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Influence of artificially restricted rooting depth on soybean yield and seed quality

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ABSTRACT

The amount of plant available soil water is strongly influenced by soil type and rooting depth. This study was conducted to investigate the influence of limited plant available soil water on soybean (*Glycine max* (L.) Merr.) yield and seed composition. Six soybean cultivars were grown in 2007, 2008, and 2009 in a field with plastic liners inserted at depths of 0.30, 0.45, 0.60, 0.75, and 0.90 m to limit the rooting depth and thus the amount of available water. Compared to the long term mean (508 mm), distinct distribution patterns and amounts of rainfall among the three growing seasons (290, 675, and 440 mm in 2007, 2008 and 2009, respectively) resulted in significant differences in yield and seed composition among years. The overall yield, seed weight (g seed^{-1}), oil concentration, linoleic acid and linolenic acid were the lowest and protein concentration, palmitic acid, stearic acid and oleic acid were the highest in 2007 compared to the other two years. These differences were greater in plants grown under severe rooting depth restrictions. Restricted rooting depth affected soybean seed quality such as protein and oil concentration and fatty acid composition, not only when rainfall was below average, but also when it was above average. The amount of rainfall received from beginning of pod development through full pod (R3–R4) stages was highly correlated with yield, seed weight, oil and protein. Yield and seed weight were negatively correlated with protein and positively with oil, and protein and oil were strongly negatively correlated. Linoleic and linolenic acids were negatively correlated with palmitic, stearic and oleic acids. Under non-limiting moisture conditions (2008), a rooting depth of 0.30 m appeared to provide ample resources for plant growth, indicating that effects observed in drier years were largely a function of water availability. Results presented in this study illustrate that artificially limiting rooting depth under field conditions may serve as means to manipulate plant-available soil water to study plant responses to water deficit stress without modifying the above-ground environment.

1. Introduction

Water availability is a major determinant of crop yield. Water supply is often suboptimal relative to crop water demand, thus frequently limiting crop growth and yield. In fact, water deficit stress is considered the most important abiotic stress limiting crop yield world-wide (Boyer, 1982). Agriculture is the largest user of fresh water (70%, rivers and ground water) (FAO, 2003), and faces increasing competition from a growing population. Combined with predicted environmental changes such as altered precipitation patterns (Longenberger et al., 2006), increased future demand for water and food associated with population growth will pose a significant challenge, thus providing strong impetus for the development of more drought tolerant crop plants.

Soybean (*Glycine max* (L.) Merr.) seeds contain high levels of both protein (≈42%) and oil (≈23%) and are the primary source of the world's supply of protein and vegetable oil (Conner et al., 2004; Dornbos and Mullen, 1992). Environmental factors such as water availability and temperature can drastically influence seed composition (Conner et al., 2004; Dornbos and Mullen, 1992; Rotundo and Westgate, 2009). The reproductive stages (Fehr et al., 1971) from beginning of flowering (R1) to seed filling (R6) are particularly sensitive to water stress (Dogan et al., 2007; Eck et al., 1987; Sweeney et al., 2003). Eck et al. (1987) reported that water deficit stress from early flowering (R1) until the beginning of pod development (R3) reduced seed yields by 9–13%, but when water stress was extended until after full pod stage (R4.5), yields were reduced by 46%. In addition to seed yield, seed composition is also influenced by water deficit stress. Rotundo and Westgate (2009) conducted a meta analysis of published information and reported water deficit induced decreases in total (mg seed^{-1}) protein, oil, and carbohydrate contents. These reductions were associated with greater reduction in oil and carbohydrate accumulation in seed as compared to the protein, resulting in an increase in the final protein concentration (% seed dry weight).

Crop plants adjust to water availability by altering their vegetative and reproductive growth which ultimately affects yield and seed quality such as concentration and nature of protein, oil

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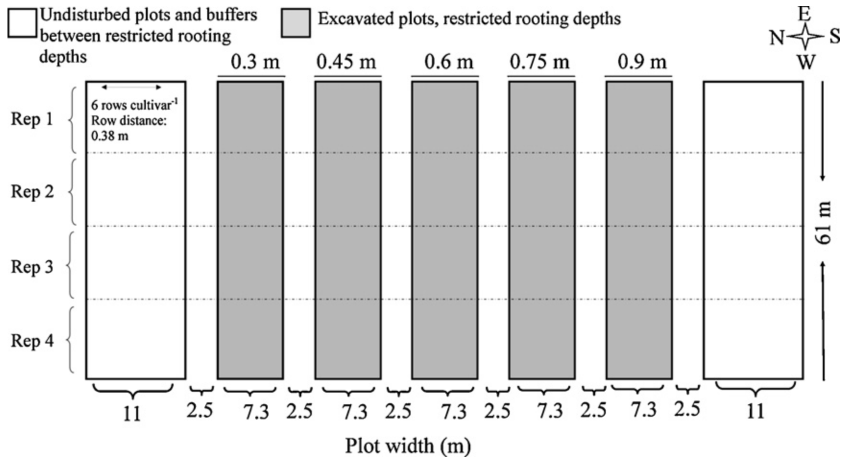

Fig. 1. Layout of the field site including organization of the replications, orientation of the rows, arrangement and dimensions of the undisturbed plots and buffers, and the restricted rooting depths treatments.

and fatty acids (Rotundo and Westgate, 2010). Under water deficit stress, selection for physiological and biochemical traits that confer adaptation to drought could complement breeding programs that are mainly based on direct selection for grain yield. Detailed understanding of the mechanisms underlying tolerance to water deficit stress is necessary for trait based selection in breeding programs aimed at developing drought tolerant genotypes. However, a major difficulty and cost for physiological research and breeding of drought tolerant cultivars in humid regions is the unpredictability of drought stress, and the imposition of stress year after year to allow direct selection for yield. Because of this, as well as the complexity of drought research under field conditions, much of the research on plant adaptation to drought stress is conducted in controlled environments. While such studies have advanced our understanding of the fundamental principles, results do not always translate directly to field situations (Samarah et al., 2004). In environments where drought is a predictable occurrence, field experiments can be conducted using supplemental irrigation to ensure a desired range of water stress conditions. However, in regions where the climate is either mostly favorable for crop growth or unpredictable, field research on water deficit stress is difficult. Fields with limited water holding capacity, soil uniformity, non-limiting nutrient availability and with a reasonable chance of a drought are required, but not readily available to many researchers and breeders (Pathan et al., 2007). Therefore, field facilities that provide additional control and/or increased likelihood of water deficit stress can prove useful and cost effective.

Various field techniques have been developed to restrict plant access to water. Movable rainout shelters have been used to carry out drought experiments (Arkin et al., 1976). Factors such as construction costs along with maintenance expenses and restricted area covered are significant drawbacks. Other methods such as water table management (Mejia et al., 2000) and managed soil moisture systems (Reetz et al., 1979) aim either to restrict the soil water from reaching the rooting zone or restrict root access to soil water by imposing mechanical impedance (Young et al., 1997), buried mesh layers in the soil profile (McKenzie et al., 2009) or root pruning (Ma et al., 2008). Each system tends to have limitations associated with its design, including aspects such as stress caused by root pruning, soil physical strength, and root system plasticity leading to selective penetration of roots through mechanical barriers, thus causing inconsistencies in response to drought. The system employed in this study consists of impermeable plastic liners buried horizontally at different depths in the soil to completely impede roots from accessing water deeper in soil profile, and may also be fraught with similar limitations, thus restricting its utility to study plant adaptations to water deficit stress. The main objectives of this study were to test the utility of this system with varying soil profile depths imposed by artificial restricted rooting depth (RRD), and to examine the influence of the series of RRDs on soybean yield and seed quality.

2. Materials and methods

A field study was conducted at the Bradford Research and Extension Center, Columbia, Missouri USA (38° 53′N, 92° 12′W) in 2007, 2008 and 2009.

2.1. Field description

The system used for this study was designed to alter the amount of plant available soil water by confining the root system to specific depths, and was constructed in 1978 as described by Griffin (1980). In brief, a series of five parallel channels 61 m in length and 7.3 m wide were excavated to depths of 0.30, 0.45, 0.60, 0.75 and 0.90 m (hereafter referred to as rooting depths or treatments) in the direction of the slope (≈1.2%, East to West) of the field (Fig. 1). The bottom of each channel was lined with plastic, and drain tiles (2″ Turf Flow pipe, Hancor Inc., Findlay, OH, USA) were installed on top of the plastic liner parallel to the slope to avoid water logging. Channels were filled with thoroughly mixed top soil (Mexico Silt Loam [fine, smectitic, mesic, Vertic Epiaqualf]) that was carefully repacked as the soil was added. To prevent interference, 2.5 m wide strips were left undisturbed between treatments. In addition, areas of 61 by 11 m remained undisturbed as check plots (control treatment, thus there were six treatments) along the sides of the shallowest and deepest channels. These check plots allow for comparisons between crops grown on an undisturbed, natural soil profile and the channels whose upper soil horizons were excavated and then used to refill the plot thus creating a disturbed profile.

2.2. Crop management

Six cultivars ranging in maturity group (MG) from 3.0 to 3.9 were planted in 2007, 2008 and 2009. Cultivars 'Pioneer 93M11′ (MG 3.1), 'Asgrow 3705′ (MG 3.7), 'Asgrow 3905′ (MG 3.9), and 'Pioneer 93M90′ (MG 3.9) hereafter referred to as C1, C2, C3 and C4, respectively, were planted in all three years. Cultivar 'DeKalb 36–52' (MG 3.6) was planted in 2007 and 2008 and replaced with 'DeKalb 38–52' (MG 3.8) in 2009, hereafter referred to as C5. In 2008 and 2009, 'Merschman Kennedy 836RR' (MG 3.6) that was grown in