Table 1. Growth, yield components, and incremental benefit-cost ratio of chickpea with different sources and levels of sulfur at Sehore, Madhya Pradesh, India.

Treatment	Growth and yield attributes[1] Plant height (cm)	No. of branches $plant^{-1}$	No. of pods $plant^{-1}$	100-seed mass (g)	Seed yield ($kg\ ha^{-1}$) 1993/94	1994/95	1995/96	Mean	Additional net return ($Rs\ ha^{-1}$)	Incremental benefit-cost ratio
Sulfur level ($kg\ ha^{-1}$)										
0	29.30	4.50	31.70	15.90	1218	1088	759	1021	–	–
20	31.92	5.48	40.20	16.12	1543	1391	998	1314	2074	3.84
40	32.00	5.92	42.26	16.24	1539	1384	1035	1319	2035	2.64
SE ±	0.89	0.18	1.12	0.03	26.78	35.20	21.55	35.3	–	–
CD (5%)	1.27	0.63	3.16	0.11	87	101	79	99.0	–	–
Sulfur source										
Elemental sulfur	31.80	5.20	38.95	16.15	1513	1368	900	1260	1588	2.65
Gypsum	33.50	6.45	43.70	16.40	1518	1467	1120	1368	2624	2.75
Single super phosphate	31.65	5.85	43.50	16.20	1635	1452	1077	1388	3233	4.60
Ammonium sulfate	30.95	5.45	39.15	16.00	1500	1351	984	1278	1822	3.20
Pyrite	31.85	5.55	40.85	16.15	–	1336	1003	1169	1005	3.00
SE ±	0.21	0.92	0.65	0.82	29.66	31.02	32.20	32.2	–	–
CD (5%)	0.61	NS[2]	1.96	NS	98	90	88	96.0	–	–

1. Data is mean of three years.
2. NS = Not significant.

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Genetic Diversity of Drought-avoidance Root Traits in the Mini-core Germplasm Collection of Chickpea

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Drought stress is a major cause for yield losses in chickpea (*Cicer arietinum*). A large portion of the losses can be prevented through crop improvement. Better drought-adapted genotypes could more effectively be bred when traits that confer yield under water-limited conditions can be identified and used as selection criteria (Ludlow and Muchow 1990). Rooting depth and density were among the main drought avoidance traits identified to confer seed yield under terminal drought environments (Ludlow and Muchow 1990, Subbarao et al. 1995, Turner et al. 2001). Though they were rated as highly useful traits, these were also categorized as very difficult to screen. Efforts made at ICRISAT, Patancheru, India to identify sources for deep and large root system, led to the identification of the chickpea variety ICC 4958 (Saxena et al. 1993) and later to the development of drought tolerant varieties by incorporating the deep and large root system of chickpea into a well-adapted genetic background (Saxena 2002). However, most of these studies were based on a narrow genetic base involving only one genotype, i.e., ICC 4958. The recent efforts in molecular mapping of genes and marker-assisted selection for root traits in chickpea will facilitate the identification of alternate sources to widen the genetic base for crop drought-avoidance improvement. These efforts have become relatively easier as a representative list of accessions, core (Upadhyaya et al. 2001) and mini-core (Upadhyaya and Ortiz 2001), for the whole range of variation has been made available. The main objectives of this study were to assess the extent of genetic variation available for the root system traits (Figs. 1 and 2) in the mini-core germplasm of

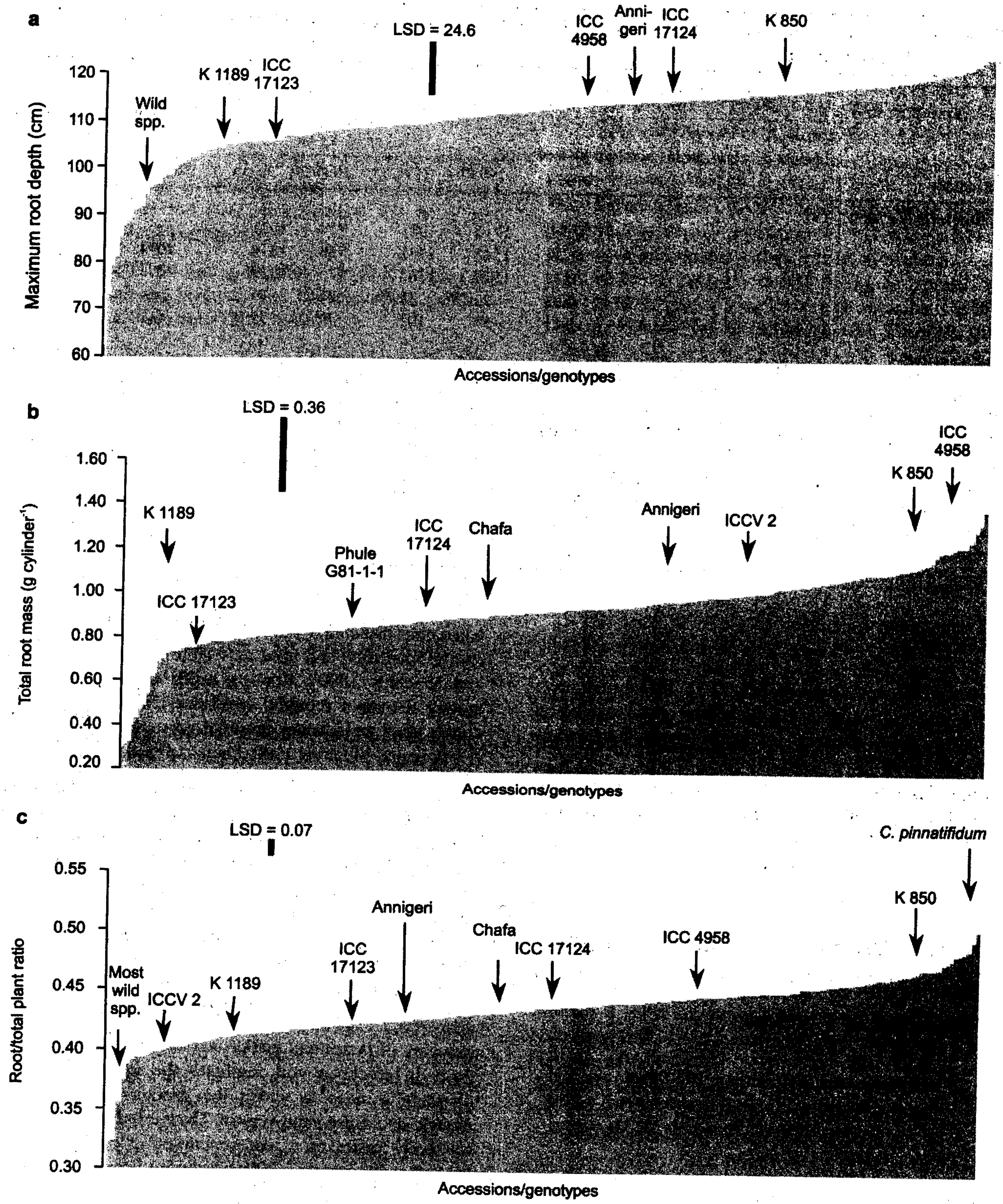

Figure 1. Rooting depth and density of the mini core chickpea germplasm accessions (n=211), 12 cultivated genotypes and 10 accessions of wild species at 35 days after sowing: (a) Maximum root depth attained; (b) Total root dry mass; and (c) Root/total plant ratio. (Note: The values are means of two replications.)

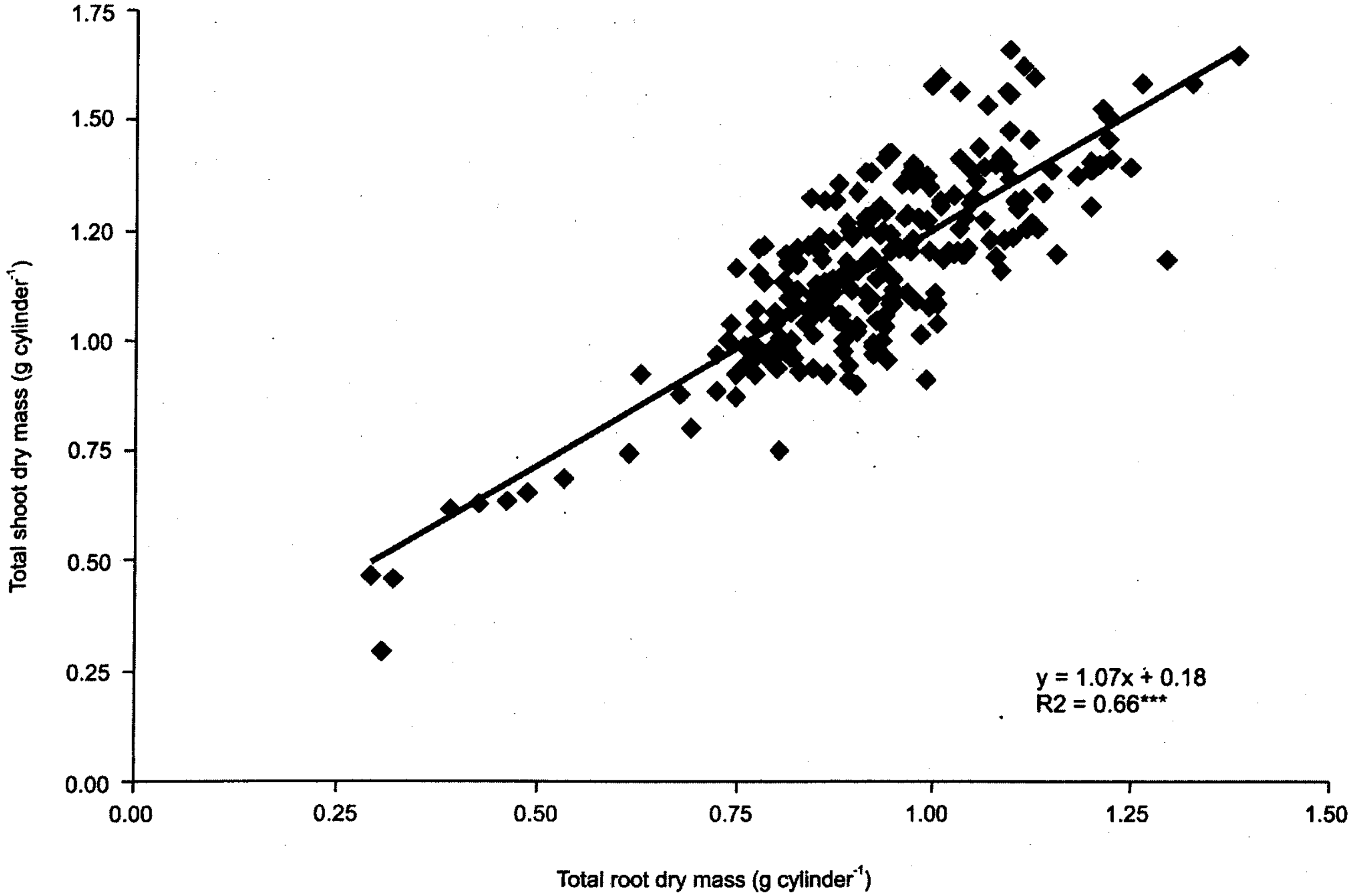

Figure 2. Relationship between total root dry mass and total shoot dry mass of the mini-core chickpea germplasm accessions, some wild species and chickpea cultivars.

chickpea, to identify accessions with contrasting root growth in the early stages of development, and to compare them with familiar cultivars and wild relative species.

The whole mini-core germplasm collection of *C. arietinum* (211 accessions) along with 12 cultivars (Annigeri, ICC 4958, JG 62, JG 74, ICCC 42, Phule G81-1-1, Chafa, K 850, K 1189, ICCV 2, KAK 2, and ICC 898) as references and 10 accessions of wild annual species (ICC 17116 of *C. yamashitae*, ICC 17123 and ICC 17124 of *C. reticulatum*, ICC 17156 of *C. bijugam*, ICC 17200 and ICC 17210 of *C. pinnatifidum*, ICC 17241 of *C. chorassanicum*, ICC 17148 and ICC 17180 of *C. judaicum*, and ICC 17162 of *C. cuneatum*) were evaluated by growing three plants in PVC cylinders (18 cm diameter, 120 cm long). The cylinders were filled with an equi-mixture (w/w) of Vertisol and sand, with initial soil water content equivalent to 70% field capacity. The plants were allowed to grow under receding soil moisture conditions thereafter, to mimic field terminal drought. The cylinders were placed in pits to avoid heating due to direct solar radiation. The experiment was conducted in an Alpha design (6 × 40) with two replications. The sampling was done at 35 days after sowing, a time when early duration genotypes (well adapted to the lower latitudes) are known to exhibit maximum differences in root growth (Saxena et al. 1993). The data was analyzed using REML (residual maximum likelihood) analysis treating accessions as the random components.

The differences of entries were significant at <0.001 level for both root and shoot traits presented (Fig. 1). The root and shoot growth of the wild species was relatively poor compared to *C. arietinum* lines. However, the growth of *C. reticulatum* (ICC 17123 and ICC 17124) was relatively good and close to *C. arietinum* accessions (Fig. 1a). The maximum root depth of ICC 17241 (*C. chorassanicum*) was the least (62 cm). The range (73–91cm) of maximum root depth of the rest of the wild species, except *C. reticulatum*, was not significant. The maximum root depth of ICCV 2, ICC 4958, and Annigeri was 115, 114, and 114 cm, respectively. The maximum root depth differences among cultivars were not statistically significant. Some of the accessions with a deep root system are ICCs 1431, 8350, 15697, 3512, and 11498.

Total root dry mass of the accessions of wild species except *C. reticulatum* was about one third of the maximum value (Fig. 1b). The linear growth phase of the root occurs later in most accessions of the wild species compared to the cultivated species as the growth duration of these are longer. As a result, maximum root depth and the root dry mass were poor in these accessions. The root dry mass of ICC 4958 and K 850 was significantly higher than that of K 1189 and Phule G81-1-1 (Fig. 1b). The top germplasm accessions for this trait were ICCs 5337, 7255, 13077, 15294, and 8261 with a root dry mass of more than 1.2 g cylinder^{-1}.

Ratio of root to total plant biomass also showed a vast range of variation (Fig. 1c). Most wild species showed very low ratio of root to total pant biomass (<0.39). Most of the cultivated genotypes and *C. reticulatum* exhibited a moderate value. Some of the accessions exhibiting significantly higher values of about 0.48 were ICC 17200 from *C. pinnatifidum* and ICCs 16207, 1397, 13077, 11627, and 12307 from *C. arietinum*.

Total root dry mass of the test entries showed a close linear relationship with the total shoot dry mass (Fig. 2) as well as the total leaf area of the plants. This relationship is very valuable for further root trait screening as it permits a less cumbersome preliminary selection of genotypes for large root mass on the basis of above ground shoot biomass or visual scores on shoot biomass or leaf area.

The germplasm accession ICC 4958 was previously used as the only source for deep and large root system parent or control in most of the drought avoidance related studies. The new genotypes identified, if confirmed, could be utilized as valuable alternative sources for diversification of mapping populations with varying growth duration and to get the required polymorphism for successfully mapping the root traits of chickpea.

This screening of the mini-core germplasm is being repeated during 2002/03 to confirm the results obtained. Any queries related to this study may be directed to Dr R Serraj, Principal Scientist, Crop Physiology, ICRISAT.

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Root and Shoot Growth Dynamics of Some Chickpea Genotypes Under Two Moisture Levels

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Chickpea (*Cicer arietinum*) is usually grown under progressively receding soil moisture and terminal drought stress conditions. It is often grown on land, less preferred for cultivation of cereals, where soils are generally marginal in their physico-chemical characteristics. The chickpea root system gains importance under such environment as the yield stability depends more on the