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# Sustaining Soil Health and Soybean Productivity with Partial Substitution of Nutrients through Gliricidia Green Manuring and Chemical Fertilizers in Vertisols of Central India

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**Abstract:** The present study was conducted to study the effect of partial substitution of nutrient through Gliricidia with chemical fertilizers on soil health and soybean productivity in Vertisols under AICRP for Dryland Agriculture, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola-444104 (M.S.) during 2009-13. The experiment was laid out with nine treatments comprised of application of potassium through chemical fertilizers and gliricidia along with recommended dose of N and P (inorganic source) in a randomized block design with three replications. The pooled data indicated that application of 100% NP + 25 kg K $ha^{-1}$ + biofertilizers had highest soybean grain yield followed by application of 50% N through gliricidia +50% N through inorganics+ biofertilizers + 25 kg K $ha^{-1}$ which were on par with each other. The higher SYI and monetary returns were obtained with the application of substitution of 50 % N through gliricidia along with 50 % N through inorganics and biofertilizer which were statistically on par with application 100 % NP along with 25 kg K through chemical fertilizers. The results of the study also indicated significantly higher enhancement in soil organic carbon, residual soil fertility and nutrient uptake by soybean with the application of 50 % N through gliricidia along with 50 % N through inorganics and biofertilizer. Hence, it can concluded that for sustaining soil fertility and soybean productivity with higher economic returns, application of 50% N (25kg $ha^{-1}$) through gliricidia +50% N through inorganics + biofertilizers + 25kg $P_2O_5$ + 25kg $K_2O$ $ha^{-1}$ is recommended as an integrated plant nutrient supply system on Vertisols under dryland condition in central India.

**Kew words:** *Gliricidia green manuring, soil health, soybean productivity and Vertisols*

## Introduction

Soybean (*Glycine max* (L) Merill), a grain legume is considered as a wonder crop due to its dual quality *viz.* high protein (40-43 %) and oil content (20%). Soybean being a potentially high yielding crop can play a greater role in boosting oil seed production in the country. This legume is making straight way in Indian agriculture to meet protein and oil requirement. In addition to this, soybean protein has five per cent lysine, which is deficit in most of the cereals and enriching the cereal flour with soybean improves the nutritive quality.

The green manures are a valuable potential source of N and organic matter. They play an important role in improving physical, chemical and biological properties of soil with increase in the microbial population in soil. Biofertilizers are preparations containing live or latent cell of efficient strains of nitrogen fixing, phosphate solubilizing or cellulolytic

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microorganisms used for application to seed, soil or composting areas with the objectives of increasing the population of such beneficial microorganisms and accelerate certain microbial processes to augment the extent of the availability of nutrients in a form which can be easily assimilated by the plants.

Constraint analyses have indicated that unbalanced nutrition is one of the important reasons for restricted growth in productivity of soybean (Sharma *et al*. 1996 and Tiwari 2001). Soybean like most legume perform nitrogen fixation by establishing a symbiotic relationship with bacteria *Rhizobium japonicum*. Use of organic manures with optimum rate of fertilizers under intensive farming system increases the turnover of nutrients in the soil plant system. The organic fertilizers along with biofertilizers help in reducing the dose of inorganic fertilizer, which in turn reduces the cost of cultivation and help in improving the soil health. Farmyard manure is an important component of integrated nutrient management for maintaining soil fertility and yield stability.

Now a days, the fertilizer requirements are increasing due to adoption of new high yielding varieties and hybrids in intensive cultivation. Therefore, to maintain crop productivity, the use of chemical fertilizers in balanced quantity is important. But looking into the continuous increasing prices of fertilizers, it becomes necessary to minimize the expenses on fertilizers by using alternative sources like farmyard manure, crop residues, green manuring along with chemical fertilizers for sustaining the crop yields and soil fertility. These practices not only increase the crop yield but also improve the physical, chemical and biological properties of soil. When integrated nutrient management through chemical fertilizers and different organic sources are applied on long term basis, they show beneficial impact on soil quality (Swarup 2010).

The effects and costs of organic and inorganic nutrient sources are different, but may be complementary. Thus, the combined use of organic and inorganic nutrient sources is now considered a better way to maintain soil fertility. Organic matter is the life of soil, and the practices that support organic matter build-up also favour sustainable productivity (Katyal *et al.* 2001). Hence, the present study was carried out to assess the effect of conjunctive use of Gliricidia green leaf manure and chemical fertilizers on soil fertility, nutrient uptake by soybean, productivity and economics of soybean on Vertisols in Vidarbha region of Maharashtra.

**Materials and Methods**

A field experiments (gross plot size 5.4x9 $m^2$; net plot size 4.5x8 $m^2$) on Vertisols was initiated on the research field of AICRP for Dryland Agriculture, Dr. PDKV, Akola during 2009-13. This region has a typical semi-arid climate with most of the rainfall received between June and October. The soil at the site was a medium deep Vertisols (Typic Haplusterts). The soil was slightly alkaline in reaction (pH 8.1), low in organic C (5.2 g $kg^{-1}$ soil), low in available N (195 kg $ha^{-1}$), available P (15.5 kg $ha^{-1}$) and high in available K (319 kg $ha^{-1}$).

The experiment was laid out in a randomized block design with nine treatments comprising of Control (T1), 100 per cent NP (30:75:00 NPK kg $ha^{-1}$ (T2), (T3) 100 per cent NP + biofertilizers, (T4)100 per cent N through FYM + biofertilizers, (T5) 100 per cent NP + 25 kg K $ha^{-1}$ , (T6) 100 per cent NP + 25 kg K $ha^{-1}$ + biofertilizes, (T7) 50 per cent N through green leaf manure + 50 per cent N through inorganics, (T8) 50 per cent N through green leaf manure + 50 per cent N through inorganics + biofertilizers, (T9) 50 per cent N through green leaf manure +50 per cent N through inorganics + biofertilizers + 25 kg potassium $ha^{-1}$. The seeds were inoculated with carrier based culture of Biofertilizers *Rhizobium* and PSB (25 g $kg^{-1}$ seed). Recommended P was applied to all the treatments except control (T1) and100 per cent N through FYM + biofertilizers (T4). The recommended dose of soybean was 30:75:00 kg NPK $ha^{-1}$. FYM was applied before sowing in the first fortnight of June in both the years as per the treatments. Soybean (cv. JS-335) was sown at 0.45 m inter-row and 0.08 m intra-row spacing. Nitrogen, phosphorus and potassium were applied at the time sowing through urea, single super phosphate and muriate of potash, respectively at the time of sowing. The FYM had 0.51% N, 0.19% P and 0.48 % K. The gliricidia green leaves were applied after the germination of soybean crop. The green leaves had 0.68

% N, 0.10 % P and 0.48 % K. The total seasonal rainfall received during experimentation years was 537.6, 966, 455.7, 684.1 and 725.7 mm in 2009, 2010, 2011, 2012 and 2013, respectively.

Treatment-wise surface (0-20 cm) soil samples were collected at the harvest of soybean each year, air dried, processed and analysed for various soil properties. The soil organic carbon was determined by wet oxidation method (Nelson and Sommer 1982). The available N in soil was determined by modified alkaline potassium permanganate method as described by Subbiah and Asija (1956). Available phosphorus (Olsen P) was measured using sodium bicarbonate ($NaHCO_3$) as an extractant (Watanabe and Olsen 1965). Soil available K was extracted by shaking with neutral normal ammonium acetate for 5 minute (Hanway and Heidel 1952) and potassium in the extract was estimated by flame photometer.

The treatment-wise plant samples were selected randomly from each net plot at harvesting stage. The plant samples were dried in shade and then placed in oven at $65^0$ C. These plant samples were analysed for total N, P and K as per procedure outlined by Piper (1966).

For calculating the sustainability yield index (SYI) (Sharma *et al*. 2005), the following equation was used.

$$SYI = \frac{\check{y} - s}{Y_{max}}$$

Where, $\check{y}$ = Average yield of the treatment.

s = Treatment standard deviation.

$Y_{max}$ = Maximum yield in the experiment over the years.

The productivity rating index (PRI) was calculated as per the following formula

PRI = (Actual yield / Standard yield) X 100

Rain water use efficiency (RWUE) was calculated as under

RWUE = (Crop yield / Total seasonal rainfall)

The data was tested for their level of significance at P = 0.05 as per the procedure outlined by Panse and Sukhatme (1971).

**Results and Discussion**

The year-wise (2009-2013) data on soybean grain and straw yields as are presented in table 1.

*Soybean grain yield*

The grain yield of soybean was significantly influenced by different treatments in all the years and in pooled mean (Table 1). Data indicated that the highest soybean grain yield (1426.2, 2629 kg $ha^{-1}$) was obtained with the application of 100 % NP + 25 kg K along with the biofertilizers followed by 100 % NP + 25 kg K (1350.7 and 2540.7 kg $ha^{-1}$), 100 % NP + biofertilizer (1292.3, 2458.3 kg $ha^{-1}$) 100 % NP (1254.5, 2307.2 kg $ha^{-1}$) and 50 % N (GLM)+ 50 % N (inorganic)+ biofertilizers + 25 kg K (1272.4, 2238.5 kg $ha^{-1}$) in initial two years which were on par with each other. This clearly demonstrated that the nutrients applied through chemical fertilizers are readily available to the crop which resulted into significant increase in yield during initial years (2009, 2010).

From third year onwards (from 2011 to 2013), the significantly highest soybean grain yield was obtained with the application of 50% N from gliricidia green leaf manuring + 50 % N from chemical fertilizers along with biofertilizers and 25 kg K from inorganic source followed by 100 % NP + 25 kg K along with the biofertilizers. These treatments were on par with each other. This might due to the fact that nutrients from green leaf manuring did not meet the nutrient requirement of soybean during initial years of experiments.

The lowest grain yield was observed with 100 % NP through chemical fertilizers from the second year of study. From third year onwards, 100 % NP did not sustain the grain yield than the integrated use of N through green leaf manure and inorganic with biofertilizers and potassium application. The higher yield in subsequent year under the integrated treatments attributed to the improvement in soil physical conditions due to organic inputs (green leaf manuring and biofertilizers) which helps in steady supply of nutrients. This clearly indicated that the balanced nutrition through chemical fertilizers did not result in highest soybean

**Table 1.** Effect of INM on soybean grain and straw yield (kg $ha^{-1}$)

| | Treatments | Grain yield of Soybean ( kg $ha^{-1}$) | | | | | | Straw yield of soybean (kg $ha^{-1}$) | | | | | | PRI | SYI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2009 | 2010 | 2011 | 2012 | 2013 | Pooled Mean | 2009 | 2010 | 2011 | 2012 | 2013 | Pooled Mean | | |
| $T_1$ | Control | 1098.7 | 1895.2 | 1368.3 | 1721.5 | 939.6 | 1404.7 | 2664.3 | 3121.3 | 2071.3 | 1982.2 | 1352.0 | 2238.2 | 56.19 | 0.38 |
| $T_2$ | 100% NP (30:75:00 NPK kg $ha^{-1}$) | 1254.5 | 2307.2 | 1450.6 | 2016.4 | 1063.1 | 1618.4 | 2432.9 | 3618.7 | 2561.7 | 2030.2 | 1707.2 | 2470.1 | 64.74 | 0.42 |
| $T_3$ | 100% NP + biofertilizers | 1292.3 | 2458.3 | 1426.6 | 2057.6 | 1083.7 | 1663.7 | 2830.4 | 3632.5 | 2235.9 | 2091.9 | 1819.3 | 2522.0 | 66.55 | 0.41 |
| $T_4$ | 100% N through FYM + biofertilizers | 1152.9 | 2204.2 | 1419.7 | 1865.6 | 1028.8 | 1534.2 | 2508.4 | 3481.4 | 2352.5 | 2064.5 | 1574.3 | 2396.2 | 61.37 | 0.40 |
| $T_5$ | 100% NP + 25kg K $ha^{-1}$ | 1350.7 | 2540.7 | 1457.5 | 2119.3 | 1193.4 | 1732.3 | 2929.3 | 3680.5 | 2383.4 | 2078.2 | 1871.0 | 2588.5 | 69.29 | 0.44 |
| $T_6$ | 100% NP + 25kg K $ha^{-1}$ + biofertilizers | 1426.2 | 2629.9 | 1642.7 | 2167.3 | 1220.8 | 1817.4 | 3068.0 | 3927.7 | 2472.5 | 2119.3 | 1894.4 | 2696.4 | 72.70 | 0.47 |
| $T_7$ | 50% N through green leaf manure + 50% N through inorganics | 1194.1 | 2224.8 | 1611.8 | 2115.9 | 1042.5 | 1637.8 | 2658.1 | 3577.5 | 2572.0 | 1995.9 | 1662.1 | 2493.1 | 65.51 | 0.42 |
| $T_8$ | 50% N through green leaf manure + 50% N through inorganics + biofertilizers | 1233.9 | 2217.9 | 1673.5 | 2085.0 | 1179.7 | 1678.0 | 2659.5 | 3495.1 | 2335.4 | 2033.6 | 1870.5 | 2478.8 | 67.12 | 0.46 |
| $T_9$ | 50% N through green leaf manure +50% N through inorganics+ biofertilizers + 25kg K $ha^{-1}$ | 1272.4 | 2238.5 | 1680.4 | 2352.5 | 1255.1 | 1759.8 | 2735.0 | 3426.5 | 2606.3 | 2263.4 | 2039.7 | 2614.2 | 70.39 | 0.47 |
| | SE (m) ± | 60.6 | 108.2 | 73.2 | 90.6 | 61.6 | 39.5 | 100.3 | 134.8 | 135.0 | 97.1 | 114.9 | 57.4 | | |
| | CD at 5% | 181.7 | 324.5 | 219.4 | 271.7 | 184.8 | 118.5 | 300.7 | 404.2 | NS | NS | 344.6 | 172.0 | | |

yield on long run than the conjunctive use of organic and inorganic fertilizers along with biofertilizers. Significant increase in seed cotton yield due to application of 100 kg N (Recommended dose of N) through mineral fertilizers during first year of experimentation was also recorded in cotton by Blaise (2011). Nitrogen through chemical fertilizer had a positive and significant effect on maize yield in the first three seasons (Kihara *et al.* 2011). Choudhary *et al.* (2018) also reported that balanced use of inorganic fertilizer initially produced higher grain yield of wheat compared to integrated nutrient management treatments (fertilizer + FYM/ green gram/ green manuring), but with the passage of time, integrated treatments showed higher yield over inorganic fertilizer treatment.

The of combined use of organic manure, inorganics and biofertilizers increased nutrients availability through enhanced microbial activity, conversion from unavailable forms and also due to improved physical, chemical and biochemical conditions (Tomar *et al.* 2018) of soil. Increase in crop yield with gliricidia loppings compared to crop residue was also reported by Sharma *et al.* (2005).

The pooled results indicated significantly higher grain yield with the application of 50% N through organic + 50% N through inorganic + 25 kg K from inorganic fertilizers along with biofertilizers which was statistically at par with 100% NP from fertilizers + 25 kg K along with biofertilizers and 100 % RDF + 25 kg K from chemical fertilizers. The increase in the pooled yield due to 50% N through green leaf manure + 50% N from inorganic + 25 kg K (inorganic) along with biofertilizers was 1.6, 8.7 and 14.7% higher over 100% NP + 25 kg K $ha^{-1}$ (Inorganic sources), 100% NP (30:75:00 NPK kg $ha^{-1}$) and 100% N through FYM + biofertilizers. Among all the treatments, the yield trend of soybean grain was as follows : 100% NP + 25 kg K through chemical fertilizers along with biofertilizers > 50% N through Gliricidia + 50% N + 25 kg K from chemical fertilizers along with biofertilizers > 100 % NP + 25 kg K through chemical fertilizers > 50% N through gliricidia + 50% N from chemical fertilizers along with biofertilizers > 100 % NP + biofertilizers > 50% N through green leaf manure + 50% N through inorganics > 100 % NP through chemical fertilizers > Control.

The application of 100% N from FYM did not sustain the soybean grain yield during all the years of experimentation indicating that nutrients from FYM are slowly mineralized thereby it did not meet nutrient requirement of soybean. Besides this, soybean required more phosphorus than N and FYM contains very less amount of P, this resulted in low yields of soybean when nutrients was applied only through FYM on N basis. Dass *et al.* (2013) noted that the effect of Gliricidia with INM, RDF, or bio-fertilizers was better than that of integration with FYM. This might be due to the higher concentration of nutrients in Gliricidia biomass and its fast decomposition (succulent nature) resulting in an early release of nutrients into the soil (Zaharah and Bah 1999). Mundus *et al.* (2008) reported that Gliricidia leaves decomposed twice as fast as cattle manure, and N release is more synchronized with plant demand; 86% of its N is released before $42^{nd}$ day of its incorporation into soil (Lehmann *et al.* 1995).

This clearly suggests that instead of using chemical fertilizers alone for 100 % RDF, integration of organics (Gliricidia) and chemical fertilizers in a 50:50 proportion is agronomically more effective which also saves chemical fertilizers to the extent of 50% and also improves the effectiveness of the individual source when applied in association. Similar enhancement in rice yield with integrated application of nutrients in a 50:50 proportion was also reported by Babar and Dongale (2013). Data indicated that application of FYM and gliricidia lopping to substitute 50 % N along with compensation of RD from mineral fertilizers was found beneficial in sustaining the soybean grain yield.

*Soybean straw yield*

The pooled data (2009-2013) indicated the highest straw yield (2696.4 kg $ha^{-1}$) with the application of 100% NP + 25kg K $ha^{-1}$ + biofertilizers ($T_6$) and it was on par with application of 50% N through Gliricidia +50% N through inorganics+ biofertilizers + 25kg K $ha^{-1}$ ($T_9$) and 100% NP + 25kg K $ha^{-1}$ ($T_5$).

*Productivity Rating Index (PRI)*

The data (Table 1) revealed that the highest PRI (72.70) was recorded with the application of 100% NP + 25kg K $ha^{-1}$ + biofertilizers ($T_6$) followed by 70.39 in treatment $T_9$ having application of 50% N through Gliricidia +50% N through inorganics+ biofertilizers + 25kg K $ha^{-1}$. The lowest PRI was recorded in control followed by application of 100 % N from FYM with biofertilizers.

*Sustainable Yield Index (SYI)*

Maintenance of soil fertility for higher productivity is the goal of sustainable agriculture. The Sustainable Yield Index (SYI) for each treatment was worked out using the respective mean yields of the treatment, standard deviation determined in each treatment and maximum yield observed in any treatment during the study.

The data on sustainable yield index of soybean indicated that the highest SYI (0.47) was with the application of 50% N through Gliricidia +50% N through inorganics+ biofertilizers + 25kg K $ha^{-1}$ ($T_9$) and 100% NP + 25kg K $ha^{-1}$ + biofertilizers ($T_6$) followed by 0.46 in 50% N through glyricidia + 50% N through inorganics + biofertilizers (Table 1). The higher SYI in these treatments may be due to continuous supply of reserved nutrients by addition of green lopping along with chemical fertilizers. Therefore, combined application of nitrogen in a 50:50 proportion through Gliciridia loppings and chemical fertilizers increased the sustainability yield index (SYI) of soybean grain compared with control or alone application of 100 % N from FYM. In earlier studies, the application of FYM @ 10 t $ha^{-1}$ along with 50 % RDF from chemical fertilizers also increased the SYI of seed cotton on Vertisols of semi-arid tropics (Gabhane *et al.* 2014). Similar positive effects of substitution of N through FYM/ GLM/ GM on SYI under semi -arid conditions of central India also reported by (Sonune *et al.* 2012, Mali *et al.* 2015). Xie *et al.* (2016) reported increase in SYI with replacing N through green manure in paddy soil.

Although the SYI values showed comparable figures at 100% dose of only chemical fertilizers, this suggests necessity of regular addition of organics in order to sustain crop productivity of cotton-based cropping system in this tract without declining the soil quality further (Katyal *et al.* 1999; Manna *et al.* 2005 and Mali *et al.* 2015).

*Nutrient uptake by soybean*

The data on the effect of the INM treatments on total N, P and K uptake by soybean are presented in table 2. The data indicated that the higher N, P and K uptake by soybean (96.04, 21.19 and 33.50 kg $ha^{-1}$) was with the application of 50% N through glyricidia +50% N through inorganics+ biofertilizers + 25 kg K $ha^{-1}$ and was on par with application of 100% NP + 25kg K $ha^{-1}$ + biofertilizers. The increase in N uptake on application of inorganic in combination with organics is due to increase in yield, effective root system and increased concentration of nutrients in soil solution as well as better soil physical environment coupled with sufficiency of water and nutrients helped in better uptake of water and nutrients (Mali *et al.* 2015).

*Rain water use efficiency*

The data on rain water use efficiency (RWUE) indicated that during the first two years (2009 and 2010), the higher RWUE was recorded in treatment $T_6$ (100% NP +25kg K $ha^{-1}$+biofertilizers),while from third year onwards the higher RWUE was recorded in treatment having 50% N through Gliricidia +50% N through inorganics + biofertilizers + 25 kg K $ha^{-1}$), indicating the important role of INM in increasing the RWUE (Table 3).

*Gross monetary returns (GMR)*

During 2009 and 2010, higher GMR was recorded in 100% RDF + 25kg K $ha^{-1}$ + biofertilizers ($T_6$) followed by the application of 50% N through Gliricidia +50% N through inorganics +biofertilizers +25 kg K $ha^{-1}$ ($T_9$) while in 2011,2012 and 2013, the higher gross

**Table 2**. Effect of INM on nitrogen uptake by soybean (kg ha$^{-1}$)

| | Treatments | Total uptake | | |
|---|---|---|---|---|
| | | N | P | K |
| $T_1$ | Control | 52.79 | 10.15 | 18.39 |
| $T_2$ | 100% NP (30:75:00 NPK kg ha$^{-1}$) | 72.35 | 13.50 | 24.56 |
| $T_3$ | 100% NP + biofertilizers | 77.29 | 15.93 | 26.91 |
| $T_4$ | 100% N through FYM + biofertilizers | 62.72 | 12.64 | 22.43 |
| $T_5$ | 100% NP + 25kg K ha$^{-1}$ | 84.21 | 17.29 | 29.45 |
| $T_6$ | 100% NP + 25kg K ha$^{-1}$ + biofertilizers | 87.84 | 19.48 | 30.92 |
| $T_7$ | 50% N through green leaf manure + 50% N through inorganics | 68.67 | 15.27 | 25.74 |
| $T_8$ | 50% N through green leaf manure + 50% N through inorganics + biofertilizers | 84.95 | 18.52 | 29.97 |
| $T_9$ | 50% N through green leaf manure +50% N through inorganics+ biofertilizers + 25kg K ha$^{-1}$ | 96.04 | 21.19 | 33.50 |
| | SE (m) $\pm$ | 3.55 | 0.64 | 1.37 |
| | CD at 5% | 10.64 | 1.91 | 4.12 |

**Table 3.** Effect of INM on rain water use efficiency (kg ha$^{-1}$mm$^{-1}$)

| | Treatments | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|
| $T_1$ | Control | 2.04 | 1.96 | 3.00 | 2.52 | 1.29 |
| $T_2$ | 100% NP (30:75:00 NPK kg ha$^{-1}$) | 2.33 | 2.39 | 3.18 | 2.95 | 1.46 |
| $T_3$ | 100% NP + biofertilizers | 2.40 | 2.54 | 3.13 | 3.01 | 1.49 |
| $T_4$ | 100% N through FYM + biofertilizers | 2.14 | 2.28 | 3.12 | 2.73 | 1.42 |
| $T_5$ | 100% NP + 25kg K ha$^{-1}$ | 2.51 | 2.63 | 3.20 | 3.10 | 1.64 |
| $T_6$ | 100% NP + 25kg K ha$^{-1}$ + biofertilizers | 2.65 | 2.72 | 3.60 | 3.17 | 1.68 |
| $T_7$ | 50% N through green leaf manure + 50% N through inorganics | 2.22 | 2.30 | 3.54 | 3.09 | 1.44 |
| $T_8$ | 50% N through green leaf manure + 50% N through inorganics + biofertilizers | 2.30 | 2.30 | 3.67 | 3.05 | 1.63 |
| $T_9$ | 50% N through green leaf manure +50% N through inorganics+ biofertilizers + 25kg K ha$^{-1}$ | 2.37 | 2.32 | 3.69 | 3.44 | 1.73 |

monetary returns were recorded with the application of 50% N through Gliricidia + 50% N through inorganics+biofertilizers+25kg K $ha^{-1}$ ($T_9$) followed by 100% NP + 25kg K $ha^{-1}$+ biofertilizers ($T_6$) (Table 4). However the pooled results indicated slightly higher GMR in treatment $T_6$.

*Net monetary returns (NMR)*

The data on NMR 4 indicated that during first three years (2009 to 2011) of experimentation, the higher net monetary returns were observed with 100% RDF+25kg K $ha^{-1}$+biofertilizers (Table 4) while in last two years (2012, 2013), the higher NMR were obtained with the application of 50% N through Gliciridia +50% N through inorganics+biofertilizers+25kg K $ha^{-1}$ . During the initial years significantly higher grain yield was obtained with the application 100 % RDF + 25 kg K along with biofertilizers which reflected in net returns of soybean. However, from third year onwards, the significantly highest NMR was obtained with the application of 50% N through GLM + 50 % N from chemical fertilizers + 25 kg K along with biofertilizers.

The pooled data indicated slightly higher NMR in treatment $T_6$. During fiveyear study, the increase in net returns due to substitution of 50 % N from GLM rangedfrom 544 to 10535 Rs $ha^{-1}$ and on an average increase was 4171 Rs $ha^{-1}$ over 100 % NPK (T2). The increase in net returns due to application of N in 50:50 proportion through green lopping and inorganic + 25 kg K (inorganic) along with biofertilizers ranged from 880 to 5813 Rs $ha^{-1}$ over 100 % NP + 25 kg K along with biofertilizers.

Growing soybean crop with alone NPK or FYM was not economically beneficial over 50 % N from green lopping + 50 % N from inorganic + 25 kg K (inorganic) along with biofertilizers, when cost of FYM was considered. FYM was the most commonly used organic manure in the past. However, due to its acute shortage in recent days its use has become very scare and rare which is by and large responsible for decline in soil quality. Gliricidia can serve as the most potential alternative to FYM. The practice of Gliricidia green leaf manuring is simple as it can be grown on the field bunds successfully since it is quick growing species. It produces significant amount of green biomass which can be easily used for partially substituting costly chemical fertilizers. Its application on farmers field minimizes the expenses on chemical fertilizers besides improvement in soil quality. Net returns and benefit:cost ratio recorded from Gliricida biomass-treated plots was far higher than those of FYM-treated plots because of relatively higher procurement cost of the latter. Mong'omba and Akinnifesi (2020) reported that the use of Gliciridia biomass reduced a high inorganic fertilizer requirement as a combination of either a half or full dose of inorganic fertilizer with Gliciridia biomass increased maize grain yield with almost the same amount. In such situation, farmers can reduce the quantity of inorganic fertilizer by half in soybean upto 50 % N through Gliciridia and hence farmers are better off using gliricidia biomass with reduced rate of recommended inorganic fertilizer as this saves the costs of inorganic fertilizer.

*B:C ratio*

The data on B:C ratio (Table 4) indicated that during first three years (2009 to 2011) of experimentation, the higher B:C ratio were obtained with 100% NP + 25kg K $ha^{-1}$ + biofertilizers ($T_6$) while in last two years (2012, 2013) the higher B:C ratio were obtained with the application of 50% N through glyricidia +50% N through inorganics +biofertilizers + 25kg K $ha^{-1}$ ($T_9$). The pooled results indicated comparable B:C ratios in $T_6$ and $T_9$ treatments.The pooled data in respect of NMR and B:C ratio (Table 4) also indicated the comparable NMR and B:C ratio in treatments $T_6$ and $T_9$.

*Organic carbon*

The results presented in table 5 showed that, there was a build-up of organic carbon in soil in all treatments except control over the initial status (5.2 g $kg^{-1}$). The higher soil organic carbon 6.40g $kg^{-1}$ was observed with the application of 50% N through Gliciridia +50% N through inorganics+ biofertilizers + 25kg K $ha^{-1}$ ($T_9$) and was on par with application of 100%

**Table 4.** NMR (Rs $ha^{-1}$) of various treatments in soybean

| | Treatments | Net monetary returns (Rs. $ha^{-1}$) | | | | | | B:C ratio | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2009 | 2010 | 2011 | 2012 | 2013 | Mean | 2009 | 2010 | 2011 | 2012 | 2013 | Mean |
| $T_1$ | Control | 12562 | 25413 | 13530 | 36070 | 13576 | 20230 | 1.97 | 2.45 | 1.80 | 2.97 | 1.78 | 2.19 |
| $T_2$ | 100% NP (30:75:00 NPK kg $ha^{-1}$) | 13318 | 31637 | 12858 | 38867 | 11594 | 21655 | 1.86 | 2.54 | 1.65 | 2.58 | 1.49 | 2.02 |
| $T_3$ | 100% NP + biofertilizers | 13521 | 33950 | 11362 | 39262 | 11446 | 21908 | 1.83 | 2.58 | 1.55 | 2.54 | 1.47 | 1.99 |
| $T_4$ | 100% N through FYM + biofertilizers | 6975 | 24929 | 7627 | 28997 | 2571 | 14220 | 1.35 | 1.96 | 1.32 | 1.97 | 1.08 | 1.54 |
| $T_5$ | 100% NP + 25kg K $ha^{-1}$ | 15287 | 36230 | 12611 | 41733 | 15513 | 24275 | 1.96 | 2.72 | 1.63 | 2.67 | 1.64 | 2.12 |
| $T_6$ | 100% NP + 25kg K $ha^{-1}$ + biofertilizers | 16155 | 37373 | 15620 | 42324 | 15511 | 25397 | 1.96 | 2.70 | 1.74 | 2.63 | 1.62 | 2.13 |
| $T_7$ | 50% N through green leaf manure + 50% N through inorganics | 11622 | 28862 | 15139 | 43940 | 13029 | 22518 | 1.73 | 2.34 | 1.73 | 2.94 | 1.60 | 2.07 |
| $T_8$ | 50% N through green leaf manure + 50% N through inorganics + biofertilizers | 11670 | 27838 | 15449 | 42163 | 16568 | 22738 | 1.69 | 2.25 | 1.71 | 2.79 | 1.73 | 2.04 |
| $T_9$ | 50% N through green leaf manure +50% N through inorganics+ biofertilizers + 25kg K $ha^{-1}$ | 12217 | 27932 | 15426 | 50058 | 18790 | 24885 | 1.71 | 2.23 | 1.70 | 3.09 | 1.82 | 2.11 |
| | SE (m) ± | 1341 | 2359 | 1592 | 2790 | 1964 | 928 | | | | | | |
| | CD at 5% | 4021 | 7071 | 4774 | 8364 | 5889 | 2612 | | | | | | |

Average cost of inputs and outputs: FYM - @ Rs. 2800 $ha^{-1}$, urea @ Rs. 5.7 kg $^{-1}$, SSP @ Rs. 8 $kg^{-1}$, MOP @ Rs. 16 $kg^{-1}$, COC for T1 to T9 :Rs. 16656, 20824, 21712, 26030, 21216, 22143,20524, 21405 and 21765 $ha^{-1}$ respectively; . Soybean grain @ Rs. 3200 qt $^{-1}$ and soybean straw @ Rs. 75 qt $^{-1}$

**Table 5.** Effect of INM on organic carbon and fertility status of soil

| | Treatments | OC $(g\ kg^{-1})$ | Available nutrients $(kg\ ha^{-1})$ N | P | K | OC balance $(g\ kg^{-1})$ | Nutrient balance $(kg\ ha^{-1})$ N | P | K |
|---|---|---|---|---|---|---|---|---|---|
| $T_1$ | Control | 5.11 | 189.00 | 11.20 | 312.63 | -0.09 | -6.00 | -4.30 | -6.37 |
| $T_2$ | 100% NP (30:75:00 NPK kg $ha^{-1}$) | 5.33 | 197.78 | 13.03 | 316.92 | 0.13 | 2.78 | -2.47 | -2.08 |
| $T_3$ | 100% NP + biofertilizers | 5.47 | 199.03 | 14.80 | 318.83 | 0.27 | 4.03 | -0.70 | -0.17 |
| $T_4$ | 100% N through FYM + biofertilizers | 5.64 | 190.67 | 13.12 | 316.66 | 0.44 | -4.33 | -2.38 | -2.34 |
| $T_5$ | 100% NP + 25kg K $ha^{-1}$ | 5.91 | 209.07 | 13.86 | 347.39 | 0.71 | 14.07 | -1.64 | 28.39 |
| $T_6$ | 100% NP + 25kg K $ha^{-1}$ + biofertilizers | 6.21 | 211.16 | 16.99 | 352.65 | 1.01 | 16.16 | 1.49 | 33.65 |
| $T_7$ | 50% N through green leaf manure + 50% N through inorganics | 6.00 | 197.36 | 14.31 | 330.03 | 0.80 | 2.36 | -1.19 | 11.03 |
| $T_8$ | 50% N through green leaf manure + 50% N through inorganics + biofertilizers | 6.18 | 201.54 | 16.37 | 340.67 | 0.98 | 6.54 | 0.87 | 21.67 |
| $T_9$ | 50% N through green leaf manure +50% N through inorganics+ biofertilizers + 25kg K $ha^{-1}$ | 6.40 | 215.34 | 17.34 | 357.95 | 1.20 | 20.34 | 1.84 | 38.95 |
| | SE (m)± | 0.08 | 4.77 | 0.60 | 3.55 | -- | -- | -- | -- |
| | CD at 5% | 0.23 | 14.29 | 1.80 | 10.65 | -- | -- | -- | -- |
| | Initial (2009-10) | 5.2 | 195 | 15.5 | 319 | -- | -- | -- | -- |

NP +25kg K $ha^{-1}$+biofertilizers ($T_6$) and 50% N Gliciridia + 50% N through inorganics +biofertilizers ($T_8$) while lowest organic carbon content (5.11g $kg^{-1}$) was observed in control. The treatment having Gliciridia and fertilizers with biofertilizer had 0.49 and 1.07 organic carbon (8.3 and 20.1 % higher) compared to application 100 % NP (30:75:00 kg NPK $ha^{-1}$) and 100 % NP with 30 kg K $ha^{-1}$. The increase in soil organic carbon with integrated use of Gliciridia and chemical fertilizers with biofertilizer was due to direct incorporation of organic matter, better root growth and addition of more plant residues. These results suggest that soil carbon levels can be improved substantially even under semi-arid regions by regular addition of organic manures along with mineral fertilizers.

The continuous increase in soil organic carbon in treatments receiving different organics may be due to their stimulating effect on growth and activity of microorganisms. This effect was further enhanced by addition of fertilizers that improved the root and shoot growth. Higher production of root biomass might have increased the organic carbon content (Bajpai *et al.* 2006).

The treatments of chemical fertilizers also had higher organic carbon in comparison to unfertilized control, because it helped in higher contribution of biomass to soil in the form of greater root biomass through crop residues. The subsequent decomposition of these materials might have resulted into enhanced organic carbon content of soil. This clearly demonstrated that use of Gliciridia loppings along with reduced fertilizer dose was equally effective in enhancing SOC in Vertisols under rainfed conditions.

*Organic carbon balance*

The data on the organic carbon balance (Table 5) indicated higher gain of organic carbon with the application of 50% N through Gliciridia +50% N through inorganics+ biofertilizers + 25kg K $ha^{-1}$ ($T_9$) followed by treatment $T_6$ and $T_8$.

Soil water and temperature are the limiting factors of the dryland agriculture and have direct influence on the soil organic carbon. Natural incorporation of the crop residues in to the soil after harvest of the crop is common phenomenon, but year after year, continuous addition of the crop residues or green manuring or even FYM has a very little effect on soil organic carbon in dryland condition. The soil moisture availability in dryland area soils is only for a period of 150 days, which hamper the *in-situ* decomposition process of crop residues/green manures, on the other hand rise in summer temperature may lead to oxidation of the organic carbon. Hence, under the dryland conditions judicious integration of nutrients is very much essential.

*Available nitrogen*

The residual soil fertility was significantly increased due to different treatments receiving 50 % N through FYM, GLM or their combinations along with chemical fertilizers (Table 5). Application of 50 % N from GLM + 50 % N from inorganic + 25 kg K along with biofertilizers (T9), 100 % NP + 25 kg K along with biofertilizers (T6) and 50 % N from GLM + 50 N from fertilizers along with biofertilizers increased 8.9, 6.8 and 1.9 % available N than 100 % NP from chemical fertilizers (T2). This increase was due to direct addition of N from Gliciridia and nitrogen fixation by nodules of green manuring crop into the soil as compared to the other treatments. Beside this, soils under gliricidia lopping along with NPK fertilizer treated plots produced more plant biomass and therefore, possibly had more extensive root system that might have contributed to increased N availability in soil (Choudhary *et al.* 2018). Similar enhancement in available N due to green manuring with reduction in fertilizer dose in Vertisols of semi-arid region was also reported by Sonune *et al.* (2012) and Pawar *et al.* (2013).

The available N status although showed increase under INM, it has not been increased much due to the prevailing climatic condition accelerating oxidation of organic matter as well as the nature of nitrogen forms in soil and its losses through volatilization and leaching. This necessitates regular addition of organics for maintenance of soil fertility in the soils of semi-arid eco-regions. (Mali *et al.* 2015).

*Available phosphorus*

The highest available P (17.34 kg ha$^{-1}$) was recorded in treatment receiving 50% N through Gliciridia +50% N through inorganics+ biofertilizers + 25 kg K ha$^{-1}$ followed by 100% NP + 25 kg K ha$^{-1}$ + biofertilizers ($T_6$) (16.99 kg ha$^{-1}$) and 50% N Gliciridia + 50% N through inorganics +biofertilizers ($T_8$) (16.37 kg ha$^{-1}$) which were found at par with each other. The increase in Olsen P due to treatment receiving 50 % N from Gliciridia + 50 % N from fertilizers + 25 kg K along with biofertilizers (T9), 100% NP + 25 kg K ha$^{-1}$ + biofertilizers ($T_6$) and 50% N Gliciridia + 50% N through inorganics +biofertilizers ($T_8$) was to the tune of 33.1, 30.4 and 25.6 % over 100 % NP (T2). The lowest available P (11.20 kg ha$^{-1}$) was recorded in control treatment. The application of Gliciridia loppings with fertilizer P resulted in appreciable enhancement in Olsen P owing to additional supply of P through organic manures and partly due to reduction of applied P in soil (Singh *et al.* 2007). Moreover, organic matter decomposition produces organic acids, which help in solubilization of soil fixed P (Mohorana *et al.* 2012). Similarly, significantly highest available phosphorus content (38.0 kg ha$^{-1}$) in the soils was observed with the application of Gliciridia loppings and nitrogen @ 90 kg ha$^{-1}$under minimum tillage (Sharma *et al.* 2020).

*Available potassium*

The highest available K (357.9 kg ha$^{-1}$) was observed in treatment having 50% N through glyricidia+50% N through inorganics+ biofertilizers + 25kg K ha$^{-1}$ followed by 100% NP + 25 kg K ha$^{-1}$ + biofertilizers ($T_6$) (352.6 kg ha$^{-1}$) and 100% NP + 25kg K ha$^{-1}$ (T5) (347.39 kg ha$^{-1}$) which were found at par with each others. The increase in available K due to treatment 50 % N from Gliciridia + 50 % N from fertilizers + 25 kg K along with biofertilizers (T9), 100% NP + 25 kg K ha$^{-1}$ + biofertilizers ($T_6$) and 100% NP + 25kg K ha$^{-1}$ (T5) was to the magnitude of 12.9, 11.3 and 9.6 % over 100 % NP (T2).

Available K was also significantly higher in the Gliciridia-containing treatments as compared with 100 % NPK (T2). This could be attributed to a very high K content of Gliricidia biomass and its release into the soil. The higher fertility status (particularly N and P) treated with Gliciridia caused higher crop yields. The lowest available nitrogen was observed in absolute control ($T_1$). These results clearly suggest that application of 100 % RDF without K was not effective for sustaining the residual soil fertility. The increase in availability of NPK attributed to N mineralization besides addition (Tolanur and Badanur 2003), solubilization of native P and reduction of P fixation and direct addition of K to the available pool of soil with reduction in K fixation and release of K (Sharma *et al.* 2001).

*Nutrient balance*

The data on the effect of INM treatments on nutrient balance ( Table 5) indicated the higher gain of nitrogen in treatment $T_9$ (50% N through Gliciridia +50%N through inorganics+ biofertilizers +25kg K ha$^{-1}$) over 100% NP K and 100 % RDF with K. This clearly indicated that 50% chemical fertilizer can be safely substituted with 50% N through green leaf manure along with recommended K and biofertilizers.

In general, significant gain in available nitrogen was observed in treatments barring treatment $T_4$ and control. The data also indicated the loss of phosphorus in all the treatments except the treatments $T_6$, $T_8$ and $T_9$ where biofertilizer and 25 kg K was applied . The higher gain in phosphorus was recorded in treatment $T_9$ followed by $T_6$ and $T_8$. In order to minimize the conversion of plant available phosphate to unavailable form due to the calcareous nature of black soil 21% calcium content in the SSP fertilizer, the addition of green leaf manure in combination with fertilizers is necessary which not only contain phosphorus but also increases the availability to crops in dryland condition.

The data also indicated the loss of potassium in all the treatments where potassium was not applied. However, gain of potassium was recorded in all INM treatments and other treatments where potassium was applied. The higher gain of potassium was recorded with the application of 50% N through Gliciridia +50% N through inorganics+biofertilizers+25kg K ha$^{-1}$($T_9$) followed by application of 100% NP +25kg K ha$^{-1}$+biofertilizers ($T_6$) and100% NP +25kg K ha$^{-1}$($T_5$). In general, the treatments ($T_5$, $T_6$, $T_8$, $T_9$) which received 25 kg K/Gliciridia loppings in combination with fertilizers had higher available potassium over other treatments. This may be due to the fact that Gliciridia contains $K_2O$ and addition of 2 t Gliciridia ha$^{-1}$ as a source of 15kg N ha$^{-1}$ add about same quantity of $K_2O$ ha$^{-1}$ to soil.

## Conclusion

For sustaining soil fertility, soybean productivity and obtaining higher monetary returns, application of 50% recommended N (15kg ha$^{-1}$) through glyricidia+50% N through inorganics + biofertilizers + 75kg $P_2O_5$ + 25kg $K_2O$ ha$^{-1}$ is recommended as an Integrated Plant Nutrient Supply System under dryland condition.

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