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Peanut genotypic variation in transpiration efficiency and decreased transpiration during progressive soil drying

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ABSTRACT

Peanut (*Arachis hypogaea* L.) is commonly grown on sandy soils in warm climates where water-deficit can impose a limitation on yield. Identification of plant traits related to increased productivity under water-deficit conditions could be used to increase yields in these water-limited environments. Two traits were examined among 17 peanut genotypes. Transpiration efficiency (TE), ratio of mass increase to water transpired, was the first trait examined. TE was measured both under well-watered conditions (greenhouse) and soil drying (outdoors in pots) conditions. Virtually no difference was observed in TE among genotypes under well-watered conditions indicating the gas exchange properties were similar. However, under soil drying conditions there were substantial differences among genotypes. These results indicated that TE with drying soil might interact with traits associated with water loss on drying soils. Therefore, the second trait examined in this study was the fraction transpirable soil water (FTSW) content at which the decline in transpiration with soil drying was observed. This greenhouse experiment showed large variability among the 17 genotypes. A second-order polynomial described the relationship between TE under soil drying conditions and the threshold for the decline in transpiration. The FTSW for maximum TE was 0.55, but this value is expected to depend on the environmental conditions to which the plants influence TE.

1. Introduction

Water-deficit causes enormous decreases in yield in many crops grown in drought-prone areas. Peanut (*Arachis hypogaea* L.) is an important oil-seed legume that is especially vulnerable to water-deficit limitations because it is usually grown on sandy soils. An annual peanut yield loss due to drought world wide has been estimated at US $520 million (Sharma and Lavanya, 2002). In Asia and Africa, peanut is grown under rainfed conditions during the rainy season and suffers intermittent drought spells due to gaps in rainfall that can occur at any time during the crop cycle.

Under conditions of intermittent drought, genotypes that perform better under these water-deficit conditions are likely those achieving high transpiration efficiency (TE), the ratio of plant mass produced to amount of water transpired. In peanut, various studies have revealed genotypic variation for TE (Krishnamurthy et al., 2007; Rao and Wright, 1994; Rao and Nigam, 2001; Rao et al., 1993; Sheshshayee et al., 2003, 2006; Wright et al., 1994, 1996). An important question to resolve is whether the genotypic variation in TE is an inherent consequence of basic physiological activity of a genotype regardless of soil moisture conditions. That is, do major genotypic variations exist both under well-water and water-deficit conditions, and is there consistency in such variation between the two levels of soil moisture? The first objective of this research was to measure the TE of the same set of peanut genotypes subjected both to well-watered and water-deficit treatments.

High TE may be particularly important for crop improvement as soil water deficits develop. Soil drying strongly influences a number of physiological processes that could influence TE including stomatal conductance, photosynthesis rate, and leaf area development (Nobel, 1999; Salih et al., 1999). Decreases in both stomatal conductance and leaf expansion have been considered the main mechanisms in which plants respond to soil water-deficit (Jones, 1992; Turner, 1997). The point during the soil drying cycle at which stomata conductance starts declining in response to soil water-deficit could be a key trait explaining genotypic differences in TE. Early decreases in stomata conductance during the midday period will decrease canopy gas exchange at times of the day with high vapor pressure deficit, and as a consequence TE is increased.

Ritchie (1981) proposed that the characterization of plant response to soil water content could result in consistent relationships across crops and soils. Indeed, when expressing plant water

Abbreviations: FTSW, fraction transpirable soil water; NTR, normalized transpiration rate; TE, transpiration efficiency.

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loss rate as a function of normalized available soil water, he found that transpiration rate of plants on drying soil relative to well-watered plants was unchanged until about one-third of the available water remained in the soil. After reaching that threshold, soil water content transpiration rate decreased linearly with further soil drying. Subsequently, a number of studies with a wide range of crop species and environmental conditions have confirmed this general response (Sadras and Milroy, 1996). Sinclair and Ludlow (1986) refined the definition of the lower limit of the available soil moisture by identifying this limit as the point where transpiration, and hence gas exchange supporting crop growth, became negligible. In practice, this lower limit was defined as the soil water content at which transpiration of plants on drying soil decreased to 10% or less of the well-watered plants. Studies that have normalized plant response to fraction of transpirable soil water (FTSW) reported that the threshold for the decrease in transpiration rate with most plant species and under many experimental conditions is in the FTSW range of 0.3–0.4 (Gollan et al., 1986; Kuppers et al., 1988; Meyer and Green, 1981; Ray and Sinclair, 1998; Rosenthal et al., 1987; Sadras and Milroy, 1996; Sinclair and Ludlow, 1986; Weisz et al., 1994). The second objective of this research was to determine if there are variations in plant response to drying soil, i.e. the FTSW threshold for decline in transpiration, which might explain variation of TE under water-deficit conditions.

2. Materials and methods

A preliminary screen of peanut germplasm was undertaken at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to identify potential genotypic variability among a broad base of peanut germplasm (unpublished). Genotypes were selected from this preliminary study of 440 genotypes that expressed possible variation in TE. Also, it was necessary that seed was available in the U.S. of the selected genotypes. Eventually, 17 genotypes were selected for study (Table 1).

2.1. Transpiration efficiency under well-watered conditions

Measurement of TE of the genotypes was done in an experiment established in a greenhouse in Gainesville, FL [29°38′N, 82°22′W]. Pots (16.5-cm diameter × 16.5-cm tall) were filled with approximately 2 kg of silty loam soil (Miracle-Gro Lawn Products, Inc., Marysville, OH). Seeds were treated with 2% ethrel to break dormancy and inoculated with a rhizobia mixture (peanut bacteria, Southern States Cooperative, Richmond, Virginia). Twelve pots were sown with two seeds in each pot for each genotype on 9 May 2008. After a week, the pots were thinned to a single plant per pot. All pots were maintained in a well-watered condition until the start of the TE measurements. From the 12 pots of each genotype, 10 plants were selected for the experiments.

Measurements for determination of TE were begun on 11 June 2008. The plants of all genotypes were flowering but not yet pegging. The minimum temperature in the greenhouse during the experiment averaged 24 °C and the maximum temperature was 30 °C. The midday vapor pressure deficit in the greenhouse on nearly all days was in the range of 2.2–2.6 kPa. One set of four replicate pots of each genotype were harvested on this date to estimate initial plant mass. Both the shoots and roots were harvested, dried at 60 °C in an oven, and weighed to obtain plant mass. The remaining six replicate pots of each genotype were over watered and allowed to drain overnight. The following morning pots were placed in polythene bags and the bags were sealed at the base of the plant stem to prevent soil evaporation. Immediately after bagging the initial weights of the pots were recorded. All pots were weighed every day beginning at 08:00 (Eastern Standard Time). Each pot was watered each day to return pot weight to 100 g less than the initial weight. The experiment was terminated after 2 weeks and the shoots and roots of each plant were harvested separately. The plant samples were dried at 60 °C in an oven and the dry weights were recorded. Transpiration efficiency was calculated as the difference in total plant weight between the final and initial harvest, divided by the total amount of water transpired during the experimental period. Statistical analysis of differences among genotypes in TE was done using analysis of variance (ANOVA). Tukey's method was used for the comparison of mean TE among genotypes.

2.2. Transpiration efficiency under water-deficit conditions

Transpiration efficiency under progressive exposure to water-deficit was measured at ICRISAT on plants grown in pots under continuously drying soil. The experiment was carried out under outdoor conditions, during the post-rainy season, between mid-February and mid-April 2006. Pots (25-cm diameter × 20-cm tall) were filled with 9 kg of a soil mixture. The soil mixture consisted of a sandy clay loam Alfisol collected on the ICRISAT farm to which farm manure was added (50:1, v/v). In addition, 2.25 g of single

Table 1
Seventeen genotypes compared for their transpiration efficiency and response of transpiration to drying soil. The four experiments identified in this table are those used to resolve the response of transpiration rate to drying soil.

Experiment	Genotype	Date of sowing	Dates of experiment
Experiment 1	ICG 3179 ICGV 86015 ICGV 86388 ICGV 91284 Kopergagon 3	22 November 2007	4 January 2008 to 22 January 2008
Experiment 2	ICGV 86564 ICGV 86699 PI 544346	12 February 2008	4 April 2008 to 19 April 2008
Experiment 3	ICG 11376 ICGV 87128 PI 259747 Gajah TMV 2	18 February 2008	29 April 2008 to 15 May 2008
Experiment 4	ICGS 44 ICGV 86031 TAG 24 ICGV 87141	23 May 2008	10 July 2008 to 23 July 2008