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Water deficit effects on root distribution of soybean, field pea and chickpea

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Abstract

Cropping diversity in the central Great Plains of the United States could be increased by including suitable legumes in crop rotations. Water is limiting to all crops grown in this region and agronomic crops frequently experience water deficit stress during their life cycle. The ability of a plant to change its root distribution to exploit deeper stored soil water may be an important mechanism to avoid drought stress.

An experiment was conducted to examine legume root system response to water deficit stress. Chickpea (*Cicer arietinum* L.), field pea (*Pisum sativum* L.), and soybean (*Glycine max* L. Merr.) were grown at two water regimes: under natural rainfall conditions and irrigated to minimize water deficit stress. Root distributions for each species were measured at 0.23 m depth intervals to a depth of 1.12 m directly beneath the plants at the late bloom and mid pod fill growth stages. Roots were washed free of soil and were separated from soil debris by hand. Root surface area measurements were made and root weights were recorded for each depth interval.

Water deficit did not affect the relative soybean root distribution. Approximately 97% of the total soybean roots were in the surface 0.23 m at both sampling times and under both water regimes. In contrast, water deficit stress resulted in a greater proportion of chickpea and field pea roots to grow deeper in the soil. Under irrigated conditions, about 80% of the chickpea and field pea roots were in the surface 0.23 m. Under dry conditions, about 66% of the total chickpea and field pea roots were in the surface 0.23 m and the remainder of the roots was deeper in the soil profile. Field pea had a root surface area to weight ratio (AWR) of 35–40 $m^2 kg^{-1}$, chickpea had a AWR of 40–80 $m^2 kg^{-1}$, whereas soybean had a AWR of 3–7 $m^2 kg^{-1}$, depending on plant growth stage. The greater AWR indicates a finer root system for the field pea and chickpea compared with soybean. From a rooting perspective, chickpea may be the best suited of these species for dryland crop production in semi-arid climates due to an adaptive root distribution based on water availability and large root surface area per unit root weight.
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Keywords: Chickpea; Dryland agriculture; Field pea; Root surface area; Soybean; Water deficit stress

1. Introduction

No-till soil management and chemical weed control have helped increase cropping intensity in the central Great Plains of the United States (Anderson et al., 1999). The amount of land devoted to the traditional wheat (*Triticum aestivum* L.)–fallow cropping system has steadily decreased while the amount of land with more intensive rotations has increased. Crops grown in rotation with wheat in this region include corn (*Zea mays* L.), sorghum (*Sorghum bicolor* L. Moench), proso millet (*Panicum miliaceum* L.), and sunflower (*Helianthus annuus* L.). Cropping diversity would be improved if legumes were found that could be included in rotation with cereals. Chickpea (*Cicer arietinum* L.), field pea (*Pisum sativum* L.) and lentil (*Lens culinaris* Medik.) have shown promise for inclusion in dryland cropping systems, either as grain or as forage (Nielsen, 2001). There has been increasing interest in soybean (*Glycine max* L. Merr.) for this region because of the high value and ready market for this crop. Chickpea and field pea have a relatively short growing season and use less water than many other broadleaf crops such as sunflower or safflower (Johnson et al., 2002). They may fit better in rotation with grasses than other broadleaf crops because they use less water and thereby leave more water available for succeeding crops.

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deeper soil layers. Chickpea may be the best suited of these species for dryland crop production in Colorado. The chickpea root system responded to water deficit stress by increasing roots deeper in the soil profile. Greater root density deeper in the soil profile and the larger proportion of fine roots compared with field pea or soybean could lead to better exploitation of water stored at lower soil depths.

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area (Benjamin and Nielsen, 2004). After scanning, the roots were removed from the sample tray, dried and weighed.

An analysis of variance was conducted by species on the total root weight and root surface area within the soil volume and also for each soil layer. A protected LSD test was used to determine treatment differences. The LSD was used to distinguish treatment effects only if the F-test was significant at the 0.05 probability level.

3. Results

Rainfall for field pea and chickpea was less than half of the average cumulative precipitation at each growth stage during the growing season (Table 1) indicating severe drought stress during the growth period. Cumulative rainfall for soybean was about 2/3 of the 30-year average at the late bloom growth stage but, because of rainfall that occurred later in the season, the total precipitation at the mid pod fill growth stage was near the 30-year average. The irrigated plots received water equivalent to about 200% of the 30-year average.

Total pea root weight at the late bloom growth stage was similar for both water regimes (Table 2). By mid pod fill growth stage, the irrigated treatment had about 150% of the root weight as the dryland treatment. Root surface area was similar between dryland and irrigated treatments at both growth stages. The changes in pea root weight and root surface area occurred primarily in the surface 0.23 m of soil (Fig. 1). Root weight density for both sampling times under non-irrigated conditions and for the late bloom sampling time under irrigation were about 0.25 kg m^{-3}. Root weight increased with time under irrigated conditions so that the root weight density for irrigated conditions at the mid pod fill sampling time was nearly double the other treatments at 0.47 kg m^{-3}. Root weight density in deeper soil layers was similar regardless of treatment or time. Field pea had greater root surface area density under irrigated conditions than non-irrigated conditions (Fig. 2). There was a shift in the root distribution between the irrigated and non-irrigated conditions. Under irrigation, about 80% of the root mass was in the 0–0.23 m soil layer. With non-irrigated conditions, less than 70% of the total root weight was in the topmost layer. A greater proportion of the roots was found in deeper soil layers for pea grown under non-irrigated conditions than for irrigated conditions. About 20% of the roots were in the 0.23–0.46 soil layer under non-irrigated conditions compared with about 12% of the total roots in this layer under irrigation.

Total chickpea root weights were similar at the late bloom growth stage between irrigation treatments and total root weight increased by the mid pod fill growth stage (Table 2). Neither irrigation treatment nor growth stage had a significant effect on chickpea root surface area. Total root surface area was similar at about 50 m^2 m^{-2} for each sampling time and irrigation treatment. Significant root weight increases between growth stages occurred in almost every soil depth (Fig. 1). The greatest change in root weight density was at the soil surface, with the irrigated treatment increasing from 0.63 kg m^{-3} at late bloom to 1.24 kg m^{-3} at mid pod fill. Root weight density for the non-irrigated treatment changed from 0.48 kg m^{-3} at late bloom to 0.72 kg m^{-3} at mid pod fill. Irrigation increased root surface area density for chickpea in the topmost layer of soil (Fig. 2). The greater root surface area in the surface layer of the soil

Table 2
Total root weight (kg roots/m^2 soil surface area) and root surface area (m^2 roots/m^2 soil surface area) in a 1.12 m soil profile for field pea, chickpea, and soybean under dryland and irrigated growing conditions

Crop	Irrigation (I)	Growth stage (GS)					
		Root weight (kg)		LSD (0.05)	Root surface area (m^2)		LSD (0.05)
		Late bloom	Mid pod fill		Late bloom	Mid pod fill	
Field pea	Dryland	0.38 a	0.46 a	0.11	14.0 a	15.7 a	7.3
	Irrigated	0.28 a	0.67 b		13.7 a	22.4 a	
				$P > F$			$P > F$
			GS	0.0009		GS	0.14
			I	0.26		I	0.34
			GS × I	0.0099		GS × I	0.30
Chickpea	Dryland	0.74 a	1.21 a	0.62	53.1 a	47.5 a	11.7
	Irrigated	0.78 a	1.72 b		52.5 a	54.5 a	
				$P > F$			$P > F$
			GS	0.03		GS	0.55
			I	0.34		I	0.73
			GS × I	0.40		GS × I	0.48
Soybean	Dryland	3.4 a	4.5 a	1.6	12.2 a	23.9 b	5.7
	Irrigated	5.0 a	5.0 a		13.4 a	35.9 c	
				$P > F$			$P > F$
			GS	0.46		GS	0.0001
			I	0.18		I	0.027
			GS × I	0.48		GS × I	0.058

Within each species, values followed by the same letter are not significantly different at the 0.05 probability level.