

Root traits of different crops under rainfed conditions in the High Barind Tract of Bangladesh

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Summary

Root traits of six different crops grown on residual soil moisture in the post-rainy season in the High Barind Tract (HBT) of Bangladesh were investigated to better understand their adaptation to this moisture-limited environment. Deep-rooting chickpea is the currently favored rainfed crop grown after rainy-season rice in the HBT, but it is necessary to identify alternative crops to chickpea in order to avoid buildup of pests and diseases. Averaged over 2 y, barley (1.72 Mg ha⁻¹) produced significantly more grain than chickpea (1.4 Mg ha⁻¹) which, in turn, yielded better than linseed (1.0 Mg ha⁻¹), wheat (0.93 Mg ha⁻¹), and mustard (0.77 Mg ha⁻¹). Lentil did not produce any grain at all. Grain yield for all crops increased as total root length increased above a threshold value of 0.05 to 0.1 km m⁻². In general, grain yield increased

as the proportion of total root produced below 60 cm depth increased, although barley also had thin roots that could more effectively extract soil moisture. Expression of root traits varied considerably between seasons, which was attributable to the different rainfall patterns and bulk-density characteristics of the soil profile in the 2 years of the study. Although favorable root traits, particularly rooting ability below 60 cm, are a prerequisite for acceptable yield levels of crops grown on residual soil moisture in the HBT, it is recognized that farmers' choice of a post-rice crop will depend on its economic return or food-security value.

Key words: roots / rainfed crops / soil moisture / chickpea / lentil / linseed / mustard / barley / wheat

1 Introduction

Chickpea (*Cicer arietinum* L.) is well adapted to growing on residual soil moisture in a post-rainy season because of its deep and prolific root system (Saxena and Singh, 1987). This crop has proved to be particularly suitable as a post-rice crop under nonirrigated conditions of the High Barind Tract (HBT) in the north-west of Bangladesh (latitude 24°25'–25°10' N and longitude 88°–89° E, about 30 m above sea level) (Islam et al., 1994). This is an uplifted, terraced landscape with soil of calcareous alluvial origin modified by weathering in a subtropical environment. It has high bulk density, low organic matter, and low available nitrogen (N) and phosphorus (P) (Mazid et al., 1998). Traditionally, the area had grown only rainfed rice during the rainy season of June–November and the puddling for rice cultivation without recycling of organic matter made the soil particularly unsuitable for cultivation of post-rice crops. However, research from the early 1980s showed that post-rice cropping of chickpea using residual soil moisture was both feasible and remunerative (Islam et al., 1994). The area of chickpea grown in the HBT has increased from less than 1,000 ha in the 1980s to more than 10,000 ha in 2002 (A. M. Musa, PROVA, Rajshahi, personal communication). This increase has been attributed to the availability of short-duration varieties, simple interventions to promote rapid crop establishment and high initial growth rate, deep-rooting capability, and other drought-resistance characteristics (Krishnamurthy et al., 1996; Rahman et al., 2000; Musa et al., 2001). However, currently about 80,000 ha of the HBT

remains fallow after harvest of rice, and those areas have potential for growing chickpea and other post-rice winter crops (Subbarao et al., 2001). Bangladesh imports increasing amounts of pulses, oilseeds, and other non-rice cereals, and increased post-rice cropping with these crops could alleviate import requirements.

Unfortunately, repeated cultivation of chickpea on the same land inevitably leads to build-up of pests (e.g., *Helicoverpa* pod borer) and diseases (e.g., soil fungal diseases such as *Fusarium* wilt). It is therefore desirable to identify alternatives to chickpea, so as to diversify the post-rainy season phase of the current rainfed rice-chickpea cropping system in the HBT. It is hypothesized that, like chickpea, post-rainy season rainfed crops most likely to succeed in the HBT would have good ability to root at depth and thus effectively exploit the receding soil moisture front. Therefore, five crops with climatic adaptation to the post-rainy season of the HBT were compared with chickpea in their rooting ability with depth in natural soil profiles of the HBT.

2 Materials and methods

Six crops adapted to the region were tested: chickpea (*Cicer arietinum* L. cv. BARI chola 2); wheat (*Triticum aestivum* L. cv. Kanchan); mustard (*Brassica campestris* L. cv. Dhali [also called BARI sarisha 6]); barley (*Hordeum vulgare* L. cv. Local); linseed (*Linum usitatissimum* L. cv. Nila); and lentil (*Lens culinaris* Medic. cv. L-5). Field experiments were conducted in farmers' fields at the OFRD-BARI Farming Systems Research and

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Development site in Chabbisnagar, Godagari Upazila, Rajshahi District, Bangladesh during November to March in two consecutive post-rainy seasons, 2000–01 and 2001–02. Some physical and chemical properties of the surface (0–15 cm) soils of the experimental plots in 2000–01 were: 3.1% coarse sand, 40.5% fine sand, 32.8% silt, 23.6% clay, pH 6.9, 0.62% organic matter, 500 mg kg⁻¹ total N, 29.3 mg kg⁻¹ Olsen-P, 0.71 cmol kg⁻¹ K, and 8.9 mg kg⁻¹ S. The trial in 2001–02 was sown in a field near the site used in 2000–01, because of the soil disturbance associated with root sampling in the first year. The average maximum and minimum air temperatures during the crop-growing period were 28.3°C and 15.5°C, respectively. The season 2000–01 was rainless and in 2001–02, there was 16 mm rainfall during the crop-growing period.

The experiment was laid out in a randomized complete block design with three replications, with a 4 m × 5 m unit plot size. The experimental land was initially tilled to about 15 cm depth using a bullock-drawn plough, and then the coarse clods were broken up by one run of a power-tiller (Chinese roto-tiller). Fertilizers were hand-broadcast at the time of final land preparation at the currently recommended rates (kg ha⁻¹) of N₂₀ P₂₀ K₂₀ S₁₅ for chickpea, N₈₀ P₃₀ K₆₀ S₂₀ for wheat, N₇₀ P₂₀ K₂₀ S₂₀ for mustard, N₅₀ P₂₀ K₄₀ S₁₀ for barley, N₃₀ P₁₀ K₁₀ S₈ for linseed, and N₂₀ P₂₀ K₂₀ S₁₅ for lentil. Seeds of the crops were hand-broadcast, according to the local practice (i.e., not line-sown) on November 15, 2000 and November 25, 2001, before the final plowing. The locally recommended seed rates (kg ha⁻¹) used were 50 for chickpea (33 plants m⁻²), 120 for wheat (178 plants m⁻²), 8 for mustard (150 plants m⁻²), 120 for barley (184 plants m⁻²), 8 for linseed (162 plant m⁻²), and 40 for lentil (165 plants m⁻²). After broadcasting of seed and fertilizers, the area was plowed by bullock and two runs of a bullock-drawn ladder (leveler) were made to ensure that seeds were buried. The crops were weeded by hand and kept pest free. Chickpea pod borer (*Helicoverpa armigera*) was controlled by hand-picking of larvae and by spraying Dimecron® 100EC@ 6 mL per 12 L water at 80, 95, and 115 days after sowing (DAS).

Root-monolith sampling was done during January 20–25 (66–70 DAS) in 2001 and February 5–7 (72–75 DAS) in 2002 according to the procedure of Heeraman and Juma (1993). At the pod- or grain-filling stage, roots were extracted from a 30 cm × 20 cm area, selected at random in each replicate. An access trench 80 cm wide and 70–145 cm deep was excavated manually, adjacent to the 30 cm × 20 cm area previously identified for sampling. Depth of the trench depended on root depth of each crop, and digging continued to a depth 10 cm deeper than where no more roots could be found. Soil with roots was cut at each 15 cm depth within the chosen sampling area, and each 30 cm × 20 cm × 15 cm soil block was removed and placed in plastic buckets. On the following day, these blocks were soaked in water for 1–2 h, soil was removed by washing with water, and roots were recovered by passing the soil-water suspension through a 2 mm wire-mesh sieve. Roots were manually separated from other organic material after placing the sieved material in trays of water. Material passing through the sieve was also inspected for any fine or broken pieces of root/rootlet, and these were also manually recovered. Roots were separated from the debris

and weeds, mainly *Cyperus* sp. Also dead roots (if any) were discarded by observing the color, as dead roots were black while live roots were white. Roots were stored in sealed plastic bags and kept at <4°C before root length was measured with a root scanner (Commonwealth Aircraft Corporation). Roots were then oven-dried at 80°C for 72 h and root dry weights (RDW) measured. Total root length (TRL, km m⁻²) was calculated as length of the root per area of the soil sample, while root-length density (RLD, cm cm⁻³) was calculated as length of the root per volume of the soil sample.

At 66 DAS in 2001 and 72 DAS in 2002, soil samples were taken at each depth from three pits for calculation of bulk density and from one pit for calculation of gravimetric water content. The gravimetric water content of the 0–15 cm soil layer was calculated at field capacity (0.33 bar) and wilting point (15 bar) using a pressure plate apparatus. Gravimetric water content was multiplied by bulk density of each layer to estimate the volumetric water content.

Aboveground biomass and grain yield were measured at the respective maturity time of each crop from a randomly located sample area of 2 m × 2 m in each plot. The harvest dates of crops in 2001 were March 4 for mustard, March 13 for chickpea, March 18 for wheat, March 20 for linseed, and March 28 for barley. In 2002, harvest dates were March 7 for mustard, March 18 for linseed, March 19 for wheat, March 22 for barley, and March 27 for chickpea. Lentil was not harvested because all plants died prior to the pod-setting stage.

The data were subjected to an analysis of variance, except for calculation of economic return.

3 Results and discussion

Grain yields generally reflected aerial-biomass yields, except in 2001–02 where chickpea had a high yield ranking in relation to its biomass and the reverse was the case for wheat (Tab. 1). Lentil crops died before they could produce any grain. Barley produced the highest grain yields over the 2 y, followed by chickpea. Averaged over the 2 y, wheat, mustard, and linseed all yielded similarly, at lower levels than barley or chickpea. There were significant year × crop interactions for both aerial biomass and grain yield. Wheat and chickpea yielded consistently in both years, whereas mustard and barley both produced significantly higher yields in 2000–01 than in 2001–02. Conversely, linseed produced almost three times as much grain in 2001–02 as it did in 2000–01 (Tab. 1).

Grain yield correlates well with total root length (TRL) for all six crops tested (Tab. 1, Fig. 1), despite large interspecific differences in harvest index that ranged from 0.28 in mustard to 0.46 in chickpea. From Tab. 1, it is apparent that year-to-year yield variation for each crop in 2 y was related to variation in TRL. There seems to be a threshold value of TRL between 0.05 and 0.01 km m⁻² below which grain production would not be expected in the HBT. Barber and Silberbush (1984) similarly showed a good correlation between root length and grain yield for rainfed soybean.

Table 1: Aerial biomass, grain yield, and mean total root length (TRL) of six different crops grown on residual soil moisture in the HBT of Bangladesh during 2000–01 and 2001–02 post-rainy seasons.

Crop	2000–01			2001–02		
	Aerial biomass (Mg ha ⁻¹)	Grain yield (Mg ha ⁻¹)	TRL (km m ⁻²)	Aerial biomass (Mg ha ⁻¹)	Grain yield (Mg ha ⁻¹)	TRL (km m ⁻²)
Chickpea	3.50	1.37	0.13	2.91	1.42	0.29
Wheat	2.75	0.85	0.07	4.00	1.01	0.17
Mustard	4.37	0.93	0.17	3.33	0.61	0.10
Barley	5.80	2.00	0.60	4.44	1.43	0.30
Linseed	2.40	0.57	0.08	3.61	1.42	0.33
Lentil	0	0	0.08	0	0	0.07
SE ($\pm$)	0.332	0.039	0.041	0.276	0.036	0.038

With the exception of barley, RLD was greater at depth in 2001–02 than in 2000–01 (Fig. 2). This might have been a result of the lower bulk density near the soil surface in 2001–02 (Tab. 2), permitting easier root penetration. Among the crops, barley had the highest RLD in deeper layers (30–90 cm) in 2000–01, but linseed and chickpea had greater rooting at depth in 2001–02. Roots of barley, chickpea, and mustard were found in the deepest profile sampled in 2000–01 (90–105 cm), but only linseed roots were found at depths below 105 cm in 2001–02 (Fig. 2). This corresponds with the much higher grain yield of linseed in the second year (Tab. 1). Lentil had the least root development with depth, and its roots did not penetrate below

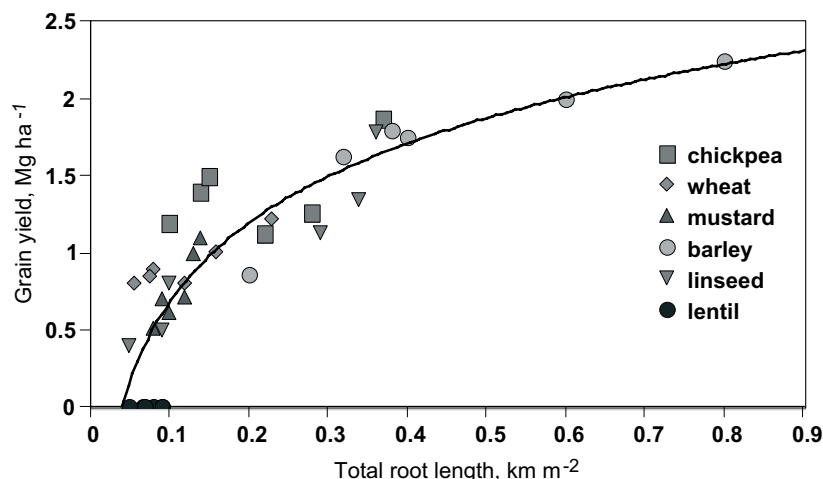
60 cm in either year (Fig. 2). Mustard behaved similarly to chickpea in distribution of RLD with depth, although it had lower RLD than chickpea in 2001–02. Wheat behaved somewhat similarly to lentil in 2000–01 but had deeper rooting and greater RLD than lentil in 2001–02 (Fig. 2).

The differences in rooting pattern of each crop between years were quite large, even though the deep-rooting ability of chickpea, linseed, barley, and mustard remain apparent in both years (Fig. 2). The extreme plasticity of plant root systems in relation to soil-environment factors is well known (Zucconi, 1996). In this study, differences between the sea-

Table 2: Bulk density (BD^a) and soil moisture (SM^a) $\pm$ standard errors of the experimental sites where roots were sampled during the 2000–01 and 2001–02 post-rainy seasons, HBT, Bangladesh.

Soil depth (cm)	2000–01		2001–02	
	BD (g cm ⁻³)	SM (% by vol.)	BD (g cm ⁻³)	SM (% by vol.)
0–15	1.55 $\pm$ 0.055	17.6 $\pm$ 1.68	1.40 $\pm$ 0.049	15.7 $\pm$ 1.1
15–30	1.60 $\pm$ 0.045	23.1 $\pm$ 1.99	1.55 $\pm$ 0.042	19.6 $\pm$ 1.4
30–45	1.70 $\pm$ 0.041	24.5 $\pm$ 2.0	1.70 $\pm$ 0.035	23.7 $\pm$ 1.8
45–60	1.75 $\pm$ 0.038	27.3 $\pm$ 2.1	1.80 $\pm$ 0.031	24.4 $\pm$ 2.0
60–75	1.81 $\pm$ 0.049	29.4 $\pm$ 2.4	1.82 $\pm$ 0.028	27.8 $\pm$ 2.1
75–90	1.76 $\pm$ 0.039	33.4 $\pm$ 2.5	1.83 $\pm$ 0.033	32.2 $\pm$ 2.7
90–105	1.72 $\pm$ 0.053	35.2 $\pm$ 2.7	1.77 $\pm$ 0.044	35.0 $\pm$ 2.9

^a BD and SM were recorded at 66 DAS in 2001 and at 72 DAS in 2002 from three pits.

**Figure 1:** Relation between grain yield and total root length for six crops grown in the HBT during the 2000–01 and 2001–02 post-rainy seasons. Points are from individual replicate plots. Fitted line: $y = 2.39 + 0.744 (\ln x)$; $R^2 = 0.757$, $n = 36$.

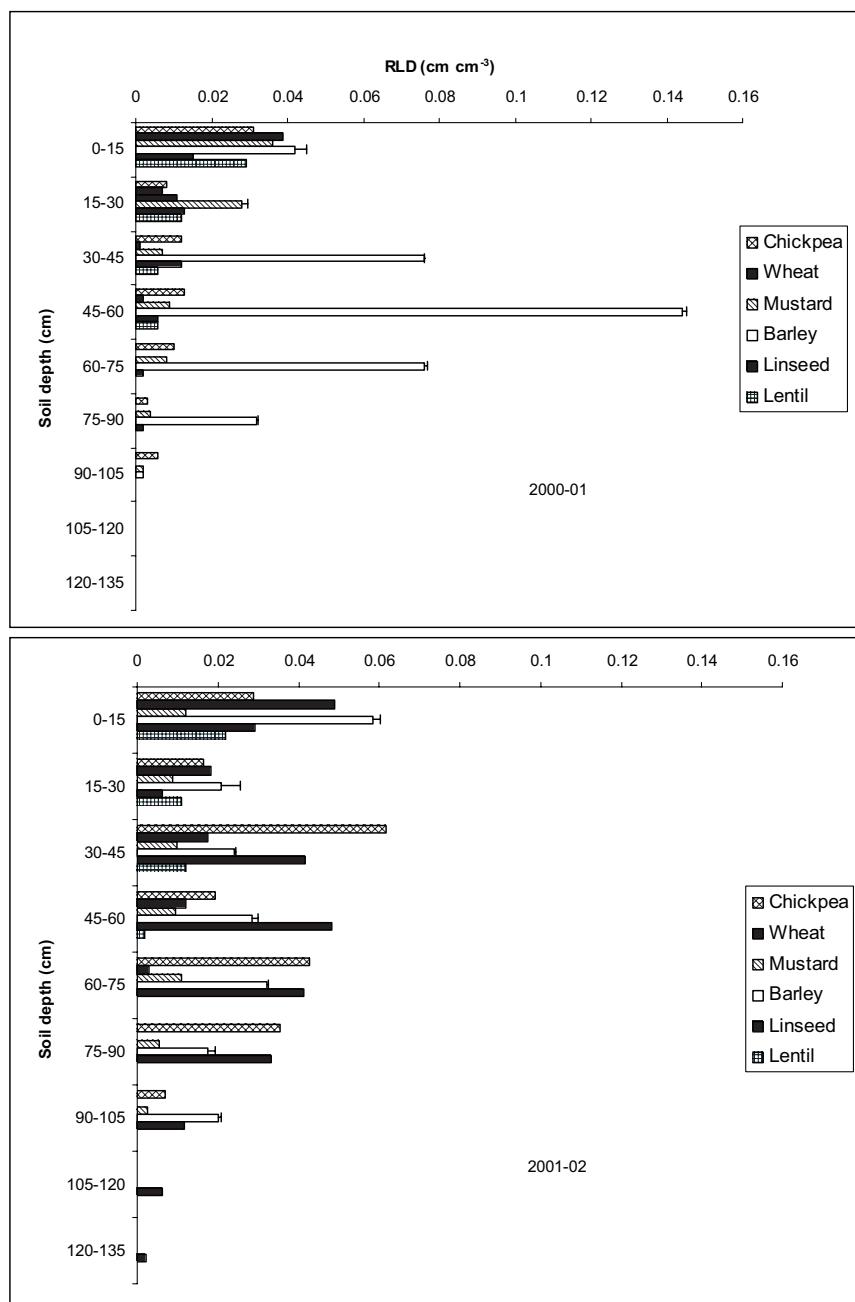


Figure 2: Root-length density (RLD) of six crops grown in the HBT during the 2000–01 and 2001–02 post-rainy seasons (horizontal bars indicate SE of crops within a depth).

sons would have been mainly contributed to by the different soil bulk-density profiles (Tab. 2), different rainfall patterns, and possibly different soil chemical characteristics of the soil profiles in each year (not measured in 2001–02).

The RLD values recorded at each soil depth and in both years were very low. The RLD of chickpea was lower in these soils than in Vertisols in India, where chickpea is normally cultivated (Krishnamurthy et al., 1996). Ali (2000) also found much higher RLD even at 105–120 cm soil depth for the same chickpea cultivar in Vertisols in India in comparison to the present study. This can be attributed to the Indian Vertisols having lower bulk densities (1.40–1.48 g cm^{-3} ; cf., Tab. 2) and more residual soil moisture. Root distribution and function is greatly affected by soil compaction or high bulk density (Jayasundara et al., 1998).

Roots developed under high mechanical impedance are usually shorter and thicker with less proliferation in the subsoil; thus, the volume of soil that they explore is reduced (Bennie, 1991). As an example, field-pea roots can penetrate to 1.5 m depth in well-drained deep sandy soils (Armstrong et al., 1994), but only to 0.4 m in soils with high bulk density (Henderson, 1991). Moreover, soil pore volume is less in compacted soils, reducing gaseous diffusion. Inadequate aeration may adversely affect root growth, in addition to the physical resistance of compacted soils. These two conditions are often synergistic and difficult to separate (Eavis, 1972).

Trends in RDW with depth among species are generally similar to those for RLD (Fig. 3). However, there are some important differences with respect to the ratio of RDW to RLD (Tab. 3).

Mustard has a higher RDW : RLD ratio, especially near the soil surface, and barley a lower ratio, in comparison with the other species. This implies that mustard has thick roots and barley thin roots. Chickpea and linseed also have relatively thin roots. Thinner roots are more effective for absorption of water and nutrients (Fitter, 1991). In general, increased root thickness (i.e., RDW : RLD) was more likely deeper in the soil (75–90 cm to 120–135 cm) because of increased soil bulk density (Ali et al., 2005). Presence of root hairs and mycorrhizas further increase the absorptive area, but these were not quantified for the genotypes used in this study. Thus, in terms of root thickness alone, the root systems of barley, chickpea, and linseed appear better adapted to the compact soils of low fertility and marginal moisture levels in the High Barind Tract.

Other studies have also shown that deep rooting positively correlates with grain yield in water-limited environments, e.g., White and Castillo (1988) and Sponchiado et al. (1989) for soybean, Wright et al. (1991) and Ketring (1984) for groundnut, Cortes and Sinclair (1986) for soybean, and Saxena et al. (1993) for chickpea. For the rainfed situation of the HBT, a criterion for high yields is vigorous rooting capability at depth, to permit capture of the scarce resources of water and nutrients.

Although it can be argued that dry-matter partitioning to roots to generate a more prolific root system diverts carbon from yield formation, capture of the requisite amount of nutrients and water is a necessary first step before yield can be considered. This is particularly well illustrated by the failure of lentil in this study to produce reproductive structures. Passioura (1983) argued that the dry-matter gain associated with increased water capture should offset the dry-matter investment into new roots. In sorghum, an increase in RLD from 1 to 2 cm cm⁻³ requires partitioning of an extra 800 kg ha⁻¹ to the root system (Jordan and Millar, 1980). Simulation studies indicated that yields of deeper rooting sorghum genotypes were at least 20% more than control genotypes in one out of every 3–5 years across locations (Jordan et al., 1983).

At sowing time in 2000, the field capacity of 0–15 cm soil layer was 40.2% by volume and the wilting point 18.6% by volume. The corresponding values in 2001 were 40.4% and 17.4%. These values were not determined at depth in this study, but they were determined in an adjacent plot previously (Ali, 2000). At the depths of 0–15, 15–30, 30–45, and 45–60 cm, field capa-

city was 40%, 44%, 53%, 54% by volume, respectively, and wilting point 19%, 24%, 27%, and 31% by volume, respectively. The soil-moisture data in Tab. 2 can be explained with the help of the data of Ali (2000). Probably from the 75–90 cm soil layer, soil moisture remained above wilting point and supposedly available for growing crops. Ali (2000) demonstrated that in the HBT, the soil moisture in the 0–60 cm soil profile falls below wilting point from late December, but that it remained above wilting point below 60 cm until March. This difference in soil-moisture availability could be due to year-to-year variation of soil moisture storage. In the HBT, the available residual soil moisture in the post-rainy season is in the range of 150–200 mm (m soil depth)⁻¹ (Ali et al., 1999). Thus, the ability to proliferate roots below 60 cm is crucial if rainfed crops are to utilize soil moisture effectively in the HBT. Indeed, the data in Fig. 2 show that chickpea (32%), barley (31%), linseed (26%), and mustard (25%) were all able to produce significant proportions of their root length below 60 cm depth, whereas neither lentil nor wheat could produce any roots beyond that depth. However, wheat was able to produce some grain in both seasons whereas the lentil crop died at early pod setting. These results illustrate one reason why lentil is particularly sensitive to drought, among post-rainy season crops, in Bangladesh. Selection of lentil genotypes with deeper-rooting capability would be necessary to adapt lentil to more drought-prone areas of Bangladesh, such as the HBT.

Although acceptable yields of linseed, barley, and mustard could be obtained in this study, above the national average, their lower grain price would make them less attractive to farmers than chickpea (Tab. 4). Chickpea appears to be by far the most remunerative rainfed post-rice crop in the HBT. Nevertheless, continued growth of chickpea on the same land would lead to a build-up of pests and diseases of this crop (Rahman et al., 2000), eventually reducing its profitability. In that situation, alternative crops like linseed, mustard, and barley might be suitable. Further, there has been little attempt to improve varieties and agronomy of these crops for the particular conditions of the HBT, to the extent done for chickpea (Musa et al., 2001).

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Table 3: Mean (of two seasons) ratio of root dry weight (RDW) to root-length density (RLD) for six crops grown in the HBT during the 2000–01 and 2001–02 post-rainy seasons.

Crop	Soil depth (cm)						
	0–15	15–30	30–45	45–60	60–75	75–90	90–105
Chickpea	365.7	108.5	44.3	34.0	27.0	30.6	76.3
Wheat	140.8	46.0	42.5	33.8	41.0	–	–
Mustard	929.7	62.9	49.7	74.6	21.3	27.5	26.8
Barley	70.9	40.1	23.2	20.3	23.3	30.1	28.4
Linseed	332.9	118.2	92.8	48.4	43.6	44.5	46.0
Lentil	114.7	14.8	26.2	22.5	–	–	–
SE (±) ^a	6.10	3.57	1.79	1.74	1.01	0.80	1.11

^a Mean SE of difference between means.

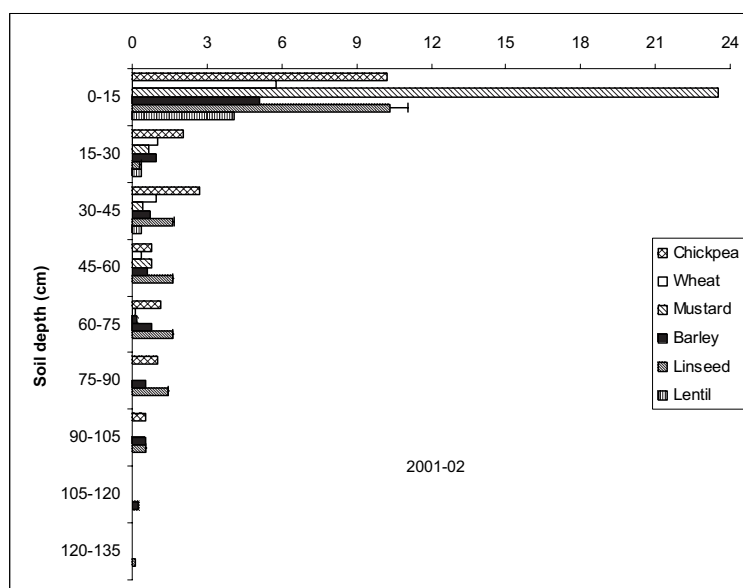
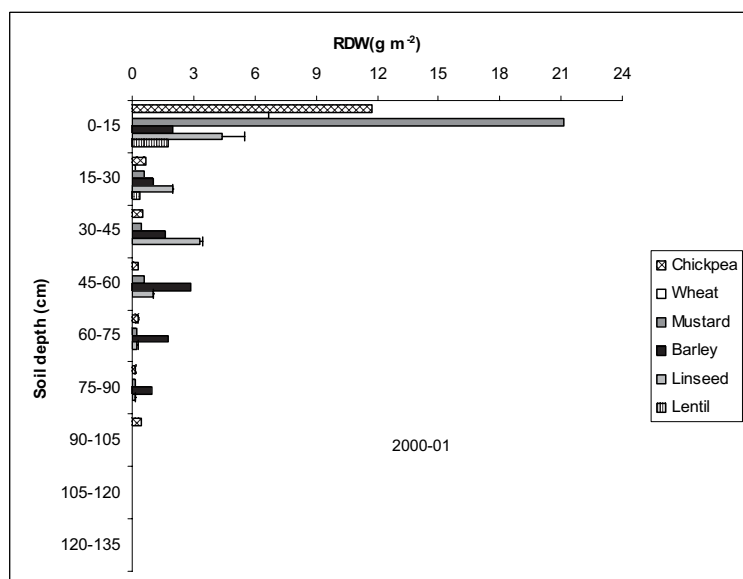


Figure 3: Root dry weight (RDW) of six crops grown in the HBT during the 2000–01 and 2001–02 post-rainy seasons (horizontal bars indicate SE of crops within a depth).

Table 4: Profitability of six crops grown in the HBT during the 2000–01 and 2001–02 post-rainy seasons. Data are means of the two seasons.

Crop	Production cost (Euro ha ⁻¹) ^a	Farm gate price of grain (Euro kg ⁻¹) ^b	Gross return (Euro ha ⁻¹)	Net return (Euro ha ⁻¹)
Chickpea	98	0.32	446	348
Wheat	128	0.115	107	–21
Mustard	84	0.192	148	64
Barley	111	0.089	153	42
Linseed	62	0.153	152	90
Lentil ^c	97	–	0	–97

^a 1 Euro = 78 Bangladesh Taka (Tk).

^b Only the grain yield of each crop was considered.

^c Lentil plants died between flowering and pod set.

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