Chapter 2

# LITERATURE REVIEW

## 2.1 Development of research on saturated soil culture

Acclimation of soybean to saturated soil culture (SSC) was first reported by Hunter et al in 1980. Positive dry matter responses were recorded for twenty four soybean lines grown for 36 days in a glasshouse. In the same year, yield increases of up to 22% for 14 cultivars under SSC was reported in a field study (Garside et al, 1980).

In a follow-up glasshoue study (Nathanson et al, 1984 and Troedson et al, 1986), higher growth rates and higher yield were achieved under SSC than that in CI. Meantime, the physiological reason behind the positive response was partly explored. In 1986-1987, the SSC technique was tested in central Thailand and similar results to the earlier studies were reported by Chinchat et al (1987). From 1985-1988, Hartley studied the response of soybean to SSC in Australia and in 1989, Troedson et al undertook further investigation on SSC.

## 2.2 Soybean response to saturated soil culture

### 2.2.1 General response to SSC

Soybean is sensitive to changes in the amount and distribution of moisture. Moisture stress at any stage of growth can decrease yield. For optimum yield, soybean generally requires between 500 to 750 cm of water (Chapman et al, 1976).

Reduced yields are commonly reported when soybean is exposed to fluctuating water tables, but soybean is able to withstand a temporary watertable in certain growing stages. Stanley et al (1980) found that roots could withstand 7 days exposure to a watertable during flowering but not later.

Nathanson et al (1984) carried out a study in the greenhouse at the University of Queensland with two short-season soybean lines. The results showed that yields of the longer duration line in the 15 and 3 cm water table treatments were 71% and 65% higher respectively than that from conventionally irrigated soybeans, while the yields of shorter season variety were no different.

Chinchat et al (1987) studied SSC with three varieties, early maturity NW1, medium SJ 4 and late P44 on a heavy clay soil in central Thailand. The results showed that SSC produced 56% higher grain yields in which 1000 seeds weight, seeds per plant and pods per plant were 20%, 44% and 25% higher respectively. While nodules and branches per plant were 3% and 12% lower in SSC.

Pookpakdi et al (1988) tested this technique with five varieties, SJ4, SJ5, NW1, P44 and A138 during the raining season in 1986 and dry season in 1987 at Kasetsart University, Kamphaengsaen Campus. Although growth and yield of soybean tended to be lower under SSC than that of CI and local varieties seemed to be more affected than the Australian varieties. In terms of dry matter accumulation, soybean nodule production and nitrogen fixation activity, SSC showed a clear response, especially in later stages of growth.

Hartley (1988) designed four experiments to study genotypic variations in relation to SSC from 1985 to 1988. He concluded that there was considerable genotypic variation; responsive varieties usually had delayed flowering after acclimation, longer duration of flowering, later maturity and increased yields in SSC.

Troedson et al (1986) suggested that although previous investigations on SSC had been conducted on heavy, fertile clay soils the SSC procedure would also be applicable to sandy loam soils.

2.2.2 Vegetative growth

After the watertable is raised, roots below water level die and root absorbing surfaces decline. As a consequence a lighter leaf coloration is usually discernible during the second week of SSC. It has been proposed that this phenomenon is related to reduced total nitrogen uptake. However, soybean can adapt to the high watertable and ultimately have an improved growth rate (Nathanson et al, 1984 and Troedson et al, 1986).

Troedson et al (1986) measured total dry weight for SSC and

CI from 13 days after sowing (in greenhouse). The results indicated that initially the net assimilation rate and total growth rate in SSC was lower than those in CI, but these progressively increased during plant development. It appeared that after acclimation, the plants were somehow stimulated to produce more dry matter than the control. This change was also observed by Garside (1987) who reported differential changes in growth rates under SSC before and after 60 days from sowing.

During the acclimation period, a greater proportion of photosynthate appears to be allocated to the roots and nodules. Nathanson et al (1984) found that the ratio of root and shoot dry matter was higher than those in CI, which provided the basis for later improved growth. This compensatory root may have resulted in an increased dependence on nitrogen fixation through stimulated nodule growth.

2.2.3 Nodulation and nitrogen fixation

SSC may result in lowered plant available soil nitrogen. Nathanson et al (1984) found that soil nitrogen in SSC was lower after the water table was raised. IRRI (1984) reported low ammoniacal nitrogen was noted when soil was flooded with 5 cm water.

Wilson (1940) hypothesized that an internal carbohydrate nitrogen ratio governs nodule formation and nitrogen fixation. At low C:N ratio both nodule formation and nitrogen fixation are reduced whereas both processes are improved at higher C:N ratios.

However, if the C:N ratio is too high nitrogen fixation would again be inhibited.

SSC clearly increases nodulation; Nathanson et al (1984) reported that both the number and fresh weight of nodules in SSC were higher than those from the CI treatment from about 25 days after sowing, until physiological maturity. On the surface of the nodule in SSC, profuse development of white, thin-walled aerenchyma cells was evident. However, average weight per nodule was lower in SSC than that in CI. One consequence of the smaller nodule size in SSC was a higher surface area per unit weight of nodules, which, together with the aerenchyma tissue, may have improved gas exchange in the saturated soil.

It is possible, in association with the enhanced nodulation that SSC nitrogen fixation might also be improved as a result of the prolonged growing season. When soil nitrogen levels are low, nitrogen fixation is a major nitrogen source for plant growth in both CI and SSC, but particularly in SSC where the soil nitrogen contribution is believed to be negligible (Troedson et al, 1986). Field experimentation showed that crops under SSC absorbed only half the combined nitrogen of that in CI while nitrogen fixation was improved by 10 percent. Using acetylene reduction ($C_2H_4$), Troedson et al (1987) reported a doubling in the rate of nitrogen accumulation during seed-filling in SSC compared with CI. Nathanson et al (1984) on the other hand found that there were neither large or consistent differences between soil water regimes in nodule specific acetylene reduction activity.

2.2.4 Genotypic variation

Pookpakdi et al's result (1987) showed that responses to SSC in soybean genotypes varied with the length of their growing season which were longer under SSC. The longer period of soybean growth in SSC may be one reason for the observed higher yields. Yet SSC may also reduce yield if unsuitable varieties are selected. Garside et al (1987) reported a reduction in yield of 42 per cent in SSC compared with CI for one very early maturing accession. In this case plant recovery from leaf chlorosis induced by the SSC did not occur until after the commencement of flowering.

Large genotypic variability exists in the relative yield response of soybean to SSC. Hartley (1988) reported responses to SSC in two studies that were between -52 to +37 percent and -36 to +22 percent of the control. It appears possible therefore to select responsive cultivars for use with SSC. One major consideration in selecting a suitable cultivars would be to include medium or late maturing varieties which would be expected to have better capacity to respond to SSC.

2.2.5 Starter N

There is usually a period of nitrogen hunger during seedling development before an effective symbiosis can be established. Both the formation of nodules and the activity of the enzyme responsible for nitrogen fixation (nitrogenase) are strongly reduced in the presence of moderate or high levels of combined nitrogen. However, small amounts of fertilizer nitrogen are often beneficial to overall plant growth and nitrogen fixation. It is assumed that this occurs because the early period of nitrogen deficiency is overcome, thereby allowing earlier nodule functioning and the development of more nodule tissue (Dart et al, 1974).

The period of nitrogen deficiency is more pronounced under SSC. Within several days of application of the SSC treatment, plants developed chlorotic leaf symptom characteristic of nitrogen deficiency (Nathanson et al, 1984 and Troedson et al, 1986). If plants can′t recover before the commencement of reproduction, SSC will greatly reduce the yield, especially to short season varieties.

Troedson et al (1980) examined the effect of mineral nitrogen addition on the initial lag phase in the greenhouse where high water tables were established at either 7 or 13 days after sowing. It was observed that nitrogen depressed nodule fresh weight, but this effect disappeared several days after the high water table was established. Nitrogen deficiency during acclimation, therefore, can be relieved by starter nitrogen with only a marginal and temporary effect on nodule establishment. It is likely to be particularly important for short season varieties. But there is insufficient evidence to prove that nitrogen applications can both shorten the period of acclimation and prolong or maintain nodule activity.

The soil nitrogen level obviously affects soybean nodulation. Beard et al (1971) showed that the number of nodules was reduced when nitrogen was added at planting time but not when nitrogen was applied at the flowering stages. Plants grown on a low nitrate level can have higher symbiotic nitrogen fixation rates than those grown on no nitrate (Harper, 1974).

The application of nitrogen fertilizer may not necessary increase soybean yield (e.g. Welch et al, 1973). Olsen et al´s study (1975) indicated that the yield of Bragg soybeans was not increased by nitrogen fertilizers applied at rates of 112 and 224 kg N per hectare, but it could be increased if 448 kg N per hectare was used. However, positive responses of dry matter, nitrogen uptake and yield to lower application of nitrogen fertilizer have been reported by others (e.g. Bezdicek et al, 1974). The effect of nitrogen fertilizer application on the soybean yield therefore is unpredictable. This probably reflects the diverse range of environments under which such studies have been conducted and is likely to be dependent upon whether initial yield was limited by nitrogen supply either through inadequate nodulation and/or low soil fertility.

## 2.3 Soybean in waterlogging area

In Asia, there are many large regions of coastal low land, flood plains and deltas such as Mekong, the Chao Phya, etc. Large areas in these regions are inundated during the monsoon season, where rice is the only crop that can be effectively grown (Pons et al, 1982).

In the Changjiang delta area of China where waterlogging is a very common problem, monoculture of rice has been practiced over a long period of time. Double rice-based cropping systems have resulted in the deterioration of soil fertility (Guo and Fei, 1985). An introduction of grain legumes such as soybean may provide a degree of diversity that may be beneficial to the economy of the farming systems as well as to the soil and pest management. When soybean is introduced into waterlogged or flooded area, the yield will generally be greatly decreased. Herrera et al (1979) found that when flooding occurred 30 days after sowing, the yield of soybean was reduced by 30 %; when flooding was imposed 15 days after sowing and during pod filling stage, yield reduction were even more serious. However, the SSC procedure allows for the maintenance of an aerated zone close to the soil surface; and the deleterious effects of waterlogging may not necessary occur. Therefore, the saturated soil culture technique may be an appropriate innovation in many areas, and could provide an opportunity for farmers to diversify their cropping systems with a food legume.

## 2.4 The contribution of saturated soil culture to soil nitrogen fertility

Grain legumes have often been recommended as component crops to help sustain productivity of cropping systems because of their ability to fix nitrogen from the air (Giri et al, 1980;

Clegg, 1982; Doughton et al, 1984 and Myers et al, 1986). Myers et al (1986) indicated that the nitrogen fixed by a leguminous crop can be considered as having two distinct but overlapping roles; (1) to provide adequate nitrogen to meet the demands of the leguminous crop itself, and (2) to provide nitrogen to an associated intercrop or following crops.

Doughton et al's (1984) results showed that to achieve similar sorghum yields to those obtained after crops of black bean or green gram fertilizer applications of 68 kg N/ha were required to be added to a sorghum-sorghum sequence. Sorghum grown after sorghum in another study required 55 kg/ha of fertilizer nitrogen to achieve the same yield as sorghum grown after soybean (Clegg, 1982).

Pearl millet produced more grain after groundnut, cowpea or pigeonpea compared with a pearl millet-pearl millet sequence (Giri et al, 1980). The effect of groundnut on yield was equivalent to the supply of 60 kg N/ha as fertilizer.

If a legume crop is to contribute positively towards sustainability of a cropping system, the amount of nitrogen fixed from the atmosphere must exceed that removed with the harvest products. However, soybean does not always leave the soil with a positive balance of nitrogen. In the U.S.A., field grown soybean has been found to obtain an average of only 25% of its total nitrogen by fixation (Weber, 1966); although somewhat higher proportions of 50-60% have also been reported both in the U.S.A.

(Vincent, 1965) and elsewhere (Bergersen et al, 1985, 1989) On the other hand, the nitrogen harvest index (nitrogen removed in the harvested seed as percentage of total plant nitrogen) in soybean is generally about 60-80%. Thus, it is very likely that, in general, nitrogen fertility of cropping systems may tend to be depleted, rather than enriched, as a consequence of soybean cropping. If SSC can increase soybean nitrogen fixation compared with conventional irrigation, the crop may deplete less soil nitrogen and can better maintain the balance between nitrogen removal and inputs in a cropping system.