yr	2nd yr	1st yr	2nd yr	1st yr	2nd yr
Residual effect																
Control	1.21	1.15	0.103	0.107	10.3	10.6	177.3	177.7	12.0	12.8	1.35	1.49	4.60	5.06	5.04	6.54
Half RDF	1.21	1.20	0.106	0.113	11.3	12.5	181.7	184.0	12.5	13.4	1.49	1.54	4.92	5.27	6.41	6.80
RDF	1.26	1.26	0.117	0.121	15.4	15.5	189.0	192.0	13.2	14.1	1.66	1.72	5.43	5.68	7.09	7.39
Half RDF+B	1.28	1.22	0.094	0.115	14.4	14.6	187.0	190.0	12.9	14.4	1.67	1.67	5.28	5.47	6.95	7.13
LSD (*p*=0.05)	NS	NS	NS	0.016	1.0	2.4	NS	8.8	NS	0.8	0.15	0.05	0.25	NS	0.34	NS
Direct effect																
Control	1.17	1.11	0.075	0.080	9.8	10.8	161.5	154.0	9.80	10.6	1.31	1.21	4.20	4.24	5.51	5.45
40 kg N ha^{-1}	1.19	1.17	0.091	0.095	11.2	11.7	164.7	165.8	11.9	12.8	1.39	1.56	4.53	4.99	5.89	6.54
80 kg N ha^{-1}	1.22	1.20	0.104	0.110	12.0	12.4	179.3	182.5	12.2	14.2	1.45	1.61	4.83	5.15	6.28	6.76
Half RDF	1.25	1.24	0.114	0.125	13.7	13.9	189.5	189.8	13.5	14.6	1.61	1.69	5.22	5.51	6.84	7.20
RDF	1.33	1.27	0.125	0.143	16.1	15.9	212.5	216.5	14.7	15.4	1.80	1.80	5.97	6.47	7.76	8.27
Half RDF+B	1.29	1.25	0.121	0.134	14.4	15.0	205.5	207.0	13.7	14.5	1.70	1.75	5.67	5.86	7.32	7.60
LSD (*p*=0.05)	NS	NS	0.010	0.010	1.3	1.6	11.0	9.5	NS	1.5	0.11	0.05	0.24	0.67	0.31	0.68

1st yr: 2003-04 2nd yr: 2004-05; B: *Azotobacter* + PSB

Oil and protein yields were significantly affected by preceding and directly applied nutrients to mustard (table 4). Residual effect of RDF and half RDF + biofertilizers were statistically similar and both significantly out yielded half RDF and control. Regarding direct effect, oil and protein yields improved gradually and reached the highest with RDF (80 kg N + 17.2 kg P ha^{-1}). However, it remained at par with half RDF + biofertilizers with regard to oil yield. The data also revealed that, O/P ratio declined mainly due to continuous increase in protein content of mustard seeds.

3.2.4. Removal of N and P

N and P removal by mustard was significantly influenced

Treatments	Oil content (%)		Oil yield (kg ha^{-1})		Protein content (%)		Protein yield (kg ha^{-1})		Oil/ Protein ratio (avg. of two years)
	1st yr	2nd yr	1st yr	2nd yr	1st yr	2nd yr	1st yr	2nd yr	
Residual effect									
Control	37.3	37.2	506.8	554.7	15.7	15.5	212.2	231.0	2.39
Half RDF	37.6	37.1	560.9	572.3	17.1	16.1	258.8	248.2	2.25
RDF	38.3	37.8	637.7	641.5	17.7	17.6	295.8	304.3	2.15
Half RDF + Biofert	38.3	38.3	643.0	631.2	17.3	17.4	290.2	291.4	2.21
LSD (*p*=0.05)	NS	NS	44.1	NS	NS	NS	38.1	29.8	-
Direct effect									
Control	38.5	38.0	504.8	456.2	14.3	15.3	186.5	185.6	2.59
40 kg N ha^{-1}	37.2	37.0	504.7	573.2	15.2	15.9	207.2	246.1	2.38
80 kg N ha^{-1}	36.6	36.6	533.1	580.2	15.9	16.3	229.7	261.8	2.27
Half RDF	37.5	37.1	608.6	628.4	18.3	16.9	298.8	287.8	2.12
RDF	39.5	39.2	710.4	704.9	19.3	18.1	346.6	328.9	2.10
Half RDF + Biofert	38.7	37.9	660.0	655.4	18.5	17.4	316.7	302.3	2.13
LSD (*p*=0.05)	1.2	NS	49.7	40.3	1.0	1.1	23.9	18.8	-

Table 4: Effect of N, P and bio-inoculants on quality parameters of mustard

1st yr: 2003-04 2nd yr: 2004-05

by residual and direct effect of nutrients application (table 5). Residual RDF and half RDF + biofertilizers being at par removed N (78.3 and 75.6 kg ha^{-1}) and P (29.3 and 29.7 kg ha^{-1}) in significantly greater amounts than residual half RDF and control. Direct application of RDF (80 kg N + 17.2 kg P ha^{-1}) to mustard enabled plants to remove significantly higher amounts of N and P than rest of treatments.

3.2.5. *Indices of N use*

The response of mustard declined with increasing increments in N (agronomic efficiency). However, response was high when mustard seeds were treated with biofertilizers besides N and P supply. The positive role of biofertilizers in increasing the agronomic efficiency was observed (table 5). Mustard plants removed highest amount of N (apparent recovery efficiency of N) (78.9 kg ha^{-1}) when fed with half RDF + biofertilizers. Same is true with amount of grain produced kg^{-1} N applied (Partial factor productivity). The decline in response of mustard with the addition of N (agronomic efficiency) in the present investigation was in accordance with that of Dreceer et al. (2000) who reported similar results in wheat and oilseed rape. However, response was high when mustard seeds were treated with biofertilizers besides N and P supply. The results indicate positive role of biofertilizers in increasing the agronomic efficiency (table 5). Same is true with apparent recovery efficiency of N (78.9 kg ha^{-1}) and partial factor productivity.

3.3. *System productivity, production efficiency and economic returns of fodder sorghum - mustard cropping system*

The highest mustard equivalent yield, N and P removal (Figure 1) in fodder sorghum-mustard sequence was obtained due to residual and as well with directly applied RDF. It was significantly superior to rest of the treatments. Highest amount of gross and net returns were obtained due to application of RDF. On the contrary, B:C ratio was highest (2.41 and 2.38) with the integrated application of half RDF + biofertilizers (table 5).

3.4. *Nutrient dynamics*

The Figure 2 and 3 revealed that in most of the treatments

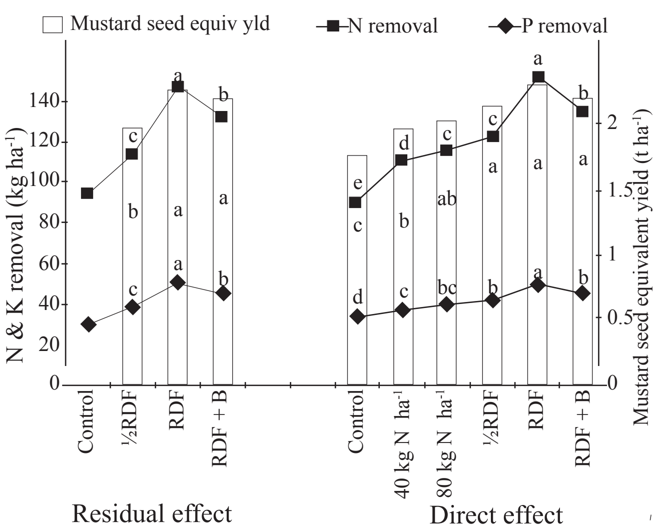

Figure 1: Effect of N, P and bio-inoculants on mustard equivalent yield, N and P removal by fodder sorghum-mustard sequence (averaged over 2 years)

Table 5: Effect of N, P and bio-inoculants on N and P uptake, indices of N use in mustard and monetary returns in fodder sorghum-mustard cropping sequence (averaged over 2 years)

Treatments	Nr	Pr	AE	ARE	PFP	GR	NR	B:C ratio
Residual effect								
Control	58.7	22.3	4.88	32.3	-	29774	19867	2.00
Half RDF	65.9	25.2	5.33	39.0	50.7	32689	22012	2.06
RDF	78.3	29.3	4.54	50.5	28.3	37307	25862	2.26
Half RDF+B	75.6	27.7	3.54	43.2	55.3	36410	25721	2.41
LSD (*p*=0.05)	6.1	4.3	-	-	-	-	-	-
Direct effect								
Control	48.3	18.6	-	-	-	28859	19082	2.95
40 kg N ha^{-1}	58.4	22.4	4.99	25.3	37.3	32155	21944	2.15
80 kg N ha^{-1}	64.9	24.5	3.37	20.6	19.1	33314	22667	2.12
Half RDF	74.9	27.4	6.67	68.9	40.5	35483	24681	2.28
RDF	91.1	34.1	4.61	53.6	22.5	37987	26080	2.19
Half RDF+B	80.5	29.7	7.70	78.9	43.3	36553	25739	2.38
LSD (*p*=0.05)	4.8	2.6	-	-	-	-	-	-

1st yr: 2003-04 2nd yr: 2004-05; RDF for fodder sorghum: 60 kg N + 12.9 kg P ha^{-1}; RDF for mustard: 80 kg N + 17.2 kg P ha^{-1}; B: *Azotobacter* + PSB; Nr: N removal (kg ha^{-1}); Pr: P removal (kg ha^{-1}); AE: Agronomic efficiency (kg grain increase kg N $applied^{-1}$); ARE: Apparent recovery efficiency of N (% N absorbed kg N $applied^{-1}$); PFP: Partial factor productivity of N (kg grain kg N $applied^{-1}$); GR: Gross returns (₹ ha^{-1}); NR: Net returns (₹ ha^{-1})

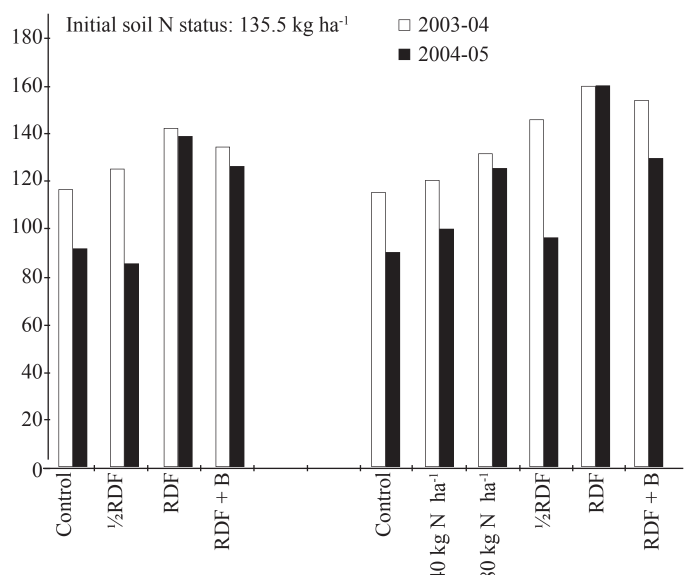

Figure 2: Post harvest soil N status

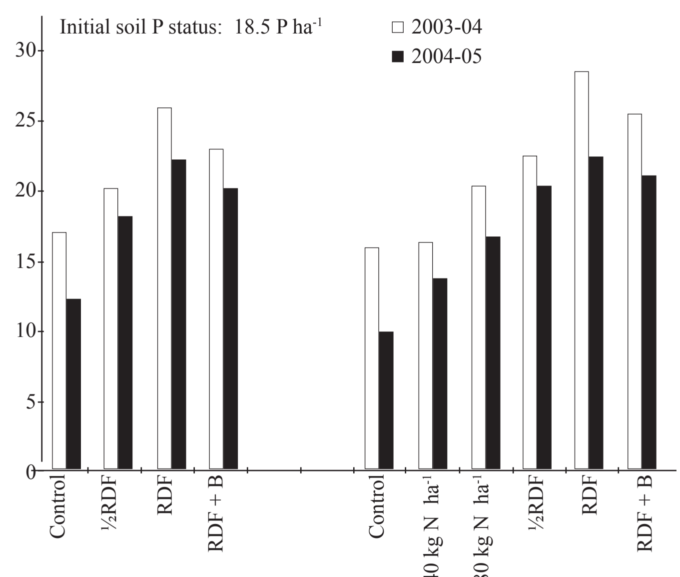

Figure 3: Post harvest soil P status

under test, the nutrient status declined continuously from the initial status of 135.5 kg N and 18.5 kg P ha^{-1}. However, the N status improved from 135.5 to 160.0 and 160.4 kg ha^{-1} in the treatment where RDF was applied. Next best treatment was half RDF+biofertilizers.

Residual RDF and half RDF + biofertilizers being at par , removed N and P in significantly greater amounts than residual half RDF and control. Direct application of RDF (80 kg N + 17.2 kg P ha^{-1}) enabled mustard plants to remove significantly higher amounts of N and P than rest of treatments. It could be ascribed to higher dry matter and total biomass accumulation (table 3) and nutrient concentration (data not shown). Mean uptake by mustard due to directly applied RDF increased to the tune of 13.2 and 40.4 % compared to half RDF + biofertilizers and 80 kg N ha^{-1}, respectively. In case of P, it was greater by 14.8 and 39.2 % higher.

4. Conclusion

The present study revealed that integrated application of half RDF + biofertilizers resulted in mustard seed and mustard equivalent yield that were on par with that of RDF but b:c ratio of the system was obtained with half RDF + biofertilizers alone. The study suggests that nutrients were better utilized by the system when bio sources of nutrients were applied in conjunction with inorganic sources by reducing half the dose of N and P, thus providing a means to save inorganic resources.

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