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A procedure for determining average root length density in row crops by single–site augering

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Abstract

A simplified procedure has been formulated and tested for determining average root length density (RLD) by auger sampling at a single site in wheat, corn and mustard. It involves the determination of horizontal root distribution in the representative half of the unit soil strip (distance from base of plant to mid-point in the rows) by excavating small monolith segments in the top soil layer. Average RLD is computed by dividing the integral of polynomial function fitted to the horizontal root distribution (in the unit soil strip) with its length. The average RLD, thus, obtained is interpolated on the curve between root length density and horizontal distance from the plant base (d) in the representative half of the unit soil strip. Root length density determined by centering 5 cm diameter auger at the interpolated d gave minimum deviation from the average RLD of that layer compared to the other possible single site sampling schemes with same-sized auger. These results indicate that for row crops, the best centre for single-site augering is about one-third of distance from the plant base to mid-way between the two rows.

Introduction

Knowledge about root growth and distribution is vital for understanding the mode of crop response to management practices. This information is also required for modelling nutrient and water uptake by the crop. But, due to the difficulties involved in sampling and estimating root growth in the field, only limited information on this aspect is available. Rooting density (mass or length of roots per unit soil volume) is the commonly employed parameter to characterise the extent and distribution of roots. Heterogeneity in the root distribution due to soil, plant and management factors make it difficult to assess average rooting density. Van Noordwijk et al. (1985) reported that in row crops, average rooting density distribution in the unit soil strip can be used for describing the root system. The 'unit soil strip' represents the area bounded by the lines mid-way between neighbouring rows and consists of two symmetrical halves on either side of a row. For precise estimation of average rooting density, sampling entire soil volume is required (through monolith excavation) in the representative half of unit soil strip. In view of sampling size, monolith excavation becomes highly destructive and laborious. In the field, rooting density is generally determined by less laborious and simple auger sampling method (Bohm, 1979). However, a large number of replicate samples and a carefully chosen sampling scheme by augering are required to obtain reasonably accurate estimates of average rooting density (Van Noordwijk et al., 1985; Vepraskas and Hoyt, 1988). A literature survey revealed that researchers chose sampling site(s) according to their convenience. Gajri and Prihar (1985) and Proffitt et al. (1985) employed two sampling sites for determining root growth viz., on the plant row and midway between two rows. Gregory et al., (1978) sampled wheat roots within plant row while, Wilhelm et al., (1982) sampled roots only mid-way between rows and Gajri et al. (1989) sampled wheat roots from three sites viz., starting from the base of the plant to the mid-point between rows. Sampling roots by this way provides only comparative effects of chosen management practices on root growth of crops, but such estimates may not be truely representative. It may be possible to find a single sampling location which would reflect average root length density (RLD) in the unit soil strip, but little is known on where such a sample should be taken and what the precision would be. Kumar et al. (1993) reported that single-site augering on the row or mid-way between two rows gave maximum bias from average rooting density inferred from monolith sampling. Nevertheless, analysis of horizontal root distribution in the representative half of unit soil strip with monolith sampling can be employed to locate the position of auger for single site sampling. This paper reports a procedure for determining average rooting density of row crops by single-site augering.

Materials and methods

The procedure

Formulation and testing of a procedure for estimating average RLD($\bar{R}$) of row crops by single-site augering involved the following steps:

1. Determination of horizontal RLD distribution in representative half of unit soil strip by vertical sectioning of monoliths in a soil layer for a given crop.
2. Fitting a polynomial function to horizontal RLD data.
3. Computing average RLD ($\bar{R}$) by integrating the fitted function between the limits of zero (plant base) and midpoint in the rows and dividing by difference between two limits.
4. Determination of the best centre for single site augering by interpolating $\bar{R}$ on the curve between root length density and distance from plant base (d).
5. Assessing the reliability of a sampling scheme from root mean square of the differences (RMSD) between R's and $\bar{R}$.

Experimental details

Field experiments with wheat, corn and mustard were conducted on a deep alluvial loamy sand (Typic Ustipsament) and a sandy loam (Typic Ustochrept) soil at the research farm of Punjab Agricultural University, Ludhiana (30°56′ N, 75°52′ E and 247 m above sea level), India. The location represents a semi-arid subtropical climate. The soils have developed under a hyperthermic regime and are low in organic matter (less than 0.4%) and are devoid of root restricting layer down to 2 m depth. Root data were generated from ongoing replicated experiments on tillage and irrigation effects in wheat, tillage effects in corn and tillage, irrigation and nitrogen effects in mustard.

Wheat was raised on loamy sand and sandy loam soils. The field plots were tilled conventionally (one discing, two cultivations to 10 cm depth and culti-packing) after a preseeding irrigation. Cultivar – HD 2329 was seeded in the first week of November in 22 cm apart rows (200 plants m^{-2}). Fertilization included 120 kg N, 28 kg P, 30 kg K and 25 kg $ZnSO_4$ ha^{-1}. Corn (cv. Partap) was seeded on a sandy loam soil in 60 cm × 22.5 cm spacing in first week of June. The field preparation and fertilization rate was same as in wheat. Mustard (cv. RL 1359) was seeded on a loamy sand soil in 30 cm × 15 cm spacing in conventionally tilled plots in the last week of October. Fertilization included 80 kg N and 26 kg P ha^{-1}. All three crops were kept free from weeds, diseases, and pests.

Root sampling

Roots were sampled by monolith excavation and augering at grain/seed-fill stage in wheat and mustard and 75% silking in corn. The above ground biomass from the area used for root sampling by these methods was removed at the same time in order to avoid growth during the time elapsed between monolith and auger sampling. Roots from the augering sites were sampled within 2–3 days of monolith sampling.

Monoliths

Soil monoliths, 11 cm (towards mid row) × 15 cm (along the row) × 10 cm (depth) in wheat, 30 cm × 22.5 cm × 10 cm in corn and 15 cm × 15 cm × 10 cm in mustard (Fig. 1), were excavated down to 30 cm depth in four replications for determining horizontal root distribution in a representative half of unit soil strip. In wheat, each monolith was vertically sectioned in six segments, five of which were two cm thick and the last in the mid row was one cm thick. In corn, there were 6 segments of 5 cm thickness each, while in mustard, sectioning was done in 5-cm segments each of 3 cm thickness. Soil from each monolith segment was washed on a one-mm screen in a water channel. Roots were cleaned and the length of living roots, distinguished by staining with 1% aqueous solution of congo red (Ward et al., 1978), was measured by the line intercept technique of Newman (1966). Root length density (average of 4 replications, cm cm^{-3}) in each monolith segment was regressed against corresponding horizontal distance from the base of the plant row to the mid-point of each segment (d) using a polynomial function to determine horizontal root distribution. Average root length density ($\bar{R}$) was computed by integrating the polynomial fitted to the horizontal root distribution over the half of the unit soil strip and dividing it by distance between base of the plant and mid-point between two rows. The $\bar{R}$ was interpolated on the horizontal root distribution curve to determine centre for single site augering.

Augering

For a given soil layer, RLD determined by centering 5 cm ID auger with sampling scheme A (estimated site) were compared with other possible single-site sampling schemes (Fig. 1) in the representative half of the unit soil strip. This auger size was used to sample roots as close to pre-determined site as possible. For each of these schemes, auger samples were collected from 10 sites (2 sites each in two replications and 3 sites each in other two replications). The

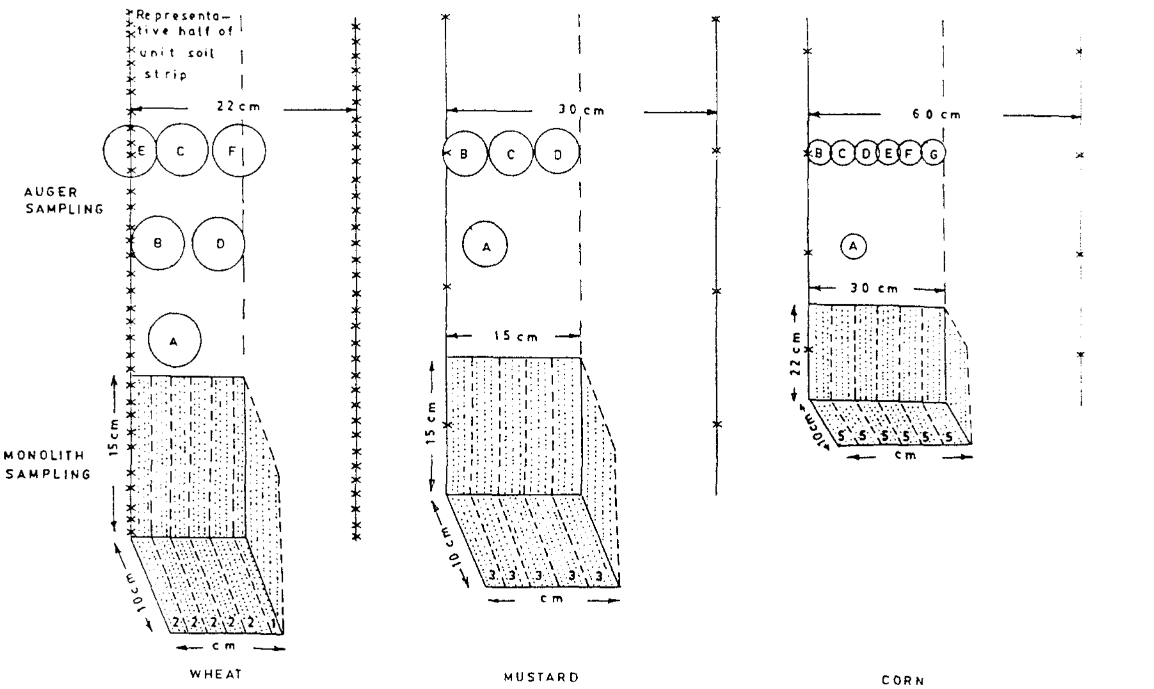

Fig. 1. Sampling schemes for monolith excavations and single-site augering in different crops. X-indicates plant position in the row.

procedure for washing and estimating root length was same as in monolith excavation.

Reliability of a sampling scheme was assessed from root mean square of difference (RMSD) in RLD with a given scheme R from $\bar{R}$.

Results and discussion

Horizontal distribution of RLD determined by vertical sectioning of excavated monoliths in representative half of the unit soil strip in different soil layers for the three crops is given in Table 1. Root length density was highest close to the base of the plant and decreased with increasing distance to a point and then increased due to contribution of roots from adjacent row. Of the different functions attempted, quadratic polynomial fitted best the horizontal root distribution with d as the coefficient of determination (r^2) ranging between 0.88 to 0.99 irrespective of crop, layer and soil (Figs. 2, 3 and 4). This is also substantiated by close matching between the arithmetic mean of horizontal RLD and $\bar{R}$ in a soil layer for a given crop.

Position for centering the auger for single site sampling, computed from interpolation of $\bar{R}$ on the horizontal root distribution curve, was 3 cm (loamy sand) and 4 cm (sandy loam) away from the plant base in wheat for all the three soil layers (Fig. 2). Corresponding distance was 10 cm in corn (Fig. 3) and 4.0 cm in mustard (Fig. 4). Interestingly, these positions were about one third of the distance between plant base and midpoint between the two rows or one sixth of row to row distance regardless of the crops.

Root length density determined by centering the auger at the estimated site by this procedure (scheme A) resulted in minimum deviation from $\bar{R}$ compared to RLD determined at other possible single site samplings (Table 2). In 0–10 cm layer in wheat on loamy sand, RMSD was 0.11 at position A compared to 0.47 at position B and 0.44 at position C. Similarly, in 0–10 cm layer in corn, RMSD were 0.28, 1.85 and 0.32 at position A, B and D, respectively. Similar trends were observed in mustard. Deviations were maximum with sampling schemes close to plant base (B and E in wheat and B in mustard and corn), whereas the RMSD with other schemes were intermediate. Almost the same location of single site sampling for all three soil layers suggests that the

Table 1. Horizontal distribution of root length density in the representative half of unit soil strip (mean of four replications)

Soil layer (cm)	Root length density ($cm\ cm^{-3}$)						Arithmetic mean
	Distance from the base of the plant (cm)						
Wheat (loamy sand)	*0–2*	*2–4*	*4–6*	*6–8*	*8–10*	*10–11*	
0–10	1.31 ± 0.61	1.21 ± 0.45	1.05 ± 0.33	0.94 ± 0.25	1.13 ± 0.37	1.20 ± 0.42	1.14
10–20	0.48 ± 0.20	0.40 ± 0.09	0.38 ± 0.24	0.37 ± 0.13	0.36 ± 0.20	0.45 ± 1.18	0.41
20–30	0.41 ± 0.20	0.33 ± 0.10	0.26 ± 0.12	0.24 ± 0.10	0.27 ± 0.13	0.31 ± 0.5	0.30
Wheat (sandy loam)							
0–10	0.96 ± 0.33	0.60 ± 0.25	0.49 ± 0.22	0.40 ± 0.15	0.26 ± 0.10	0.45 ± 0.07	0.53
10–20	0.28 ± 0.11	0.25 ± 0.08	0.24 ± 0.09	0.23 ± 0.10	0.19 ± 0.04	0.22 ± 0.03	0.24
20–30	0.25 ± 0.13	0.22 ± 0.10	0.20 ± 0.10	0.17 ± 0.02	0.13 ± 0.05	0.17 ± 0.05	0.19
Corn	*0–5*	*5–10*	*10–15*	*15–20*	*20–25*	*25–30*	
0–10	1.32 ± 0.52	0.42 ± 0.14	0.38 ± 0.09	0.26 ± 0.11	0.20 ± 0.07	0.28 ± 0.20	0.48
10–20	0.35 ± 0.27	0.17 ± 0.07	0.15 ± 0.05	0.12 ± 0.06	0.14 ± 0.11	0.12 ± 0.04	0.18
20–30	0.23 ± 0.02	0.17 ± 0.03	0.07 ± 0.05	0.03 ± 0.02	0.03 ± 0.03	0.05 ± 0.01	0.10
Mustard	*0–3*	*3–6*	*6–9*	*9–12*	*12–15*		
0–10	0.49 ± 0.25	0.37 ± 0.15	0.27 ± 0.12	0.37 ± 0.17	0.39 ± 0.17		0.38
10–20	0.22 ± 0.16	0.11 ± 0.05	0.09 ± 0.04	0.06 ± 0.03	0.08 ± 0.02		0.11
20–30	0.24 ± 0.13	0.07 ± 0.02	0.07 ± 0.02	0.11 ± 0.04	0.13 ± 0.04		0.10

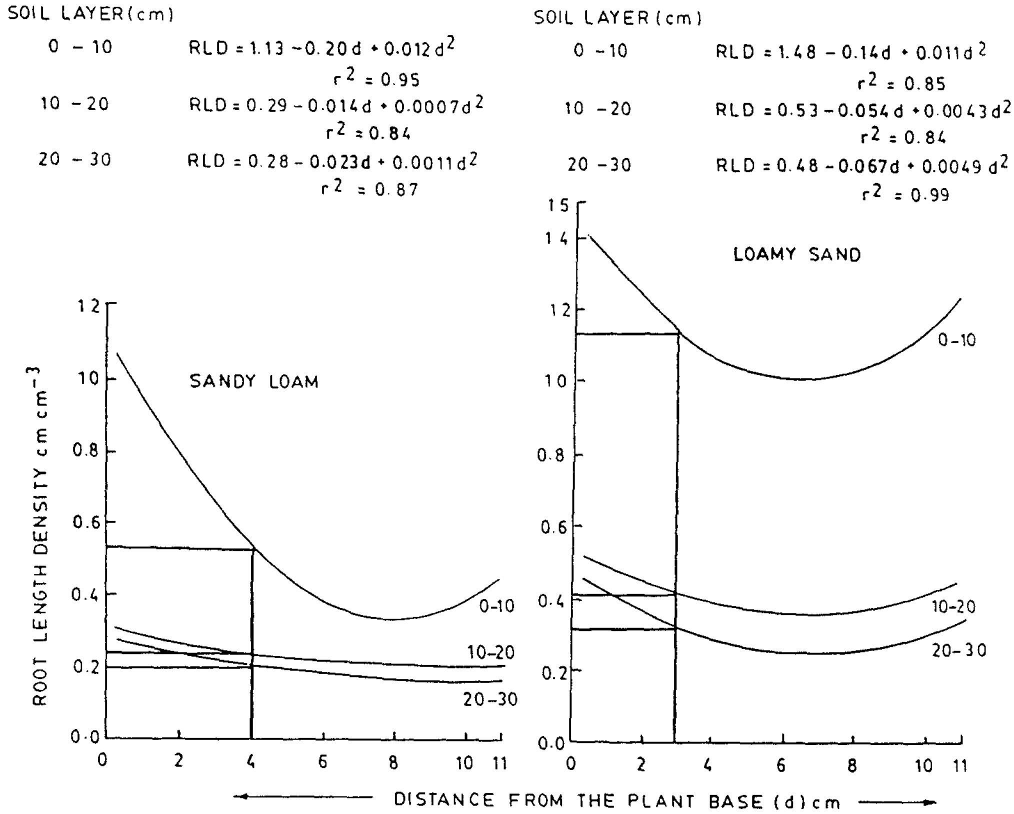

Fig. 2. Horizontal root distribution in wheat on the two soils.

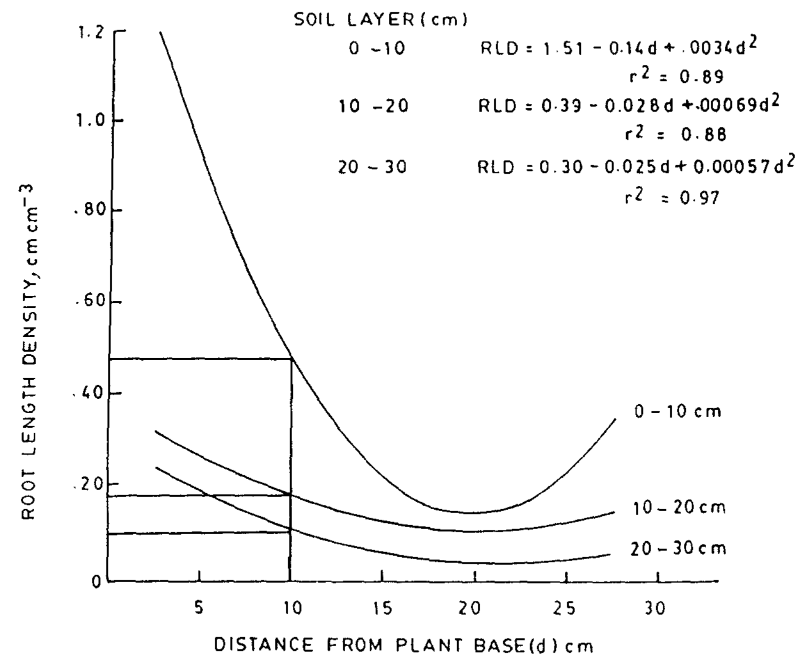

Fig. 3. Horizontal root distribution in corn on a sandy loam soil.

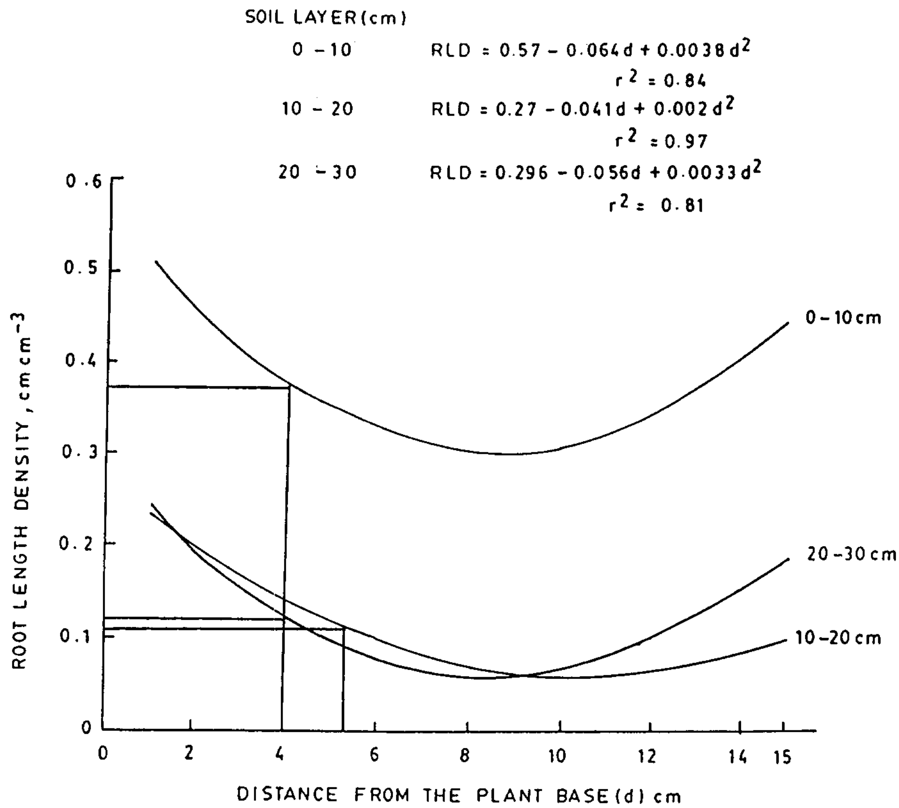

Fig. 4. Horizontal root distribution in mustard on a loamy sand soil.

Table 2. Root mean square of difference in RLD for different sampling schemes in different crops

Crop	Soil	Soil layer (cm)	Root mean square of differences in RLD						
			Sampling schemes						
			A	B	C	D	E	F	G
Wheat	ls	0–10	0.11	0.47	0.44	0.30	0.79	0.34	–
		10–20	0.05	0.08	0.10	0.07	0.11	0.08	–
		20–30	0.05	0.05	0.13	0.12	0.07	0.05	–
	sl	0–10	0.11	0.24	0.22	0.25	0.50	0.27	–
		10–20	0.05	0.04	0.04	0.08	0.07	0.08	–
		20–30	0.03	0.05	0.04	0.07	0.06	0.06	–
Corn	sl	0–10	0.28	1.85	0.32	0.32	0.34	0.30	0.36
		10–20	0.15	0.43	0.12	0.10	0.14	0.23	0.14
		20–30	0.05	0.14	0.06	0.07	0.06	0.07	0.12
Mustard	ls	0–10	0.13	0.33	0.12	0.20	–	–	–
		10–20	0.02	0.14	0.02	0.08	–	–	–
		20–30	0.01	0.06	0.04	0.03	–	–	–

determination of horizontal root distribution of the top 10-cm soil with monolith sampling, would be sufficient to locate auger position.

In this approach monolith sampling in the top soil layer is the first step to determine RLD by single augering. This sampling is required to capture the effects of soil and weather characteristics, irrigation, fertilizer and tillage management and crop age on root growth. In this study, single site approach for average RLD determination was tested for maximum root development. It is possible that the best location at maximum root growth may not hold good for determining average RLD in the initial stages of crop growth when the root spread in the representative half of unit soil strip is not complete. It is expected that the effect of specific management practice on root distribution would also be captured in monolith sampling in the top soil layer. Though this procedure has been used for determining average RLD, it appears that the same could be used for determining average root mass density after establishing horizontal root mass distribution in the representative half of the unit soil strip.

Conclusions

The results of this study show that single site augering at the site estimated through this procedure results in minimum deviation from average rooting density determined through monolith excavations. The simplicity and precision of this method allows larger number of replications and rapidity of sampling with reduced labour input and least destruction of experimental plots/crops.

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