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Evaluation of soil physical properties as influenced by various green manuring legumes and phosphorus fertilization under rain fed conditions

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ABSTRACT: A field experiment was conducted under rainfed environment of Pothowar region of Pakistan to assess physical properties of soil as influenced by various green manure legumes (sesbania, cluster bean and rice bean) and different P levels (0, 30, 60, 90 kg P_2O_5/ha). Highest fresh biomass was observed in sesbania (23 t/ha) followed by cluster bean (19 t/ha) and lowest in rice bean (17 t/ha). Maximum crude protein content was found in sesbania (17%) followed by rice bean (10%) and cluster bean (8%). Green manuring crops, on average reduced soil bulk density (5%), enhanced total porosity (8%), and macropores and large mesopores (28%). Maximum reduction (7%) in soil bulk density, and an increase (11%) in total soil porosity and available water (17%) was observed in plots where sesbania was incorporated as green manuring crop. The order of effectiveness in improving bulk density, macro and mesopores was sesbania > cluster bean > rice bean. Sesbania produced greater number of macro and large mesopores about 41% increase over control followed by cluster bean (29%) and rice bean (16%). Phosphorus application showed meager positive impact on various soil physical properties but did not significantly increased porosity or reduced bulk density. Significant differences in volume fraction in pore space suggest that pore space on a volume basis was much higher in sesbania-amended soil than in other treatments.

Key words: *Green manuring legumes, phosphorus application, soil physical properties, rainfed environments*

INTRODUCTION

Green manuring has been known to improve soil fertility. The benefits of green manuring are multifold. It increases soil organic matter, available nitrogen, concentration of nutrients near the soil surface in available form, and reduces the N losses through leaching and soil erosion. Increases organic matter in soil as a result of green manure improves soil physical properties by increasing the distribution and stability of soil aggregates and decreasing soil bulk density (McRae and Mehuys, 1988). Vegetative cover prevents the build-up of the aggregates, which could lead to the formation of surface crusts that reduce water infiltration. Green manuring is the most important way to influence topsoil. The vegetative cover reduces runoff as well as the concentration and the size of the transported sediment particles and thus, the rates of loss of both soil and moisture. It also influences the soil moisture and temperature dynamics. The reduction of moisture losses can be attributed to the combination of several factors (Shukla, *et al.* 2004): (i) a significant reduction in the rate of surface evaporation and surface runoff, and (ii) increases in infiltration rates and moisture retention capacity of the soil The soil physical properties that are affected by incorporation of the green manure include the structure, moisture retention capacity, consistency and density. Other properties such as the porosity, aeration, conductivity, hydraulics and infiltration are allied to the modifications to the soil structure. Post-harvest decaying roots significantly increase macropores in soil. This effect depends on climatic factors and the soil characteristics. Both legumes and non-legumes are used as green manures. However, legumes are superior green manure crops as they fix atmospheric nitrogen and add it to the soil nitrogen pool (Carlson and Huss-Danell, 2003; Mayer, *et al.*, 2003). Legumes are known to improve soil fertility by adding much needed organic matter in the soils. Use of annual forage legumes such as sesbania, cluster

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bean and/or rice bean as green manures, can improve soil fertility and can help increase the productivity of the succeeding crop (Carlsson and Huss-Danell, 2003). These forage legumes could be included in the rainfed farming system of the Pothowar region (Pakistan) to improve soil fertility and increase crop productivity. The present study was thus conducted to evaluate the green manuring effect of forage legumes and phosphorus fertilization on the physical properties of the soil under rainfed environment of the Pothowar region.

MATERIALS AND METHODS

A field experiment was conducted during June 2002 to May 2003 at the experimental area of the National Agricultural Research Center, Islamabad, Pakistan. The Center is located in the Pothowar region in a sub-tropical, sub humid continental highland climatic zone characterized by hot long summers and cold winters. Soils of the area are inceptisol and loess in nature, slightly alkaline with pH 8.2 and low in organic matter (0.5%). The mean annual rainfall is 1000 mm, 70% of which occur during the monsoon (July to September) while the rest is received during the remaining months of the year. Metrological data for rainfall and temperature during experimental period are given in Figs. 1 and 2. The experiment was conducted as a randomized complete block design with two factors and four replications. The factors used were green manures legumes and phosphorus fertilization. Three legumes {Sesbans, *Sesbania aculeata* (L.); rice bean, *Vigna umbellate* (Thunb.), cluster bean, *Cyamopsis tetragonaloba* (L.)} were used as green manure crops. There was a combination of 16 treatments consisting of a fallow soil and three green manure legumes each with four phosphorus fertilization treatments consisting of 0, 30, 60 and 90 kg/ha applied as P_2O_5. The land was plowed with double disc to prepare a suitable seed bed. The legumes were sown with a hand drill at a row distance of 40 cm. The seeding rate was 50 kg/ha for sesbania and cluster bean and 80 kg/ha for rice bean. The tender stem and plants of these forage legumes were manually harvested at blooming stage 60 days after their establishment, and were later chopped and incorporated into the soil by rotavator. Soil samples from two depths (0-15 and 15-30 cm) were taken before and after incorporation of these legumes from each plot at random using double cylinder core samplers with sample holder (inner cylinder) diameter and height of 50 mm high (Black and Hartge, 1986). The sampler was pressed vertically into the soil surface enough to fill the sampler, but not so far to compress the soil in the compound space of the sampler. The sampler and its contents were carefully removed to preserve the natural structure and packing of the soil as best as possible. The two cylinders were sorted, retaining the undisturbed soil in the inner cylinder. The soil extending beyond each end of the sample holder was trimmed to flush with a straight edged knife. The soil sample volume was thus established to be the same as the volume of the sampler holder. The soil cores were wrapped in paper, transported and safely stored in the laboratory safely. Crude protein content of these forage legumes at harvest was calculated from total nitrogen of plants as determined by Kjeldahl method (Nelson and Sommers, 1980).

Bulk density

The soil was transferred from the sample holders of core sampler to a container and placed in an oven at 105°C, and dried to constant weight. The weight of soil was recorded and bulk density was calculated by the formula of Black and Hartge, 1986.

$$Bulk\ Density\ (\rho) = \frac{Oven\ dry\ weight\ soil}{Sample\ volume}$$

Total Porosity

Total porosity of the soil was calculated from bulk density assuming a particle density of 2.65 mg/m^3 with the following formula:

$$Total\ Porosity = 1 - \frac{Bulk\ density}{Particle\ density}$$

Available water and water retention

The core samples were placed on smoothened wet sand and kept overnight. Four pieces were cut from each core and placed on pre-wetted plates having appropriate bubbling pressure. Soil water retention was determined, at lower suction, using a fine-sand tension tube with a hanging water column and at higher suction using pressure plate apparatus. Pore size distribution was calculated from the water release curve, and equivalent radius was determined by assuming cylindrical pores. Water was removed from a pore of a given radius when suction was exerted on that water which was greater than the forces acting to retain the water in the pore. The smallest drained pore neck radius r for a particular soil water or suction (h) was calculated using the soil water capillary model (Klute, 1986).

$$r = \frac{2\gamma Cos\ \Phi}{hg\ \rho w}$$

Where γ is the surface tension of water (72.75 x 10^{-3} N/m), ϕ is the contact angle between water and solid (the contact angle is usually considered zero and *Cos* $\phi = 1$), ρw is the density of the water (988.2 kg/m^3 at 20 ºC), and *g* is the acceleration due to gravity (9.8 m/s). The different parameters depend on temperature; at 20 ºC, (with appropriate changes in units) the equation may be written as

$$\gamma = \frac{0.149}{h}$$

Where *h* is expressed in cm of water and γ in cm. Water retention and available water was determined successively at -0.1, -5 and -15 MPa using a pressure plate apparatus (Klute, 1986). Two years data of both the experiments were combined to get broad based reliable results. Data were subjected to statistical analysis using single factor randomized complete block design.

RESULTS

Effect of P levels on total biomass production

Application of phosphorus at various levels in loess soils of Pothowar had significant effect on fresh weight of the three green manuring legume species. Highest fresh biomass was observed in sesbania (23 t ha^{-1}) and lowest in rice bean (17 t ha^{-1}) that was 35% less than sesbania. Cluster bean produced fresh biomass (19 t ha^{-1}) that was 15% higher than rice bean. Maximum crude protein content was found in sesbania (17%) followed by rice bean (10%) and cluster bean (8%). Fresh biomass production increased with increased P-fertilization in various green manuring legumes as examined individually in these experiments.

Residual effect of green manures and P fertilization

The biomass production of various green manure crops for following year was comparatively better than preceding year for each legume species and at each level of P application. Overall 3% improvement was observed which might be due to integrated residual effect of previous green manuring legume and P fertilization. Though the difference was statistically non-significant, it could have great ecological importance. Considerable improvement could be expected within a few years if such little improvement continues unabated year after year.

Effect of green manuring legumes and P levels on physical properties of soil

Considerable influence of green manuring crops on physical properties of the soil was noticed as shown in Figs. 3-7. Green manuring on the average reduced soil bulk density by 5% and enhanced total porosity by 8% (Fig. 3). Maximum reduction of 7% in soil bulk density and an increase of 11% in total soil porosity were observed in plots where sesbania was incorporated as green manuring crop (Fig. 4). The order of effectiveness in improving bulk density was sesbania > cluster bean > rice bean > control treatment. The effect of green manuring legumes especially sesbania was more pronounced at 0-15 cm than 15-30 cm depth of soil. P application did not contribute significantly in the reduction of bulk density but with 90 kg P/ha the differences between green manuring legume treatments were more obvious at the surface soil. The observed decrease in bulk density was attributed to a significant increase of 8% in total porosity of soil under green manuring amendments. Maximum increase in total porosity was observed in surface soil where sesbania was incorporated as green manuring crop. The order of effectiveness of green manuring treatments improving total porosity of soil was sesbania > cluster bean > rice bean > control. It was observed that green manuring crops on the average enhanced macropores (> 15 μm) and larger mesopores of size (15-0.3 μm) up to 28%. Sesbania was able to produce greater number of macropores (> 15 μm) and larger mesopores (15-0.3 μm) in the surface soil which accounted for the about 41% increase over the control whereas the pore increase was 29% in cluster bean and 16% in rice bean. There was no significant change in other pore size classes such as macropores, smaller mesopores (0.3- 0.1 μm) and micropores (< 0.1 μm). This was likely due to the addition of organic matter and extensive root penetration to deeper layers. Similar observations were made by Gupta and Larson (1979) and Hill and Cruse (1985). Soil water retention was significantly influenced by 5% green manuring crops (Fig. 5). Soil under sesbania retained 7% more moisture than control at a metrics potential of -10 MPa whereas cluster bean resulted in 5% greater moisture retention than the control (Fig. 6-a). It was observed that soil under sesbania retained the greatest volume of water followed by cluster bean and rice bean. Reduced tilled soil generally retained a significantly larger quantity of water than conventionally tilled soil. Green manuring substantially increased the amount of available water to plants by 17% than the control. This effect was more pronounced in the surface soil than in the sub-soil (Fig. 6-b). Soil with sesbania as green manure had maximum plant-available-water that was 23% than the control. P application has no effect on plant-available-water content of soil (Figs. 6-a, b). Green manuring in general increased macro and larger mesopores by 31%. Sesbania was more effective in producing greater number of macropores and larger mesopores (15-1.5 μm) in the surface soil by about 47% increase over control, whereas positive influence of cluster bean and rice bean was 35% and 21%, respectively (Figs. 7-a, b). There was no significant variation in pores of other size classes. Soil water retention was significantly (P=0.05) affected by 6% in green manuring crops. Soil under sesbania retained 9% more moisture over control followed by cluster bean (5%) and rice bean (3%). Green manuring significantly (P=0.05) increased the availability of water by 15% to plants by enhancing water retention of water in the soil. Sesbania as green manuring again had significantly (P=0.05) greater plant available water that was 18% higher than the control, whereas cluster bean and rice bean did not show any effect on plant-available water. Sesbania has deeper root system which helps produce greater number of macropores.

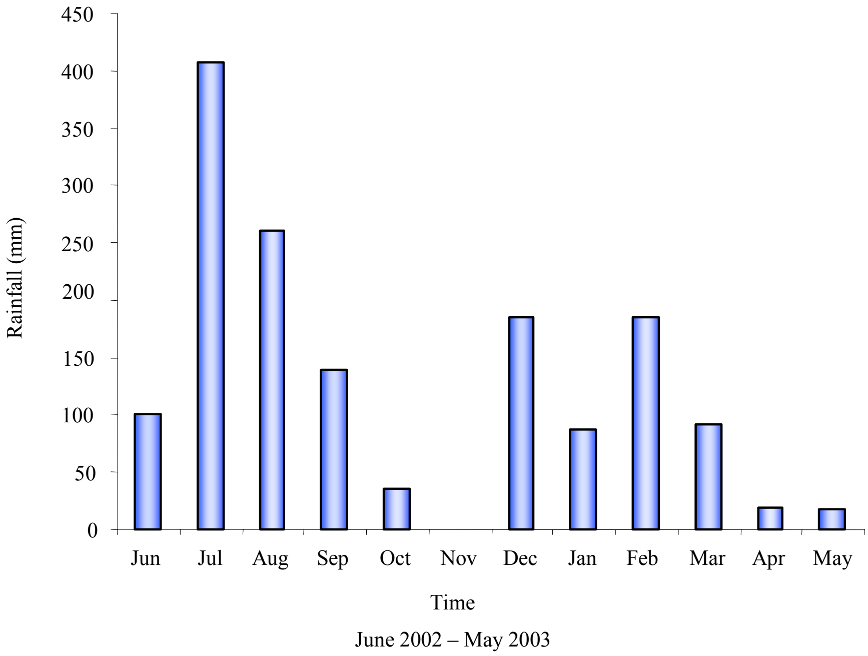

Fig. 1: Rainfall during the experimental period 2002-2003

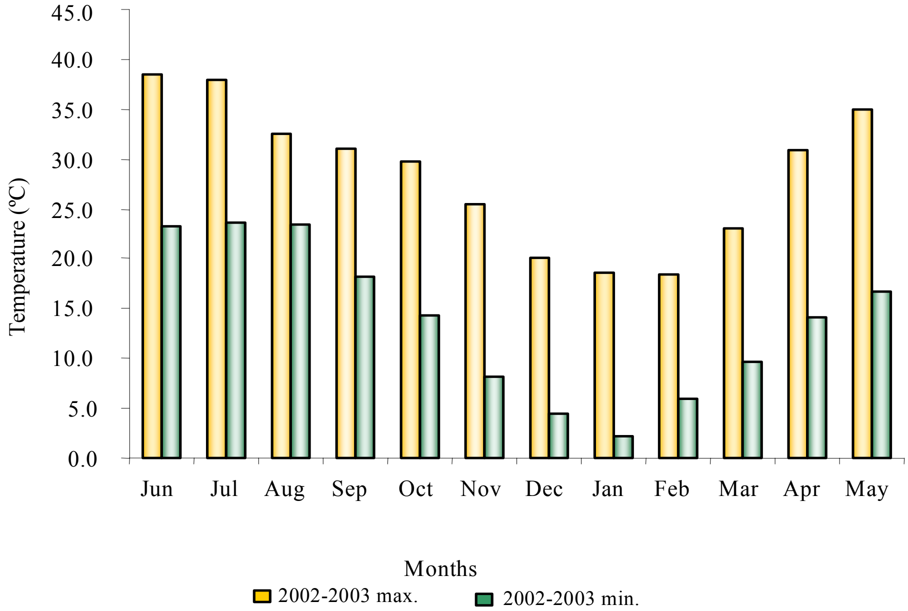

Fig. 2: Temperatures (ºC) regime during the experimental period 2002-2003

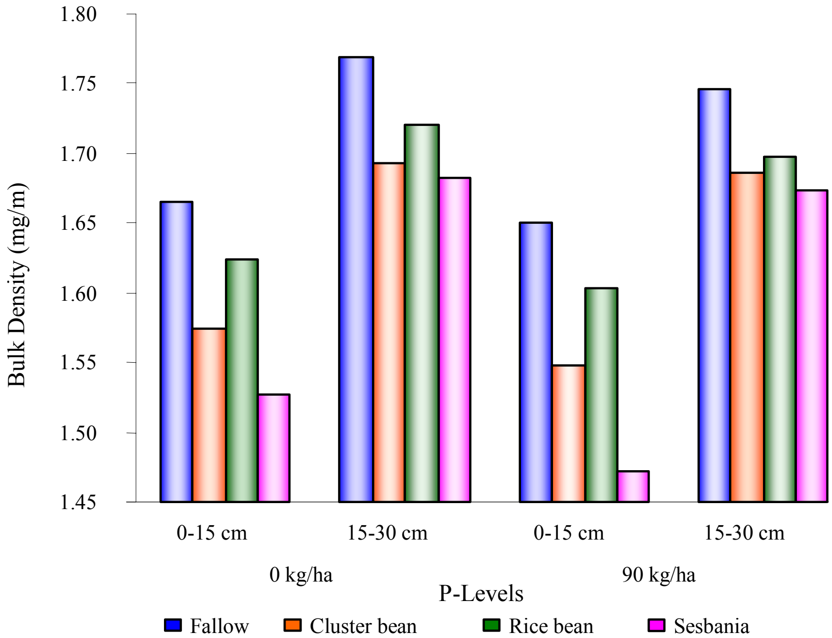

Fig. 3: Effect of green manuring legumes and P-fertilization on bulk density of soil

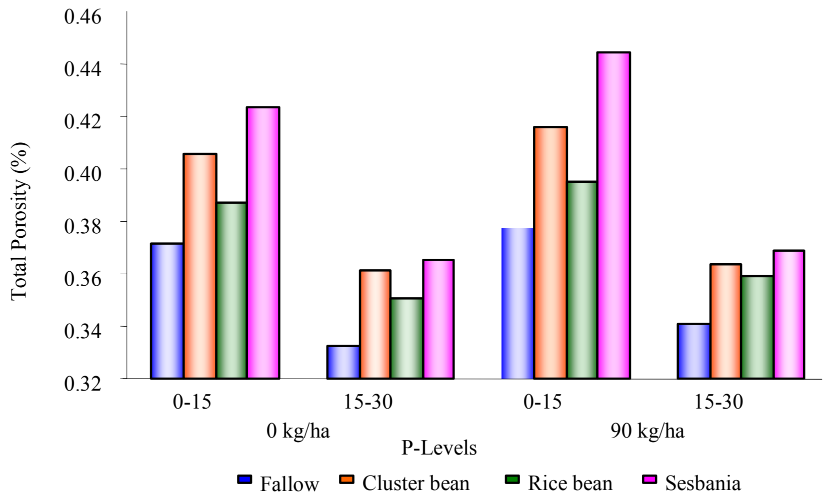

Fig. 4: Effect of green manuring legumes and P-fertilization on total porosity of soil

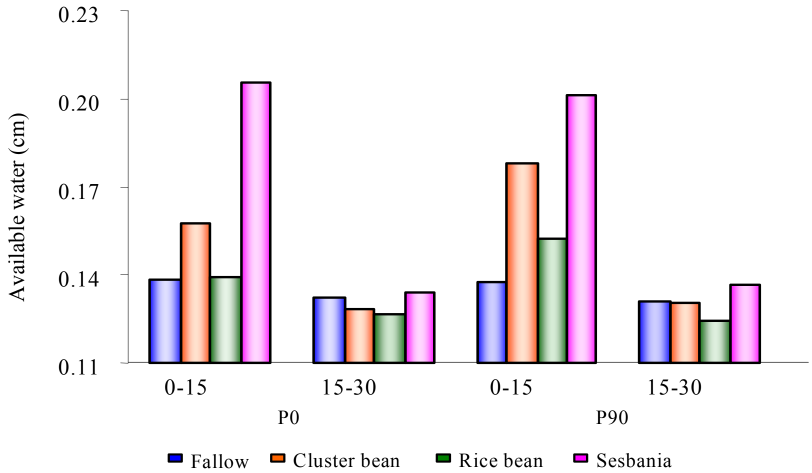

Fig. 5: Effect of green manuring legumes and P-fertilization on available water contents of soil

DISCUSSION AND CONCLUSION

Sustainable agricultural management practices are known to influence soil physical properties to maintain functional capacity of soil for crop growth (Ekwue, 1990; Islam and Weil, 2000-a; Min, *et al,*. 2003; Scott, *et al.,* 1994). Phosphorus fertilization showed mild positive effect on various physical properties but did not contribute significantly in reducing bulk density or increasing porosity. No significant effect on soil water contents or on available water could be observed in this experiment. A significant decrease in bulk density with an associated increase in total porosity of soil under sesbania is probably related to greater amount of organic matter deposition and loosening of soil by root action (Haynes, 2000; Lampurlanes and Cantero-Martinez, 2003). Bulk density is inversely related to total porosity, which provides a measure of the porous space left in the soil for air and water movement (Min *et al.,* 2003; Tester, 1990). Lower bulk density implies greater pore space and improved aeration, developing a suitable environment for biological activity (Islam and Weil, 2000-b; Min, *et al.,* 2003; Werner, 1997). Green manuring crops, like sesbania specifically influence soil structural properties by enmeshing soil primary particles and microaggregates into macroaggregation through direct physical action of roots, and production of cementing agents from enhanced microbial activities.

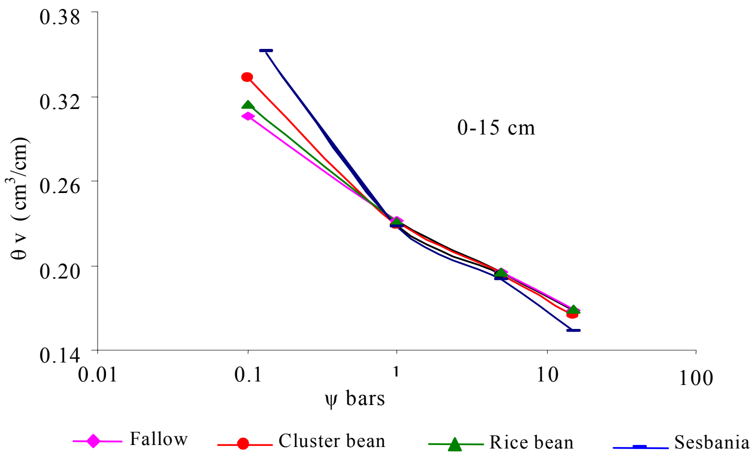

Fig. 6-a: Effect of green manuring legumes and P-fertilization on water retention characteristics of soil (0-15 cm)

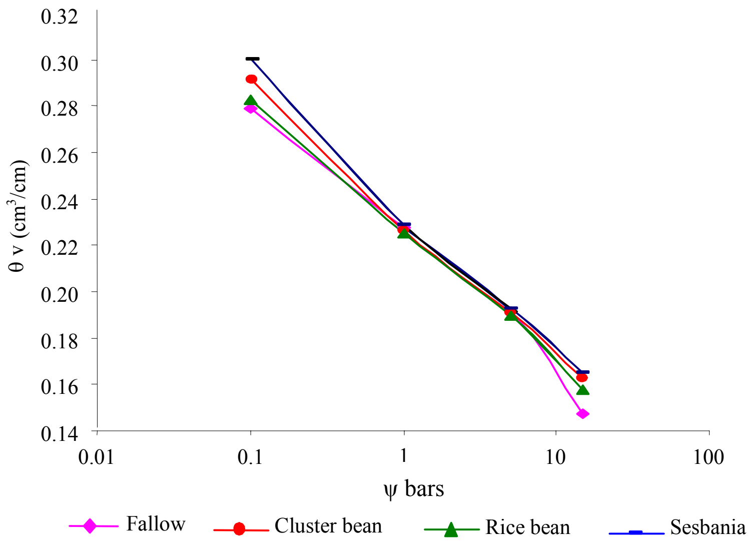

Fig. 6-b: Effect of green manuring legumes and P-fertilization on water retention characteristics of soil (15–30 cm)

These aggregation processes and properties may reduce soil bulk density and increase porosity with greater water retention and transmission capacities (Goldhamer, *et al*., 1994; Hargrove, *et al*., 1989; Islam and Weil, 2000-b; Min, *et al.,* 2003; Tester, 1990; Werner, 1997). Likewise Chikowo, *et al.* (2004) reported that incorporation of woody legumes into the soil reduces bulk density and increases soil granulation and porosity. The positive effect of P application in increasing biomass production of legumes has been widely reported (Azad, *et al.*, 1988; Bhadoria, *et al.,* 2004; Hundal and Biswas, 1988; Nayyar and Chhibba, 2000; Ogoke, *et al.,*2004). The overall increase in biomass production is attributed to increases in P application that in turn triggers better root development and thereby increase nutrient absorbtion. It may be inferred that legume crops without P may, however, suffer from nitrogen deficiency resulting in reduced biomass production. Malik, *et al.* (2002) reported that highest fresh biomass production of rice bean was found at 90 kg P/ha. These results suggest that higher doses of P appear to produce maximum biomass production in this region. Significant differences in volume fraction of pore space suggest that sesbania amended soil pore space is much higher than other treatments on a volume basis. It means there was a range of pore size in soils under different green manures

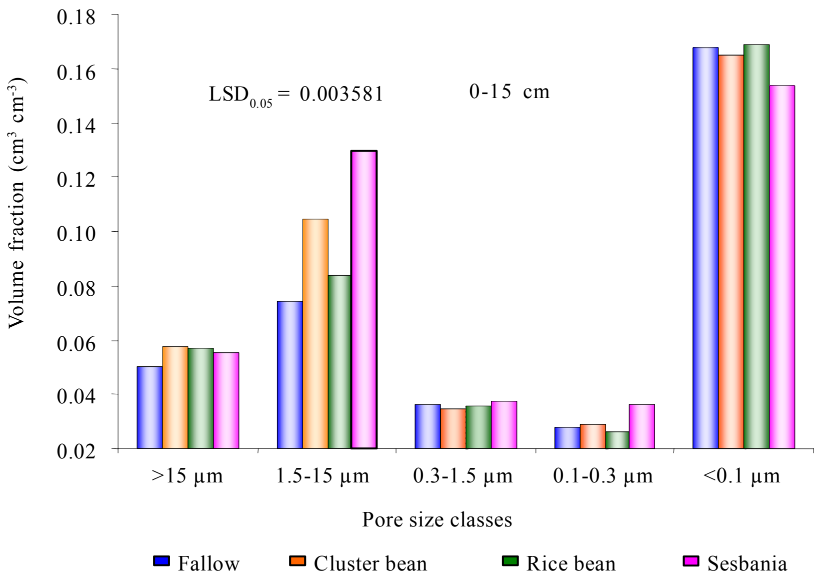

Fig. 7-a: Effect of green manuring legumes and P-fertilization on pore size distribution in soil (0-15 cm)

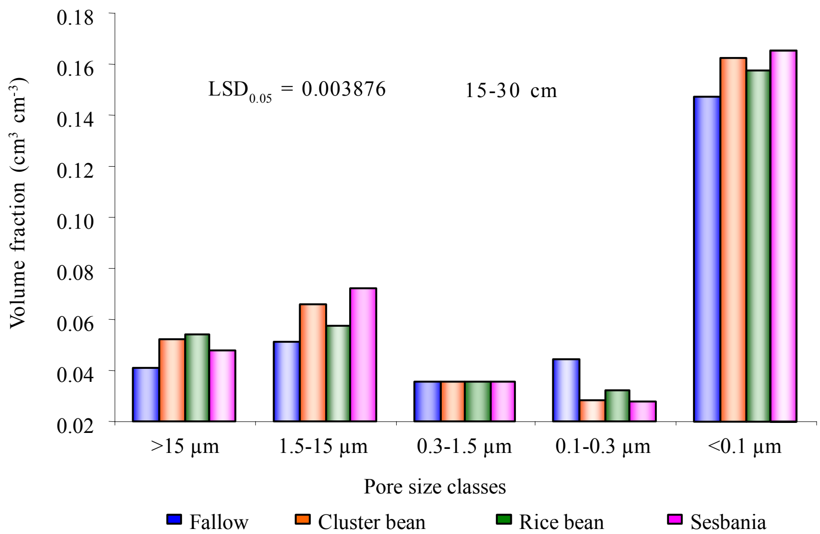

Fig. 7-b: Effect of green manuring legumes and P-fertilization on pore size distribution in soil (15-30 cm)

Those in turn are related to pore size distribution and continuity. This is very important for the air and water balance of soil since aeration critically depends upon pore size distribution (Aon, *et al.,* 2001). Increased total porosity of soils under sesbania suggests that sesbania is able to increase larger pores and the soil is far more likely to be regulated by macropores over micropores. Sesbania exhibited greater soil pore space in 1.5 to 15 µm radius range that should retain plant-available water. Pores with diameters between 0.1 and 15 µm are assumed to retain more plant available water than larger pores (Azooz, *et al.*, 1996; Hill and Meza-Montalvo, 1990). The use of sesbania as green manure consistently increased macro and mesopores, and maintained micropores continuity undisturbed, which consequently resulted in greater plant available water holding capacity. Changes in pore network could result in changes in the storage and transmission of water, which in turn may lead to improved crop performance (Barzegar, *et al*., 2003). A significant increase in volumetric moisture content supported our results that the soil under sesbania had more porosity with a pore size distribution shifted toward macropores from micropores compared to the soils under other treatments. It may be concluded from the field study that green manuring leguminous crops (sesbania, rice bean and cluster bean), reduced soil bulk density (5%), enhanced total porosity (8%), and macropores and large mesopores (28%). Maximum reduction (7%) in soil bulk density, and an increase (11%) in total soil porosity and available water (17%) was observed in plots where sesbania was incorporated as green manuring crop. The order of effectiveness in improving bulk density, macro and mesopores was sesbania > cluster bean > rice bean. Sesbania produced greater number of macro and large mesopores about 41% increased over control followed by cluster bean (29%) and rice bean (16%). Phosphorus application showed meager positive impact on various soil physical properties. However, this did not have any significant effect on increasing porosity or reducing bulk density of soil. Significant differences in volume fraction in pore space suggest that pore space on a volume basis was much higher in sesbania-amended soil than in other treatments.

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