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Water transmission characteristics of a Vertisol and water use efficiency of rainfed soybean (*Glycine max* (L.) Merr.) under subsoiling and manuring

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Abstract

In Vertisols of central India erratic rainfall and prevalence of drought during crop growth, low infiltration rates and the consequent ponding of water at the surface during the critical growth stages are suggested as possible reasons responsible for poor yields (<1 t ha^{-1}) of soybean (*Glycine max* (L.) Merr.). Ameliorative tillage practices particularly deep tillage (subsoiling with chisel plough) can improve the water storage of soil by facilitating infiltration, which may help in minimizing water stress in this type of soil. In a 3-year field experiment (2000–2002) carried out in a Vertisol during wet seasons at Bhopal, Madhya Pradesh, India, we determined infiltration rate, root length and mass densities, water use efficiency and productivity of rainfed soybean under three tillage treatments consisting of conventional tillage (two tillage by sweep cultivator for topsoil tillage) (S_1), conventional tillage + subsoiling in alternate years using chisel plough (S_2), and conventional tillage + subsoiling in every year (S_3) as main plot. The subplot consisted of three nutrient treatments, viz., 0% NPK (N_0), 100% NPK (N_1) and 100% NPK + farmyard manure (FYM) at 4 t ha^{-1} (N_2). S_3 registered a significantly lower soil penetration resistance by 22%, 28% and 20%, respectively, at the 17.5, 24.5 and 31.5 cm depths over S_1 and the corresponding decrease over S_2 were 17%, 19% and 13%, respectively. Bulk density after 15 days of tillage operation was significantly low in subsurface (15–30 cm depth) in S_3 (1.39 mg m^{-3}) followed by S_2 (1.41 mg m^{-3}) and S_1 (1.58 mg m^{-3}). Root length density (RLD) and root mass density (RMD) of soybean at 0–15 cm soil depth were greater following subsoiling in every year. S_3 recorded significantly greater RLD (1.04 cm cm^{-3}) over S_2 (0.92 cm cm^{-3}) and S_1 (0.65 cm cm^{-3}) at 15–30 cm depth under this study. The basic infiltration rate was greater after subsoiling in every year (5.65 cm h^{-1}) in relation to conventional tillage (1.84 cm h^{-1}). Similar trend was also observed in water storage characteristics (0–90 cm depth) of the soil profile. The faster infiltration rate and water storage of the profile facilitated higher grain yield and enhanced water use efficiency for soybean under subsoiling than conventional tillage. S_3 registered significantly higher water use efficiency (17 kg ha^{-1} cm^{-1}) over S_2 (16 kg ha^{-1} cm^{-1}) and S_1 (14 kg ha^{-1} cm^{-1}). On an average subsoiling recorded 20% higher grain yield of soybean over conventional tillage but the yield did not vary significantly due to S_3 and S_2. Combined application of 100% NPK and 4 t farmyard manure (FYM) ha^{-1} in N_2 resulted in a larger RLD, RMD, grain yield and water use efficiency than N_1 or the control (N_0). N_2 registered significantly higher yield of soybean (1517 kg ha^{-1}) over purely inorganic (N_1) (1392 kg ha^{-1}) and control (N_0) (898 kg ha^{-1}). The study indicated that in Vertisols, enhanced productivity of soybean can be achieved by subsoiling in alternate years and integrated with the use of 100% NPK (30 kg N, 26 kg P and 25 kg K) and 4 t FYM ha^{-1}.

Keywords: Soybean; Subsoiling; Root length density; Water storage; Infiltration rate; Water use efficiency; Yield

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1. Introduction

Soybean (*Glycine max* (L.) Merr.) is the most important oilseed crop grown in the rainy season on Vertisols of the semi-arid tropical region of central India. Annual rainfall and its monthly distribution are highly variable in this zone (Painuli et al., 2002). Drought of unpredictable intensity and duration results in poor and unstable crop production of soybean in the region.

Vertisols and vertic intergrade soils, with shrink-swell characteristics and having a clay content of 60–65% cover about 73 million ha of the subhumid and semi-arid tropical regions of India and are the predominant soil type in Madhya Pradesh (Kanwar, 1988) central India. Here the soil at 15–30 cm soil depth is particularly dense (bulk density (BD) of 1.71 mg m^{-3}). The bulk density is greater than the growth limiting value for the soil (1.41 mg m^{-3}) and restricts roots penetration and growth in deeper soil layer, and resulted in significant yield reduction (Daddow and Warrington, 1983). Compaction in sub-surface layers of the Vertisol has been reported by Singer and Munns (1987), Braunack (1995), Kar et al. (1997), Painuli and Yadav (1998). In most cases, the large soil pores (macro-pores) are destroyed by the compactive force acted on the soil, which results in reduced content and movement of air, water and nutrients in the soil. Compaction also increases soil strength, thereby increasing the resistance to root penetration. Plants, thus, cannot explore greater soil volume to meet their demand for water and nutrients. So these inputs become positionally unavailable (Kirby and Blunden, 1994).

Under such climatic conditions water stored in the soil and its availability to the crop is of great importance to increase or even stabilize yields. Kirkegaard et al. (1992) reported that the restricted growth of pigeon pea (*Cajanus cajan* L.) resulting from soil compaction was primarily related to poor root exploration causing reduced water uptake. Decreased infiltration and storage of water also is critical to root growth. Practicing proper tillage system can increase water availability for crops in this soil often by increasing infiltration and by facilitating root exploration (Lal, 1989; Bordovsky et al., 1994; Lopez and Arrue, 1997; Lampurlanes et al., 2001). In soils that are prone to compaction, and while demonstrate crusting and natural cracking, but only have a restricted capacity to low water infiltration, subsoiling can increase rooting depth (Lampurlanes et al., 2001; Rajkannan and Selvi, 2002), improve infiltration and water storage (McDonald and Fisher, 1987; Heatherly and Spurlock, 2001; Sharma et al., 2004), and ultimately increase crop yield. In these soils, loosening by deep tillage, however, may or may not be required every year (Lal, 1989). Subsoiling can increase the yield of various crops, viz; soybean (Barbosa et al., 1989; Wesley et al., 1994; Wesley et al., 2001), corn (*Zea mays* L.) (Singh and Chaudhary, 1998; Diaz-Zortia, 2000), cotton (*Gossypium hirsutum* L.) (Salih et al., 1998) and sorghum (*Sorghum vulgare* L.) (Rajkannan and Selvi, 2002). It has been proven to be the most practical method for increasing water uptake by roots and depth-of-profile-wetted in slowly permeable clays (Kirby and Blunden, 1994; Rajkannan and Selvi, 2002).

In this paper we attempted to evaluate the effect of subsoiling on (i) water transmission, storage and other soil physical properties such as bulk density and soil penetration resistance in the soil profile and (ii) root growth water use efficiency and yield of rainfed soybean.

2. Materials and methods

2.1. Soil and climate

The field experiment was conducted during the rainy season (June–October) of 2000, 2001 and 2002 on a deep Vertisol at the research farm of the Indian Institute of Soil Science, Bhopal. The soil of the experimental site was clayey in texture and classified as Typic Haplustert having pH 7.8, organic carbon 0.5%, and EC 0.52 dS m^{-1} at 0–15 cm soil layer. The soils are low in available N (alkaline permanganate N 145 kg ha^{-1}) (Subbiah and Asija, 1956), available P (Olsen P, 10.7 kg ha^{-1}) and high in available K (ammonium acetate K, 325 kg ha^{-1}) (Page et al., 1982). The water

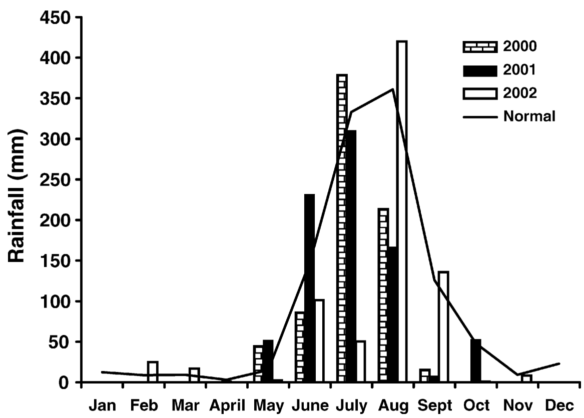

Fig. 1. Rainfall pattern during the year 2000, 2001, 2002 and 22-year average (normal) at Bhopal.