Field Crops Research, 2 (1979) 135—143 135

VEGETATIVE DEVELOPMENT OF SOYBEANS GROWN ON DIFFERENT SOIL TYPES*

LARRY G. HEATHERLY and W.J. RUSSELL

Soybean Production Research, USDA—SEA, Delta Branch Exp. Stn, Stoneville, Miss. 38776 (U.S.A.)

*Cooperative investigations of the USDA—SEA/AR, and the Delta Branch, Miss. Agric. and For. Exp. Stn, Stoneville, Miss. 38776 (U.S.A.)

(Accepted 5 March 1979)

ABSTRACT

Heatherly, L.G. and Russell, W.J., 1979. Vegetative development of soybeans grown on different soil types. *Field Crops Res.*, 2: 135—143.

Nine soybean (*Glycine max* (L.) Merrill) genotypes, three from each of Maturity Groups V, VI, and VII, were grown on Dubbs silt loam (Typic Hapludalf, fine-silty, mixed, thermic) and Sharkey clay (Vertic Haplaquept, very fine montmorillonitic, thermic) soils to evaluate the effect of soil environment on vegetative development. Leaf enlargement rate (cm^2 $leaf^{-1}$ day^{-1}), final leaf size, internode length, plant height, and number of nodes per plant were all significantly greater on the silt loam for each genotype. The lowered leaf enlargement rate on the clay may have been due to the lower hydraulic conductivity of the clay, and thus fewer hours during the night conducive to leaf enlargement. A highly significant correlation (R^2 = 0.96) was found between leaf enlargement rate and final leaf size, indicating that number of days to the different maximum leaf sizes is nearly identical regardless of soil environment. These results indicate that the soil environment and its related physical and textural properties are important factors in determining canopy development of soybeans.

INTRODUCTION

The daily cycle in plant water stress is controlled mainly by transpiration rate, with long-term decrease in plant water potential being controlled mainly by soil water potential and soil water conductivity (Kramer, 1969). Total leaf area and individual leaf size have significant effects on water loss from individual leaves and whole plants. Plants subjected to water stress not only show a general reduction in size (Higgins et al., 1964), but also exhibit modifications in canopy structure. Leaf area is usually reduced (Penfound, 1931; Denmead and Shaw, 1960; McCree and Davis, 1974; Ciha and Brun, 1975) and rate of leaf enlargement or elongation reduced or halted (Higgins et al., 1964; Boyer, 1968; McCree and Davis, 1974; Barlow et al., 1976; Gandar and Tanner, 1976; Heatherly et al., 1977). Rate of leaf enlargement can in turn influence net photosynthetic rate (Barlow and Boersma, 1976), rate of vegetative growth (Muramato et al., 1965; Shibles and Weber, 1965; Kaplan and Koller, 1977), and stomatal frequency (Penfound, 1931; Ciha and Brun, 1975). Leaf area is also an important factor in the prediction of evapotranspiration (Tanner and Jury, 1976). Rate of leaf area development and total leaf area of a crop canopy have also been shown to modify distribution of radiation within the canopy (Shibles and Weber, 1965; Blad and Baker, 1972; Lemeur and Rosenberg, 1975).

The above reports indicate the importance of the rate of vegetative development and resulting leaf surface area of crops. The study reported here was designed to evaluate the effect of soil type on leaf area and vegetative development of soybean (*Glycine max* (L.) Merrill).

MATERIALS AND METHODS

This study was conducted on Dubbs silt loam (Typic Hapludalf, fine-silty, mixed, thermic) and Sharkey clay (Vertic Haplaquept, very fine, montmorillon itic, thermic) soils. Desorptive moisture characteristics for the two soils are presented in Table I. The sites were approximately 1.6 km apart. On 21 May

TABLE I

Desorptive moisture characteristics of Sharkey clay and Dubbs silt loam soils

Soil water potential (bars)	Volumetric water content (%)	
	Sharkey	Dubbs
−0.3	36.8	27.5
−0.7	34.1	21.0
−1.0	32.8	18.4
−3.0	30.0	13.0
−5.0	28.4	11.2
−10.0	27.0	9.0
−15.0	26.0	8.0

1975 three genotypes from each of Maturity Groups V ('Hill', 'Essex', and 'Forrest'), VI ('Tracy', 'Davis', and 'Pickett 71'), and VII ('Bragg', 'Semmes', 'D66-8666') were planted at the rate of 33 seeds/m. No detectable difference in emergence date was observed between soils. Each plot consisted of eight rows 90 cm apart and 12.2 m long. Genotypes within each maturity group were planted in a Latin Square design with three replicates on each soil. Weeds were controlled by cultivation. Soil pH and fertility at both sites were measured, and levels of both were in the range considered optimum for soybean growth and development.

The area of one new expanding trifoliate leaf on two plants in each plot of both soil environments was measured with a portable leaf area meter (Lambda

Instrum. Corp.)[1]. Measurement was begun on 8 July and continued through 17 July. All of the leaves which were measured during this study were located on nodes 9—13. We have determined from many field and greenhouse measurements that final area of leaves at these positions on individual plants is very uniform. Maximum leaf area accumulation of each measured leaf occurred on 14 July, or 6 days after leaflets had unrolled to a flattened orientation. Leaf enlargement rate is reported as the average daily rate for the 6-day period of 8—14 July. Length of the internode subtending the measured leaf was measured concurrently with the leaf area. Leaf area index (LAI) was calculated and plant height was measured on 17 July. Node number was counted on each measured plant according to the method of Fehr et al. (1971).

Xylem pressure potential (*P*) of the uppermost fully expanded leaf of all genotypes except Davis was measured between 1400—1600 (CDT) on 17 July using the pressure chamber technique (Scholander et al., 1965). One leaf from each plot was excised and measured within 1 min. Boyer and Ghorashy (1971) observed very close agreement between *P* and leaf water potential in soybeans. Values of *P* are used to evaluate leaf water status as it relates to conditions necessary for leaf enlargement.

Weather data for the 1975 growing season are shown in Table II. The rainfall pattern was one of uniform distribution and above-normal amount for the period 1 May—8 July. During the 8—17 July measurement period, no rainfall occurred. Plants never showed visible stress before or during the measurement period and the rainfall amount and distribution pattern allowed inference that soil moisture supply was adequate for normal growth and development on both soil sites through 17 July. Visible stress did occur later, however, during the 25 August—5 September period on the Dubbs site when beans were in the pod-fill stage. Measurements of air temperature throughout the season at both sites indicated no detectable difference in above-canopy readings.

TABLE II

Meteorological data for the 1975 soybean growing season at Stoneville, Miss.

Month	Monthly ave temp. (°C)		Rainfall (cm)	Pan evaporation (cm)
	Max.	Min.		
May	28	18	24.3	16.7
June	31	21	11.6	19.9
July	33	22	8.6	21.4
August	32	22	7.0	15.5
September	28	15	7.5	15.1
October	25	11	5.6	11.2

[1]Mention of a trademark, proprietary product or vendor does not constitute a guarantee or warranty of the product by the USDA nor imply its approval to the exclusion of other products or vendors that may also be suitable.

On 30 October, the two center rows of each plot were harvested for grain yield determination. Yield data were adjusted to 13% moisture. Yield and growth data from each maturity group were analyzed both within and across soil type. Statistical significance is based on the 0.05 level of probability throughout this report.

RESULTS AND DISCUSSION

Soil texture is an important factor in controlling both rate and amount of water availability for plant growth through its effect on water adsorption or retention as well as its effect on water movement through the soil to the root surface. Measurement of vegetative development of soybeans in this study indicated that the inherent qualities of a silt loam soil promoted a significantly higher level of growth than those of a clay soil. Leaf enlargement rate, final leaf size, final internode length, and plant height (Table III) of each genotype were all consistently and significantly greater on the Dubbs silt loam. Analyses of the data within each maturity group across soil type indicated no significant genotype × soil interaction for leaf size, leaf enlargement rate, or plant height. A significant genotype × soil interaction occurred for internode length in Maturity Groups V and VI (Table III). However, in neither case was the trend of greater growth on the silt loam reversed; only the difference among genotypes between individual soils was affected. This consistency of difference in genotypic performance between soil environments signifies the capacity of the soil environment to influence vegetative development of soybeans.

Rate of leaf enlargement and leaf area at full development are largely dependent on leaf water potential and turgor pressure (Penfound, 1931; Higgins et al., 1964; Lockhart, 1965; Boyer, 1968; McCree and Davis, 1974; Ciha and Brun, 1975; Barlow et al., 1976; Gandar and Tanner, 1976). The availability of soil moisture also affects growth rate by altering the supply end of the water potential gradient and therefore altering leaf water potential. Soybean leaves do not expand when leaf water potential is below about −12 bars (Boyer, 1970; Heatherly et al., 1977). In our study P values (Table IV) obtained between 14.00 and 16.00 (CDT) on 17 July indicated that leaf water status of plants growing on both soils was not conducive to mid-afternoon leaf enlargement. The lower daily leaf enlargement rate of plants growing on the clay soil cannot therefore be attributed to less favorable leaf water status at all times of the day. Boyer (1968) found that leaf enlargement of some species is so sensitive to water stress that it may be largely confined to the night. A likely explanation for the lower leaf enlargement rate on the Sharkey clay was the probable difference in leaf P recovery rate at night, which was in turn probably due to the lower hydraulic conductivity of the clay soil (Buckman and Brady, 1969), and hence lower soil water availability during a larger portion of the night. Plants growing on the silt loam soil evidently had a longer period during each night when leaves had recovered to P levels favorable for cell enlargement, resulting in the measured greater accumulation of leaf area

TABLE III

Leaf enlargement rate, final leaf size, final internode length, and plant height of nine soybean genotypes grown on two soil types

Genotype	Leaf enlargement rate (cm^2/day)		Final leaf size (cm^2)		Internode length (mm)		Plant height (cm)	
	Clay	Loam	Clay	Loam	Clay	Loam	Clay	Loam
Hill	14.7	28.9 a*	126.8	247.2 a	57.2 c***	120.5 a	45.2	84.3 a
Essex	12.7	19.8 b	109.2	187.6 b	37.8 d	66.0 b	36.6	69.1 b
Forrest	10.0	22.4 b	94.0	206.5 b	41.8 cd	84.3 b	38.6	85.8 ab
Mean	12.5 b**	23.7 a	110.0 b	213.8 a	45.6 b	90.3 a	40.1 b	79.7 a
Tracy	18.6	28.7 a	156.6	264.3 a	52.5 c	84.0 b	45.0	86.4 a
Davis	16.8	33.5 a	149.3	279.2 a	42.3 cd	91.3 b	35.6	91.9 a
Pickett 71	17.7	36.6 a	155.4	311.7 a	38.0 d	101.7 a	40.1	90.2 a
Mean	17.7 b	32.9 a	153.8 b	285.1 a	44.3 b	92.3 a	40.2 b	89.5 a
Bragg	14.7	28.7 a	129.8	242.6 a	47.3	97.2 a	48.5	96.5 a
Semmes	17.9	33.2 a	154.0	289.9 a	29.3	79.5 b	32.3	93.5 a
D66-8666	14.1	32.3 a	125.6	284.9 a	38.7	87.2 ab	36.3	88.1 a
Mean	15.6 b	31.4 a	136.5 b	272.5 a	38.4 b	88.0 a	39.0 b	92.7 a

*A single column of letters within each group of three genotypes indicates no significant genotype × soil interaction. Genotype means (not shown) across soil types followed by the same letter are not significantly different as determined by the Waller– Duncan k-ratio t test (k-ratio = 100).

**Soil means across genotypes followed by the same letter are not significantly different.

***A double column of letters within each group of three genotypes indicates a significant genotype × soil interaction. Values followed by the same letter are not significantly different.

TABLE IV

Xylem pressure potential (P), leaf area index (LAI), average number of nodes per plant, and grain yield of soybeans grown on two soil types (Values in parentheses represent ± standard error of the mean)

Genotype	P (bars)		LAI		No of nodes		Grain yield (kg/ha)	
	Clay	Loam	Clay	Loam	Clay	Loam	Clay	Loam
Hill	−15.2(1.2)	−17.7(0.9)	3.27	4.20	9.8(0.3)	12.0(0.1)	2495a*	2361a
Essex	−12.8(1.8)	−15.1(0.7)	3.63	6.97	10.5(0.2)	14.0(0.1)	1796b	2655a
Forrest	−11.8(0.4)	−15.7(0.3)	3.95	7.08	9.7(0.3)	13.0(1.0)	2274a	2173a
Mean	−13.3(0.9)	−16.2(0.5)	3.62	6.08	10.0(0.2)	13.0(0.4)	2188a	2396a
Tracy	−16.6(0.6)	−15.0(1.2)	3.60	4.27	9.0(0.0)	13.7(0.2)	3514a	2881b
Davis	—	—	3.14	5.98	10.8(0.3)	13.8(0.3)	3430a	3049b
Pickett 71	−16.6(1.0)	−15.0(0.9)	3.13	5.95	10.3(0.6)	13.7(0.2)	3137a	2844b
Mean	−16.6(0.5)	−15.0(0.7)	3.29	5.40	10.0(0.3)	13.7(0.2)	3360a	2925b
Bragg	—	−16.4(0.8)	2.86	6.26	9.0(0.4)	13.7(0.5)	3167a	3108a
Semmes	−16.4(0.8)	−16.2(0.7)	2.22	5.49	9.0(0.3)	12.2(0.3)	2467b	2789b
D66-8666	−17.2(0.4)	—	3.39	8.99	9.3(0.3)	13.5(0.2)	2719b	2880b
Mean	−16.8(0.4)	−16.3(0.4)	2.82	6.91	9.1(0.2)	13.1(0.3)	2784a	2926a

*Values within each group of three genotypes followed by the same letter are not significantly different as determined by the Waller—Duncan k-ratio t test (k-ratio=100).

per day (Table III). The importance of soil hydraulic conductivity in night-time leaf growth of potatoes (*Solanum tuberosum* L.) has been indicated (Gandar and Tanner, 1976). These conclusions, though speculative, are strengthened when consideration is given to the fact that both soil sites had a high level of fertility, and rainfall amounts and temperatures at the two sites were identical.

On 8 July, plants of all genotypes growing on the silt loam averaged from 2.2 to 4.7 more nodes, and subsequently more leaves, than comparable plants growing on the clay soil (Table IV). Use of leaf number as an index of plant response to soil moisture conditions has been documented (Higgins et al., 1964). This advanced morphological development of the shoot in addition to the increased internode length (Table III), contributed to the greater plant height on the silt loam (Table III). The increased number of leaves per plant resulting from the increased node number, in addition to the larger leaf size (Table III), also resulted in a higher LAI on the loam for all genotypes (Table IV).

A highly significant positive relationship ($R^2 = 0.96$) was found between leaf enlargement rate and final leaf size. Thus, the time required to reach the different full leaf sizes on both soils (Table III) was relatively constant, in this case about 6 days. Similar results have been obtained with grain sorghum (*Sorghum bicolor* (L.) Moench), in which both rate of increase in leaf area and final leaf size declined progressively from moist soil (above −0.2 bar soil water potential) conditions to stress (−4 bars soil water potential) conditions (McCree and Davis, 1974). The time required to reach full leaf size under each condition was 5.5 days for the grain sorghum. Other studies have shown significant relationships between rate of leaf area development and vegetative growth (Muramato et al., 1965; Kaplan and Koller, 1977), net photosynthetic rate (Barlow and Boersma, 1976), and stomatal frequency (Penfound, 1931; Ciha and Brun, 1975). The results of our study point out the significant effect of soil environment on rate of vegetative development in crop plants, which in turn can influence other physiological and morphological processes and thereby alter plant response.

The observed increase in vegetative growth of soybeans growing on the silt loam soil did not increase grain yield significantly (Table IV). Conversely, the average yield of the Group VI genotypes growing on the clay soil was significantly greater. Only one significant genotype × soil interaction for grain yield occurred: in Maturity Group V, Essex grown on the loam significantly out-yielded Essex on the clay, with Hill and Forrest producing yields on each soil which were not significantly different. The reduced yield of Essex grown on the clay was probably due to its being susceptible to phytophthora root rot which is caused by a soil-borne pathogen which commonly occurs in the clay soils at this location. From these results, improved vegetative growth of soybeans due to a more favorable soil environment cannot be used as an indicator of potentially increased grain yield. Reduction in corn grain yield caused by stress imposition during vegetative development has been accounted for by a reduction in leaf area (Denmead and Shaw, 1960). Either the soybeans growing on the clay soil in our study were able to compensate for the reduced leaf area compared to that on the silt loam, or the plants growing on the silt loam were unable to utilize the increased leaf area for yield increase because of conditions prevailing during the remainder of the growing season. In either case, the soybeans showed a definite capability to adapt to a less favorable soil moisture situation (clay), and still produce a yield equal to that produced in a soil environment that was more favorable (loam) for growth and development.

REFERENCES

Barlow, E.W.R. and Boersma, L., 1976. Interaction between leaf elongation, photosynthesis, and carbohydrate levels of water-stressed corn seedlings. Agron. J., 68: 923—926.

Barlow, E.W.R., Ching, T.M. and Boersma, L., 1976. Leaf growth in relation to ATP levels in water-stressed corn plants. Crop Sci., 16: 405—407.

Blad, B.L. and Baker, D.G., 1972. Reflected radiation from a soybean crop. Agron. J., 64: 277—280.

Boyer, J.S., 1968. Relationship of water potential to growth of leaves. Plant Physiol., 43: 1056—1062.

Boyer, J.S., 1970. Leaf enlargement and metabolic rates in corn, soybeans, and sunflower at various leaf water potentials. Plant Physiol., 46: 233—235.

Boyer, J.S. and Ghorashy, S.R., 1971. Rapid field measurement of leaf water potential in soybean. Agron. J., 63: 344—345.

Buckman, H.O. and Brady, N.C., 1969. The Nature and Properties of Soils. The MacMillan Co., Toronto, Ont., 653 pp.

Ciha, A.J. and Brun, W.A., 1975. Stomatal size and frequency in soybeans. Crop Sci., 15: 309—313.

Denmead, O.T. and Shaw, R.H., 1960. The effects of soil moisture stress at different stages of growth on the development and yield of corn. Agron. J., 52: 272—274.

Fehr, W.R., Caviness, C.E., Burmood, D.T. and Pennington, J.S., 1971. Stage of development descriptions for soybean, *Glycine max* (L.) Merrill. Crop Sci., 11: 929—931.

Gandar, P.W. and Tanner, C.B., 1976. Leaf growth, tuber growth, and water potential in potatoes. Crop Sci., 16: 534—538.

Heatherly, L.G., Russell, W.J. and Hinckley, T.M., 1977. Water relations and growth of soybeans in drying soil. Crop Sci., 17: 381—386.

Higgins, J.J., Haun, J.R. and Koch, E.J., 1964. Leaf development: index of plant response to environmental factors. Agron. J., 56: 489—492.

Kaplan, S.L. and Koller, H.R., 1977. Leaf area and CO_2 - exchange rate as determinants of the rate of vegetative growth in soybean plants. Crop Sci., 17: 35—38.

Kramer, P.J., 1969. Plant and Soil Water Relationships. McGraw-Hill, New York, N.Y.,482 pp

Lemeur, R. and Rosenberg, N.J., 1975. Reflectant induced modification of soybean canopy radiation balance. II. A quantitiative and qualitative analysis of radiation reflected from a green soybean canopy. Agron. J., 67: 301—306.

Lockhart, J.A., 1965. Cell extension. In: J. Bonner and J.E. Varner (Editors), Plant Biochemistry. Academic Press, New York, N.Y., pp. 826—849.

McCree, K.J. and Davis, S.D., 1974. Effect of water stress and temperature on leaf size and on size and number of epidermal cells in grain sorghum. Crop Sci., 14: 751—755.

Muramato, H., Hesketh, J. and El-Sharkawy, M., 1965. Relationships among rate of leaf area development, photosynthetic rate, and rate of dry matter production among American cultivated cottons and other species. Crop Sci., 5: 163—166.

Penfound, W.T., 1931. Plant anatomy as conditioned by light intensity and soil moisture. Am. J. Bot., 18: 558—572.
Scholander, P.F., Hammel, H.T., Bradstreet, E.D. and Hemmingsen, E.A., 1965. Sap pressure in vascular plants. Science, 148: 339—346.
Shibles, R.M. and Weber, C.R., 1965. Leaf area, solar radiation interception, and dry matter production in soybeans. Crop Sci., 5: 575—577.
Tanner, C.B. and Jury, W.A., 1976. Estimating evaporation and transpiration from a row crop during incomplete cover. Agron. J., 68: 239—243.