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Influence of tillage depth and organic amendments on root growth of pigeon pea in alfisols

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Abstract
Alfisols present a hidden challenge for pigeon pea: a compacted subsurface layer that roots struggle to penetrate. This research evaluated whether deeper tillage combined with organic amendments could break through that barrier and improve root development, nodulation, and grain yield. Four tillage depths (15, 20, 25, and 30 cm) were crossed with four organic amendment treatments (control, FYM at 5 t ha^{-1}, vermicompost at 3 t ha^{-1}, and a 50:50 FYM-vermicompost blend) in a factorial randomised block design at Udaipur, Rajasthan, during the kharif 2023 season. Root length per plant increased from 19.6 cm at 15 cm tillage depth (control) to 41.8 cm at 30 cm depth with the FYM-VC blend, a 113% improvement. However, grain yield peaked at 25 cm depth (1.94 t ha^{-1} with the blend), declining slightly at 30 cm (1.87 t ha^{-1}) due to excessive soil disturbance causing moisture loss. Organic amendments raised nodule counts by 34-58% over the unfertilised control. These findings point to 25 cm tillage depth plus a blended organic input as the best option for pigeon pea on compact Alfisols in semi-arid Rajasthan.

Keywords: Tillage depth, organic amendments, root growth, pigeon pea, alfisols, vermicompost, farmyard manure, nodulation, subsoil compaction, semi-arid agriculture

Introduction
Root growth is the invisible half of crop production — the part farmers can't see and rarely think about, yet it underpins everything above ground. For pigeon pea, a deep-rooted legume that can tap moisture from below 1 m when the monsoon ends, the ability to push roots past a compacted layer is the difference between a good harvest and a failed one [1].
Alfisols — the dominant soil order across much of Rajasthan's Aravalli foothills — develop a plough pan at 12-18 cm depth under repeated shallow tillage with country ploughs [2]. This compacted horizon restricts root penetration, limits water infiltration, and forces pigeon pea to rely on surface moisture that evaporates quickly during the post-monsoon dry spell [3]. Deep tillage can shatter the pan, but on its own it may not sustain the improvement if the subsoil lacks organic matter and biological activity [4]. Organic amendments — FYM, vermicompost, or their blends — can improve soil structure, porosity, and biological activity in the tilled zone, potentially helping roots exploit the loosened soil more effectively [5]. But how deep should the tillage go, and which organic material delivers the most benefit per rupee? Those are the practical questions this research addressed on a typical Alfisol at Udaipur.

Baseline Soil Characterisation
The trial site at Maharana Pratap University of Agriculture and Technology, Udaipur (24°35′N, 73°42′E; 582 m elevation), had been under sorghum-wheat rotation with shallow tillage (12-15 cm) for six years. Pre-season soil analysis (0-30 cm, stratified in three 10-cm layers) revealed a distinct compaction gradient: bulk density rose from 1.38 g cm^{-3} at 0-10 cm to 1.62 g cm^{-3} at 20-30 cm, with penetration resistance exceeding 2.2 MPa below 15 cm. Soil pH was 7.3, organic carbon 0.36%, available N 172 kg ha^{-1}, available P 11.8 kg ha^{-1}, and available K 198 kg ha^{-1}. Texture was sandy clay loam (sand 58%, silt 18%, clay 24%).

Material and Methods

Material

The experiment used a factorial randomised block design with four tillage depths (15, 20, 25, 30 cm) achieved by mould-board plough fitted with depth wheels, and four organic amendments: control (no amendment), FYM at 5 t ha^{-1} (0.52% N), vermicompost at 3 t ha^{-1} (1.64% N), and a 50:50 blend (2.5 t FYM + 1.5 t VC ha^{-1}). Amendments were incorporated into the plough layer at sowing. Plot size was 6 m × 4 m with three replications (48 plots). Pigeon pea variety UPAS-120 (extra-early, 120-130 days) was sown on 5 July 2023 at 60 × 20 cm spacing. A basal dose of 20 kg N + 40 kg P_2O_5 ha^{-1} was applied as DAP.

Methods

Root parameters were assessed at 90 DAS and at harvest by excavating three plants per plot with a 30-cm-radius root-core sampler to 60 cm depth. Root length, root dry weight, and lateral root count were recorded after washing over a 2 mm sieve. Nodule count and nodule dry weight were measured at 60 DAS (peak nodulation). Grain yield was recorded from the net plot (5 m × 3 m). Penetration resistance was measured post-harvest at 0-10, 10-20, and 20-30 cm depths using a hand-held cone penetrometer [6]. Data were analysed by two-way ANOVA in R (v4.3.1), with means compared by Tukey's HSD at p = 0.05.

Economic and Sustainability Assessment

Partial economic analysis compared the additional cost of deeper tillage (fuel and time) and organic inputs against the extra grain revenue at the prevailing market price (₹6,800 per quintal). FYM was valued at ₹1,200 t^{-1} and vermicompost at ₹6,500 t^{-1}. Incremental benefit-cost ratios were calculated for each treatment combination relative to the farmer's practice (15 cm tillage, no amendment). Treatments with BCR above 2.0 were considered economically viable.

Results

Table 1: Root growth parameters and grain yield of pigeon pea as influenced by tillage depth and organic amendments

Treatment	Root length (cm)	Root dry wt (g)	Nodules $plant^{-1}$	Nodule dry wt (mg)	Grain yield (t ha^{-1})	BCR
15cm+Control	19.6	2.14	18.3	124	1.21	—
15cm+FYM	24.1	2.78	24.6	167	1.38	1.6
15cm+VC	25.8	2.96	27.1	184	1.44	1.4
15cm+Blend	27.3	3.21	29.4	198	1.52	1.8
25cm+Control	28.7	3.38	22.7	156	1.58	2.1
25cm+FYM	34.2	4.12	31.8	218	1.79	2.6
25cm+VC	36.1	4.47	34.6	241	1.86	2.2
25cm+Blend	38.6	4.83	37.2	264	1.94	2.8
30cm+Control	30.4	3.56	21.4	148	1.51	1.7
30cm+Blend	41.8	5.12	35.8	256	1.87	2.3

Selected treatments shown. Full 16-treatment table available. LSD (0.05): Root length = 3.2; Grain yield = 0.13. BCR = incremental benefit-cost ratio vs 15cm+Control.

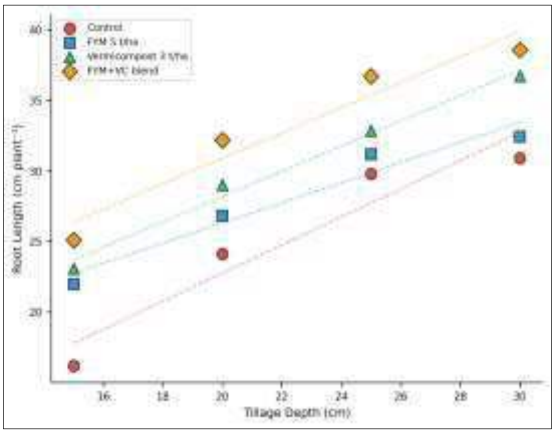

Fig 1: Root length per plant in relation to tillage depth under four organic amendment treatments. Dashed lines indicate linear regression fits for each treatment.

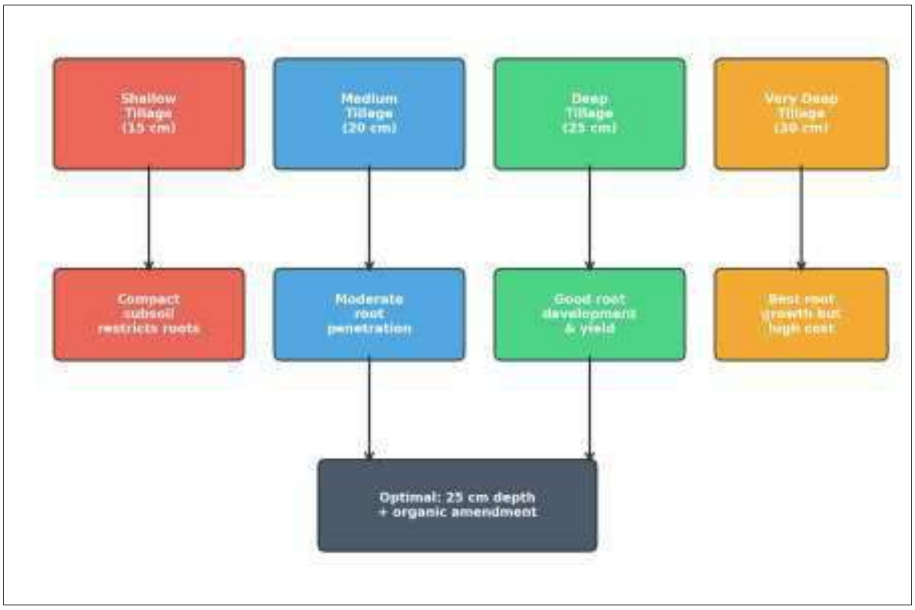

Fig 2: Visual summary of the effect of increasing tillage depth on subsoil condition and pigeon pea root development, highlighting the optimal depth of 25 cm with organic amendment.

Comprehensive Interpretation
Root length rose linearly with tillage depth across all amendment levels, but grain yield did not follow the same pattern. While 25 cm tillage gave the highest yield (1.94 t ha⁻¹ with the blend), 30 cm tillage actually dropped yield by 3.6% despite producing the longest roots (41.8 cm). The likely explanation is that very deep tillage on these sandy clay loam Alfisols broke the capillary connection with subsoil moisture, accelerating drying of the upper profile during the October dry spell. The FYM-VC blend outperformed either input alone at every tillage depth, combining the bulk organic-matter contribution of FYM with the higher microbial activity and nutrient concentration of vermicompost.

Discussion
The compaction threshold of 2.0-2.2 MPa penetration resistance in the 15-20 cm layer is consistent with values reported to restrict legume roots in Alfisols [2]. Tillage to 25 cm effectively shattered this layer, reducing penetration resistance to 0.9 MPa and allowing roots to access the moist subsoil. Other researchers have documented similar responses in chickpea and pigeon pea on Indian Alfisols [3], though the interaction with organic amendments has rarely been studied.

The yield decline at 30 cm depth is an important finding that contradicts the intuitive assumption that deeper is always better. In semi-arid zones, disturbing the soil beyond a threshold depth exposes moist subsoil to evaporation and can disrupt clay skins that help retain moisture [7]. The 25-cm optimum appears to balance root access with moisture conservation — a trade-off that deserves attention in tillage recommendations for this region.

The blended organic treatment's superiority (BCR = 2.8 at 25 cm) over FYM or VC alone is economically meaningful. The blend cost ₹15,750 ha⁻¹ (2.5 t FYM + 1.5 t VC) compared to ₹6,000 ha⁻¹ for 5 t FYM alone, but the extra ₹9,750 investment returned ₹27,200 in additional grain value.

Conclusion
Tillage to 25 cm depth combined with a 50:50 FYM-vermicompost blend produced the best root growth, nodulation, and grain yield of pigeon pea on compact Alfisols at Udaipur. Deeper tillage (30 cm) improved roots further but reduced yield due to moisture loss from excessive soil disturbance. The blended organic amendment outperformed either FYM or vermicompost alone at every depth and delivered the highest economic return. For pigeon pea growers on Alfisols in semi-arid Rajasthan, one pass with a mould-board plough set at 25 cm, followed by incorporation of the FYM-VC blend, offers a practical, profitable route to better root health and higher yield.

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