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EFFECT OF SOIL MOISTURE FLUCTUATION ON LEGUME NODULATION AND NITROGEN FIXATION IN A BLACK EARTH SOIL

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SUMMARY

The field nodulation of cowpea (*Vigna sinensis*) and four native legumes—*Cassia mimosoides, Glycine tomentosa, Psoralea tenax* and *Vigna lanceolata*—was examined under fluctuating moisture conditions. An absence of nodules was recorded during excessively wet or dry conditions. Nodule loss with decreasing moisture was attributed partly to mechanical removal of nodules from the roots by the shrinking clay. During wet periods, soil aeration was considered to be the limiting factor.

Improved aeration of wet soil increased the plant dry weight and nodule numbers in soybeans, resulting in an increase in nitrogen fixation. Nitrogen analysis showed that with improved aeration 61% of the total plant nitrogen came from fixation, in comparison with 33% under poor aeration.

I. INTRODUCTION

A number of environmental and biological factors have been described as having an effect on legume nodule populations. These include seasonal changes in meteorological conditions (Lange 1959), insect attack (Mulder 1948; Diatloff 1965), defoliation by grazing and cutting (Bowen 1959) and moisture stresses and excesses (Wilson 1942). The effect of soil moisture and aeration on nodule activity has not received the same amount of attention, although it is generally believed that a high moisture content in the substrate is conducive to more prolific nodulation (Fred, Baldwin, and McCoy 1932; Masefield 1961).

In the black earth soils of the Darling Downs in southern Queensland the nodulation of cowpea (*Vigna sinensis*) is very variable and often absent after rains despite the presence of suitable rhizobia in the soil.

This paper deals with the effect of soil moisture fluctuations on nodule numbers and activity in field-grown legumes in this region.

II. FIELD OBSERVATIONS

(a) Cowpeas

Materials and methods.—Observations were made on uninoculated cowpeas sown at Bongeen in mid October 1964. At monthly intervals 20-40 plants were sampled by removing the roots and nodules carefully from the soil. During dry periods the plants were watered prior to removal or clods with plants intact were soaked in water. Nodule activity was assessed on the colour of the nodule centre, red-centred being classed as active, brown and green as inactive and white-centred as young nodules of limited activity. The nodule number per plant was expressed as the number of nodules per gram root weight to compensate for the varying sizes of the roots between successive samplings. The soil moisture was estimated on a mean of four samples taken with an auger to a depth of 6 in. and dried at 105°C for 24 hr. The soil nitrate level at 0–6 in. deep did not exceed 38 p.p.m. N during the course of the observations.

Results.—Figure 1 shows the fluctuation in nodule numbers and activity with changes in soil moisture. A complete loss of nodules occurred after 4·53 in. of rain fell in the area in late December. No further rain fell; as the moisture decreased the nodulation returned to maximum but then declined until all nodules were shed as the moisture neared permanent wilting point (27%).

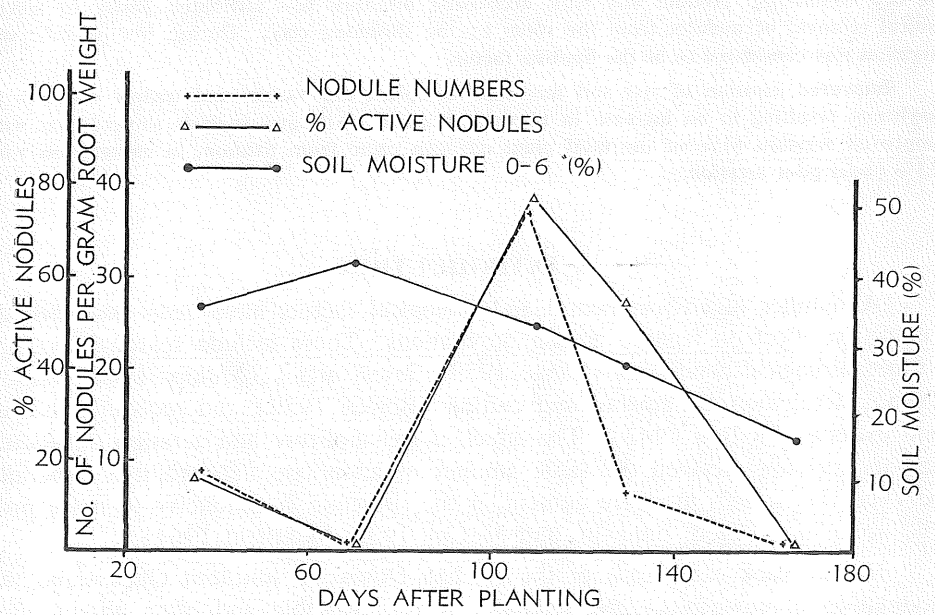

Fig. 1.—Effect of soil moisture on nodule numbers and activity in cowpea.

Severe chlorosis was induced in the cowpeas by the wet conditions, the symptoms being similar to those corrected by a 0·2% iron chelate spray in previous tests by the author. An odd nodule was not shed during this period but renewed its activity with the return of favourable moisture conditions. These

were brown-centred, with a ring of active red tissue beneath the cortex, or in extreme cases hollow-centred where the senescent central tissue had collapsed and shrunken while the activity was resumed in the outer meristematic zone.

(b) Native Legumes

Materials and methods.—Although native legumes are not abundant in the black earths, some do occur on headlands and roadsides in association with native grasses. Four of the most abundant were selected for detailed study of the periodicity in nodulation. These were *Glycine tomentosa* Benth., *Vigna lanceolata* Benth., *Cassia mimosoides* L. and *Psoralea tenax* Lindl. Samples, taken from natural field populations, often varied in size and age within one site. Roots and nodules were carefully removed from the soil as previously outlined.

Results.—Table 1 records the nodulation of four native legumes sampled during 1964-65 at Bongeen and the moisture conditions where data were available. Again, nodules were lost during excessively wet or dry times as well as during the winter following frosting. No perennial nodules were observed on these legumes. *Glycine tomentosa* and *Psoralea tenax* showed some ability to retain nodules during adverse soil conditions, but this seems to be related to decay resistance of the nodule itself. Nodules recovered from plants during the wet period in January 1965, although firmly attached to the roots, were inactive. These nodules had a thick suberized cortex and often persisted on the roots long after their contents decayed.

III. GLASSHOUSE STUDIES ON SOIL AERATION

In field soils a negative correlation exists between soil moisture and the volume occupied by air (Williams 1955). Loss of nodules under high moisture levels could be due to limiting aeration. Facilities were not available for measuring the oxygen tensions developed in wet black soil. However, an experiment was designed to establish to what extent the physical nature of wet black soil can limit aeration and thus affect root growth and nodulation of soybeans.

Methods.—Two states of aeration were established by employing a concept, proposed by Eastoe and Pollard (1959), that the porosity of the pot wall can affect the growth of the contained plant through aeration effects. Modified agricultural pipes 12 in. x 3 in. diam. were used. Glazed terracotta pipes created an aeration state designated as "poor aeration" and the other of porous concrete as "improved aeration". Non-porous bottoms were affixed to each pipe and a concrete plug 1 in. thick poured into the bottom of each tube. Sieved air-dried black soil was added to each tube and tamped in a constant way to avoid differences between pots. Prior to filling, five nitrate levels (16, 61, 106, 151 and 196 p.p.m. N) were applied evenly to the soil by means of an atomizer, as varying amounts of calcium nitrate. Six inoculated pregerminated soybean seeds were planted in each pot and 1 in. of quartz sand added to the surface to minimize cracking. The pots were watered daily with distilled water to maintain a 40% moisture level by weighing. The plants were harvested at 6 weeks.

Results.—The plant weights were increased significantly (5% level) by improved aeration in all nitrate treatments (Figure 2). Soil nitrates were growth-determining under improved aeration and non-determining in the poor aeration treatments, so maximum growth was not achieved under fixation nitrogen alone. The nodule numbers, on the other hand, were reduced by poor aeration only in the low-nitrate treatments. Associated with this reduction in nodule numbers and nodule weights was a reduction in nitrogen fixation in the soybean. Nitrogen analysis of soil, seed and plant material showed that 61% of the total plant nitrogen was obtained from fixation under improved aeration but only 33% under poor aeration at the low-nitrate level (16 p.p.m.).

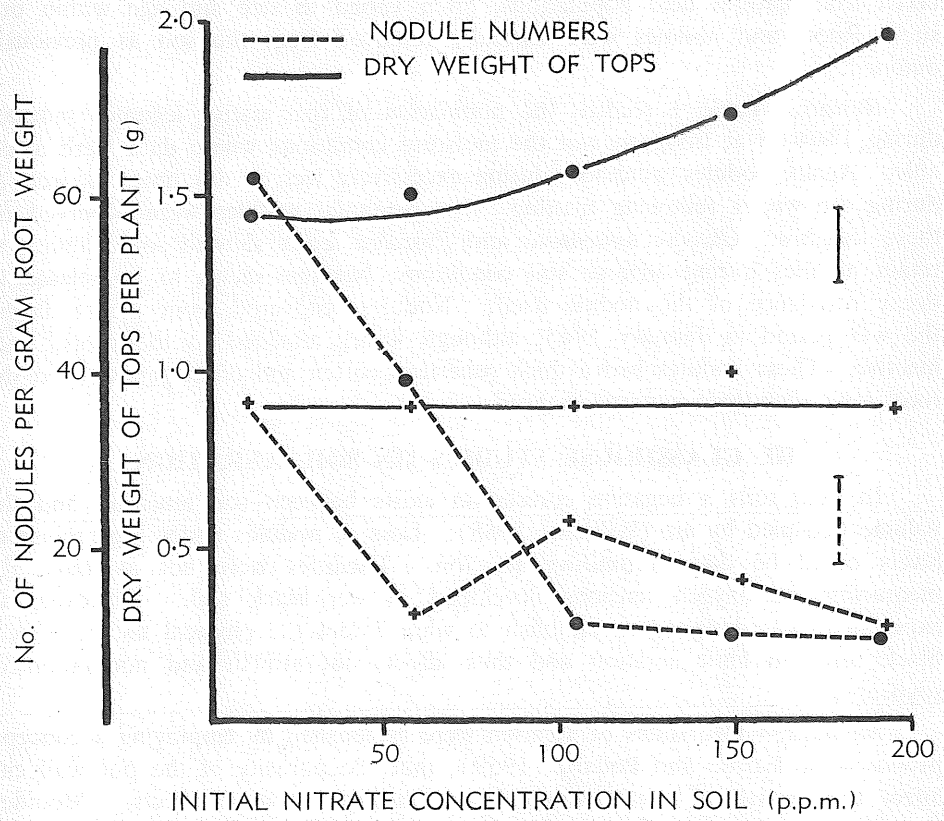

Fig. 2.—Effect of improved aeration on growth and nodulation of soybean in black soil (showing 95% confidence limits). The dots represent concrete pots and the crosses terracotta pots.

IV. DISCUSSION

Although a high soil moisture was generally conducive to better nodulation, heavy rain could eliminate all nodules. The results presented support the observations of Wilson (1942) on the loss and renewal of nodules with moisture fluctuations, but demonstrate a more profound influence on nodulation than mere elimination of nodules. By limiting aeration, high moisture could affect the extent of nodulation and hence the nitrogen fixation by the plant. Conditions

TABLE 1

NODULATION OF NATIVE LEGUMES ON BLACK SOIL, 1964–65

Native Legume	Sampling Date and Soil Moisture												
	14.i.64 Good	17.ii.64 Good	17.iii.64 Wet	25.iii.64 Fair	7.v.64 Very Wet	16.vi.64 Good	22.viii.64 Dry	27.x.64 Good	3.xii.64 Good	5.i.65 Very Wet	4.ii.65 Fair	4.iii.65 Dry	13.iv.65 Very Dry
		(34%)		(32%)	(42%)		(24%)		(35%)	(43%)			(17%)
Glycine tomentosa ..	14/14†	8/8	0/13	25/25	0/10	Frost 0/11	No regrowth	2/10	3/4	4/12*	6/6	0/7	0/8
Vigna lanceolata ..	..	..	0/6	7/10	..	Frost 0/8	No regrowth	10/10	6/6	0/6	8/8	0/7	0/8
Cassia mimosoides ..	14/16	0/6	1/24	1/25	0/11	Frost 0/6	No regrowth	8/10	6/6	0/10	8/8	2/8	0/10
Psoralea tenax ..	..	..	2/4	1/12	3/3	Frost 3/6	No regrowth	10/10	3/4	2/4*	5/6	0/6	0/4

† No. of plants nodulated/Total No. examined. * Brown-centred nodules.

in the terracotta pots could be considered close to field aeration conditions in wet black soil, aeration being by way of soil surface only. Improved lateral aeration in the concrete pots increased the number of nodules per gram root weight as well as the dry weight of nodules. The results are similar to those obtained by Hely, Bonnier, and Manil (1954) with the addition of synthetic aggregating substances to soil, but contrary to those of Bond (1950), who found no reduction in nodule numbers with reduced oxygen supply in water culture.

A quicker decline in nodule numbers than in nodule activity with the lowering soil moisture in the field suggests that both active and senescent nodules could be eliminated. The mechanical removal of nodules from the roots by the shrinking clay is a likely explanation; this was supported by observations of cracking of the surface soil away from the roots. On rewetting, the clays expand and the resultant pressure gives rise to flat distorted nodules.

Hollow active nodules which survived wet conditions were recorded. A delicate equilibrium must exist within such nodules to permit renewed activity.

The practical implications of these results are that excessively wet or dry conditions could adversely affect nodulation of a leguminous crop grown in this region and hence the nitrogen fixation. Indeed, observations of this nature have been made in the Brookstead area on furrow-irrigated soybeans, where nodules were shed after watering and in the following fortnight an intense nitrogen deficiency occurred and persisted until the nodulation was renewed.

Soil moisture fluctuation also seems to be a significant factor determining the seasonal nodulation habits of native legumes on the black soil, as is the case in semi-arid zones (Beadle 1964).

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