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Assessing above- and below-ground traits of disparate peanut genotypes for determining adaptability to soil hydrologic conditions

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ABSTRACT

Crop water deficit stress contributes to more global crop loss than any other abiotic or biotic stress. To help achieve greater crop production under water scarcity, much emphasis has been placed on identifying irrigation management practices and crop genotypes for improving water stress resilience in agriculture. The objectives of this research were to: (i) quantify genotypic differences between subspecies of peanut (*Arachis hypogaea* L.), *hypogaea* and *fastigiata*, in root and canopy architecture, and evaluate their relationship with pod yield; and (ii) examine the response of these above- and below-ground traits of peanut genotypes to various irrigation regimes conducted in a humid climate. Field trials were implemented in 2015 and 2016 in north central Florida. Irrigation treatments included 1.9 cm per application (100%); a primed acclimation treatment consisting of 1.1 cm of water per application until mid-bloom and then 1.9 cm of water for the remainder of the season (60% PA); 1.1 cm of water per application for the entire season (60%); and a rainfed only (RF) system. Peanut genotypes included two Valencia (*Arachis hypogaea* L. subsp. *fastigiata* Waldron) market types COC 041 (PI 493631) and New Mexico Valencia C (NMVC), and two runner (*Arachis hypogaea* L. subsp. *hypogaea*) commercial cultivars FloRun™ '107′ and TUFRunner™ '511′. Genotypic total root length (TRL) and leaf area index (LAI) did not interact with irrigation treatments, but decreasing the total amount of irrigation over the growing season reduced LAI and pod yield, with no impact on TRL growth or distribution to 80 cm of soil depth. Genotypic effects influenced the TRL development over the growing season, and genotypes of subspecies *fastigiata* had greater TRL deep in the soil profile. However, all genotypes had similar amounts of root total surface area (TSA) distribution to 80 cm of soil depth. A positive relationship was observed between pod yield and maximal LAI in both study years, although this relationship was weak ($R^2 = 0.15$) in 2016 when greater water deficit stress severity occurred during reproductive growth. A significant low coefficient of determination of 0.15 and 0.20 was observed for the negative relationship between pod yield and maximal TRL in 2015 and 2016, respectively. The lack of interaction between irrigation and genotype for pod yield demonstrates that peanut genotypes with more prolific root growth at depth may not necessarily have an advantage for increased amounts of water acquisition and utilization that are translated into yield.

1. Introduction

Since 1950, U.S. peanut yield has increased approximately 46 kg ha^{-1} yr^{-1} (National Agricultural Statistics Service, 2017). Major contributions to yield advances during this time have been attributed to the advancement of crop protection pesticides, disease tolerance, and the development of cultivars with greater yield potential (Isleib et al., 2001). Increasing yield potential by breeding new cultivars has been attributed to increasing numbers of reproductive structures, reproductive efficiency (percentage of flowers resulting in pods and seeds), and seed weight (Coffelt et al., 1989; Seaton et al., 1992; Haro et al., 2013). An interesting historical change in global production practices occurred when the preference shifted from growing cultivars with erect canopy growth habits of *fastigiata* descent to cultivars with

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Abbreviations: TRL, total root length; TSA, total surface area; RSA, root system architecture; NMVC, New Mexico Valencia C; PA, primed acclimation; HI, harvest index

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procumbent canopy growth habits of *hypogaea* descent (Haro et al., 2013). This shift to cultivars with procumbent canopy architectures has been linked to increases in LAI and light attenuation within the canopy, contributing to an overall increase in peanut above-ground biomass and crop harvest index (HI) (Haro et al., 2017). Although there is much documentation on the influence peanut breeding has had on above-ground traits, to our knowledge, no evidence exists on how peanut breeding trends have influenced root architecture. Concomitant changes in root architecture may also have been driven in commercial production by the shift from cultivars of *fastigiata* descent to ones of *hypogaea* descent. Knowledge of subspecies root system architecture (RSA), and the relationship of this trait to above-ground partitioning could be critical in genotypic selection for improving water deficit stress resilience.

Root trait responses that improve soil water acquisition and possibly reduce yield loss from water deficit stress have been documented in the literature. Many studies have reached similar conclusions showing that peanut genotypes with inherently deep root architectures, or that respond to water deficit stress by proliferating roots deep into the soil profile have relatively greater pod yields, and under water stress conditions, are deemed as more water deficit stress tolerant (Rucker et al., 1995; Songsri et al., 2008; Jongrungklang et al., 2011; Jongrungklang et al., 2012). Further, the study conducted by Jongrungklang et al. (2012) observed a negative relationship between pod yield and percent root length density (%RLD) in the top 30 cm of the soil when water deficit stress was imposed during mid-season development. This indicates that there may be a trade-off between greater root production and yield under stress conditions.

The interaction of genotype with environment and/or management has made it difficult to directly utilize the results of physiological studies under controlled conditions of water deficit stress in breeding programs (Cattivelli et al., 2008) because the utility of a physiological adaptation depends on the specific environmental or management conditions the crop experiences. Water deficit stress impacts vary in relation to the timing of stress with phenological development, the rate at which soil drying occurs to achieve water deficit stress conditions, and the severity of water stress conditions imposed. Therefore, it is critical that experimental approaches to evaluate germplasm traits (especially root characteristics) relative to water stress be consistent with the intended typical stress severity and timing for the region for which a specific cultivar is developed (Sinclair, 2011). Another critical factor when studying water deficit stress resilience is to distinguish the difference between biological and agronomic water deficit stress tolerance. For example, although relative genotypic crop survival under severe water deficit stress conditions may demonstrate water stress tolerance in a biological sense, survival of crop plants is irrelevant in a commercial setting because it does not necessarily preserve harvestable yield and therefore economic viability for the farmer (Sinclair, 2011).

Experiments that focus on trait assessment for improving water deficit stress tolerance must be conducted within the region of interest, and under water deficit stress conditions that are relevant to the particular deficit conditions experienced in the area where the cultivar is to be produced. One particular environment relevant to peanut production is the southeastern U.S., which encompasses an agronomic region known as the “peanut belt” where the majority of the U.S peanut hectarage is planted (National Agricultural Statistics Service, 2015). The climate in this region is characterized as humid, where the annual precipitation exceeds evaporation, and average seasonal precipitation is often greatest during the summer months coinciding with peanut production (Henry, 2005; The Southeast Regional Climate Center, 2017). A large percent of this region has soils with high sand content and low organic matter, characterizing them as well-drained with little water holding capacity. Because of these edaphic conditions, water scarcity stress can occur quickly in periods of less frequent precipitation due to rapid soil water depletion; but dry periods are often intermittent due to the high probability of summer precipitation. However, in some drought prone years, the duration of water stress can be prolonged causing more severe water deficit stress, and the inability to completely alleviate water deficit stress using irrigation. Mitigating the risk of water scarcity in this region has led to an irrigation infrastructure on 60% of the harvested peanut hectarage, thus reducing the duration and the severity of crop water scarcity compared to rainfed production systems (National Agricultural Statistics Service, 2014). However, both irrigated and rainfed production scenarios of this region have a heavy reliance on in-season water supply from precipitation.

An irrigated production environment also allows for more control of the level of water scarcity stress experienced by the crop over the course of phenological development. For example, irrigated growers may choose to utilize regulated deficit irrigation (RDI), an irrigation practice designed to reduce the amount of water application below the full water requirement for optimum plant growth (Chai et al., 2016). Developmental stage-based RDI has been successful for peanut, particularly the use of reduced amounts of irrigation during early season vegetative growth, thus eliciting increased root proliferation deeper into the soil profile without reducing pod yields (Rowland et al., 2012; Thangthong et al., 2016). However, root distribution and pod yield responses have been reported to vary across peanut genotypes demonstrating variation in phenotypic plasticity (Jongrungklang et al., 2011). Furthermore, the phenotypic plasticity to increase root distribution deeper into the soil profile during vegetative water defecit stress is likely heavily influenced by environmental conditions. This is of particular importance since success using vegetative RDI has been documented in arid environments (Rowland et al., 2012), or under controlled conditions with rainout shelters (Jongrungklang et al., 2011; Thangthong et al., 2016). In both scenarios, total water received is primarily through irrigation in contrast to peanut production in humid environments where stochastic precipitation is the primary water source, and water stress is more likely to be mild.

By characterizing above- and below-ground characteristics in relation to pod yields of peanut genotypes varying in subspecies descent, knowledge of innate carbon partitioning can be obtained which could be useful for germplasm selection. Further evaluating these traits under various irrigation management strategies provides additional information on phenotypic plasticity which could possibly be utilized in determining genotypic adaptability to water deficit conditions, and possible irrigation management strategies which can be utilized for a particular production region. The objectives of this field research trial were to: (i) assess phenotypic variation in RSA, LAI, and their relationship to pod yield among genotypes classified into peanut subspecies *hypogaea* and *fastigiata*; and (ii) characterize the possible phenotypic interactions of these genotypic traits with environmental variability under various irrigation management strategies relevant for a humid climate. We hypothesized that genotypic differences in RSA exist among subspecies of *hypogaea* and *fastigiata* descent which would provide more or less resilience to water deficit stress conditions, and that pod yield production would be negatively related to below-ground traits due to trade-offs in carbon partitioning between root and shoot systems. Furthermore, we suspected that above- and below-ground genotypic traits would interact with the range of irrigation treatments implemented in this study because of the disparate descent of these genotypes which may be adapted to different soil hydrologic conditions. The information gained from this study will provide knowledge of both above- and below-ground biomass partitioning between subspecies *hypogaea* and *fastigiata* that could be used for: i) selecting germplasm best adapted to a range in hydrologic conditions; and ii) evaluating the feasibility of utilizing reduced irrigation management strategies in humid climate peanut production regions.