Kasetsart J. (Nat. Sci.) 37 : 14 - 26 (2003)

Soybean Yield and Nutrient Composition as Affected by Soil and Foliar Fertilizations

Chin Theng Phiv[1], Chawalit Hongprayoon[1], Peerasak Srinives[2], Arunsiri Kumlung[1] and Yongyuth Osotsapar[1]

ABSTRACT

Soil fertilizer application and foliar fertilization offer a possible means of increasing soybean [*Glycine max* (L.) Merr.] yield in Thailand but little is known of appropriate foliar fertilizer use to supplement soil fertilization. Field experiment was conducted twice to determine the effects of soil N P K fertilization together with foliar fertilizers containing macronutrients and micronutrients on growth, yield and nutrient composition of soybean (Sukhothai 1 and KUSL 20004 cultivars). The treatments were arranged in 3×3 factorial experiment in randomized complete block. Three methods of soil fertilization were control (S0), 18 kg N ha^{-1} at 7 days after seeding (DAS) (S1), and 18 kg N ha^{-1} at 7 DAS + 18 – 18 – 18 kg N – P_2O_5 – K_2O ha^{-1} at 30 DAS (S2). Foliar fertilizer contained both macronutrients and micronutrients. The three methods of foliar fertilization were control (F0), 3 applications at 34, 42 and 49 DAS (F1) and 6 applications at 20, 27, 34, 42, 49 and 56 DAS (F2). Throughout the studies, soil and foliar fertilizations did not significantly affect growth, yield and yield components of soybean. The concentration of N P K Fe and Zn in shoot at 68 DAS and N P K and Ca in leaves at 89 DAS were not consistently affected by soil and foliar fertilizations. The remarkable effects of soil fertilizers on the concentrations of Ca Mn and Cu in shoot, and Mg Fe Mn and Cu in leaves were observed. Foliar fertilizations increased Fe and Cu concentrations in leaves. The nutrient concentrations of soybean shoot and leaves under this investigation were in sufficient ranges which were agreeable with soil test results. This finding indicated that the soil can provide sufficient nutrients for soybean growth and yield under this condition. Therefore, soil and foliar fertilization will not be economically feasible.

Key words: soybean, soil fertilizer, foliar fertilizer, macronutrients, micronutrients

INTRODUCTION

Soybean [*Glycine max* (L.) Merr.] has efficient symbiotic nitrogen fixation that can provide over 80% of the nitrogen in the crop at maturity, however in most cases fixation accounts for 25 – 75% of total plant nitrogen (Deibert *et al*., 1979). One metric ton of soybean grain removes approximately 59 kg N, 60 kg P, 19 kg K and different amount of other macronutrients and micronutrients (Fageria *et al*., 1997). To maintain soil fertility, at least nutrients (other than nitrogen) removed in the grain should be returned into soil by applying the fertilizers. Soybeans grown in Thailand were reportedly response to N P and K fertilization. The recommendation rates for soybean

[1] Department Soil Science, Faculty of Agriculture, Kasetsart University, Kamphaeng Saen, Nakhon Pathom 73140 , Thailand.
[2] Department of Agronomy, Faculty of Agriculture, Kasetsart University, Kamphaeng Saen, Nakhon Pathom 73140 , Thailand.

Received date : 01/11/02 Accepted date : 27/12/02

producers are 18 kg N, 36 kg P_2O_5 and 18 kg K_2O ha^{-1} for clay loam and silty loam soils. However, only 36 kg P_2O_5 ha^{-1} was applied at planting for soybean grown in clayey texture soil (Division of Soil Science, 1999). The suitability of these fertilizer rates to different soybean cultivars grown in different soil types need further clarification.

Foliar fertilization of soybean with a liquid N–P–K–S fertilizer during pod filling period (R5 to R6) has received considerable attention in various parts of the United States since 1975 (Garcia and Hanway, 1976). During seed growth period, soybean plants translocate large quantities of N, P, K and S from leaves to developing pods and seeds resulting in decreasing photosynthesis and ultimately premature senescence (Sinclair and de Wit, 1975). Soybean yield was increased by foliar boron application due to increasing final number of branches and pods on branches (Schon and Blevins, 1990). Foliar spray containing Ca and B improved pod development and pod retention of soybean in field condition (Weaver *et al*., 1985). Furthermore, increasing soybean yield from foliar B + Mg treatment was resulted from an increased number of pods on the main stem and branches (Reinbott and Blevins, 1995).

Some information is available on the effectiveness of foliar applied fertilizers for leguminous crops in Thailand. Foliar applications of B and Fe can ameliorate the deficiency problems of these elements on blackgram, peanut and mungbean. Two foliar applications of borax, at a very low rate of 50 gha^{-1}, during flower development and pod set, were as effective in correcting boron deficiency in backgram as a high rate applied to soil (Rerkasem, 1989). Five foliar applications of 0.5% $FeSO_4$ solution at 10, 20, 30, 40 and 50 days after emergence was the most effective way to alleviate iron chlorosis, and substantially improved yield of peanut (Ratanarat *et al*., 1990). Mungbean plants given a foliar spray with a nutrient solution contained 0.5% Fe, Zn and Mn recovered from the chlorosis and produced greater number of pods (Oonkasem and Thavarasook, 1988). Foliar fertilization of a solution of 5 gL^{-1} ferrous sulfate was effective in correcting chlorosis that was induced by iron deficiency, and it enhanced both growth and yield of susceptible mungbean cultivars (Ohwaki *et al*., 1997).

At present, foliar fertilization together with soil application have been practiced in many areas of Thailand but limited information was available (Pongsakul and Ratanarat, 1999). Suanmalee *et al*. (1990) reported that only soil N P K fertilization or soil fertilization in combination with foliar applications of N P K fertilizers significantly increased soybean yield in Pak Chong soil series (clayey, kaolinitic, Oxic Paleustults) and Wang Saphung soil series (fine – clayey, mixed Ultic Haplustalfs). However, N P K foliar fertilization without soil fertilizer application did not improve soybean yield. It is obvious that research on the effects of foliar fertilizers containing both macronutrients and micronutrients on soybean yield in this country is almost non. More studies are, therefore, needed to clarify the roles of foliar fertilization on soybean yield improvement. The objective of this study was to determine the effects of soil N P K fertilization together with foliar fertilizers containing macronutrients and micronutrients which applied during vegetative and reproductive stages on growth, yield and nutrient composition of soybean.

MATERIALS AND METHODS

Field experiment was conducted on Kamphaeng Saen soil series (fine-silty, mixed, Typic Haplustalfs) at the Asian Regional Center (ARC) of the Asian Vegetable Research and Development Center (AVRDC), Kamphaeng Saen Campus, Kasetsart University during November 2001 – March 2002 and was repeated during May – August 2002. Before land preparation of each cropping, a composite soil sample was collected from the depth of 0 to 20 cm and tested for pH, electrical conductivity (EC), organic matter (OM), P, K, Ca, Mg, Fe, Mn, Zn and Cu. Briefly, pH was analyzed in a 1 : 1 soil/water ratio, EC of saturated extract by EC meter, organic matter by Walkley and Black method, P by the Bray P–2 method, K, Ca and Mg by ammonium acetate method (Jackson, 1973). Soil Fe, Mn, Zn and Cu were detemined by atomic absorption spectrophotometry on the DTPA extract (Linsay and Norvel, 1978). The soil test values for the first and second trials are shown in Table 1.

Before planting of soybean, land was ploughed once and harrowed twice. Each plot measured 5 m in length and 3 m in width. The planted spacing between hills was 25 cm and between rows was 60 cm. Soybean cultivars ‘Sukhothai 1’ and ‘KUSL 20004’ were used in the first and second trials, respectively. Soybean seed was inoculated with rhizobium bacteria before seeding. About 3-4 seeds were dropped in each hill. Upon establishment, plants were thinned to 2 plants per hill. To minimize moisture stress, furrow irrigation was applied throughout the growing season. Weeds were controlled chemically and hand weeded as necessary.

The experimental design was randomized complete block with four replications. The fertilizer treatments were factorially arranged in 3×3 soil application and foliar fertilization methods. Soil fertilizer application methods were control (So), 18 kg N ha^{-1} at 7 days after seeding or DAS or growth stage Vc (S1) and 18 kg N ha^{-1} at 7 DAS + 18-18-18 kg N- P_2O_5-K_2O ha^{-1} at 30 DAS or growth stage R1 (S2). Ammonium sulfate (21–0–0) and compound fertilizer (15–15–15) were used in soil fertilizer treatments. The foliar fertilization methods were control (water sprayed plots, F0), foliar fertilizer application 3 times at 34, 42 and, 49 DAS or growth stages R2, R3 and R4 (F1) and application 6 times at 20, 27, 34, 42, 49 and 56 DAS or growth stages V4, V6, R2, R3, R4 and R5 (F2). The concentration of each element in solution applied at early growth stages was lower than those used at later stages. The detail of soil and foliar fertilizer applications were given in Table 2. The sources of nutrients for foliar fertilizer mixture were urea (46–0–0), ammonium sulfate (21–0–0), potassium nitrate (13–0–46), magnesium sulfate (10% Mg and 14% S), Fe EDTA (13.2% Fe), Zn EDTA (14% Zn), Mn EDTA (13% Mn), Cu EDTA (14% Cu) and calcium-boron-molybnenum solution (6% Ca, 2% B and 0.2% Mo) under the commercial trade name B Plus^{TM*}.

Alkyl aryl polyethoxylate and sodium alkylsulfonate alkylate 60% adjuvant was used at the rate of 0.1 mlL^{-1} . All foliar fertilizer solutions were applied with backpack hand sprayer in the early morning (8 – 10 am). The nozzle size was adjusted to deliver an appropriate rate and uniform distribution. Foliar fertilizer mixtures were sprayed uniformly across each plot.

Table 1 Soil test values for the first and second fertilizer trials conducted at ARC, Kasetsart University, Kamphaeng Saen.

Trial	pH	EC (dSm^{-1})	OM (%)	P	K	Ca	Mg	Fe	Mn	Zn	Cu
				($mg\ kg^{-1}$)							
1	6.5	0.8	1.4	238.4	131.6	1721.5	246.6	30.8	1.3	36.2	1.1
2	6.8	1.1	1.9	130.1	143.1	1921.6	232.7	24.9	1.0	52.3	1.2

* Use of trade name does not imply endorsement of the product name nor criticism of similar ones not named.

Table 2 Soil fertilizer rates, foliar fertilizer concentrations and application schedule of the fertilizer trials.

Treat-ment	Dates and rates of soil and foliar fertilizer application							
	7DAS* (kg N ha^{-1})	20DAS (2L/plot)	27DAS (2L/plot)	30DAS (kg N-P_2O_5-K_2O ha^{-1})	34DAS (3L/plot)	42DAS (4L/plot)	49DAS (4L/plot)	56DAS (4L/plot)
S_0	-	-	-	-	-	-	-	-
S_1	18	-	-	-	-	-	-	-
S_2	18	-	-	18–18–18	-	-	-	-
F_0	-	-	-	-	-	-	-	-
F_1	-	-	-	-	P_3	P_3	P_3	-
F_2	-	P_1**	P_2	-	P_3	P_3	P_3	P_3

* DAS = Days after seeding;** P_1, P_2 and P_3 = Concentration (mg kg^{-1}) of elements in the solution as follows :
P_1 = 250 N, 50 P, 100 K, 25 S, 15 Mg, 30 Ca, 15 Fe, 10 Mn, 7.5 Cu, 7.5 Zn, 10 B, 1 Mo
P_2 = 500 N, 100 P, 200 K, 50 S, 30 Mg, 45 Ca, 30 Fe, 20 Mn, 15 Cu, 15 Zn, 20 B, 2 Mo
P_3 = 750 N, 150 P, 300 K, 75 S, 45 Mg, 60 Ca, 45 Fe, 30 Mn, 22.5 Cu, 22.5 Zn, 30 B, 3 Mo

To study plant growth parameters, 5 plants were collected from two sampling rows at 46, 54, 69 and 89 DAS or growth stages R4, R5, R6 and R7 of the first trial and 65 and 79 DAS or growth stages R6 and R7 of the second trial. The plants were cut at ground level and determined for node number, branch number and plant height. After growth measurement, plant samples were air-dried at 70°C for 3 days to measure dry weight. Whole plant samples were taken at 68 DAS or growth stage R6. They were washed thoroughly with tap water containing mild detergent, rinsed three times with deionized water, dried and ground for chemical analysis (Schon and Blevins, 1990).

Ten plants were randomly collected from sampling rows at maturity and counted for number of pods per plant and number of pods on branches. One hundred pods were randomized and counted for the total number of seeds to obtain average number of seeds per pod.

The soybean was harvested at maturity when 95% of total pods turned brown (R8). Grain yield was measured from a 5 m length of the center two rows. Plant number per plot was recorded before threshing. Grain yield was weighed and a grain sample was collected from each plot to determine grain moisture. The grain yield was adjusted to 13% moisture. Subsamples from each plot were obtained to detemine 100 - seed weight.

Samples of trifoliate leaves (including petioles) consisting of 25 uppermost fully expanded leaves were randomly collected one week before harvesting from each plot to analyze for the nutrient concentration of leaves in the last growth stage. Leaf samples were washed in 0.1 N HCl for approximately 30 seconds, rinsed in deionized water for 30 seconds to remove of residual foliar fertilizer (Moraghan, 1991). Leaf samples were dried in a hot air oven at 70°C and ground to pass a 2-mm screen. Plant samples were digested with perchloric/nitric/sulfuric tertiary acid. Total N was determined by auto analyzer and P by vanado-molybdate colorimetry. The concentrations of K, Ca, Mg, Fe, Mn, Zn and Cu were determined by atomic absorption spectrophotometry (Walsh, 1971).

Data were analyzed with analysis of variance (ANOVA) using IRRISTAT package. The treatment means were separated using Duncan's multiple range test.

RESULTS AND DISCUSSION

1. Plant growth

The effects of soil and foliar fertilizer applications on plant height, number of nodes per plant, number of branches per plant and dry weight of shoot are shown in Tables 3 and 4. Soil and foliar fertilizer treatments did not influence plant height at 46 days after seeding (DAS) of the first trial and 79 DAS of the second trial (Table 3). However, soil fertilizer treatments decreased plant height at 69 DAS of the first trial but increased that of the second trial. The heavy rainfall at that plant age in the first trial may contribute to this variation. Faliar treatments did not show any influence on soybean height. The results corroborated the work of Edmisten *et al*. (1994) which indicated that foliar treatments of complete fertilizers at 10 – 14 days intervals starting at 2 – 3 leaf stage had no effect on height of cotton. There was an interaction between soil and foliar treatments on plant height at 79 DAS of the second trial. This interaction indicated that one application of soil fertilizer (S1) increased plant height when foliar fertilizer was not used.

Soil fertilizer and foliar fertilizer applications did not result in a significant increase in number of nodes per plant (Table 3). The result revealed that the effect of fertilizer treatments on plant height may be due to the increase in length of the internodes.

There was no response of shoot dry weight to soil fertilizer treatments. Foliar fertilizer application, however, significantly increased dry weight at 89 DAS of the first trial (Table 4). The interaction between soil and fertilizer treatments remarkably affected dry weight at 54 DAS of the first trial. This interaction indicated that one application of soil fertilizer (S1) in plots without foliar fertilizer (F0) tended to increase dry weight of soybean. In contrast to the result of this experiment, Haq and Mallarino (2000) indicated that foliar fertilization with N P K at early season seldom influenced dry weight of soybean at the R2

Table 3 Plant height (cm) and number of nodes per plant of soybean after soil and foliar fertilizations.

Fertilizer	Height (1st trial)		Height (2nd trial)		Node no. (1st trial)		Node no. (2nd trial)
treatment	46 DAS	69 DAS	65 DAS	79 DAS	46 DAS	69 DAS	65 DAS
Soil							
S_0	60.4	91.9 b	85.6 a	86.7	11.3	14.7	16.3
S_1	58.9	87.7 a	90.9 b	89.6	11.2	15.3	16.1
S_2	56.4	87.9 a	91.0 b	88.2	11.2	14.6	16.5
F- test	ns	*	**	ns	ns	ns	ns
Foliar							
F_o	56.7	88.1	87.9	87.5 a	11.3	14.9	16.8
F_1	59.7	90.6	90.4	89.3 ab	11.0	15.0	16.5
F_2	59.3	88.2	89.4	87.5 a	11.3	14.9	16.5
F-test	ns	ns	ns	ns	ns	ns	ns
S x F	ns	ns	ns	*	ns	ns	ns
CV (%)	9.4	4.9	4.5	4.2	5.4	5.0	5.4

ns = not significant different ,* significant different at P ≤ .05, ** significant different at P ≤ .01
Means in each column followed by the same letter are not different by DMRT at P ≤ .05

growth stage.

It was noted that foliar treatment did not significantly increase number of branches per plant in the cultivar 'Sukhothai 1' (Table 5). Therefore, the promotion of six split foliar fertilizer applications (F2) on plant dry weight was likely due to the effects of treatments on increasing dry weight of leaves, branches or stems. Similar results were obtained by Poole *et al.* (1983).

Soybean is relatively sensitive to phytotoxicity due to foliar fertilizer treatments (Weaver *et al.*, 1985). The ammonium polyphosphate mixed solution damaged the foliage more than potassium polyphosphate mixed solution or urea alone. Repeated applications of foliar fertilizer increase leaf injury (Parker and Boswell, 1980). Visual leaf injury evaluation in this experiment was made 3 days after each spray. Only less than 5% of leaf area was affected by F1 treatment, a little more leaf burn developed on mature leaves sprayed with F2 solution. Although leaf burn was not serious and the plants recovered within two weeks without an adverse effect on plant growth, this may cause negative effect on foliar treatments in general.

The number of branches per plant of 'KUSL 20004' soybean from the second trial was shown in Table 6. Soil and foliar fertilizer treatments did not cause a considerable increase in number of branches per plant at 89 DAS of the first trial (Table 5), and 65 DAS of the second trial (Table 6).

Soybean canopy was relatively dense from 35 DAS. Foliar application tended to increase humidity in leaf canopy which was favorable for the growth of pathogens and pest control by chemicals was not effective under this condition.

2. Soybean yield and yield components

Soybean yield of the first trail is shown in Table 5. The yield of the second trial is not presented due to the damage of plants by white flies during the final stage of seed filling which seriously affected seed yield but not some yield components (Table 6).

Soil and foliar fertilizer applications had

Table 4 Dry weight (kg ha^{-1}) at different stages of soybean growth after soil and foliar fertilizations.

Fertilizer treatment	First trial			Second trial	
	54 DAS	69 DAS	89 DAS	65 DAS	79 DAS
Soil					
S_0	544	1995	2515	2562	2608
S_1	586	2101	2733	2494	2547
S_2	536	2087	2523	2419	2679
F – test	ns	ns	ns	ns	ns
Foliar					
F_o	539	2039	2572a	2395	2673
F_1	565	2048	2399a	2633	2603
F_2	560	2096	2800b	2444	2559
F – test	ns	ns	*	ns	ns
S x F	**	ns	ns	ns	ns
CV (%)	11.5	14.3	13.9	12.8	11.9

ns = not significant different, *significant different at P ≤ .05, ** significant different at P ≤ .01
Means in each column followed by the same letter are not different by DMRT at P ≤ .05

no significant effects on seed yield of soybean in the first trial. Even, split application of foliar fertilizer (F1 and F2) did not increase seed yield over the control (Table 5). Further increasing to six - split application gave no increase in seed yield. On the contrary, Suanmalee *et al.* (1990) reported that soil fertilization significantly increased yield of soybean grown in Pak Chong

Table 5 Yield and yield components of 'Sukhothai 1' soybean in the first trial.

Fertilizer treatment	Branches/plant 89 DAS	Pods/plant 46 DAS	Pods/plant 89 DAS	Seeds/plant 89 DAS	Weight of 100 seeds (g)	Grain yield (kg ha^{-1})
Soil						
S_o	3.1	8.8	47.6	140.8	14.7	2254
S_1	2.9	9.2	51.2	142.5	14.3	2225
S_2	2.6	9.4	53.2	139.3	14.0	2238
F – test	ns	ns	ns	ns	ns	ns
Foliar						
F_o	2.7	9.1	52.5	139.2	14.8	2229
F_1	3.0	8.1	51.0	140.8	14.0	2281
F_2	2.9	10.2	49.2	140.7	14.2	2208
F – test	ns	ns	ns	ns	ns	ns
S x F	ns	ns	ns	ns	ns	ns
CV (%)	29.8	22.9	14.8	4.70	8.2	16.8

ns = not significant different

Table 6 Yield and yield components of 'KUSL 20004' soybean in the second trial.

Fertilizer treatment	Branches/plant 65 DAS	Pods on main stem 65DAS	Pods on main stem 79 DAS	Pods on branches 65 DAS	Pods on branches 79 DAS	Seeds/pod	Seeds/plant
Soil							
S_0	3.6	39.9	39.5	20.0	19.4	2.4	141.7
S_1	3.4	40.9	40.1	20.6	19.5	2.5	140.5
S_2	3.4	40.8	40.6	24.3	19.4	2.3	141.1
F – test	ns	ns	ns	ns	ns	ns	ns
Foliar							
F_0	3.6	40.3	40.0	21.1	19.9	2.4	141.0
F_1	3.3	40.9	40.5	20.0	19.0	2.5	139.7
F_2	3.6	42.6	39.7	23.8	19.4	2.4	143.6
F – test	ns	ns	ns	ns	ns	ns	ns
S x F	ns	ns	ns	ns	ns	*	ns
CV (%)	15.2	7.8	6.5	24.8	22.3	9.4	3.8

ns = not significant different, *significant different at $P \leq .05$

and Wang Saphung soil series. Supplementing with six applications of foliar fertilizers in 10 days interval did not further increase grain yield in either locations. The effective response of soybean yield to soil fertilizer treatments in both soils was mainly due to low level of available P and K.

The effects of fertilizer treatments on yield components of both trials are shown in Table 5 and 6. Total pods per plant at 46 and 89 DAS of the first trail was not increased by increasing soil and foliar fertilizer applications. Average number of pods per main stem and pods on branches per plant were also slightly affected by soil and folair fertilizer applications. One application of soil fertilizer (S1) or three split applications of foliar fertilizers (F1) slightly increased the average number of seeds per plant but not on seed size of the first trial (Table 5). Both soil and foliar fertilizer treatments did not affect branch number, pod number per main stem, pod number on branches, number of seeds per pod, and number of seeds per plant of the second trial (Table 6). Our results are in contrary to the finding of Parker and Boswell (1980) which indicated yield reduction of soybean in NPKS foliar treated plots and presented the positive correlation between leaf injury and yield depression. Little leaf injury produced from foliar fertilizer treatments could possibly explain a lack of positive yield response or a small yield decrease. It did not result in a significant yield reduction (Haq and Mallarino, 2000). In order to avoid leaf burning and to improve the chance of positive yield response, Poole *et al*. (1983) suggested that foliar fertilization should be conducted before 0800 or after 1700 hours which is not practical to general field conditions. Although our sprayed solution contained both boron and magnesium but the result of foliar application was not in agreement with the works of Schon and Blevins (1990), and Reinbott and Blevins (1995) which suggested that foliar treatments with both nutrients promoted higher soybean yield, mainly due to increase in number of branches per plant, number of pods on branches, and seed size.

3. Shoot and leaf nutrient concentrations

Soil and foliar fertilization treatments did not show significant effect on N P K and Mg in shoot sampled at 68 DAS (Table 7). However, the effect of soil fertilization on shoot Ca content was inconsistent. Calcium concentration in shoot from soil fertilizer treated plots of the first trial was relatively lower than control. Little influence of soil treatments on Ca in shoot was noted in the second trial. The data in Table 5 showed slight trend towards increasing shoot dry weight with soil fertilization. The relatively larger biomass production in these treatments may contribute to the dilution of Ca in shoot.

Concentrations of Fe Zn Mn and Cu in soybean shoot were shown in Table 8. Shoot Fe and Zn were not affected by soil fertilizer treatments but two split applications of soil fertilizers (S2) remarkably increased Mn and Cu in soybean shoot of the first trial and Cu in shoot of the second trial. The content of Zn Mn and Cu was not affected by foliar treatments of both trials. Shoot Fe declined in foliar treated plant of the first trial but tended to increase in the second trial. This indicated the inconsistent effect of foliar fertilization on Fe content in soybean shoot.

Concentration of macronutrients in leaves sampled at 89 DAS are shown in Table 9. Soil and foliar fertilizer applications did not significantly increase the concentration of N P K and Ca in leaves, but one application of soil fertilizer (S1)remarkably increased leaf Mg content. Macronutrient concentration in leaves from all treatments are in sufficient range. Our data are in contrary with the finding of Boote *et al*. (1980) that foliar application of N P K and S during pod filling stages increased the concentration of all the elements in soybean leaves without significantly improved seed yield. Generally, soybean plant requires high amount of N for seed production. The major part of N is accumulated in seed during pod filling stages. As much as 75% of the total N is found in the seeds at harvest time (Vasilas *et al*.,

Table 7 N, P, K,Ca and Mg concentrations (% dry weight) in shoot at 68 DAS of both trials.

Fertilizer	First trial					Second trial				
treatment	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Soil										
S_o	2.80	0.22	2.27	1.58a	1.31	2.18	0.21	2.39	1.17	0.98
S_1	2.79	0.23	2.29	1.44b	1.23	2.42	0.24	2.59	1.19	1.02
S_2	2.73	0.24	2.33	1.48b	1.24	2.23	0.23	2.48	1.18	1.06
F – test	ns	ns	ns	*	ns	ns	ns	ns	ns	ns
Foliar										
F_o	2.73	0.22	2.16	1.51	1.25	2.18	0.22	2.39	1.12	0.99
F_1	2.78	0.24	2.37	1.53	1.31	2.27	0.23	2.57	1.21	1.04
F_2	2.82	0.23	2.36	1.48	1.28	2.38	0.23	2.49	1.20	1.01
F – test	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
S x F	ns	ns	ns	*	ns	ns	ns	ns	ns	ns
CV (%)	11.5	9.1	9.3	7.4	6.3	13.8	9.2	10.0	13.1	8.1

ns = not significant different, *significant different at P ≤ .05
Means in each column followed by the same letter are not different by DMRT at P ≤ .05

Table 8 Fe, Zn, Mn and Cu concentrations (mg kg^{-1}) in shoot at 68 DAS of both trials.

Fertilizer	First trial				Second trial			
treatment	Fe	Zn	Mn	Cu	Fe	Zn	Mn	Cu
Soil								
S_0	150.8	18.4	67.7 b	9.4 a	77.4	15.3	27.6	7.0 a
S_1	172.7	23.5	59.6 a	10.5 a	99.9	19.3	32.0	11.6 b
S_2	175.3	25.7	72.4 b	16.6 b	100.2	19.9	31.4	12.4 b
F – test	ns	ns	*	**	ns	ns	ns	**
Foliar								
F_0	195.0 b	23.6	70.1	12.6	90.4	18.0	27.6	10.6
F_1	147.7 a	21.3	63.4	12.7	90.3	18.5	33.0	9.3
F_2	165.7 a	22.7	66.2	11.2	96.7	18.0	30.3	10.7
F – test	*	ns	ns	ns	ns	ns	ns	ns
S x F	ns	ns	**	**	ns	ns	**	ns
CV (%)	28.0	38.4	16.1	22.6	30.2	32.2	18.0	27.0

ns = not significant different, * significant different at P ≤ .05, ** significant different at P ≤ .01
Means in each column followed by the same letter are not different by DMRT at P ≤ .05

Table 9 N, P, K, Ca, Mg, Fe, Mn, Zn and Cu concentrations in leaves of 'Sukhothai' 1at 89 DAS of the first trial.

Fertilizer treatment	N	P	K	Ca	Mg	Fe	Zn	Mn	Cu
	(%)					(mg kg^{-1})			
Soil									
S_0	2.51	0.26	1.98	2.05	0.80 b	297 a	27.0	75.9 a	14.6 a
S_1	2.45	0.27	2.03	2.16	1.03 a	219 b	29.7	97.8 b	15.6 b
S_2	2.45	0.28	2.08	1.97	0.96 ab	215 b	28.9	99.8 b	15.9 b
F – test	ns	ns	ns	ns	**	**	ns	*	*
Foliar									
F_0	2.43	0.27	2.03	2.11	0.98	172 a	26.6 a	82.7 a	14.8 a
F_1	2.37	0.28	2.04	2.05	0.95	220 b	25.9 a	91.0 b	15.0 a
F_2	2.47	0.27	2.03	2.01	0.89	237 b	33.6 b	99.8 c	15.9 b
F – test	ns	ns	ns	ns	ns	**	*	*	*
S x F	ns	ns	ns	*	ns	ns	ns	ns	ns
CV (%)	18.1	8.7	7.7	10.3	14.8	26	23.4	16.7	12.3

ns = not significant different, * significant different at P ≤ .05, ** significant different at P ≤ .01
Means in each column followed by the same letter are not different by DMRTat P ≤ .05

1995). The results of our experiments indicated that N concentration in soybean leaves collected one week before harvesting was not affected by either soil or foliar fertilizer treatments. A well established soybean-rhizobium symbiosis from inoculation may be effective in providing enough N to plants.

It is important to note that the soil used in this experiment was previously grown to soybean and amended with duck manure and chemical fertilizers. The roots and stover were incorporated to the soil after harvest. The C:N ratio of soybean roots and stover was favorable for fast mineralization and would provide some available N to soybean in the succeeding crop (Goss *et al*., 2002). The residual N benefit of soybean stover to succeeding crop was 13.16% of their total N or equal to 12.7 kg N ha^{-1} (Yataputanon *et al*., 2002). Nitrogen gained from symbiotic fixation together with the mineralized N from soil organic matter may have contributed to sufficiency of this element in untreated control.

The soil and foliar fertilizer applications did not affect the concentration of P K and Ca in leaves but one application of soil fertilizer (S1) significantly increased Mg content in leaves as compared to control (Table 9). However, there was no marked influence of foliar fertilization on Mg concentration in leaves. The result of leaf analysis at 89 DAS also revealed that soil and foliar fertilization did not change nutrient composition especially N P K and Ca as compared to control. The values of N P K Ca and Mg were in sufficient ranges for soybean at this growth stage. These were consistent with the adequacy of available P, extractable K Ca and Mg in Kamphaeng Saen soil series. It is obvious that these nutrients were not the limiting factors under the studied conditions.

The concentration of Fe Zn Mn and Cu in leaves sampled at 89 DAS are shown in Table 9. Soil fertilizer application did not affect the concentration of Zn but one application of soil fertilizer (S1) remarkably increased Fe Mn and Cu concentration in leaves. In addition, three applications of foliar fertilizer (F1) significantly increased Fe and Mn concentration while six applications (F2) markedly increase concentration of Zn and Cu in leaves. Our finding is in agreement with the work of Bednarz *et al*. (1999) in cotton. However, none of the four elements were deficient in untreated plots and the increases of Zn and Cu were beyond the plant required concentration (Reuter ond Robinson, 1997).

Application of foliar fertilizers containing macronutrients and micronutrients at reproductive stage have been shown to increase soybean seed yield in some studies (Schon and Blevins, 1990; Smith *et al*., 2000). However, the other studies showed that foliar fertilization of soybean either did not influence or decrease yield (Parker and Boswell, 1980; Freeborn *et al*., 2001). Generally, nitrogen limitation of this crop during early to mid pod filling stages is due to rapidly decreasing of N_2-fixation by *Bradyrhizobium* spp. (Haper, 1987). Furthermore, root activity also decreases during that growth period and nutrient uptake is not sufficient to meet the seed demand for nutrients (Garcia and Hanway, 1976). However, the contrary result from the study on ^{15}N-labeled urea absorption and translocation of soybean indicated that changes in the rate of nutrient absorption by root during pod-fill were minimal and unlikely to be a major factor determining the effectiveness of foliar fertilization (Vasilas *et al*., 1978). Early season foliar fertilization for soybean was also studied if foliar application could increase P and K supplied to young plants (Haq and Mallarino, 2000). However, they reported that foliar fertilization of soybean with various nutrient mixtures resulted in very small and infrequent yield increase. Addition of a mixture of micronutrients to the N P K S fertilizer did not result in additional yield response (Mallarino *et al*., 2001). These findings are in agreement with the result of our experiment which indicated that three-split foliar fertilization at reproductive stage (F1) or two-split applications at early season together with four-split applications at seed filling stage (F2) did not increase yield of irrigated soybean in this fertile soil. In addition, positive response to foliar fertilization tended to occur when soil or weather condition reduced plant growth and nutrient availability (Haq and Mallarino, 2000). It is obvious from the result of soil test before planting, shoot analysis at 68 DAS and leaf analysis at 89 DAS that there was no limited nutrient for soybean under this studied condition. Soil and foliar fertilizations in this fertile soil, therefore, will not offset the application costs.

CONCLUSIONS

Three methods of soil fertilization and three methods of foliar fertilization did not significantly affect growth, yield and yield components of soybean. The concentrations of nutrients in shoot at 68 DAS and leaves at 89 DAS were not consistently affected by soil and foliar fertilizations. The nutrient concentrations of soybean shoot and leaves were in sufficient ranges. This finding indicated that soil can provide sufficient nutrients for soybean growth and yield under this condition.

LITERATURE CITED

Bednarz, C.W., N.W. Hopper and M.G. Hickey. 1999. Effects of foliar fertilization of Texas Southern High Plains cotton : Leaf phosphorus, potassium, zinc, iron, manganese, boron, calcium and yield distribution. **J. Plant Nutri.** 22 : 863-875.

Boote, K.J., R.N. Gallaher, W.K. Robertson, K. Hinson and L.C. Hammond. 1980. Effects of foliar fertilization on photosynthesis, leaf nutrition, and yield of soybeans. **Agron. J.** 72 : 271-275.

Deibert, E.J., M.D. Jeriego and R.A. Olson. 1979.

Utilization of ^{15}N fertilizer by nodulating and nonnodulating soybean isolines. **Agron. J.** 71 : 717-723.

Division of Soil Science. 1999. **Fertilizer Recommentation for Field Crops.** Department of Agriculture, Bangkok, 60 p. (In Thai).

Edmisten, K.L., C.W. Wood and C.H. Burmester. 1994. Effects of early-season foliar fertilization on cotton growth, yield and nutrient concentration. **J. Plant Nutr.** 17 : 683-692.

Fageria, N.K., V.C. Ballger and C.L. Jones. 1997. **Growth and Mineral Nutrition of Field Crops.** 2nd ed. Marcel Dekker Inc., New York. 624 p.

Freeborn, J.R., D.L. Holshouser, M.M. Alley, N.L. Powell and D.M. Orcutt. 2001. Soybean yield response at reproductive stage to soil-applied nitrogen and foliar-applied boron. **Agron. J.** 93 : 1200-1209.

Garcia, L.R. and J.J. Hanway. 1976. Foliar fertilization of soybeans during the seed-filling period. **Agron. J.** 68 : 653-657.

Goss, M.L., A. de Varennes, P.S. Smith and J.A. Ferguson. 2002. N_2 fixation by soybean grown with different levels of mineral nitrogen, and the fertilizer replacement value for a following crop. **Can. J. Soil Sci.** 82 : 139-145.

Haq, M.U. and A. P. Mallarino. 2000. Soybean yield and nutrient composition as affected by early season foliar fertilization. **Agron. J.** 92 : 16-24.

Harper, J.E. 1987. Nitrogen metab olism, pp. 497-533. *In* J.R. Wilcox (ed.). **Soybean : Improvements, Production, and Uses.** 2nd ed. Agron. Mono. 16. ASA, CSSA, and SSSA, Madison, WI.

Jackson, M.L. 1973. **Soil Chemical Analysis.** Prentice-Hall, New Delhi. 498 p.

Lauer, D.A. 1982. Foliar fertilization of dry beans with Zn and NPKS. **Agron. J.** 74 : 339-344.

Linsay, W.L. and W.A. Norvel. 1978. Development of a DTPA soil test for zinc, iron, manganese and copper. **Soil Sci. Soc. Am. J.** 42 : 421-428.

Mallarino, A.P., M.U. Haq, D. Wittry and M. Bermudez. 2001. Variation in soybean response to early season foliar fertilization among and within fields. **Agron. J.** 93 : 1220-1226.

Moraghan, J.T. 1991. Removal of endogenous iron, manganese, and zinc during plant washing. **Commun. Soil Sci. Plant Anal.** 22 : 323-330.

Ohwaki, Y., Y. Kraohaw, S. Chotechuan, Y. Egawa and K. Sugahara. 1997. Differences in responses to iron deficiency among various cultivars of mungbean (*Vigna radiata* (L.) Wilczek). **Plant and Soil** 192 : 107-114.

Oonkasem, B. and C. Thavarasook. 1988. Micronutrient deficiency of mungbean in Takhli soil, pp. 172-185. *In* **Proceedings of the 3rd Mungbean Conference.** Kanchanaburi, November 21-23, 1988. (In Thai).

Parker, M.B. and F.C. Boswell. 1980. Foliar injury, nutrient intake, and yield of soybean as infuenced by foliar fertilization. **Agron. J.** 72 : 110-113.

Pongsakul, P. and S. Ratanarat. 1999. On overview of foliar fertilization for rice and field crops in Thailand, pp. 199-220. *In* A. Suriyapan, E. Hansakdi, P. Parkpian, R. Simmons and C. Traynor, (eds.). **Proceedings of the 2nd International Workshop on Foliar Fertilization.** April 4-10, 1999. Bangkok.

Poole, W.D., G.W. Randal and G.E. Ham. 1983. Foliar fertilization of soybeans. I. Effects of fertilizer sources, rates and frequency of application. **Agron J.** 75 : 195-200.

Ratanarat, S., W. Masangsan, P. Vadeesirisak, C. Ditsantia and V. Phanuvas. 1990. Effects of iron foliar spray and specific *Rhizobium* strains on yield components of three peanut cultivars, pp. 120-128. *In* **Proceedings of 8th National Groundnut Research Meeting.** 3-5 May

1989. Roi-Et, Thailand (In Thai).

Reinbott, T.M. and D.G. Blevins. 1995. Response of soybean to foliar-applied boron and magnesium and soil applied boron. **J. Plant Nutr.** 18 : 179-200.

Rerkasem, B. 1989. Boron deficiency in food legumes in Northern Thailand. **J. Soil Fert.** 16 : 130-152. (In Thai with English abstract).

Reuter, D.J. and J.B. Robinson. 1997. **Plant Analysis : An Interpretation Manual.** CSIRO, Victoria, Australia. 572 p.

Schon, M.K. and D.G. Blevins. 1990. Foliar boron applications increase the final number of branches and pods on branches of field grown soybeans. **Plant Physiol.** 92 : 602-607.

Sinclair, T.R. and C.T. de Wit. 1975. Photosynthate and nitrogen requirements for seed production by various crops. **Science** 189 : 565-567.

Smith, G., W. Weibold, T.L. Niblack, P. Scharf and D.G. Blevins. 2000. Yield components of soybean plants infected with soybean cyst nemathode and sprayed with foliar applications of boron and magnesium. **J. Plant Nutr.** 23 : 827-834.

Suanmalee, N., N. Tiaranan, R. Deemark and Y. Soravisuitra. 1990. **Foliar fertilization for soybean production on Pak Chong and Wang Sapung soil series.** Annual Report, Field Crops and Fertilizer Research Group, Soil Science Division, Department of Agriculture, Thailand. (In Thai).

Vasilas, B.L., J.O. Legg and D.C. Wolf. 1978. Foliar fertilization of soybeans : absorption and translocation of ^{15}N – labeled urea. **Agron. J.** 70 : 787-791.

Vasilas, B.L., R.L. Nelson, J.J. Fuhrmann and T.A. Evans. 1995. Relationship of nitrogen utilization patterns with soybean yield and seed filling period. **Crop Sci.** 35 : 809-813.

Walsh, L.M. 1971. **Instrumental Methods for Analysis of Soil and Plant Tissue.** ASA, CSSA and SSSA, Madison, WI. 221 p.

Weaver, M.L., H. Timm, H. Ng, D.W. Burke and M.J. Silbernagel. 1985. Pod retention and seed yield of beans in response to chemical foliar applications. **HortScience** 20 : 429-431.

Yataputanon, J., P. Chaivanakupt, S. Wunprasert and T. Arayangkul. 2002. N-fixation of soybean and residual effect from N-fixation of soybean to rice yield in rice-soybean cropping system using N-15 technique. **J. Soil and Fert.** 24 : 1-21. (In Thai with English abstract).