*Indian Journal of Agronomy* **57** (3): 222–228 (September 2012)

**Research Paper**

# Long-term effects of integrated nutrient management on productivity and soil fertility in pearlmillet (*Pennisetum glaucum*) – mustard (*Brassica juncea*) cropping sequence

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Received : January 2012; Revised accepted : May 2012

## ABSTRACT

A field experiment on integrated nutrient management (INM) was initiated during *kharif* season 1997 at Gwalior under pearlmillet [*Pennisetum glaucum* (L.) R. Br. Emend. Stutz] — mustard [*Brassica juncea* (L.) Czern. & Coss.] cropping sequence. The treatment 100% NPK + Farmyard manure (FYM) (@10t/ha/year) + *Azotobacter* + phosphate solubilising bactria (PSB) provided highest yield of straw (8.60 t/ha and 6.79 t/ha) and grain (4.07 t/ha and 2.34 t/ ha) with net monetary returns (30,695 ₹/ha and 36,514 ₹/ha) in pearlmillet and mustard respectively and recorded the highest system productivity (10.0 t/ha). This treatment also increased OC (0.52%), available N (238 kg/ha), $P_2O_5$ (24.8 kg/ha), and $K_2O$ (218 kg/ha), sustained soil pH (7.54) and EC (0.23 dS/m) over all other treatments. Continuous application of organic manure along with optimal dose of fertilizer (100% NPK+FYM @10t/ha/Y) was beneficial in enhancing crop productivity and soil fertility. Treatment receiving seed inoculants (*Azotobacter* and PSB), and FYM in combination with chemical fertilizers showed positive influx of N, P and K over unfertilized control and other combinations of fertility. The B: C ratio was higher for chemical fertilizer along with *Azotobacter* and PSB in pearlmillet (4.0) due to lesser cost of cultivation compared to other treatments, where as it was highest (4.0) with 100% NPK+FYM (@10t/ha/year) + *Azotobacter* + PSB in mustard. Thus, INM with organic manure, inoculants and chemical fertilizers not only provided higher productivity but also sustained the soil fertility.

***Key words :*** Fertility status, Integrated nutrient management, Long term study, Pearlmillet-mustard cropping sequence

Pearlmillet is the fourth most important cereal and widely grown in India because of its tolerance to drought, high temperature and low soil fertility. Pearlmillet grain is the staple diet and nutritious source of vitamins, minerals and protein, while pearlmillet stover is a valuable livestock feed. At present it is occupying 9.4 million ha area with a total production of 10.1 million tonnes (Economic Survey 2010-11). Rapeseed – mustard group of crops is the third largest oilseed crop in India after soybean and groundnut. This group occupies 6.5 million ha area with production of 7.7 million tonnes (Economic Survey 2010-11). In northern plains of India, pearlmillet-mustard is efficient, potential and sustainable cropping system (Parihar *et al*., 2009). If the nutrient requirements of this cropping sequence is not managed properly, then we may face the problem of decline in productivity and soil fertility status. The long-term application of chemical fertilizers alone under intensive cropping may deplete the reserve pool of non-applied nutrients and carbon, which if not properly managed, leads to deterioration of soil productivity and fertility. To achieve the target of 50 million tonnes oilseeds production by 2020 AD (Hegde, 2005), more emphasis is needed on integrated nutrient management in this cropping sequence so that we can sustain this cropping system. Hence, an attempt was made to study the long-term effects of integrated nutrient management on crop yields, nutrient status and changes in soil properties under a pearlmillet-mustard cropping sequence.

## MATERIALS AND METHODS

The present investigation is a part of an on-going long-term field experiment on integrated nutrient management in pearlmillet- mustard cropping sequence. The experiment was initiated in 1997 on permanent plots (latitude of

Based on a part of Ph.D. thesis of first author submitted to Rajmata Vijayaraje Sciendia Krishi Vishwa Vidyalaya, Gwalior during 2011 (unpublished)

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$26^0$ 13'N and longitude $76^0$ 10'E with an altitude 197 meters). The climate of experimental site is semi-arid and subtropical with extreme weather conditions having hot and dry summer and cold winter, where maximum temperature goes up to $45^0$C during summer and minimum as low as $2.8^0$C. The mean annual rainfall of area is 700-800 mm. The soil of the experimental field is alluvial, sandy clay loam in texture and classified as Typic Ustochrepts at great group level. The experimental field was cropped for Jowar fodder-mustard sequence at beginning of experiment (1997) up to *rabi* period 2002-2003. From *kharif* season of 2003-2004 pearlmillet- mustard cropping sequence was started without any changes under all fertility treatments and experimental plots.

The experiment was laid out with randomized block design having three replications comprising of 16 treatments, *viz* Control (no fertilizer/manure), 50% NPK, 75% NPK, 100% NPK, 150% NPK, 100% NP, 100% N, 100% NPK-S (sulphurfree), 50% NPK + *Azotobacter* (@10 g/kg seed), 75% NPK + *Azotobacter*, 100% NPK + *Azotobacter*, 100% NPK + *Azotobacter* + Phosphate Solubilising Bactria (PSB), 50% NPK + Farmyard Manure (FYM) @10 tonnes/ha/year, 75% NPK + FYM @10 tonnes/ha/year, 100% NPK + FYM @10 tonnes/ha/year, 100% NPK + FYM @10 tonnes/ha/year + *Azotobacter* + PSB respectively. Area of single plot was 5m × 3m and total experimental area was 1024.75 $m^2$. The recommended dose for pearlmillet was 80 N + 40 $P_2O_5$ + 20 $K_2O$ kg/ha and mustard 100 N + 60 $P_2O_5$ + 40 $K_2O$ kg/ha. Half of the nitrogen was applied in the form of urea as a basal dose and remaining was top dressed after 1st irrigation at 30 DAS under both crops. Full dose of phosphorus and potash applied as single supper phosphate and murate of potash at the time of sowing. In treatment 100% NPK-S, P was added as DAP to make it sulphurfree treatment. As per treatment FYM was added @10 tonnes/ha/year before sowing of *kharif* crop contain 0. 5% N, 0. 25% P and 0.5% K. In inoculation treatments seeds were treated with *Azotobacter* and Phosphate Solubilising Bactria both @10 g/kg seed. Pearlmillet 'JBV-3' was sown (seed rate 5kg/ha) during the middle of July and harvested in second week of October and mustard 'Pusa Bold' was sown (seed rate 5 kg/ha) during first to second week of November and harvested at the end of April each year.

The soil sample were collected from various depth (0-15, 15-30, 30-60 and 60-100 cm) of soil profile with the help of screw and tube auger in *kharif* 2011 before sowing of pearlmillet to study the impact of various fertility treatment on soil properties of profile. At the beginning of experiment (1997) under Jowar fodder-mustard sequence soil having pH (7.78) neutral to slightly alkaline, low in EC (0.13 dS/m), OC (0.36%) and available P (7.2 kg/ha) and medium in available N (145 lg/ha), and K (197 kg/ha). The cropping sequence changed to pearlmillet – mustard from 2003 (*kharif*) recorded soil pH 7.77, EC 0.15 dS/m, OC 0.34% and available N 139 kg/ha, P 6.5 kg/ha and K 185 kg/ha. The seed and straw yield data were analysed treatment wise of pearlmillet and mustard from (*kharif*) 2005-2011 and soil was tested for chemical analysis of *kharif* season 2011. Soil samples were analyzed for pH (1:2.5 soil: water suspension, Jackson, 1967), electrical conductivity by using ELICO conductivity bridge (Richards, 1954). Organic carbon by Walkley and Black,1934, available nitrogen by alkaline permanganate method (Subbaiah and Asija, 1956), available phosphorous (Olsen *et al*, 1954) and available potassium was extracted from soil with 1N $NH_4OAC$ solution (pH 7) by flame photometer (Jackson, 1967).

## RESULTS AND DISCUSSION

### *Straw yield*

The data pertaining to the pooled straw yields of pearlmillet and mustard have been presented in table 1 (average of six years) showed significantly increased yield of all treatments over control. The significantly highest straw yield of pearlmillet (8.60 t/ha) and mustard (6.79 t/ha) were recorded in treatment 100% NPK + FYM @10 t/ha/year + *Azotobacter* + PSB. The result of 14 year cycle of long-term fertility experiment indicated that the application of 100% N alone (30.0% and 29.3%) and 100% NP (47.8% and 52.1%) enhances the yield of both crops over control, but response exhibited declining trend with time due to imbalance use of nutrient. Crop performance was closely linked with fertility treatments over six year period (Fig. 1 and Fig. 2).

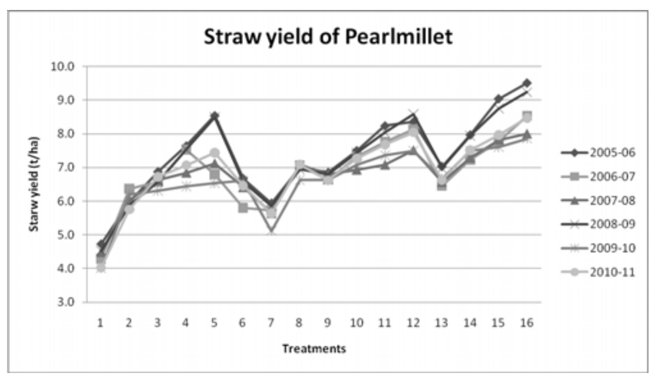


**Fig. 1.** Year wise straw yield of sixteen treatments of Pearlmillet (1) Control (no fertilizer/manure); (2) 50% NPK; (3) 75% NPK; (4) 100% NPK; (5) 150% NPK; (6) 100% NP; (7) 100% N; (8)100% NPK-S (sulphurfree); (9) 50% NPK + *Azotobacter*; (10) 75% NPK + *Azotobacter*; (11) 100% NPK + *Azotobacter*; (12) 100% NPK + *Azotobacter* + PSB; (13) 50% NPK + FYM (@10 t/ha/year); (14) 75% NPK + FYM (@10 t/ha); (15) 100% NPK + FYM (@10 t/ha); (16) 100% NPK + FYM (@10 t/ha) + *Azotobacter* + PSB

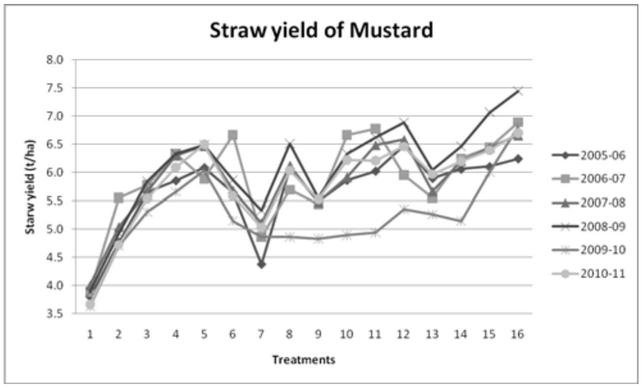


**Fig. 2.** Year wise straw yield of sixteen treatments of Mustard

Under continuous cropping the application of FYM @10 t/ha/year along with optimal dose of fertilizer was beneficial in enhancing crop productivity and soil fertility and gave highest yields of straw 8.16 t/ha in pearlmillet and 6.41 t/ha in mustard in comparison to 7.48 t/ha in pearlmillet and 6.24 t/ha mustard at 150% NPK. These findings indicate superiority of optimal dose of fertilizer with organic manure over super optimal doses of fertilizer. Treatment having optimal dose of fertilizer in combination with *Azotobacter* and PSB gave the better response yield under pearlmillet and mustard over non-inoculated treatments. Thus, the balance use of fertilizer either alone or in combination with organic manure and seed inoculants is necessary for sustaining soil fertility and productivity of crops (Tiwari *et al*., 2002 and Thakur *et al*., 2011).

### *Grain yield*

The application of optimal dose of NPK in combination with FYM, *Azotobactor* and PSB produced significantly higher seed yield of pearlmillet (4.07 t/ha) and mustard (2.34 t/ha) over other fertility treatments and control (Table 1). The continuous cycle of this cropping sequence with long term fertility treatment indicated that the treatment 100% NPK + FYM @10 t/ha/year produced higher seed yield of pearlmillet by 82.8% and mustard by 120.4% over control, while the increase in seed yield due to 150% NPK was just 76.9% in pearlmillet and 101.6% in mustard. Application of 100% NPK + *Azotobactor* caused 74.1% increase in yield of pearlmillet and 92.8% of mustard over 100% NPK alone. This increase in seed yield due to seed inoculation like *Azotobactor*, attributed to its ability to produce growth substances and anti-fungal substances in addition to nitrogen fixation (Mishra *et al*, 2008).

The treatment receiving sub optimal dose of nutrient *i.e.* 50% NPK alone or in combination with *Azotobactor*, and 50% NPK + FYM @10 t/ha/year gave increased yield performance over the six years (Fig. 3 and Fig. 4) in pearlmillet and mustard respectively over control, but there was no consistency over the years in productivity against optimal dose of fertilizer. There was increase in yield under the treatment receiving 100%NPK including sulphur over sulphur free treatment (100% NPK-S) under pearlmillet and mustard respectively, therefore addition of

**Table 1.** Effect of integrated nutrient supply system on productivity and economics of pearlmillet–mustard cropping sequence (Pooled data over 2005-11)

| Treatment | Straw yield (t/ha) | | Grain yield (t/ha) | | Cost of cultivation (₹/ha) | | Net returns (₹/ha) | | B:C ratio | | Pearlmillet equiva-lent (t/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pearlmillet | Mustard | Pearlmillet | Mustard | Pearlmillet | Mustard | Pearlmillet | Mustard | Pearlmillet | Mustard | |
| Control | 4.35 | 3.81 | 2.08 | 1.01 | 7,667 | 9,667 | 13,679 | 11,777 | 2.8 | 2.4 | 4.70 |
| 50% NPK | 6.03 | 4.96 | 3.10 | 1.51 | 8,638 | 11,072 | 23,117 | 20,838 | 3.6 | 3.0 | 6.92 |
| 75% NPK | 6.61 | 5.63 | 3.19 | 1.73 | 9,123 | 11,774 | 23,801 | 24,704 | 3.6 | 3.2 | 7.55 |
| 100% NPK | 7.18 | 6.09 | 3.57 | 1.85 | 9,609 | 12,477 | 27,071 | 26,724 | 3.8 | 3.2 | 8.25 |
| 150% NPK | 7.48 | 6.24 | 3.68 | 2.04 | 10,580 | 13,882 | 27,421 | 28,946 | 3.5 | 3.1 | 8.86 |
| 100% NP | 6.42 | 5.77 | 3.50 | 1.68 | 9,449 | 12,151 | 25,841 | 23,390 | 3.7 | 3.0 | 7.76 |
| 100% N | 5.65 | 4.93 | 2.65 | 1.30 | 8,563 | 10,809 | 19,315 | 17,134 | 3.2 | 2.7 | 6.03 |
| 100% NPK-S | 6.97 | 5.88 | 3.48 | 1.44 | 9,408 | 12,303 | 26,160 | 18,912 | 3.7 | 2.6 | 7.11 |
| 50% NPK + *Azotobactor* | 6.72 | 5.39 | 3.19 | 1.63 | 8,640 | 11,074 | 24,724 | 23,558 | 3.8 | 3.2 | 7.34 |
| 75% NPK + *Azotobactor* | 7.26 | 5.98 | 3.29 | 1.76 | 9,126 | 11,777 | 25,138 | 25,589 | 3.7 | 3.2 | 7.70 |
| 100% NPK + *Azotobactor* | 7.69 | 6.18 | 3.62 | 1.95 | 9,611 | 12,480 | 27,720 | 28,571 | 3.9 | 3.3 | 8.52 |
| 100% NPK + *Azotobactor* + PSB | 8.02 | 6.28 | 3.77 | 2.05 | 9,614 | 12,482 | 29,352 | 30,480 | 4.0 | 3.5 | 8.95 |
| 50% NPK + FYM | 6.72 | 5.73 | 3.22 | 1.77 | 10,596 | 11,072 | 22,673 | 26,546 | 3.1 | 3.4 | 7.63 |
| 75% NPK + FYM | 7.57 | 6.05 | 3.42 | 1.96 | 11,040 | 11,774 | 24,806 | 29,524 | 3.2 | 3.6 | 8.33 |
| 100% NPK + FYM | 8.16 | 6.41 | 3.78 | 2.22 | 11,525 | 12,477 | 27,694 | 33,986 | 3.4 | 3.8 | 9.38 |
| 100% NPK + FYM + *Azotobactor* + PSB | 8.60 | 6.79 | 4.08 | 2.35 | 11,530 | 12,482 | 30,695 | 36,514 | 3.6 | 4.0 | 10.00 |
| SEm± | 0.14 | 0.12 | 0.07 | 0.07 | | | 911 | 1,458 | 0.07 | 0.12 | 0.19 |
| CD (P=0.05) | 0.39 | 0.34 | 0.21 | 0.21 | | | 2,568 | 4,107 | 0.21 | 0.34 | 0.53 |

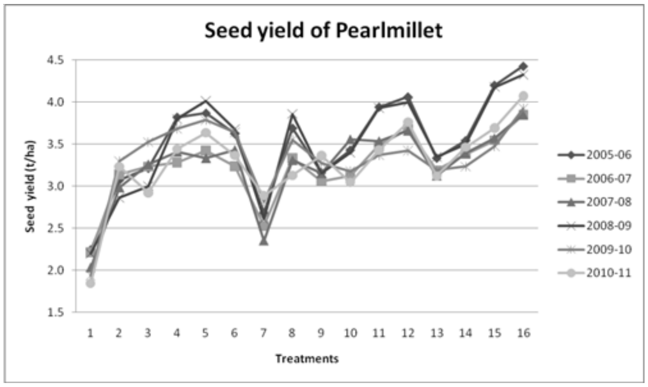


**Fig. 3.** Year wise seed yield of sixteen treatments of Pearlmillet

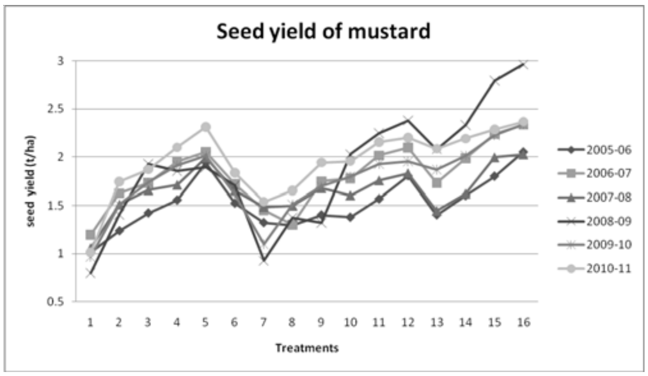


**Fig. 4.** Year wise seed yield of sixteen treatments of Mustard

sulphur become essential after a few cycle of continuous intensive cropping (Thakur *et al*., 2011). Continuous cropping without addition of potassium and imbalance fertilization (100% N and 100% NP) reduced the grain yield than treatment receiving optimal dose of fertilizer under both crops. Thus the balanced application of mineral fertilizers sustains soil physical environment and higher crop productivity under intensive cultivation (Hati *et al*., 2006).

### *Economics*

The pooled data of six years (2005-2011) on economic aspect are presented in table 1, showed that cost of cultivation was higher for treatment 100% NPK + FYM @10 t/ha/year + *Azotobacter* + PSB in pearlmillet (11,530 ₹/ha) and 150% NPK in mustard (13,882 ₹/ha) compared to other treatments. Use of higher quantity of chemical fertilizer and FYM as per treatment may lead to increase the cost of cultivation.

There was significant difference in net returns and B: C ratio (Table 1). Higher net returns were recorded under treatment 100% NPK + FYM @10 t/ha/year + *Azotobacter* + PSB for pearlmillet (30,695 ₹/ha) and mustard (36,514 ₹/ha). The B: C ratio was significantly higher for pearlmillet (4.0) under 100% NPK + *Azotobacter* + PSB treatment and in mustard (4.0) under 100% NPK + FYM @10t/ha/Y + *Azotobacter* + PSB, while the treatments receiving FYM in combination with optimal dose of fertilizer having lower B: C ratio in pearlmillet (3.6 and 3.4), which led to use of higher quantity of organic manure before sowing of *kharif* crop that raised cost of cultivation for FYM (Upadhyay *et al*. 2011), compared to treatments receiving chemical fertilizer (100% NPK) alone or in combination with *Azotobacter* and PSB as seed inoculants.

### *System productivity*

As regards, the system productivity in terms of pearlmillet equivalent yield (PEY) and profitability played a vital role in determining the most productive and profitable cropping sequence. The pooled analysis (2005-2011) of different treatments revealed that treatment 100% NPK + FYM @10 t/ha/year + *Azotobacter* + PSB produced highest (10.0 t/ha) PEY which is significantly higher than the other treatments and was followed by treatment 100% NPK + FYM @10 t/ha/year (9.4 t/ha), 100% NPK + *Azotobacter* + PSB (8.9 t/ha), 150% NPK (8.9 t/ha) and 100% NPK + *Azotobacter* (8.5 t/ha). In this system, treatments received optimal dose of fertilizer (100% NPK) management practice produced higher PEY than 75% NPK and 50% NPK dose. The treatment receiving 100% N (6.03 t/ha) alone produced lowest PEY and was superior only to control (4.70 t/ha).

### *Soil pH and EC*

pH of surface soil of control and 100% N alone remained statistically same after the 14$^{th}$ year of cropping sequence, whereas at lower depth (60cm–100cm) it increased to 8.1 under treatment receiving 100% N alone. The increase in pH at lower depth of soil profile attributes to continuous application of imbalance use of nutrient which decline soil health and increased soil pH. Soil pH of 7.52 recorded the lowest under sub surface (15-30cm) of 100% NPK along with FYM @10 t/ha/year + *Azotobacter* + PSB. The pH showed only marginal decline trend on surface by 7.68, 7.65 and 7.62 under treatments receiving 100% NPK + *Azotobacter*, 100% NPK + *Azotobacter* + PSB, 100% NPK + FYM @10 t/ha/Y respectively over initial value. Decrease in pH may be attributed to balance use of fertilizer with FYM and seed inoculants (*Azotobacter*, PSB), which released organic acids during decomposition of manures resulting decline in soil pH.

Electrical conductivity (EC) was not much affected by different fertility treatments over the experimental period. The highest EC (0.227 dS/m) found under treatment 100%NPK along with FYM @10 t/ha/year + *Azotobacter* + PSB. There was marginal increase in EC on surface under 150% NPK (0.19 dS/m) and FYM in combination with chemical fertilizer (0.17, 0.18 and 0.20 dS/m) as compare to other treatments, which received chemical fertilizer alone and sub optimal dose treatments. This increase in EC obviously due to decomposition of organic matter. These results corroborate the findings of Babu *et al*. (2007).

### *Organic carbon*

The addition of organic matter and chemical fertilizer over 14 years resulted in significant increase in organic carbon content over unfertilized control plot. The organic carbon level in control reduced over the initial status (0.36%) and showed stable response for few years *i.e.* from *kharif* 2003 (0.34%; Table 2). The OC content of surface (0-15cm) soil under study showed wide variations and ranged from 0.34% (Control) to 0.52% (100% NPK + FYM @10 t/ha/year + *Azotobacter* + PSB). Likewise at lower depth (60-100 cm) of soil profile, it ranged from 0.11% to 0.19%. A regular decrease in organic carbon content has been observed down the profile in all the treatments. The treatments receiving chemical fertilizers alone 100% NPK (0.41%) and treatments receiving chemical fertilizer in combination with *Azotobacter* and PSB (0.44%) also observed comparatively higher amount of organic carbon content in comparison to unfertilized control , 50% NPK and 75% NPK treatments in surface soil (0-15 cm) . The increase in organic carbon content due to use of chemical fertilizer, direct incorporation of organic matter through FYM can be attributed to higher contribution of biomass to the soil in the form of better root growth, crop stubbles biomass and residues (Katyal *et al.,* 2003 and Gathala *et al.* 2007).

### *Available nitrogen*

The data showed increase in available nitrogen on surface (0-15cm) layer of profile in all treatments over control (129 kg/ha), initial value (145 kg/ha) and nitrogen status in 2003 (139 kg/ha). The available nitrogen declined with increasing depth and was lowest in lower layer (60-100 cm) of soil profile irrespective of treatments. The continuous use of nitrogenous fertilizers under long-term cycle showed significantly increase in available nitrogen status in soil profile of all treatments except control (Table 3). The increased amount of available nitrogen in treatments receiving *Azotobacter* (190 kg/ha) or *Azotobacter* + PSB (195 kg/ha) in combination with chemical fertilizer over treatment receiving chemical fertilizer alone (188 kg/ha), is due to inoculation of seed by *Azotobacter* which

**Table 2.** Effect of integrated nutrient supply system on physico-chemical properties of soil in pearlmillet–mustard cropping sequence (*Kharif* 2011)

| Treatment | Available nutrients (kg/ha) under different soil depth (cm) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Soil pH | | | | Soil EC (dS/m) | | | | Soil % OC | | | |
| | 0-15 | 15-30 | 30-60 | 60-100 | 0-15 | 15-30 | 30-60 | 60-100 | 0-15 | 15-30 | 30-60 | 60-100 |
| Control | 7.79 | 7.80 | 7.83 | 7.90 | 0.11 | 0.11 | 0.10 | 0.10 | 0.34 | 0.27 | 0.18 | 0.11 |
| 50% NPK | 7.77 | 7.79 | 7.83 | 7.85 | 0.11 | 0.12 | 0.10 | 0.10 | 0.38 | 0.31 | 0.24 | 0.14 |
| 75% NPK | 7.75 | 7.79 | 7.80 | 7.85 | 0.12 | 0.12 | 0.11 | 0.11 | 0.39 | 0.33 | 0.25 | 0.14 |
| 100% NPK | 7.70 | 7.75 | 7.77 | 7.85 | 0.13 | 0.13 | 0.11 | 0.10 | 0.41 | 0.36 | 0.26 | 0.16 |
| 150% NPK | 7.69 | 7.75 | 7.80 | 7.85 | 0.18 | 0.13 | 0.12 | 0.10 | 0.42 | 0.40 | 0.26 | 0.14 |
| 100% NP | 7.71 | 7.76 | 7.80 | 7.85 | 0.12 | 0.12 | 0.10 | 0.10 | 0.39 | 0.33 | 0.26 | 0.14 |
| 100% N | 7.79 | 7.85 | 7.87 | 8.10 | 0.11 | 0.11 | 0.11 | 0.11 | 0.39 | 0.32 | 0.25 | 0.14 |
| 100% NPK - S | 7.72 | 7.79 | 7.81 | 7.85 | 0.13 | 0.12 | 0.12 | 0.11 | 0.40 | 0.34 | 0.25 | 0.14 |
| 50% NPK + *Azotobacter* | 7.73 | 7.75 | 7.76 | 7.84 | 0.12 | 0.12 | 0.11 | 0.10 | 0.39 | 0.32 | 0.21 | 0.13 |
| 75% NPK + *Azotobacter* | 7.70 | 7.75 | 7.80 | 7.85 | 0.13 | 0.13 | 0.11 | 0.10 | 0.41 | 0.34 | 0.23 | 0.14 |
| 100% NPK + *Azotobacter* | 7.68 | 7.71 | 7.75 | 7.84 | 0.14 | 0.12 | 0.11 | 0.11 | 0.42 | 0.35 | 0.25 | 0.13 |
| 100% NPK + *Azotobacter* + PSB | 7.65 | 7.70 | 7.77 | 7.83 | 0.16 | 0.14 | 0.11 | 0.11 | 0.44 | 0.37 | 0.25 | 0.14 |
| 50% NPK + FYM | 7.75 | 7.77 | 7.80 | 7.85 | 0.17 | 0.13 | 0.11 | 0.11 | 0.42 | 0.37 | 0.27 | 0.15 |
| 75% NPK + FYM | 7.70 | 7.73 | 7.76 | 7.80 | 0.18 | 0.14 | 0.12 | 0.11 | 0.46 | 0.38 | 0.28 | 0.17 |
| 100% NPK + FYM | 7.62 | 7.71 | 7.75 | 7.83 | 0.20 | 0.15 | 0.12 | 0.11 | 0.48 | 0.39 | 0.30 | 0.17 |
| 100% NPK + FYM + *Azotobacter* + PSB | 7.54 | 7.52 | 7.73 | 7.77 | 0.23 | 0.18 | 0.13 | 0.12 | 0.52 | 0.44 | 0.31 | 0.19 |
| SEm± | 0.02 | 0.03 | 0.03 | 0.03 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 |
| CD (P=0.05) | 0.05 | 0.09 | 0.06 | 0.09 | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.03 | 0.03 | 0.03 |
| (Initial status) 1997 | 7.78 | 7.80 | - | - | 0.13 | 0.11 | - | - | 0.36 | 0.34 | - | - |
| (Initial status) 2003 | 7.77 | 7.82 | - | - | 0.15 | 0.13 | - | - | 0.34 | 0.31 | - | - |

helped in increasing the supply of nitrogen through biologically fixing the atmospheric nitrogen. Similar results were recorded by Hegde (1998). The optimal dose of fertilizer in combination with FYM @10 t/ha/year showed increased content of available nitrogen by 224 kg/ha over treatment receiving 100% NPK (188 kg/ha) and treatment having super optimal dose of fertilizer (196 kg/ha). Such increase in available nitrogen is due to mineralization of FYM. Singh *et al.* (2009) observed that available nitrogen content in soil increased with the use of recommended dose of fertilizer in combinations with manure. Application of phosphorus with nitrogen improved available nitrogen status of soil as compared to application of nitrogen alone.

### *Available phosphorus*

The applied phosphorus gets fixed and only small part of it becomes available to plants. The availability of phosphorus decreased with increased soil depth of profile in all treatments. The available phosphorus status decreased under control plot (4.9 kg/ha) and treatment receiving 100% N alone (5.4 kg/ha) over the initial status (7.2 kg/ha) and in 2003 (6.5 kg/ha) (Table 3). This may occurred due to removal of phosphorus by crop under long term fertility experiment. The application of phosphorus along with nitrogen (100% NP) increased available phosphorus (11.9 kg/ha). Similar trend on available phosphorus was reported by Parmer and Sharma (2002). Further the application of 100% NPK had increased available phosphorus status over 100% NP.

The significantly higher build up of phosphorus observed under treatment receiving 100% NPK + FYM @10 t/ha/year (19.8 kg/ha), 100% NPK + *Azotobacter* + PSB (20.1 kg/ha) and 100% NPK + FYM @10 t/ha/year + *Azotobacter* + PSB (24.8kg/ha) and trend was same in each depth of soil profile compare to other treatments. The microbiological means acts on insoluble-P compounds through production of organic and inorganic acids, accompanied by acidification of the medium which enhanced the availability of P to the plant (Mahdi *et al*., 2010). The application of optimal dose of fertilizer with organic manure increased the available P to 19.8 kg/ha in comparison to 16.9kg P/ha under 150% NPK.

### *Available potassium*

Available potassium status of sub-surface soil was higher than the surface soil of all the treatments (Table 3) and ranged between 153 kg/ha to 218 kg/ha on surface (0-15 cm), 185 kg/ha to 232 kg/ha at lower depth (60-100cm). This decline trend of potassium from upper layer is due to potassium mining by crop. The long term fertility treatment showed the maximum decline trend of available K on surface soil under unfertilized control (153 kg/ha), followed by treatment receiving 100% NP (164 kg/

**Table 3.** Effect of integrated nutrient supply system on fertility status of pearlmillet–mustard cropping sequence (*Kharif* 2011)

| | Available nutrients (kg/ha) under different soil depth (cm) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nitrogen (N) | | | | Phosphorous (P) | | | | Potassium (K) | | | |
| Treatment | 0-15 | 15-30 | 30-60 | 60-100 | 0-15 | 15-30 | 30-60 | 60-100 | 0-15 | 15-30 | 30-60 | 60-100 |
| Control | 129 | 118 | 87 | 30 | 4.9 | 4.0 | 1.6 | 0.3 | 153 | 159 | 176 | 185 |
| 50% NPK | 153 | 143 | 132 | 56 | 9.9 | 6.4 | 3.9 | 0.9 | 169 | 183 | 178 | 193 |
| 75% NPK | 171 | 153 | 136 | 63 | 10.3 | 8.5 | 4.0 | 0.8 | 183 | 190 | 189 | 203 |
| 100% NPK | 188 | 170 | 141 | 66 | 12.5 | 9.2 | 4.6 | 0.9 | 194 | 186 | 194 | 214 |
| 150% NPK | 195 | 177 | 128 | 74 | 16.9 | 10.1 | 5.5 | 1.1 | 205 | 190 | 203 | 225 |
| 100% NP | 183 | 163 | 124 | 56 | 11.9 | 8.5 | 3.3 | 0.8 | 166 | 163 | 168 | 191 |
| 100% N | 178 | 155 | 116 | 66 | 5.4 | 2.7 | 1.7 | 0.1 | 164 | 166 | 168 | 194 |
| 100% NPK - S | 187 | 168 | 137 | 83 | 12.2 | 8.0 | 5.1 | 0.9 | 192 | 196 | 191 | 211 |
| 50% NPK + *Azotobacter* | 165 | 147 | 113 | 76 | 10.3 | 6.4 | 4.7 | 0.6 | 182 | 196 | 204 | 207 |
| 75% NPK + *Azotobacter* | 185 | 154 | 122 | 85 | 11.9 | 8.2 | 5.5 | 1.0 | 199 | 199 | 210 | 208 |
| 100% NPK+ *Azotobacter* | 190 | 163 | 125 | 83 | 13.8 | 10.8 | 5.7 | 1.1 | 203 | 201 | 212 | 209 |
| 100% NPK + *Azotobacter* + PSB | 195 | 159 | 106 | 77 | 20.1 | 15.8 | 9.9 | 4.2 | 211 | 203 | 214 | 215 |
| 50% NPK + FYM | 176 | 151 | 114 | 85 | 12.8 | 9.6 | 5.0 | 1.4 | 200 | 193 | 204 | 217 |
| 75% NPK + FYM | 204 | 174 | 126 | 81 | 16.2 | 14.1 | 7.5 | 2.5 | 202 | 199 | 202 | 223 |
| 100% NPK + FYM | 224 | 178 | 134 | 94 | 19.8 | 16.1 | 7.7 | 2.0 | 210 | 210 | 207 | 229 |
| 100% NPK + FYM + *Azotobacter* + PSB | 238 | 184 | 141 | 104 | 24.8 | 18.4 | 11.4 | 5.8 | 218 | 210 | 217 | 232 |
| SEm± | 1.40 | 2.11 | 1.87 | 2.51 | 0.48 | 0.44 | 0.19 | 0.20 | 2.47 | 3.85 | 4.62 | 3.37 |
| CD (P=0.05) | 4.06 | 6.09 | 5.42 | 7.25 | 1.39 | 1.27 | 0.56 | 0.59 | 7.14 | 11.11 | 13.34 | 9.73 |
| (Initial status)1997 | 145 | 138 | - | - | 7.2 | 6.7 | - | - | 197 | 202 | - | - |
| (Initial status) 2003 | 139 | 133 | - | - | 6.5 | 5.3 | - | - | 185 | 189 | - | - |

ha), 100% N (166 kg/ha), 50% NPK (169 kg/ha), and 50% NPK + *Azotobacter* (182 kg/ha), over the initial value (197 kg/ha) and in year 2003 (185 kg/ha). It is due to imbalance use of fertilizer. The continuous omission of potassium for crop nutrition caused mining of its native pools that caused reduction in potassium availability to crop and crop yield also decline (Dwivedi *et al*., 2007). The magnitude of decline was decrease with increasing level of NPK. The significantly highest potassium status of soil under surface (0-15 cm) was observed in 100% NPK + FYM @10 t/ha/year + *Azotobacter* + PSB (218 kg/ha) followed by 100% NPK + FYM @10 t/ha/year (210 kg/ha) and 150% NPK (205 kg/ha). Available potassium significantly increased in all treatments receiving FYM along with chemical fertilizers. Application of organic manure may have caused reduction in potassium fixation and consequently increased potassium content due to interaction of organic matter with clay besides the direct addition to the available K pools of soil (Prasad and Mathur, 1997).

It is concluded that over fourteen years in pearlmillet-mustard cropping sequence, treatment receiving organic manure along with optimal dose of chemical fertilizer in combination with *Azotobacter* and PSB provide higher system productivity (PEY), improves soil health and also produced higher return. These findings showed that biofertilizer and FYM are not only a substitute, but a supplement to chemical fertilizers result in build up of organic carbon, available N, P, and K and sustain soil pH and EC as compared with chemical fertilizer alone, suboptimal dose treatments and unfertilized plot.

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