Soybean: Environmentally Friendly

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Abstract

Soybean is a high protein crop containing about 40% of protein. Thus N requirement in soybean is relatively high. Soybean obtains its N requirement from soil, fertilizers and atmosphere through N_2 fixation. The proportion of N derived from which part depends largely on soil fertility and management. Since soybean is considered as N_2 fixing crop, it is possible to manage soybean to obtain its N requirement mainly from N_2 fixation. In order for soybean to fix high N a specific strain of *Bradyrhizobium japonicum* has to be selected for high fixation with a soybean cultivar. It is also possible to select or breed soybean to have high nodulation and high N_2 fixation. To maximize factors, namely, climate, soil, and plant nutrients, cropping systems are considered as important. Quantitative data from Chiang Mai illustrate the role of soybean N_2 fixation in the N economy of cropping systems.

Introduction

Soybean is a high protein crop requiring nitrogen higher than the other crops. It has been estimated that each ton of soybean seed requires approximately 100 kg N to produce. Soybean obtains nitrogen from soil, fertilizer and atmosphere through biological nitrogen fixation in symbiotic association with rhizobia. Therefore, mineral N, strain of rhizobia and soybean plant are major factors influencing N_2 fixation in soybean rhizobia symbiosis.

Effect of Mineral N

The use of N fertilizer for increasing yield of soybean has been studied for a long time. Weber (1966) reported that N fertilizer at 660 kg/ha gave small increases in seed yield of soybean on an inoculated nodulating line and that N fertilizer at high rate decreased nodulation and N_2 fixation. Similar results were found by Bezdicek *et al.* (1974). Harper and Hageman (1972) reported that N fertilizer was favorable for vegetative growth of soybean.

Boonkerd *et al.* (1978) applied different rates of N from 0, 19, 38, 56 and 75 kg N/ha with and without inoculation on soybeans grown in different locations in Thailand. They found that N fertilizer even at low rates did not stimulate nodulation and N_2 fixation in soybean. Inoculation alone increased yield of soybeans higher than application of N at 75 kg/ha. Kucey *et al.* (1989) reported that application of N fertilizer at a high rate of 250 kg/ha reduced N_2 fixation in soybean greatly. Similar results were found by Smith and Hume (1985); Senaratne *et al.* (1987). It was, however, reported that N_2 fixation during soybean podfill enhanced seed yield compared to urea N assimilation.

George and Singleton (1992) reported that attaining maximum N accumulation of soybean in the field required greater mineral N levels (900 kg/ha) applied at more frequent intervals. Additions of excess amounts of N may result in increased yield of soybean, but the increases in yield would be economically offset by the increased costs of the N fertilizer additions, and could be obtained with less contribution of biologically fixed N.

In other words, most researchers feel that additions of N fertilizer to soybeans are not necessary to obtain high and economic yields. Using good BNF practices is all that is needed and this is also very environmentally friendly.

Strains of *Bradyrhizobium japonicum*

Soybean is a relatively specific host and does not nodulate when grown in the field for the first time. *B. japonicum* strain vary in their effectiveness in N_2 fixation with soybean cultivars (Boonkerd *et al.* 1978; Kucey *et al.* 1988). Thus, to obtain high benefit from N_2 fixation the highest fixing strain of *B. janponicum* must be selected to prepare inoculant.

When soybean is grown in the field for the first time, it is necessary to inoculate. In the area where soybean is cultivated continuously, normally population of rhizobia in the soil are present and high enough to nodulate soybean. But under long period of hot and dry areas after soybean is harvested, rhizobia may not survive high enough to nodulate soybean normally. Therefore, to ensure better nodulation and yield, it is recommended that soybean seeds be inoculated every time of planting. Kucey *et al.* (1988) reported that in Northern Thailand where soybean contained high population of rhizobia, yield of soybean increased when soybean seeds were inoculated with highly effective strains of *B. japonicum*.

Factors Affecting N_2 Fixation

There are many factors affecting N_2 fixation in soybean rhizobia symbiosis, but more important are plant nutrients, environmental and management variables. *Bradyrhizobia* can provide only N through symbiotic fixation with soybean. To obtain maximum N_2 fixation and yield, soybean still needs other essential elements such as phosphorus, potassium molybdenum and others. Among plant nutrient elements, P seems to be the most limiting factor in optimizing N_2 fixation and yield of soybean. Cassman *et al.* (1981) and Singleton *et al.* (1985) found that P enhanced N_2 fixation in soybean. Boonkerd (1992) evaluated the economic status of growing soybean after rice and found that maximum yield and income could be obtained with the application of P and K together with inoculation. Environmental and management variables also influence legume yield and, as a result, the requirement of atmospheric N (Singleton *et al.* 1992).

Nitrogen Fixation by Soybean in Cropping Systems

There is no question about the nitrogen fixing potential of soybean. In farmer's field, however, it cannot be assumed that soybean would always fix large amounts of nitrogen. Thus, unless the input from atmospheric nitrogen through fixation exceeds the harvested output, the soil cannot be expected to be nitrogen-enriched after a soybean crop. In this section, we present data from Chiang Mai to illustrate the range of nitrogen fixed by soybean and its potential effect on nitrogen balance in various cropping systems.

In a series of experiments conducted at Chiang Mai University from 1988 to 1990, soybean was grown in rice based as well as rainfed cropping systems, in three major seasons; early and late wet season (rainfed) and dry season (rice-based). At Chiang Mai, soybean is generally well and effectively nodulated even without inoculation, but in these experiments seeds were always inoculated and plants were well nodulated. Plant parts were analyzed for total nitrogen fixation which was estimated by xylem sap analysis (Peoples *et al.* 1988).

Seasons and genotypes. The amount of nitrogen fixed by soybean at Chiang Mai varies from 70 kg N/ha to 226 kg N/ha, depending on season and variety (Table 1). The largest amount fixed did not necessarily come from crops with greatest degree of symbiotic dependence. For example, SJ 5 which fixed 226 kg N/ha in the early wet season derived only 62% of its N from fixation, whereas late wet season SJ 5 which got 83% from the air fixed only 94 kg N/ha. Comparing the amount of N removed in harvested grains (Table 1c) with the input of fixed N, it can be clearly seen that even when seeds only are removed from the field, soybean crop often removes more N than it fixes. The negative balance of N is much more when the whole crop is removed from the field as is commonly practiced.

Soybean after rice. Rice-soybean is one of the most common cropping systems in irrigated areas of Southeeast Asia. After a crop of unfertilized rice, mineral nitrogen available for soybean could be too low for maximum fixation (Table 2). A starter fertilizer of 25 kg N/ha could effectively increase total plant N, seed yield and fixed N (Ying *et al.* 1992). With increasingly high rate of nitrogen fertilizer used with high yielding rice varieties, a question rose on how the residual nitrogen fertilizer might affect nitrogen fixation in the follow-

Table 1. Nitrogen fixed and removal by soybean at Chiang Mai.

Varieties	Growing Season		
	Late wet	Dry	Early wet
Nitrogen fixed (kg N/ha)			
NW 1	69 e	100 cde	171 b
SJ 5	94 de	137 bcd	226 a
Wilis	89 de	108 cde	161 b
SK 1	86 de	172 b	223 a
N from fixation (% total above ground plant N)			
NW 1	78 ab	62 bcd	56 cd
SJ 5	83 a	72 abc	62 bcd
Wilis	85 a	64 bcd	48 d
SK 1	79 ab	89 a	73 abc
Nitrogen in harvested seed (kg N/ha)			
NW 1	60 f	171 ab	194 a
SJ 5	94 ef	179 ab	181 ab
Wilis	108 de	131 cd	184 ab
SK 1	75 ef	159 abc	175 ab

Table 2. Effects of rice fertilizer and starter N on soybean in rice-soybean cropping.

Soybean starter N (kg N/ha)	N fertilizer on rice (kg N/ha)		
	0	100	300
Soybean nitrogen fixation (kg N/ha)			
0	122	138	139
25	132	134	136
50	140	130	128
Soybean seed yield (t/ha)			
0	1.69	1.80	1.83
25	1.83	1.84	1.84
50	1.84	1.86	1.91

Source: Ying 1990.

Table 3. Effects of saturated soil culture on nodulation and nitrogen fixation in two soybean varieties.

Varieties	Saturated soil culture	Conventional irrigation
Nodules/plant		
SJ 5	85	75
NW 1	120	75
Nitrogen from fixation (% total above ground plant N)		
SJ 5	74	54
NW 1	106	68
Nitrogen fixed (kg N/ha)		
SJ5	174	127
NW1	106	68

Source: Wang *et al.* 1993.

ing soybean crop. One hundred kg N/ha applied to the preceding rice crop, after increasing the rice yield by 74%, also effectively increased seed yield and nitrogen fixation in the following soybean crop. Soybean following rice which received 300 kg N/ha, surprisingly fixed the same amount of N as soybean following rice with 100 kg N/ha or soybean following unfertilized rice but with a starter 25 kg N/ha. They concluded that N applied to the rice and to the following soybean was inefficiently used by those crops and had only marginal effects of symbiotic activity of the soybean. The benefit of N_2 fixing soybean in this system was to slow the decline of, rather than enhance, the soil fertility.

Saturated soil culture. Growing soybean in saturated soil culture effectively increased nodulation, amount of N fixed as well as the degree of symbiotic dependence (Table 3). By physiological maturity, the saturated soil cultured plants had, on average, fixed 44% more N than plants under conventional irrigation. For SJ5, the increased N fixation by saturated soil culture had changed the nitrogen balance after removal of harvested seed from a negative balance of 14 kg N/ha to a positive balance of 25 kg N/ha. The major benefit of saturated soil culture was to improve the N balance of the soybean crop, thereby enhancing its potential to contribute N to the soil N pool.

Contribution of fixed N to the following crops

It is often assumed that a proportion of the N_2 fixed by an intercropped legume is made available to associated non-legume during growing season. Bethlenfalvay *et al.* (1991) indicated that a direct transfer of N_2 fixed by soybean via VAM hyphae to corn was possible. However, the decaying of root and nodules are thought to be important for this transfer of N. More benefits from soybean nodule decaying could be obtained from new imrpoved variety, super-nodulating soybean. Song *et al.* (1993) reported that super-nodulating soybean produced up to 20 times nodule weight than the commercial cultivars, resulted in yields of dry matter, and grain of cereal crops, sown immediately after soybean harvest were higher after supernodulators than commercial cultivars. Therefore, in order for the following crops to benefit more from soybean it is important to improve soybean to have the capacity to nodulate and fix more nitrogen.

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