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RESEARCH ARTICLE

Effect of plough pans on the growth of soybean roots in the black-soil region of northeastern China

DONG Wen-cai[1], FU Qiang[1], WANG Quan-jiu[2], CAO Cheng-peng[1]

[1] *College of Water Conservancy and Architecture, Northeast Agricultural University, Harbin 150030, P.R.China*
[2] *Institute of Water Resources, Xi'an University of Technology, Xi'an 710048, P.R.China*

Abstract

Plough pans (PPs), common in the black-soil region of northeastern China, have significant effects on the root systems of crops. We conducted a field experiment to study the distribution of soybean roots under the influence of PPs. The soybean roots showed compensatory growth above the PP, with higher root length and weight in soil with a PP compared to those without a PP. Roots were heavier and longer in the 15–75 cm soil layer without a PP than with a PP. Soil porosity was lower in the PP and the soil below the PP, which likely decreased the oxygen content of the soil and induced more growth of roots above the PP. The PP is also likely to decrease infiltration of rain-water and hinder the migration of nitrate downward, which in turn increased the density and length of soybean root hairs, which, hence, promoted growth.

Keywords: compensatory growth, plough pans, root characteristics, soybean

1. Introduction

Soil is the matrix from where crops absorb water and nutrients. Therefore, soil has an important impact on the growth of crops. Changes in the physical and chemical properties of soil produce corresponding responses in crops. Roots are the main organs of crops that have direct contact with the soil and their morphology determines their ability to absorb water and nutrients from the soil (Costa *et al*. 2000). The physical and chemical characteristics of soil affect the morphology and function of root systems. Understanding crop production requires an understanding of root distribution and the development and changes of root systems under different conditions (Weaver 1926). For example, soil compaction has more effects on root distribution than on the root length and the total dry weight of the plant tops (Shierlaw and Alston 1984). The distribution of resources within a root system can be altered by mechanical stress (Goodmen and Ennos 1998). Goodman and Ennos (1999) found that plants are, to some extent, able to adapt their roots in response to soil hardness but that changes in root growth do not appear to fully compensate for alterations in soil conditions. Ikeda *et al*. (1997) investigated the effects of soil compaction on the numbers and community structure of the microbial populations of the rhizosphere. Jin *et al*. (2015) reported that root impedance increases the steepness of root angular spread *via* an unknown mechanism. The relationship between the environment and the characteristics of root growth in different crops has been well studied, but field studies of root systems have been impeded

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Correspondence FU Qiang, Tel: +86-451-55191534, E-mail: fuqiang232302@163.com

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by the limitation of the soil (Weaver 1926; Vamera 2003).

Soybean is an important seed crop in the black-soil region of northeastern China. The root growth of soybean is influenced by the unique plough pans (PPs) in black soil. Soybean roots have three slow-fast-slow growth rate stages (Mitchell and Russell 1971). Studies on root morphology have focused mainly on varieties with different drought resistance and maturity (Ren *et al*. 1993; Yang *et al*. 2001). These studies have found that most of the differences in root traits in soybean growth are due to the characteristics of the soybean plants rather than the soil. Although soybean roots have a certain degree of genetic stability, under field conditions, different soil environments can also cause changes in root morphology (Jin *et al*. 2002). For example, temperature, soil moisture, soil voids, and other environmental factors may significantly affect root morphology (Gilman *et al*. 1973; Heggestad and Lee 1990). Although PPs are common in the black-soil region of northeastern China, few studies have investigated the effects of PPs on the characteristics of soybean root systems. The objective of the present study was, therefore, to identify the mechanism of the effect of PPs on the soybean root system. We conducted field experiments to study the morphological characteristics of roots and the spatial distribution of root systems in soil with and without a PP, using the soil-drilling method and tomography during the seed-filling stage.

2. Materials and methods

2.1. Site description

The study was performed in Heilongjiang Province, China (46.12°N, 124.99°E). Our study site has a crop growing season of 120–130 days, an effective growing season accumulated temperature of about 2700°C, annual rainfall of about 400 mm and is flat. The basic chemical properties of the soil are shown in Table 1.

2.2. Experimental design

The experiment had two treatments, one with a PP and the other without a PP. Each treatment was replicated thrice for a total of six experimental plots, each 200 m^2 in area. In the treatment with a PP, the plough depth was (13±2) cm, soil bulk density above the PP was 1.21 g cm^{-3}, the thickness of the PP was (9±2) cm, and the average soil bulk density below the PP was 1.38 g cm^{-3}. The existing PP was broken by sub-soiling in the treatment without a PP, where the plough depth was (28±4) cm and the average soil bulk density was 1.22 g cm^{-3}. Urea and diammonium phosphate were each applied at 55 kg ha^{-1} before sowing by ridge ploughing. Ridges were 0.67 m apart and soybean planting density was 268000 plants ha^{-1}. The soybean used was the high-yielding Suinong 21 variety. Field management followed normal practices. The experiment was conducted from March to October in 2014 and 2015. In order to avoid the effects of continuous cropping, we did not use the same test plot in consecutive years. The experimental site used in 2015 was adjacent to the one used in 2014. The test sites had 3–4 years' maize plantation before our experiment.

2.3. Root system sampling and characterization

During the seed-filling period, the root system was sampled by soil-drilling (Jin *et al*. 2007), using a bipartite root sampler with a bit diameter of 8 cm and a length of 15 cm. Triplicate samples were collected near the plants, between plants (5.0 cm from the plants), and between ridges (30.0 cm from the plants) (Fig. 1). Sampling depths were 0–15, 15–30, 30–45, 45–60, and 60–75 cm. The samples were soaked in water for 12 h, and the roots were then slowly rinsed with a stream of water. A 100-mesh sieve placed under the roots prevented the loss of roots. The characteristics of the root system were determined using a SY-LA plant-root analyzer. The root samples were placed in a 30 cm×40 cm resin glass tank and injected with water to a depth of 3–4 mm to fully disperse the root system. Root surface area, root volume, and root length were determined by double light-source scanning (Jin *et al*. 2007). Root biomass was determined by weighing after drying the roots at 70°C to a constant weight.

The bulk density, water content, and porosity of the soil were determined for three randomly chosen points at depth intervals of 15 cm. Water content was determined by weighing the soil after drying the soil at 105°C for 12 h. Bulk density and porosity (capillary: diameter<0.1 mm; large: diameter≥0.1 mm) were determined as described by Liu and Li (1983). The nitrate nitrogen content of the soil was determined for the same sampling positions as the root system. Nitrogen content was determined every 5 cm up to a depth of 30 cm and every 15 cm from 30 to 75 cm. 10 g

Table 1 Chemical properties of the soil of the study site

Depth (cm)	Organic matter (%)	Total nitrogen (g kg^{-1})	Total phosphorus (g kg^{-1})	Alkali soluble nitrogen (mg kg^{-1})	Available phosphorus (mg kg^{-1})	Available potassium (mg kg^{-1})	pH
0–20	1.52	1.34	0.68	83	29.2	123	7.65
20–40	1.48	0.99	0.62	54	25.0	112	7.67
40–60	1.39	0.78	0.57	53	18.9	118	7.62