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Estimating Pearl Millet Leaf Area and Specific Leaf Area

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ABSTRACT

Leaf area and specific leaf area (SLA) are important parameters in many agronomic and ecological processes, but can be difficult and expensive to measure. This study was made to test simplified methods of estimating pearl millet [*Pennisetum glaucum* (L.) R. Br.] leaf area and SLA. Leaf length, maximum width, area, and dry mass data were obtained at 2-wk intervals from plants grown in 75-L pots. Pots contained 85 kg of acidic, P-deficient Betis sand (sandy, silicious, thermic Psammentic Paleustalf) and were treated with four P levels and two water treatments (stressed and nonstressed). Individual leaf area was estimated non-destructively with the following equations:

$$\text{Leaf area} = 0.68 \times (\text{leaf length} \times \text{maximum width}) - 0.114 \; (R^2 = 0.955)$$

and

$$\text{Ln(leaf area)} = 2.08 \times \text{Ln(length)} - 3.53 \; (R^2 = 0.939).$$

Individual leaf area and whole plant leaf area were calculated from leaf dry mass by the following linear and nonlinear equations:

$$\text{Leaf area} = 133.6 \times \text{Leaf mass} + 22.69 \; (R^2 = 0.900),$$

and

$$\text{Leaf area} = 162.84 \times \text{Leaf mass}^{0.687} \; (R^2 = 0.973).$$

Residual errors indicated that the nonlinear equation was more accurate for area estimation of small leaves (≤0.20 g), and that leaf area data were heteroscedastic. Leaf dry mass was also used to calculate SLA by the nonlinear equation

$$\text{SLA} = 176.7 \times \text{Leaf mass}^{-0.216} \; (R^2 = 0.918),$$

which gave excellent fit to experimental data independent of harvest date, P level and watering treatment. Our results demonstrate that pearl millet leaf area and SLA can be accurately estimated and easily simulated from simple regression equations.

LEAF AREA AND ITS RATIO to leaf dry mass, specific leaf area (SLA), are important parameters in many agronomic and ecological processes, including photosynthesis, transpiration, and field energy balance. Simple, accurate methods for estimating these parameters are therefore necessary for many applications, including crop simulation models. Although simple methods exist for estimating leaf area of some common crops, e.g., maize (*Zea mays* L.), sorghum (*Sorghum bicolor* Moench), and cotton (*Gossypium hirsutum* L.), we know of none reported for pearl millet. Furthermore, there are currently no well-known, simple methods of estimating crop SLA.

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Abbreviations: DAE, days after emergence; and SLA, specific leaf area.

Estimating leaf area from the equation

$$\text{Area} = C \times (\text{length} \times \text{maximum width}), \quad [1]$$

where C is an empirical coefficient, can provide nondestructive leaf area estimates to within 0.05 accuracy (Norman and Campbell, 1989). McKee (1964) used this approach to obtain a value for C of 0.73 for maize. Bonhomme et al. (1974) obtained values of 0.74 for sugarcane (*Saccharum officinarum* L.) and 0.64 for cowpea [*Vigna unguiculata* (L.) Walp.]. Stickler et al. (1961) reported a value of 0.75 for fully expanded sorghum leaves, while McCree et al. (1984) used a value of 0.68 for expanded and expanding leaves. We know of no such coefficient reported for pearl millet.

Leaf area can also be estimated for a number of plant species from a linear, log-log relation with leaf length (Wendt, 1967; Wendt et al., 1967). These authors stated that the log-log relationship between leaf area and leaf length had been found to exist in five species with widely differing leaf morphologies and may exist in all plant families. The obvious advantage of the log-log method is that it doesn't require leaf width measurements. No such equation has been reported for pearl millet.

Specific leaf area reflects leaf thickness and the relative proportions of assimilatory and conductive or mechanical tissues in leaves (Květ et al., 1971), and has been used to estimate crop leaf area (Rhoads and Bloodworth, 1964; Reddy et al., 1989) and leaf daily growth rate for partitioning of respiration (Kimura et al., 1978). The inverse of SLA, specific leaf mass, has been positively correlated with leaf water use efficiency among alfalfa (*Medicago sativa* L.) cultivars by Gutschick (1988), who reasoned that leaves with high specific leaf mass are cooler under a given radiation load due to higher stomatal conductance and lower water vapor pressure deficit. A decrease in water vapor pressure deficit increases water use efficiency (Tanner and Sinclair, 1983). Charles-Edwards (1982) has shown a positive correlation between SLA and light-use efficiency for several species. Thus, SLA is an important crop parameter to estimate.

The relations between SLA, growth stage, and environmental stress are not fully understood. As reviewed by Reddy et al. (1989), some scientists assume constant SLA for leaves after full expansion, while others maintain SLA varies with plant growth stage and the supply and demand for C. These authors showed that cotton SLA changes differentially with time and canopy layer, and can be correlated with mean daily flux of photosynthetically active radiation of the previous week. They hypothesized this was due to demand of growing parts for photosynthate, and to the resultant effect upon leaf starch content. Gibson (1975) observed an ontogenetic decrease of SLA in three field grown sorghum varieties. Similarly, McCree (1983) showed unambiguously that sorghum SLA decreased with increasing plant size under both controlled and field conditions.

Since larger plants may be expected to have larger leaves, it can be hypothesized that SLA varies with leaf mass. The objectives of this study were (i) to test two models that estimate pearl millet leaf area nondestructively, namely (a) the length-by-maximum-width method (e.g., Norman and Campbell, 1989), and (b) the log-log method used by Wendt (1967); (ii) to establish regression equations by which pearl millet leaf area can be calculated from leaf dry mass; and (iii) to test a statistical model that calculates SLA of individual leaves from their dry mass. It was a further objective that models be independent of plant age, nutrient stress, and water stress.

MATERIALS AND METHODS

Leaves for this experiment were harvested at 2-wk intervals from plants used in a growth analysis experiment conducted in the semiarid climate of Lubbock, Texas, during the summer of 1988 (Payne, 1990; Payne et al., 1991). Ten to twenty seeds of the pearl millet cultivar ICTP 8203 (Rai et al., 1990) were planted in 75-L pots lined with plastic and containing 85 kg of acidic, P-deficient Betis sand (sandy, silicious, thermic Psammentic Paleustalf). This soil was selected for its chemical, physical, and mineralogical properties, which were similar to those of sandy millet fields of Niger, Senegal, and Mali (Payne et al., 1991). The study consisted of a completely random experimental design with fixed effects due to P level and water treatment. Pots were treated with four P levels (0, 1.15, 3.38, and 7.77 g P m^{-2} in pots of 0.139 m^2 area). Each pot also received 128.1 g NH_4NO_3 m^{-2} and 40.3 g K_2SO_4 m^{-2}. Fertilizer was applied in powder form and thoroughly mixed into the upper 0.15 m of soil before planting. Phosphorus levels were subjected to two water treatments: water stressed and non-water stressed. The water stressed treatment was maintained at an average soil water content of 0.03 to 0.07 m^3 m^{-3}, whereas the non-water stressed treatment was maintained at an average soil-water content of 0.12 to 0.20 m^2 m^{-3}. Phosphorus levels and water treatments were randomly assigned to numbered pots.

At 14 d after emergence (DAE), plants were thinned to two plants per pot, and pot liners were sealed around plants to restrict water loss to transpiration. Average soil water content was determined with a load-cell balance calibrated in the field by adding known amounts of water to an empty pot. The amount of water required to maintain average soil water content within the specified range was determined twice weekly by weighing pots and calculating the average rate of transpiration for each watering level of each P rate. Additional experimental details are presented elsewhere (Payne 1990; Payne et al., 1991).

Five plants from each water treatment of each P level were randomly selected for harvest at 2-wk intervals after emergence, for a total of six harvests. At the first through fifth harvests, tops of plants selected for harvest were cut and immediately placed into large plastic bags with several moist paper towels. Bags were then quickly sealed and transported to a cool room so that leaves would retain turgor. At the first harvest, approximately 60 leaves were selected to obtain a wide range of lengths, but without regard to treatment; at the second through fifth harvests, two fully expanded, nondamaged leaves were selected from each plant, for a total of 10 leaves per treatment, or approximately 80 leaves per harvest. Within individual treatments, leaves were selected to obtain a wide range of lengths, and without regard to canopy layer.

Length and maximum width of selected leaves were measured to the nearest 1 mm. Leaf area was measured with a Li-Cor area meter (Li-Cor model LI-3100; Li-Cor, Inc., Lincoln, Nebraska[1]) which was calibrated with disks of known area. Measured leaves were placed in labeled paper bags and

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[1] Mention of trademark names does not constitute an endorsement.