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Mineral Nutrition

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1. Introduction

Sixteen nutrient elements are essential for the growth and reproduction of plants. The source of carbon (C) and oxygen (O) is air, while water is source of hydrogen (H). Ninety-four percent or more of dry plant tissue is made up of C, H and O. Remaining thirteen elements, represent less than 6 percent of dry matter, are often divided in three groups (Johnson, 1987). The primary nutrients are nitrogen (N), phosphorus (P), and potassium (K). Secondary nutrients are sulfur (S), calcium (Ca) and magnesium (Mg). Micronutrients are required by the plant in very small amounts. They are iron (Fe), manganese (Mn), boron (B), zinc (Zn), copper (Cu), molybdenum (Mo) and chlorine (Cl). Nutrient removal of soybean by tone of grain and correspondingly biomass are about 100 kg N, from 23 to 27 kg P_2O_5, from 50 to 60 kg K_2O, from 13 to 15 kg CaO, from 13 to 16 kg MgO and considerable lower amounts of the other nutrients. In general, the fertilizer requirements for soybean are typically less than for other crops such as maize and wheat. Bergmann (1992) reported adequate concentrations of nutrients in dry matter of fully developed leaves at the top plant without petioles at the end of blossom as follows: 4.50-5.0 % N, 0.35-0.60 % P, 2.5-3.70 % K, 0.60-1.50 % Ca, 0.30-0.70 % Mg, 25-60 ppm Zn, 30-100 ppm Mn, 25-60 ppm B, 10-20 ppm Cu and 0.5-1.0 % Mo.

2. Nitrogen

Symbiotic nitrogen (N) fixation had important role in supplying of leguminose plants including soybean, by N. It is estimated that by this source is possible to bind from 40 to 300 kg N/ha/year (Bethlenfalvay et al., 1990). Field studies by Bezdicek et al (1978) showed that soybeans are capable of fixing over 300 kg N/ha when the soil is low in available N and effective strains of *Bradyrhizobia* are supplied in high number. Also, part of leguminose needs for N is settled by its uptake in mineral forms, mainly in NO_3^- and NH_4^+ forms. Soybean contains in mean from 1.5 to 1.6 % and from 6.5 to 7.0 % N in dry matter of aboveground part and grain, respectively (Hrustic et al., 1998). N amounts removal from soil by soybean depending on numerous external and internal factors. For forming of 1 t of grain and correspondingly vegetative mass of soybean is needed about 100 kg N.
Worldwide some 40 to 60 million metric tons (Mt) of N_2 are fixed by agriculturally important legumes annually, with another 3 to 5 million Mt fixed by legumes in natural ecosystems, providing nearly half of all the nitrogen used in agriculture (Hungria & Campo, 2004). Therefore, biological dinitrogen fixation by leguminous plants is a significant source

of available nitrogen in both natural and managed ecosystems (Galloway et al., 1995) that contributes to soil fertility and replaces the use of synthetic nitrogen fertilizer.

The host plant provides carbon substrate as a source of energy, and bacteria reduce atmospheric N_2 to NH_3 which is exported to plant tissues for eventual protein synthesis (Vincent, 1980). Nitrogen fixation occurs in different intensities in soil, during which the energy of plant assimilates is used, and because of this, bacterial activity forms unbreakable relationship with plants. The proportion of nitrogen derived from fixation varies substantially from zero to as high as 97%, and most estimates fall between 25% to 75% (Deibert et al., 1979; Keyser & Li, 1992, Russelle & Birr, 2004).

N is mobile in plants and it is quickly translocate from old to young organs. For this reason, symptoms of N deficiency (first lightgreen and later greenyellow colours of leaves) obtain on the older leaves. In the more over stages it is found falling off the flowers and pods (Vrataric & Sudaric, 2008). Excess of N had unfavorable impacts on soybean productivity, mainly due to susceptibility to diseases, low temperatures and drought. Symptoms of N oversupplies are increasing of height of plants, longer internodies and lodging incidences. Soybean is the most susceptible leguminose to nitrate oversupplies. Under these conditions inhibition of nodule forming and nitrogenase activities were found Harper & Gipson, (1984). Also, high nitrate in apoplast of soybean had effect on pH increasing, immobilization of iron and developing of iron chlorosis in soybean (Hrustic et al., 1998).

N supplies of soybean could be estimated by number and activities of bacterial nodules of genus *Rhisobium* and *Bradyrhisobium*, contents of total and mineral N in oil, nitratreductase activities etc. Inadequate N supplies are possible to correct by mineral fertilization. Activities of bacteria are reduced under good supplies of soil by N (as results either high N fertilization or favorable conditions for organic matter mineralization) and acid soil pH.

Recommendations for soybean fertilization are depended on soil test results and planned yields. Under conditions of the northern Croatia N recommended quantities are mainly in range from 60 to 90 kg N/ha mainly in spring. Using of N as urea in autumn over 100 kg/ha resulted by absence of nodule bacteria or minimizing their amounts (Vrataric & Sudaric, 2008). By testing 12 localities in fertile soils (chernozem and similar soil types) of Vojvodina (Serbia) was found that inoculation had considerable more impacts on yields of soybean compared to N fertilization and that using 90 kg N/ha was not found nodule on soybean root (Belic et al., 1987; Relic 1988 – cit Vrataric & Sudaric, 2008). Based on experiences from very fertile soils in Ohio (Johnson, 1987), soybean is not recommend for N fertilization in case of sufficient amounts of N-fixing bacteria and only in first growing of soybean on individual soil recommendation is applying 45 kg N/ha. Also, in Illinois mineral N fertilization had not effects on soybean yields even in cases of band fertilization close to soybean rows. Also, N fertilization was superfluous for maize in soybean-maize rotation (Welch et al., 1973). However, the experiences from USA are not possible to applying in less fertile soils of middle and eastern Europe.

Soil acidity is often limiting factor of the symbiotic nitrogen fixation process. Soils with low pH values lack calcium, and have surplus of toxic aluminium, so that soybean roots in acidic soils don't have mucous coating on surface which purpose is to dissolve root pectines, enables root hair curling and root hair penetration by bacteria. This is very important during the first few days after inoculation that is after sowing inoculated seed. Therefore, soils with pH value less than 5.5 (acidic soils) are not suitable for soybean growing, because they lack necessary conditions for development of useful bacteria whose growth is slowed down or completely enabled. Strains found on soybean roots in this type of soils are mostly ineffective, and when cut in half are green in colour. Situation is completely opposite in fertile neutral or mildly alkaline soils like chernozem. In these types of soil nitrogen fixing bacteria have not only good conditions for development, but also they can survive in large numbers for many years after soybean was grown. In such soils it is not necessary to perform seed bacterisation if soybean is in rotation every four years.

In case of low effects of inoculation on nodule bacteria development it is recommend top-dressing with 50 kg N/ha in form of calcium ammonium nitrate (27% N) in term close to flowering or at beginning of flowering (Vrataric & Sudaric, 2008).

Organic manures cannot alone meet the heavy demands of nutrients in intensive soybean production because of their limited availability and restricted nutrient supply. A complementary use of organic manures and mineral fertilizers may meet the goal of adequate and balanced supply of required nutrients to crops. The soybean grain yield with recommended NPK fertilization and 25 kg N/ha + 1 t neem cake/ha combinations was significantly more than the other only chemical and organic source of nutrition (Table 1).

Soybean grain quality (crude protein and oil contents) and grain yield as affected by fertilization (in. = inoculated; neem cake = n.c.; FYM = farm-yard manure 5 t/ha; NPK 20:60:40 = recommended NPK-fertilization)							
Treatments	Percent		t/ha	Treatments	Percent		t/ha
(a-e)	Protein	Oil	Yield	(f-j)	Protein	Oil	Yield
a) Control (in.)	34.42	19.03	0.69	f) b + 1 t n.c.	37.92	18.85	1.52
b) 25 kg N/ha	37.92	16.00	0.93	g) c+ 1 t n.c.	37.04	19.65	1.23
c) 50 kg N/ha	37.04	18.72	0.89	h) b + 5 t FYM	38.06	16.83	1.57
d) 5 t FYM/ha	35.73	19.23	0.80	i) c+ 5 t FYM	37.63	18.17	1.20
e) 1 t n. c/ha	35.44	17.03	1.07	j) NPK 20:60:40	38.94	18.92	1.33
LSD 5 % (a-j)	ns	1.78	0.27	LSD 5 % (a-j)	ns	1.78	0.27

Table 1. Effects of inorganic and organic sources of nutrients on grain quality and yield of soybean (Saxena et al., 2001)

3. Phosphorus

Phosphorus (P) contents in plants are in wide range, mainly from 0.1 to 0.8 % P in dry matter. Reproductive organs, especially of leguminose plants contain high levels of P about 0.6 % P. Uptake of P into plants is intensive in the early stages of growth and in period forming of generative organs (Hrustic et al., 1998). Store of P in plants, especially in grain, are mainly in form of fitine acid. P efficiency is in close connection with water and temperature regimes in soil. Under optimal soil moisture P uptake can be up to three-fold higher than in dry soil. Also, oversupplies of water, cold weather and low pH reducing P uptake in plants.

P removal by plants is mainly from 10 to 45 kg P, while by soybean is from 15 to 30 kg P/ha/year. The end of growth is the first symptom of P deficiency. Leaves are dark green and in the later stage develops chlorosis and violet color as result of increasing antociane synthesis. Necrotic spots, drying and falling of the leaves is the latest stage of P deficiency. Active nodules (dark pink center) of N-fixing bacteria are absent or few in number under conditions of P deficiencies. Also, decreasing of protein and chlorophyll synthesis was found.

Excess of P is rare. Plants reducing growth and dark frowning spots in leaves were observed. Intensity of plant development increasing and as results are the earlier flowering, grain forming and senescence. Oversupplies of P could be reason for some nutritional unbalances, for example Zn, Fe, Mn, Cu and B deficiencies.

P, mainly in combination with N and K as NPK fertilizers, can be applied broadcast and incorporated into the soil before sowing or applied as starter at sowing time. With low soil test P levels band application of fertilizer is more efficient than broadcasting. If applied as a starter, the recommend placement of the fertilizer is in band 2 inches to the side and 2 inches bellow the seed (Dahnke et al., 1992; Barbagelata et al., 2002). P materials such as triple superphosphate or from liquid or dry formulations of ammoniated phosphates are available to improve soil P status. However, organic soybean growing has restriction in P use and it is limited on rock phosphate or manures as sources of P.

Anetor and Akinrinde (2006) found that P deficiency in soil is an important growth-limiting factor in acidic alfisolof Western, Nigeria. Lime application may not be feasible for poor resourced farmers. However, the complementary benefits (liming and nutrient supply) of organic fertilizers and rock phosphates could sufficiently ameliorate acid soil conditions and greatly reduce P fertilizer cost for effective and sustainable soil fertility management.

Win et al. (2010) tested the P effects on three soybean cultivars (CKB1, SJ5 and CM60) based on the seed oil content (SOC) and the seed protein content (SPC) and to assess the physiological responses associated with changes in shoot P-utilization efficiency (SPUE). The experiment was carried out during 2008 and 2009 with a split-plot design at the Agronomy Department, Kasetsart University, Bangkok, Thailand. The main plots were for tested three P levels in a nutrient solution (0.5, 1.0 and 2.0 m*M* P), with subplots for the three soybean cultivars. The results indicated that at maturity, the P levels of 2.0 m*M* P decreased SPUE by 27% compared to that of 0.5 m*M* P (the control). SOC was not significantly affected by the P level. Relative to the control, the P nutrition levels of 1.0 and 2.0 m*M* P significantly decreased SPC by 4% and 5%, respectively. There were no significant differences in SOC between varieties. The SPC of CKB1 was 8% greater than that of SJ5 but showed no significant difference to that of CM60 (Table 2).

Zheng et al., (2010) reported effectiveness of P application in improving regional soybean yields under drought stress of the 2007 growing season in Northern China including Heilongijang, Jilin and Liaoing Provinces. Total soybean acreage of this region was around 4.5 million ha, which accounts for about 5% of the total soybean acreage in the world (FAOSTAT, 2009). Contemporary climate change is characterized by increase in frequency and intensity of drought. Total 118 soybean fields throughout Hailun County of Northern China. Regression trees analysis showed that regional soybean yield variability was mainly induced by soil available phosphorus and the amount of P applied, which explained 16.3 and 15.2% of the yield variation, respectively. The productivity of soybean over the region did not increase when P application rate reached a threshold of 55.67 kg/ha (Zheng et al., 2010).

Effects of P levels in nutrient solution and cultivars on soybean status (DM = dry matter; Sh = shoot; Prot. = protein)											
	R5 stage (Σ = Total)			**Maturity stage**				**Maturity stage**			
	Dry matter (g/plant)			**Dry weight** (g/plant)		**P-utilization*** (Q=quotient)		**Phosphorus** (mg/plant)		**Seed** %	
	Sh.	Root	Σ	Σ	Shoot	Q[a]	Eff. [b]	Sh.	Seed	Oil	Prot.
	Effects of P levels (m*M* P)in nutrient solution										
0.5	14.1c	1.35b	15.4c	25.8b	24.6b	0.213a	5.21a	118b	47.9b	16.9	40.2a
1.0	20.5a	2.36a	22.9a	36.0a	34.4a	0.139b	4.77a	258a	72.3a	18.1	38.5b
2.0	18.2b	1.96a	20.2b	33.3a	31.6a	0.117b	3.79b	292a	64.4a	17.5	38.3b
	Effects of soybean cultivars										
CKB1	22.2a	2.54a	24.7a	34.2	32.5	0.156	4.89a	236.	59.7a	16.9	40.4a
SJ5	14.2c	1.42b	15.7c	27.1	25.9	0.147	3.72b	212	52.5b	17.3	37.1b
CM60	16.4b	1.74b	18.1b	33.8	32.2	0.167	5.17a	221	72.4a	18.3	39.4a
Duncan׳s multiple range test (within column, means by the same letter are not significantly at 5 % level): CV %											
a	12	13	12	21	21	12	10	13	14	17	2
b	8	17	8	21	22	14	12	16	15	7	2
* [a] Shoot P-utilization quotient = plant shoot dry weight/mg P in plant shoot of P [b] Shoot P-utilization efficiency (eff.) = [(shoot DM)^2/shoot P content]											

Table 2. Effects of P on seed oil and protein contents and P use efficiency in three soybean cultivars (Win et al., 2010)

4. Potassium

Potassium (K) is essential nutrient for plant growth. K concentrations in dry matter of plants vary between 1.0 and 6.0 % and more and are generally higher than those of all other cations. The exact function of K in plant growth has not been clearly defined. By numerous investigations were found that K stimulates early growth, increases protein production, improves the efficiency of water (drought resistance), improves resistance to diseases, insects and stalk lodging (Kovacevic & Vukadinovic, 1992; Rehm & Schmitt, 1997).

Soils mainly containing enormous amounts of K, but depending on soil types, 90-98 percent of total K is unavailable. Slowly unavailable K is thought to be trapped between layers of clay minerals (Johnston, 1987; Rehm & Schmitt, 1997). K deficiency is encountered mostly on light, usually acid soils with a low cation exchange capacity or on soils with a high content of three-layered clay minerals often loess soils with illite clay (Bergmann, 1992).

Soybean requires large amounts of K and K deficiencies are easy to recognize (edge necrosis of leaves – the margins of leaflets turn light green to yellow) and correcting them is inexpensive as K is to lowest-cost major nutrient. K deficiencies as result of strong K fixation and high levels of available magnesium (Mg) were found on heavy hydromorphic soils of Sava valley area in Croatia. By ameliorative KCl fertilization yields of maize and soybean drastically increased due to improved plant nutritional status (Vukadinovic et al., 1988; Kovacevic & Vukadinovic, 1992; Kovacevic 1993; Kovacevic & Grgic, 1995¸ Kovacevic & Basic, 1997).

The K deficiency in soybeans was found on the drained gleyols which had inadequate rates of the exchangeable K and Mg (low K and high Mg status). These soil characteristics affected correspondingly K and Mg status in soybean plants (Tables 3 & 4).

Soybean (the upermost full-developed threfoliate leaf before anthesis) and soil status (means of four fields)									
The state farm (year)	Soybean (K-deficieny symptoms)					Soil status (0-30 cm of depth)			
	Leaf status (precent in dry matter)				Grain yield (kg/ha)	pH		mg/100 g (AL-method)	
	P	**K**	**Ca**	**Mg**		**H_2O**	**KCl**	**P_2O_5**	**K_2O**
Zupanja (1988)	0.35	0.98	1.20	0.73	1930	7.33	6.91	6.6	15.9
Vinkovci (1989)	0.57	1.05	2.22	2.14	780	7.75	6.87	28.0	12.2
Jasinje (1988)	0.38	0.87	1.30	1.11	1410	7.68	7.20	10.6	10.2
N. Gradiska (1990)	0.32	1.16	1.82	0.92	2060	7.76	6.91	7.9	16.6

Table 3. Plant and soil status (drained gleysol): symptoms of K deficiency in soybean (Kovacevic et al., 1991)

Soybean (the upermost full-developed threfoliate leaf before anthesis) nutritional status								
The state farm and date of sampling	Percent in dry matter				mg/kg (ppm) in dry matter			
	P	K	Ca	Mg	Zn	Mn	Fe	Al
	Chlorotic soybeans (K-deficiency symptoms): means of two samples/field							
Zupanja (June 19, 1987)	0.45	2.02	1.74	2.91	13.0	28.0	609	588
Vinkovci (June 13, 1986)	0.73	0.66	1.16	1.65	19.0	25.0	600	
Jasinje (June 13, 1986)	0.52	0.70	1.11	1.29	27.0	200.0	220	
Mean	0.57	1.13	1.34	1.95	19.7	84.3	476	
	Normal soybeans (oasis in the chlorotic soybeans): means of two samples/field							
Zupanja (June 19, 1987)	0.25	2.87	1.69	1.78	12.0	28.0	386	309
Vinkovci (June 13, 1986)	0.59	1.13	1.48	1.25	17.0	26.0	260	
Jasinje (June 13, 1986)	0.59	1.06	1.25	1.11	18.0	248.0	180	
Mean	0.48	1.69	1.47	1.38	15.7	100.7	275	

Table 4. Nutritional status of normal and chlorotic (K-deficiency symptoms) soybeans (Kovacevic et al., 1991)

Response of soybeans to ameliorative KCl- fertilization (the upermost full-developed threfoliate leaf before anthesis)													
Fertilization (spring 1986)			The 1986 growing season					The 1987 growing season					
			Yield (t/ha)	Leaf (% in dry matter)				Yield (t/ha)	Leaf (% in dry matter)				
N	P_2O_5	K_2O		P	K	Ca	Mg		P	K	Ca	Mg
0	0	0	2.43	0.37	0.72	1.84	1.62	1.45	0.35	0.91	1.69	1.35
120	120	180	2.40	0.36	0.87	1.87	1.49	1.48	0.32	0.99	1.37	1.35
120	120	990	2.83	0.35	1.28	1.76	0.74	1.88	0.32	1.29	0.92	0.77
LSD 5%			0.27	ns	0.22	ns	0.25	0.29	ns	0.16	0.30	0.31

Table 5. Response of soybeans to potassium fertilization (Katusic et al. 1988; cit. Kovacevic & Basic, 1997)

KCl in spring 1987	Fertilization (KCl) impacts on soybean: grain yield and leaf (the uppermost full-developed threfoliate leaf before anthesis) K and Mg (on dry matter basis) status– the growing seasons 1987-1989								
	1987			1988			1989		
K_2O	**Yield**	Leaf (%)		**Yield**	Leaf (%)		**Yield**	Leaf (%)	
kg/ha	kg/ha	**K**	**Mg**	kg/ha	**K**	**Mg**	kg/ha	**K**	**Mg**
150	1280	0.57	1.60	1800	0.82	1.18	780	0.60	2.16
1000	2700	1.90	0.95	2350	1.74	0.84	1470	0.75	1.79
2670	2550	2.28	0.78	2740	2.22	0.52	2530	1.17	1.41
LSD 5%	270	0.20	0.20	450	0.09	0.18	240	0.07	0.21
LSD 1%	360	0.27	0.27	600	0.13	0.24	320	0.09	0.27

Table 6. Response of soybean plants to potassium fertilization (Kovacevic & Vukadinovic 1992)

Katusic et al., (1988; cit. Kovacevic & Basic, 1997) applied increasing rates of KCl on Cerna drained gleysol. Soybean responded by yield increases for 16 % and 30 %, for the first and the second year testing, respectively. Soybean under unfertilized and usual fertilization was contained in mean 0.82 % K (acute K-deficiency with correspondingly symptoms) and 1.49 % Mg. Soybean nutritional status was considerable improved by K fertilization (mean 1.29 % K and 0.76 % Mg) – Table 5.

Kovacevic & Vukadinovic (1992) tested response of soybean and maize to increasing rates of potassium application in KCl form on silty clay gleysol developed on calcareous loess. Low levels of exchangeable K, high levels of exchangeable Ca and Mg and strong K fixation were found by the soil test (Vukadinovic et al., 1988; Kovacevic & Vukadinovic, 1992). Also, clay fraction (35.2 % of soil) composition was as follows: vermiculite/chlorite 30 %, smectite 30 %, mixed layer minerals 20 %, illite 15 % and kaolinite 5 % (Richter et al., 1990). By ameliorative K fertilization soybean yields were increased drastically (3-y means: 1286 and 2607 kg/ha, for the control and the highest rate of K) and they were in close connection with improvement of leaf K and Mg status (Table 6 and Fig. 1).

Fig. 1. Soybean status (middle of July 1989) on the control (left) and the highest rate of K (2670 kg K_2O/ha in spring 1987) application (right) – the data in Table 6 (photo V. Kovacevic)

In Ontario, Canada, studies looked at the response of soybeans to potassium fertilizer as related to K leaf tissue levels (Reid and Bohner, 2007). The data collected during that study formed the basis for updated critical and normal values for potassium in soybeans. Below a leaf K concentration of 2.0% (on dry matter basis), most of the plots showed a response to added K fertilizer. Above this level, most of the plots were unresponsive. Based on the results of these experiments and other similar studies, the critical concentration for K in soybean tissue was established at 2.0% and the maximum normal concentration from 2.5 to 3.0%. According this criterion, in our investigations under strong K-fixing conditions (Table 5) only by application of enormous K rates leaf-K concentrations were increased to normal level. However, in spite of considerable improvement of soil and plant K status, yields of high-yielding soybean cultivar were less than 3.0 t/ha (Table 5).
Long-term studies conducted on integrated nutrient management in soybean-wheat system (Singh & Swarup, 2000) revealed that continuous use of FYM along with recommended NPK for 27 crop cycle not only restricted K mining by reducing non-exchangeable K contribution to grain formation but also enchanced K uptake to the system (Table 7).

Fertilizer K added in 27 crop rotation, total K uptake, available and non-exchangeable K status in soil (maize crop was discontinued in the system since 1995)						
Treatment	Potassium (kg K /ha)				Contribution of non-echangeable K	
	K added in 27 cycles	Available K status		Total K uptake		
		Before 1971	After 1999		kg K/ha	%
a) Control	0	370	252	3247	3129	96.4
b) 100 % N	0	370	263	4418	4311	97.6
c) 100 % NP	0	370	235	10067	9932	98.7
d) 100 % NPK	2117	370	308	11826	9647	81.6
e) d + 5 t FYM/ha	4142	370	324	14094	9906	70.3

Table 7. Removal and addition of K during 27 crops cycle of soybean-wheat-maize (fodder) cropping system (Singh and Swarup, 2000)

Morshed et al. (2009) applied six treatment of potassium (unfertilized, 50%, 70%, 100 % , 125% and 150% of recommend rate based on soil test) on equal N, P and S fertilization in Dhaka (Bangladesh) during Rabi season 2004-2005. By application of the highest K rate grain yield of soybean was increased for 83%. Slaton et al., (2009) found close connection of soybean response to K fertilization (five rates from 0 to 148 kg K/ha) and Mehlich-3-extractable soil K in eastern Arkansas. Experiments were established on silt loams at 34 site-years planted with a Maturity Group IV or V cultivar. Mehlich-3-extractable soil K ranged from 46 to 167 mg K/kg and produced relative soybean yields of 59 to 100% when no K was applied. Eleven sites had Mehlich-3-extractable K < 91 mg K/kg and all responded positively to K fertilization. Soybean grown in soil having 91 to 130 mg K/ g responded positively at nine of 15 sites. Mehlich-3 soil K explained 76 to 79% of the variability in relative yields and had critical concentrations of 108 to 114 mg K/kg, depending on the model. Based on these investigations, Mehlich-3-extractable K is an excellent predictor of soil K availability for soybean grown on silt loams in eastern Arkansas.

Gill et al. (2008) reported that imbalance and inadequate nutrient supply particularly devoid of K is main reason for low productivity and quality of soybean in India.

Yin and Vyn (2004) conducted field experiments at three locations in Ontario, Canada from 1998 through 2000 to estimate the critical leaf K concentrations for conservation-till soybean on K-stratified soils with low to very high soil-test K levels and a 5- to 7-yr history of no-till management. For maximum seed yield, the critical leaf K concentration at the initial flowering stage (R1) of development was 2.43 %. This concentration is greater than the traditional critical leaf K values for soybean that are being used in Ontario and in many U.S. Corn Belt states.

Nelson et al. (2005) compared response of soybean to foliar-applied K fertilizer and preplant application. Potassium fertilizer (K_2SO_4) was either broadcast-applied at 140, 280, and 560 kg K/ha as a preplant application or foliar-applied at 9, 18, and 36 kg K/ha at the V4, R1-R2, and R3-R4 stages of soybean development. Soybean grain yield increased 727 to 834 kg/ha when K was foliar-applied at 36 kg/ha at the V4 and R1-R2 stage of development in 2001 and 2002. Foliar-applied K at the R3-R4 stage of development increased grain yield but not as much as V4 or R1-R2 application timings. Foliar K did not substitute for preplant K in this research. However, foliar K may be a supplemental option when climatic and soil conditions reduce nutrient uptake from the soil.

Numerous studies investigated fertilization effects on soybean grain yield, but few focused on oil and protein concentrations. Haq & Mallarino (2005) determined fertilization effects on soybean grain oil and protein concentrations in 112 field trials conducted in Iowa from 1994 to 2001. Forty-two trials evaluated foliar fertilization (N-P-K mixtures with or without S, B, Fe, and Zn) at V5-V8 growth stages. Seventy trials evaluated preplant broadcast and banded P or K fertilization (35 P trials and 35 K trials). Replicated, complete block designs were used. Foliar and soil P or K fertilization increased ($P < 0.05$) yield in 20 trials. Foliar fertilization increased oil concentration in one trial and protein in one trial but decreased protein in two trials. Phosphorus fertilization increased oil concentration in two trials and protein in five trials but decreased oil in five trials and protein in two trials. Potassium fertilization increased oil in four trials and protein in two trials but decreased oil in two trials and protein in two trials. Total oil and protein production responses to fertilization tended to follow yield responses. Fertilization increased oil production in 20 trials and protein production in 13 trials. Fertilization that increases soybean yield has infrequent, inconsistent, and small effects on oil and protein concentrations but often increases total oil and protein production.

Potassium is known to play an important role in protecting the plants against drought stress. Quantity and distribution of rainfall in the major soybean regions in India is responsible for yield fluctuations about plus/minus 20% among years in comparison with national average yield of 1 t/ha. For example, K fertilization in level of 112 kg K_2O/ha resulted by soybean yield increases for 0. 2 t/ha in normal year (1980) and for 1.2 t/ha under drought stress conditions (1981). Profit from K fertilization was 44 and 259 USD/ha, for 1980 and 1981, respectively (Johnson, 1984). For this reason, K fertilization can help in curtailing the yield loss on account of drought.

There are several materials available to supply K to the soil and potassium chloride is the most economical form. However, certified organic soybean production is limited to the use of potassium sulfate or manures to supply K.

5. Secondary nutrients

Calcium, magnesium and sulfur comprise the secondary nutrient group. Documented deficiencies of these three elements are few (Council for Agricultural Science and Technology, 2009).

5.1 Calcium

Plant species differ greatly in their Ca needs. Total Ca contents in plants are mainly in range from 0.5 to 1.0% in dry matter. The Ca uptake of plants influenced by Ca status and pH value of the soil and by the concentrations of other cations, especially K and Mg. Lack of Ca in legumes prevents the development of the nodule bacteria, thus affecting N fixation. Ca containing materials are using in correction of soil pH from acid to close to neutral. Soil pH between 5.5 and 7.0 is optimal for symbiotic N fixation in soybean root nodules by *Bradyrhizobium japonicum* bacteria. Under these soil pH availability of nutrients such as N and P and microbial breakdown of crop residues are favorable. Calcium deficiency is unlikely if soil pH is maintained above 5.5 (Council for Agricultural Science and Technology, 2009).

5.2 Magnesium

The total Mg content in plants is generally between 0.1 and 0.5 % in dry matter. Mg is the central atom of chlorophyll and it is vital for photosynthesis, biological production and conversion of matter in the plant metabolism. Mg deficiency occurs on strongly leached diluvial sandy acid soils with a low cation exchange capacity. Mg deficiency can be induced not only by low Mg status but also by high concentrations of other cations, for example H^+, K^+, NH_4^+, Ca^+ and Mn_2^+(Bergmann, 1992). In Croatia were found nutritional problems of K uptake by soybean and maize induced by oversupplies of Mg and strong K-fixing (Kovacevic and Vukadinovic, 1992). Vrataric et al. (2006) reported increases of soybean yield for 5 %, contents of grain protein for 0.7% and oil for 0.7% due to foliar application of 0.5 % $MgSO_4$ (Epsom salt) solution on eutric cambisol. Importance of Mg in yield increases of field crops in Europe reviewed by Uebel (1999).

Vrataric et al. (2006) tested response of six soybean cultivars (*Kuna, Una, Nada, Ika, Lika and Tisa*) to foliar fertilization (FF) with Epsom salt ($MgSO_4.7H_2O$; 5% w/v solution in amount 400 L/ha) on Osijek eutric cambisol. The fertilization was applied on standard fertilization either once or two times (treatment designations FF 1x and FF 2x, respectively), while untreated plots were as a control (standard fertilization). The first FF was made in the soybean stage V2-V3 and the second FF ten days later before the R1 stage of soybean. The amounts of added nutrients were as follows (kg/ha): 3.2 MgO and 2.3 kg S, as well as 6.4 MgO and 4.6 kg S, for the treatment FF 1x, and FF 2x, respectively. In the growing season 1999 was by 22% higher compared to 1998. Yield of *Ika* cultivar was by 23% higher compared to *Una*. FF resulted by moderate yield increases up to 5% compared to the control. Differences of yield between FF 1x and FF 2x were non-significant. Oil contents were higher in the 1998 and 2000 (mean 21.27%) compared to 1999 and 2001 (mean 20.55%), while differences among cultivars (from 20.77% to 20.96%) were non-significant. In general, FF resulted by moderate but significant oil content increases (20.45%, 21.15% and 21.12%, for the treatment 0, FF 1x and FF 2x, respectively). Protein contents were significantly different among years from 38.53% (2000) to 39.38% (2001) and among the cultivars from 38.30%

(Lika) to 39.48% (Nada). ESFF resulted by significant increases of protein contents (38.62%, 39.11 and 39.21% for 0, FF 1x and FF 2x, respectively). Impacts of the fertilization on soybean yields were shown in the Table 8.

Cul-tivar (B)	Foliar fertilization (factor A) with Epsom salt (F1x in V2-V3 and F2x = F1x + ten days later) effects on grain properties (four year means: 1998-2001) of soybean cultivars (factor B)											
	Yield (t/ha)			X	**Oil content** (%)			X	**Protein cont.** (%)			X
	0	F1x	F2x	B	0	F1x	F2x	B	0	F1x	F2x	B
Kuna	3.70	3.98	3.99	*3.89*	20.5	21.2	21.1	*20.9*	38.0	38.7	38.9	*38.5*
Una	3.52	3.64	3.66	*3.61*	20.4	21.3	21.3	*20.9*	39.1	39.3	39.4	*39.2*
Nada	3.77	4.01	4.04	*3.94*	20.4	21.2	21.2	*21.0*	39.1	39.6	39.7	*39.5*
Ika	4.44	4.45	4.45	*4.45*	20.3	21.0	21.0	*20.8*	38.4	39.1	39.2	*38.9*
Lika	3.55	3.97	3.65	*3.63*	20.7	21.0	21.0	*20.9*	38.0	38.5	38.5	*38.3*
Tisa	3.89	4.05	4.11	*4.02*	20.4	21.2	21.2	*20.9*	39.2	39.6	39.6	*39.5*
X (A)	*3.81*	*3.97*	*3.98*		*20.5*	*21.2*	*21.1*		*38.6*	*39.1*	*39.2*	
LSD 5%	A: 0.13	B: 0.10	AB: 0.19		A: 0.36	B: ns	AB: 0.46		A: 027	B: 0.31	AB: 0.46	
LSD 1%	0.35	0.13	0.31		0.84		0.66		0.50	0.48	0.66	

Table 8. Impacts of foliar fertilization with Epsom salt ($MgSO_4.7H_2O$; 5% w/v solution in amount 400 L/ha) on soybean properties - four year means (Vrataric et al., 2006)

5.3 Sulphur

Soils of humid and semi humid areas mainly contain total sulphur (S) in range from 100 to 1000 mg/kg, a range that is similar to that of total P. It is divided in inorganic and organic forms but in most soils organically bund S provides the major S reservoir. S in organic matter can be divided into two fractions, carbon bonded S and non carbon bonded S. The inorganic form of S in oil consists mainly of sulphate. In arid regions soils may accumulate high amounts of salts such as $CaSO_4$, $MgSO_4$ and $NaSO_4$. Sulphate like phosphate is adsorbed to sesquioxides and clay minerals, although the binding strength for sulphate is not a strong as that for phosphate. Under waterlogged conditions, inorganic S occurs in reduced forms such as FeS, FeS_2 and H_2S. Oxidation of S results int he formation of H_2SO_4 and is promoting factor of additional soil acidification. Sulphate acid soils are mainly extremely low pH and very rich in exchangeable Al. Soil acidification by addition of elemental S is recommend for depressing the pH of alkaline soils (Mengel & Kirkbi, 2001).

Sulphur contents in plants are mainly in range from 0.1 to 0.5 % in dry matter. S uptake by plants is in sulphate form, but plants can absorb S also in gaseous form as SO_2. Sulphate must first be reduced by the plant to sulfide before it can be incorporated mainly into S-containing amino acids methionine and cistine. S deficiencies in plants are relatively rare because of the constant inputs of sulphate with NPK fertilizers and presence of SO_2 in precipitation (acid rain). Soybeans use a considerable amount of sulfur. S deficiency is mainly occurs during cool, wet weather on highly leacheable sandy soils that are low in organic matter and in little industrialization areas. In some cases are possible damages due to S excess caused by acid rain (Bergmann, 1992).

Sarker et al., (2002) tested effects of fertilization of soybean by S and B alone or in combination up to 50 kg S/ha and u to 4.0 kg B/ha. Yield, protein and oil contents of soybean grain where significant when S and B were applied individually but their interaction were not significant. The highest biological yield and most of the yield atributes were obtained for the treatment combination of 30 kg S/ha and 1.0 kg B/ha.

6. Micronutrients (Zn, Mn, Fe, Cu, B, Cl, Mo)

6.1 Zinc

Soybean, maize and flax are the most susceptible field crops to Zn deficiency. It is often found on sandy soils low in organic matter, on high soil pH and calcaric soils, as well as on soils rich in available P. Cold and wet weather promoting Zn deficiency. N improving, while Fe and especially P, decreasing Zn uptake by plants. The first symptom of Zn deficiency in soybean is usually light green color developing between the veins on the older leaves. New young leaves will be abnormally small. Bronzing of the older leaves may occur. When the deficiency is severe, leaves may develop necrotic spots. Shortened internodes will give plants a stunted, rosetted appearance (Dahnke et al., 1992).

Zinc is essential element in metabolism of protein, carbohydrate and lipids. Zinc is compound of some enzymes (carboanhydrase, glutamat and malat-hydrogenase, alcalic phosphatase, proteinase, peptidase, etc.). Zinc has influences on auxine synthesis, intensity of respiration and uptake of Cu, Mn and especially P. Also Zn contributing to increase resistance to viruses diseases, drought and low temperature stress. Soil and leaf testing use in diagnosis of Zn status in plants. Also, important is P/Zn ratio.

Incorporation of anorganic Zn in form of $ZnSO_4.7H_2O$ (2-22 kg Zn/ha) or organic Zn in chelate form (03-6.0 kg Zn/ha), as well as foliar fertilization (0.5% solution of zinc sulfate) could be use for corrections of Zn deficiencies.

Nutritional disorders were found in soybeans grown on Osijek calcareous eutrical cambisol. Growth retardation and chlorosis were accompanied with the alkaline or a neutral soil reaction. By the foliar diagnosis zinc deficiency was found. Zinc deficiency was promoted by the excess of phosphorus or iron/aluminum in plants while K deficiency was accompanied with the excess of magnesium uptake. For example, chlorotic soybean contained in means only 16 ppm Z in dry matter (into normal soybean 27 ppm Zn). At the same time, the P:Zn ratio was 239 (the normal levels are under 180), while Fe:Zn ratio was 34 (the normal levels are under 15). The analogous values for the normal soybeans were 150 and 7, respectively (Kovacevic et al., 1991). The higher soil pH and oversupplies of plant available P are factors promoting Zn deficiency in soybean (Table 9).

Soybean: The uppermost full-developed trifoliate leaf (June 6, 1990)								Soil (0-30 cm of depth); mg/100 g = AL-method			
Percent in dry matter				mg/kg in dry matter				pH		mg/100 g	
P	K	Ca	Mg	Zn	Mn	Fe	Al	H_2O	KCl	P_2O_5	K_2O
Chlorotic and growth-retarded soybean (means of three samples)											
0.39	2.36	2.51	0.88	16.3	124	547	301	7.47	6.60	62.6	45.3
Normal soybean (oasis at the same plot: means of five samples)											
0.37	2.52	1.93	0.68	26.8	86	195	147	6.70	5.90	42.5	54.5

Table 9. Plant and soil status (eutric cambisol of Agricultural Institute Osijek): symptoms of Zn deficiency in soybean (Kovacevic et al., 1991)

Response of soybean to fertilization: pods/plant (P/P), grain/pod (G/P), 100-grain weight and grain yield															
Treatments 1-6 (kg/ha)				P/P	G/P	100gw	Yield	Treatments 7-12 (kg/ha)				P/P	G/P	100gw	Yield
N	P_2O_5	K_2O	Zn			g	t/ha	N	P_2O_5	K_2O	Zn			g	t/ha
0	0	0	0	31.6	1.96	11.5	1.46	60	80	30	0	51.4	2.03	14.1	1.89
30	0	0	0	34.7	1.98	11.6	1.64	90	40	30	0	51.9	2.12	14.4	1.90
30	40	0	0	45.1	1.99	12.6	1.74	90	60	30	0	65.9	2.14	16.6	2.23
30	40	30	0	43.7	1.99	12.6	1.79	90	80	30	0	47.2	2.07	13.5	1.77
60	40	30	0	45.1	2.01	12.7	1.76	90	80	60	0	45.0	1.84	12.3	1.71
60	60	30	0	44.5	2.05	12.9	1.82	90	80	60	25	68.9	2.14	16.1	2.48
LSD (1-12) 5 %				8.51	ns	2.29	0.34	LSD (1-12) 5 %				8.51	ns	2.29	0.34

Table 10. Effect of N, P; K and Zn application on yield attributes and grain yield of soybean (Singh et al., 2001)

Rose et al. (1981) were studied response of four soybean varieties (*Lee*, *Forrest*, *Bragg* and *Dodds*) to foliar zinc fertilization ($ZnSO_4.7H_2O$ before flowering) at three sites in central and north-west New South Wales. At Narrabri one spray of 4 kg/ha gave a yield increase of 13 %. At Trangie and Breeza, two spray each of 4 kg/ha increased yield by 57 % and 208 %, respectively. Lee was the least responsive variety at each site and Dodds and Forrest the most responsive to applied zinc. Zinc fertilizer increased plant height, leaf-Zn, oil contents (at two sites) but decreased leaf-P. Leaf-P in untreated plots was indicative of varietal sensitivity to zinc deficiency both within and between sites.
Singh et al., (2001) tested twelve nutrient combinations comprising of three levels each of nitrogen (30, 60 and 90 kg N/ha), phosphorus (40, 60 and 80 kg P_2O_5/ha) two levels of potassium (30 and 60 kg K_2O/ha) and a single level of zinc (25 kg Zn/ha) along with control. Zinc fertilization in combination with N, P and K significantly increased the growth attributes and grain yield of soybean, The highest number of pods per plant and grain yield were obtained with the joint application of N, P, K and Zn at the rates of 90, 80, 60, and 25 kg/ha, respectively (Table 10).

6.2 Iron

Leguminose plants have higher needs for Fe in comparison to cereals. Fe participating in numerous metabolic processes including protein synthesis. Under F deficiency conditions were found high levels of low-molecular N substances, especially amino acid arginine. Soybean is susceptible to Fe deficiency. Fe deficiency is a common yield limiting factor for soybean grown on high-pH, calcareous soils, as well as on some seasonally poorly drained soils. Cool and wet periods are promoting Fe deficiency. Iron may be unavailable for root absorption, not transported after absorption, or may not be utilized by the plant.
In Iowa and Minnesota, over ten million dollars in potential soybean production were lost annually due to iron chlorosis (Fleming et al., 1984). With the potential increase in alkalinity of Texas soils due to irrigation, reduced soybean production may become a problem. The problem could result from decreased yield per acre or from acreage with decreased productivity due to increased alkalinity. Iron deficiency is not easy or inexpensive to correct in the field. According to Gray et al. (1982) it would take five tons of sulfuric acid per acre to neutralize one per cent calcium carbonate in a 16.5 cm layer of soil.

Fe deficiency results in a characteristic interveinal chlorosis in new leaves and can cause substantial yield loss in soybean. In some years, developed during early growth stages and disappears as the plants mature. In more severe cases, chlorosis can persist throughout the entire season. There is wide variation in susceptibility to Fe deficiencies among soybean varieties.

Soybean in chlorotic areas had lower leaf chlorophyll concentrations, stunted growth, and poor nodule development relative to nonchlorotic plants. Also, compared to nonchlorotic areas, soil in chlorotic areas had greater soil moisture contents and concentrations of soluble salts and carbonates (Hansen et al., 2003).

Correcting Fe chlorosis often requires a combination of management practices including variety selection, application of Fe fertilizers with the seed (for example iron chelate Fe-EDDHA) or foliar treatment with 1 % solution of ferrous sulfate.

Franzen and Richardson (2000) tested soil factors affecting iron chlorosis of soybean. Total 12 sites of Red River valley of North Dakota and Minnesota were studied in the 1996-1998 period. Calcium carbonate equivalence and soluble salts were most often correlated with chlorosis symptoms.

Plant response to iron chlorosis varies between cultivars and environmental conditions (Coulombe et al., 1984; Gray et al., 1982). The reduction of iron at the root surface from Fe to Fe is an adaptive mechanism which iron efficient plants use to overcome iron deficiency. Soybean cultivars like Hawkeye have been shown to be rather effective in facilitating iron uptake by this method (Brown & Jones, 1976). Iron uptake is (1) as iron in association with chelate molecules and (2) as ionic iron after chelate splitting. Iron efficient plants have a much increased rate of iron uptake after chelate splitting during iron deficiency chlorosis (IDC)-induced stress; iron inefficient plants do not (Romheld & Marschner, 1981). Iron efficient and iron inefficient plants reportedly are distinguishable in terms of extent of iron uptake as a function of phosphorus content in the soil. Chaney & Coulombe (1982) reported that increased phosphorus inhibited the increase in iron uptake of inefficient types and slightly reduced iron uptake of efficient types.

Goos & Johnson (2003) found considerable differences of resistance of soybean varieties to iron clorosis. (Table 11) Growing of more tolerant varieties is solution for alleviation of nutritional problems induced by iron deficiency.

Soybean varieties characterizing low chlorosis score (CS <2.3)			Soybean varieties characterizing high score (CS >3.2)		
Variety	Originator	CS	Variety	Originator	CS
Trail	N.D. AES	1.7	IA 2042	Iowa AES	3.7
Danatto	N.D. AES	2.0	IA 2041	Iowa AES	3.7
MN 0201	Minn. AES	2.0	MN 1103SP	Minn. AES	3.7
92 M10	Pioneer	2.0	MN 101SP	Minn. AES	3.7
IA 1005	Iowa AES	2.0	Minnatto	Minn. AES	3.5
Jim	N.D. AES	2.2	IA 2050	Iowa AES	3.3
MN 0203 SP	Minn. AES	2.2	IA 2033	Iowa AES	3.3
Mn 0302	Minn. AES	2.2	MN 2101SP	Minn. AES	3.3
Nornatto	N.D. AES	2.2	IA 2050	Iowa AES	3.3
MK 0649	Richland Organics	2.2	Parker	Minn. AES	3.3
CV = 31.7; LSD 5% = 1.0					

Table 11. Chlorosis scores of soybean varieties in Minnesota 2003 (Goos & Johnson, 2003): score 1.0 = no chlorosis, 5 = most severe chlorosis (choice 20 extremely of 104 tested genotypes)

Silman and Motto (1990) tested under greenhouse conditions in nutrient solutions influences zinc on the growth and composition of an Fe-efficient (*Hawkeye*) and Fe-inefficient (*PI-54619-5-1*) soybean genotypes in various levels of Fe. In general, increased Zn levels resulted in growth reduction in both genotypes with the Fe-inefficeint plants being more sensitive to Zn level. The Fe-efficient genotype had a higher Fe content than the Fe-inefficient at corresponding treatment levels.

6.3 Manganese

Plants vary considerably in their Mn requirements and levels only 20 ppm often being sufficient for normal plant growth. Levels of Mn in plants vary between species and soil properties more than those of other nutrients. Plants generally absorb Mn from the soil as Mn_2^+. Mn is important in plant metabolism because of its redox properties and thus its ability to control oxidation, reduction and carboxilation reactions in the carbohydrate and protein metabolism.

Mn deficiency causes soybean plants to be stunted. The leaves are yellow to whitish but with green veins. Mn deficiency is most pronounced in cool weather on alkalic and slow alkalic soils rich in organic matter. Soil pH is the most important factor affecting Mn availability because it is extremely soluble at low pH and insoluble at high pH levels.

Foliar fertilization of young and moderately young crops with 8-15 kg $MnSO_4$/ha as 1-2 % solution (2-3 applications) is recommendation for prevention of Mn deficiency on soils with a high pH value.

Manganese deficiencies in oats and soybeans were reported by Willis (1928), primarily in spots in the coastal plain of North Carolina. This problem was associated with very high soil pH, and thus this observation was likely the first evidence of "overliming." The soils in the coastal plain are inherently low in manganese, especially the more poorly drained ones, since manganese can be reduced and leached in the soil-forming process (Cox, 1965). Interveinal chlorosis is a clear symptom of manganese deficiency. Cox (1968) used both extractable manganese by the Mehlich-1 extract and soil pH and developed a yield response prediction and manganese soil test interpretation for soybeans. Extractable concentrations at the critical level, which varied from 3 to 9 with Mehlich-1 depending on pH, were sufficient to be measured readily. Critical levels of manganese in soybean leaves at various growth stages and effective rates of fertilization for correcting manganese deficiency in soybeans reported by Mascagni & Cox (1985a, 1985b).

6.4 Copper

Copper (Cu) is seldom deficient in soil. Only on soils high in organic mater and under conditions pH above 6.0 would Cu likely be deficient. The color of legume and forage plants deficient in Cu tends to be grayish-green, blue-green or olive green. The internodes become shortened to produce a bushy type of plants (Sauchelli, 1969). Soybean has low requirements for Cu.

Williams (1930) noted that crops grown on muck soils in North Carolina often responded to copper application. This observation was researched in detail by Willis (1937), Willis & Piland (1936) and these researches centered on the aspect that copper may be a catalyst in oxidation-reduction processes in soils.

6.5 Boron

Total boron (B) contents in soils are into range of 20 to 200 mg/kg dry weight, most of which is unavailable for plants. The available, hot water soluble fraction in soils adequately supplied with B ranges from 0.5 to 2.0 mgB/L. Soluble B consists mainly of boric acid which under most soil pH conditions (ph 4-8) is undissociated. In soils of arid and semi arid regions, B may accumulate to toxic concentrations in the upper soil layer because lack of drainage and the reclamation of such soils requires about three times as much water as that of saline soils. Soil organic matter is closely associated with the accumulation and availability of B in soils (Mengel & Kirkby, 2001).

B deficiency leads to disturbance of growth and development of plants. B is known to influence carbohydrate metabolism, sugar transport, the nucleic acid and protein household, N metabolism, flower formation and pollen germination, water household, energetic processes of phosphorylation and dephosphorylation, etc. Conditions that favour B shortage are high pH (7.0-8.0), soils low in organic matter, drought, high concentrations of iron and aluminium hydroxide. Difference between adequate and toxic concentrations of B is very small. Soybean is very susceptible to B toxicity. Alfalfa and sugar beet have high requirements in B. Broadcasting and incorporation of 0.5 to 1.0 kg B/ha (for example, the most commonly used borax) is satisfied for needs of crops in rotation for a few years (Berrgmann, 1992; Mengel & Kirkby, 2001).

6.6 Chlorine

Chlorine (Cl) is in group of elements which can have a beneficial effects on plant growth. Plant tissues usually contain substantial amount of Cl often in range of 2 to 20 mg/kg dry weight. Soils considered low in Cl are below 2 mg water soluble Cl/kg soil which is rare. The effects of excess Cl in plants are more serious problem. Crops growing on salt affected soils often show symptoms of Cl toxicity. These include burning of leaf tips too margins, bronzing, premature yellowing and abscission of leaves. Plant species differ in their sensitivity to Cl. Some leguminous species are very prone to Cl toxicity and using of sulfate instead of chlorine fertilizers is recommend (Mengel and Kirkby, 2001).

6.7 Molybdenum

Molybdenum (Mo) is an essential plant nutrient. The concentrations of Mo may vary from less than 0.1 to more than 300 ppm. Roots contain a greater proportion of Mg than aboveground part or seed. Molybdenum is needed by the soybean and other leguminose plant itself and also by the nitrogen-fixing *Rhizobia* bacteria in the soil. In contrast to other micronutrients, Mo availability increases with soil pH. Seldom is there Mo deficiencies with soil pH above 6.0. Since the element is critical for nitrogen fixation, the pale green or yellow plants are identical to a nitrogen deficiency. In this case, leaves generally begin to yellow first on the lower leaves. Needless to say, symptoms usually do not occur on soils high enough in nitrogen to make up for lack of nodule fixation (Holshouser, 1997). Efficiency of symbiotic N_2 fixation can be limited by micronutrient deficiencies, especially of molybdenum. Soybean generally responds positively to fertilization with Mo in soils of low fertility and in fertile soils depleted of Mo due to long-term cropping.

Sodium or ammonium molybdate are mainly used for correction of Mo deficiency either as a solid to the soil or by spraying on the foliage or by treating the seed. The first step, however, is always to establish the proper soil pH. The micronutrient can be supplied by seed treatment, however toxicity of Mo sources to *Bradyrhizobium* strains applied to seed as inoculant has been observed, resulting in bacterial death and reductions in nodulation, N2 fixation and grain yield. Therefore, use of seeds enriched in Mo could be a viable alternative to exterior seed treatment. Campo et al., (2009) demonstrated the feasibility of producing

Mo-rich seeds of several soybean cultivars, by means of two foliar sprays of 400 g Mo/ha each, between the R3 and R5 stages, with a minimum interval of 10 days between sprays (Table 12). In most cases, Mo-rich soybean seeds did not require any further application of Mo-fertilizer (Campo et al., 2009).

Soybean variety	Foliar fertilization by Mo (R3 = beginning of pod formation; R5 = beginning of pod filling; 2x = two spraying at R3+R5 with ½ dose)										
	0	400 g Mo/ha			800 g Mo/ha			1600 g Mo/ha			CV
		R3	R5	2x	*R3*	*R5*	2x	R3	R5	2x	%
	Mean contents of molybdenum in seed of soybean (ug/g)										
Embrapa 48	3g	23e	17f	31d	36c	25e	43b	39c	39c	61a	8.8
BRS 133	4f	22e	18e	35c	33d	26d	50b	50b	39c	82a	18.7
BRS 156	4f	19e	20e	35d	33d	35d	56b	52b	43c	81a	13.2

Table 12. Impacts of foliar fertilization on Mo contents in soybean grain (Campo et al., 2009)

7. Harmful elements (Cd, Cr, Hg and Pb) and heavy metal toxicities

Heavy metals are the intrinsic component of the environment. It is usually accumulated due to unplanned municipal waste disposal, mining and use of extensive pesticides. Other agro-chemicals uses as chemical fertilizer are the significant cause of elevation in environment.

Shute et al. (2006) reported results of greenhouse study regarding Cd and Zn accumulation in soybean. The highest dose of Cd (100 mg/kg) reduced plant height and dry weight (down to 40 % and 34 % of control, respectively), while the analogical data for the highest dose of Zn (2000 mg/kg) were 55 % and 70 %, respectively. With both metals present, the plants were approximately the same size as those treated with cadmium only. When both metals were added to the soil, 80-100 % of the cadmium and 46-60 % of the zinc were bioavailable. Concentrations of both metals were highest in root tissue (10-fold higher for Cd and up to 2-fold higher for Zn). Although relatively little Cd was translocated to pods and seeds, the seeds of all plants (including those from control and zinc-treated plants) had concentrations of cadmium 3-4 times above the limit of 0.2 mg/kg set by the Codex Alimentary Commission. This was surprising given that Cd in the soil was only 1 mg /kg well below the maximum allowable amount for agricultural soil.

The heavy metal content of municipal and industrial sewage sludge and swine manure lagoon sludge are quite high in Cu and Zn and cause a buildup of the elements in the soil and for this reason have potential toxicity to the environment. (King, 1986; King & Hajjar 1990). Physiological effects of zinc toxicity in soybean elaborated Fontes (1992) and Fontes & Cox, 1995, 1998). Borkert & Cox (1999) evaluated the effects of high concentrations of both Zn and Cu on soybean status. Miner (1997) looked at soil factors affecting plant concentrations of these elements in sludge-amended soils. When concentrations of heavy metals are high, knowledge of their solubility becomes important.

As soybeans are one of the principle sources of dietary intake in the Japanese population, the Codex Committee on Food Additives and Contaminants has proposed an upper limit of 0.2 mg/kg for cadmium concentration in soybean grain with aim of protection dietary uptake of harmful quantities of Cd (Arao et al., 2003).

Arao et al. (2003) tested Cd uptake and distribution of Cd in 17 soybean varieties grown in pots (three soils: Mid-Cd Soil, High-Cd Soil, Low-Cd Soil) and under field conditions in unpolluted soil (low-Cd field). The sources of cadmium pollution were thought to be mine waste in the case of the Mid-Cd Soil, and refining plant waste in the High-Cd Soil. The seed cadmium concentration was lowest for the *En-b0-1-2* soybean variety, and highest for *Harosoy*. The seed cadmium levels of *Tohoku 128*, a cross between *Enrei* and *Suzuyutaka*, were intermediate between those of the parents (Table 13). For four soil types, containing from 0.2 to 6.5 mg kg^{-1} extractable cadmium, the ranking of soybean genotypes based on seed cadmium level was similar, indicating that there is a genetic factor involved in the varietal differences in cadmium concentration. The lower levels of cadmium found in the seeds of certain varieties of soybean could be result from the combination of lower initial uptake and retention of higher levels of cadmium in the roots, thus limiting its translocation to the shoot.

Different actions can be undertaken in order to reduce the absorption of Cd by plants. The addition of amendments such as calcium carbonate, zeolite, and manganese oxide can reduce Cd uptake in plants. With that regard, zeolite was more effective in suppressing Cd uptake by plants than calcium carbonate or manganese oxide (Chen et al., 2000; Putwattanaa et al., 2010). Also, organic amendment such as farmyard manure and compost which contains a high proportion of humified organic matter can decrease the bioavailability of Cd and other heavy metals in soil (Li et al. 2006, Pichtel & Bradway, 2008; Tordoff et al., 2000). Shamsi et al. (2010) tested effects of potassium supplementation on alleviation of Cd toxicity in hydroponics experiment. K supplementation at a rate of 380 mg/l in combination either with Cd addition (1 ug Cd) or without Cd. K supplementation alleviated the reduction of growth, photosynthesis and nutrient uptake in Cd-treated soybean plants. It was concluded that Cd toxicity could be alleviated through enhanced K nutrition in soybean.

Soybean cultivars show significant differences in seed cadmium concentrations, primarily because of genetic rather than environmental factors. One-six of the total soybean produced in Japan exceeded 0.2 mg Cd/kg, the international standard proposed by the Codex Alimentarius Commission. Further, the soybean crops had considerably higher Cd contents than other field crops MAFFJ (2002). Sugiyama & Noriharu (2009) investigated the seed Cd concentrations in four soybean cultivars (*Suzuyutaka*, *Hatayutaka*, *Enrei* and *Kantou 100*) in pot experiment on Cd-polluted soil. In *Suzuyutaka*, which had high Cd concentrations in the seeds, the concentrations of Cd distributed from the shoots to the leaves was 67% and that distributed from the shoots to the seeds was 13%. In *Kantou 100* which had low Cd concentrations into seeds, 57% Cd was distributed from the shoots to the leaves and 21% from the shoots to the seeds. These results suggest that cultivars that have a low capacity for Cd accumulation in the roots have a mechanism that prevents Cd accumulation into seeds by promoting its accumulation in the leaves (Sugiyama & Noriharu, 2009).

Chromium (Cr) is a nonessential and toxic element to plants. Chromium interferes with several metabolic processes, causing toxicity to plants as exhibited by reduced seed germination or early seedling development (Sharma et al., 1995), root growth and biomass, chlorosis, photosynthetic impairing and finally, plant death (Scoccianti et al., 2006). Normal range of Cr is from 10 to 50 mg/kg depending on the parental material (Pandey & Pandey, 2008). Researchers have demonstrated experiments with plants associated with high levels of Cr. Thus, 1-5 ppm Cr present in the available form in the soil solution, either as Cr (III) of Cr (VI), is the critical level for a number of plant species. Increased Cr (VI) concentration of 10-800 mg/l in culture medium led to the detection of inhibited growth parameters. There was a reduction in growth, dry weight and vigour index in four soybean genotypes of soybean at 5 -200 mgl-1 concentrations of chromium, according to control application (Ganesh et al., 2009).

Testing of 17 soybean cultivars				High-Cd soil (66 days after sowing)		
Soybean Cultivar (1-17)	Pot experiment		Field	Soybean cultivar	Cadmium	
	High-Cd soil	Mid-Cd soil	Low -Cd		ppm	ug/plant
	Seed Cd (ppm in dry matter)			Leaves		
En-b0-1-2	1.43 a	0.46a	0.08 a	En-b0-1-2	5.5a	67.6a
Tamahomare	2.52 abc	0.70abc	0.10 ab	Tohoku 128	12.2b	152.8b
En-b0-01	1.96 abc	0.82bcd	0.10 ab	Suzuyutaka	12.9b	86.9a
Goyoukuromame	1.99 abc	1.16ef	0.10 ab	LSD 5%	1.6	27.1
Hayagin	2.22 abc	0.91cde	0.11 ab	Stem		
Enrei	2.09 abc	0.89cde	0.11 ab	En-b0-1-2	4.3a	48.0a
En-b2-110	2.06 abc	0.91cde	0.11 ab	Tohoku 128	10.3b	130.1b
Dewamusume	5.24 d	1.05def	0.12 b	Suzuyutaka	20.3c	120.1b
Tachiyutaka	3.29 c	1.47g	0.12 b	LSD 5%	5.1	51.2
En-N0-2	4.94 d	1.91h	0.13 b	Pod		
Tachinagaha	2.88 bc	1.17f	0.13 bc	En-b0-1-2	2.1a	8.4a
Nattousyouryuu	2.90 bc	0.59ab	0.13 bc	Tohoku 128	5.5ab	8.3a
Getenshirazu 1	1.72 ab	0.78bcd	0.13 bc	Suzuyutaka	13.7b	8.6a
EN 1282	5.33 d	2.21i	0.16 c	LSD 5%	9.4	5.9
Tohoku 128	2.83 bc	0.97cde	0.22 d	Total		
Suzuyutaka	7.46 e	1.50g	0.31 e	En-b0-1-2		124.0a
Harosoy	12.68 f	2.68j	0.40 f	Tohoku 128		291.3b
Average 1 - 17	3.61	1.14	0.15	Suzuyutaka		215.6a
LSD 5 %	1.35	0.28	0.03	LSD 5%		83.8

Table 13. Seed Cd concentrations of soybean varieties grown in pots (choice of High-Cd soil and Mid-Cd soil) and under field conditions (Arao et al., 2003)

Mercury (Hg) and his compounds are among the strongest phytotoxic substances and are also extremely dangerous to human and animals. It is a constituent of many crop protection agents. Non-contaminated soils contain only 0.003 to 0.03 mg Hg/kg. Hg levels of about 0.04 mg/kg in dry matter can be considered normal in plants. Maximum tolerance limit of 0.05 mg/kg in fresh matter is proposed for foodstuffs. Mercury uptake in plants is very slight because it is strongly sorbet in the soil, mainly by complexation with organic matter. Apart from growth inhibition, the symptoms of Hg toxicity include chlorosis, necrotic lesions and death. These are mainly results of severe root damage and the consequent inhibition of nutrient and water uptake. Since little Hg is translocated out of the root, there is a little danger of its entering to the food chain through the soil. The mobility of Hg and its uptake by plants can be greatly reduced by liming (Bergmann, 1992).

Lead (Pb) is major chemical pollutant of the environment, and is highly toxic for man. The major source of Pb pollution arises from petrol combustion. This source accounts for about 80% of the total Pb in the atmosphere. Pb is toxic because it mimics many aspects of the metabolic behavior of Ca and inhibits many enzyme systems. There is evidence that Pb pollution can induce brain damage in man and aggressive behavior in animals. Pb toxicity interferes with Fe metabolism and the formation of haem. The total Pb concentrations of agricultural soils lie between 2 to 200 mg/kg soil. Pb contamination very clearly follows the motorway areas. Vegetation at the side of the road may have levels of 50 mg/kg dry matter but in distance of only 150 m away from the motorway the level is normally about 2 to 3 mg/kg. Contamination occurs only on the outer part of plant seed or leaves and stem, and high proportion can be removed by washing (Mengel and Kirkby, 2001).

8. Genetic aspects of mineral nutrition of soybean

Plant varieties of the same species differ in absorption and utilization of nutrients from the environment. Varietal differences in the uptake of individual nutrients can be used as basis for the testing of both commercial varieties and selection materials under unfavorable soil conditions. An adequate distribution of soybean varieties based on their tolerance or susceptibility to less favorable conditions could contribute to better utilization of their yield potential (Saric, 1981; Saric & Loughman, 1983). According to Epstein (1976) agricultural intervention in the process of nature has two corresponding strategies: selection and genetic manipulation of the organism and modification of the environment. Many crops in Brazil have their yield improved thanks to the selection and breeding, especially in the large savanna (cerrado) region of Central Brazil. Soybean cultivation in the low-latitude acidic soils of Brazilian Savanach has become a reality since 1970's. Great contribution for this success has been achievements in soil science and plant breeding. There are however, constraints for sustainable production like high-Al and low-Ca in the deep layers of the soil. Measures can be taken to reduce the negative effects of acidity on plant growth are liming and selection of more tolerant genotypes.

Kastori (1978) found that Ca uptake was higher in *Corsoy* than in *Stella* and *Wilkin*. Later research showed that K uptake was the highest at the variety *Corsoy* (Kastori et al., 1979). Keoght et al., (1977) found lower N uptake in the varieties *Hill*, *Lee* and *Bragg* than in *Hood*. Queiroz et al. (1980) tested residual effects of P fertilizers on the yield of three soybean varieties over four years. The variety *Bossier* increased grain yield by 320 kg/ha, *Parana* by 640 kg/ha, whereas variety *Vicoja* did not show any response to P fertilization. Saric and Krstic (1982) tested ten soybean varieties 30 days in N-deficient nutrient solution. The variety *Yoslie Kataya 2* showed the lowest and the variety *Traverse* the highest N contents.

Kovacevic and Krizmanic (1987) tested 12 soybean genotypes of maturity group I (*Corsoy* and *Hodgson* as standard varieties and remaining ten are experimental lines from the F8 generation) under calcareous soil conditions. Grain yield of soybean genotypes ranged from 2.1 4 to 3.11 t/ha. The highest yield of *Vuka* and the lowest yield of *Os 155/82* on this soil may be due to the lowest Ca status by the former and the highest Ca status by the latter genotype (Table 14).

Spehar (1995a, b; 1999) studied genetic differences in the accumulation of nutrients in leaves and seeds of tropical soybean cultivars from diallel crosses with the cultivars *IAC-9, IAC-2, UFV-1, IAC-5, IAC-8, Vx5-281, IAC-7, Biloxi* and *Cristalina* under high and low Al-stress. The diallel analysis indicated that an additive-dominance model could explain the genetic differences among those genotypes for nutrient accumulation in leaves and seeds. The diallel analysis, although not conclusive, indicated that the mechanisms of mineral element accumulation in the leaves are not fully associated to those of accumulation in the seeds of soybeans. The expression of these characters is, however, dependent on mineral plant-stress.

Yield (t/ha) and leaf composition of 12 soybean genotypes (the uppermost full-developed trifoliate leaf at beginning of flowering) on calcareous soil (pH in KCl 7.35; $CaCO_3$ 7.93 %)											
Soybean genotype	t/ha	Leaf (% in dry matter)				Soybean genotype	t/ha	Leaf (% in dry matter)			
		N	**K**	**Ca**	**Mg**			**N**	**K**	**Ca**	**Mg**
Corsoy	3.10	5.20	2.05	0.91	0.55	***Os 8***	2.30	5.20	1.85	0.76	0.41
Hodgson	2.89	5.78	1.98	0.90	0.44	***Os 9***	3.00	4.82	2.18	0.85	0.36
Vuka	3.11	5.58	2.01	0.76	0.35	***Os 45***	2.41	5.07	1.99	0.82	0.35
Podunavka	2.74	5.73	2.06	0.98	0.51	***Os 89***	2.51	5.60	2.15	0.88	0.41
Sava	2.71	5.59	2.12	0.80	0.40	***Os155/82***	2.14	4.91	1.99	1.12	0.61
Os 5	2.82	5.48	2.15	0.95	0.39	***Os442/83***	2.45	5.46	2.24	0.86	0.50
LSD 5%	0.26	0.12	0.08	0.16	0.09	LSD 5%	0.26	0.12	0.08	0.16	0.09
LSD 1%	0.35	0.17	0.11	0.22	0.12	LSD 1%	0.35	0.17	0.11	0.22	0.12

Table 14. Yield and nutritional status of 12 soybean genotypes on Osijek calcareous soil (Kovacevic & Krizmanic, 1987)

Sudaric et al. (2008) reported about the effectiveness of biological nitrogen fixation in soybean linked to genotype for four growing season in eastern Croatia. Fields study involved eight cultivars in two treatments (control - without ionoculation and inoculation by *Bradyrhizobium japonicum*). The obtain results suggested on significant positive effect of rhizobial inoculation on both nitrogen fixation indicators and grain yield at all tested soybean cultivars (Table 15). Significant differences among tested cultivars in each measured trait indicate genetic diversity of tested material in both potential of biological nitrogen fixation and compatibility cultivar by *B. japonicum* strain, as well. Tested cultivars with the best potential for nitrogen fixation (OS-1-00, OS-3-0, OS-3-I) had the highest grain yield increasing (14.4%, 14.3% and 14.0%, respectively). These results indicate that the cultivars with the favorable performances of biological nitrogen fixation could be used as the parents for development new cultivars that are able to accomplish high grain yield with lower nitrogen level in soil.

Phosphorus is a major limiting factor for crop production of many tropical and subtropical soils. In Brazilian soils, high productivities of soybean are achieved by soil amendment techniques, using lime and fertilizers, supplying the nutrients required for best crop performance. The yield potential is an intrinsic factor and depends on plant germplasm characters that can be modified by selection and breeding (Furlani et al., 2002). Differences in grain yield among soybean cultivars under field conditions for P-, K- and N-efficiencies , were also reported by Raper and Barber (1970), De Mooy et al. (1973), Sabbe & Delong (1998), Sarawgi & Tripathi (1998), Hanumanthappa et al. (1998; 1999) and Ogburia et al. (1999).

Plant efficiency for phosphorus uptake and utilization may contribute to improve crop yield potential in situations of low P availability. Furlani et al., (2002) evaluated and classified twenty nine soybean cultivars in relation to the response to phosphorus (P) levels in nutrient solution. P uptake and use efficiency were estimated by the variables: shoot and root dry matter (DM) yield, P-concentrations and contents in plant parts and P-efficiency index (EI). The experiment was conducted in a greenhouse, during 1999, at Campinas, State of São Paulo, Brazil. The experimental design consisted of randomized complete blocks, arranged in split-plots, with three replications. The main plots were the P levels in the nutrient solution (64.5; 129; 258 and 516 mmol L^{-1}), and the subplots were the twenty-nine soybean cultivars, grouped according days to maturity. Multivariate analysis showed high correlation among the variables shoot-DM, total-DM and shoot P-concentration and P-efficiency index (EI). Cultivars were classified in efficient-responsive (ER)¾ *IAC-1, IAC-2, IAC-4, IAC-5, IAC-6, IAC-9*, *Sta. Rosa* and *UFV-1*; efficient-non-responsive (ENR) ¾ *IAC-7, IAC-11, IAC-15, S. Carlos* and *Cristalina*; inefficient-responsive (IR) ¾ *IAC-8, IAC-10, IAC-14, Bossier* and *Foscarin*; and inefficient-non-responsive (INR) ¾ *IAC-12, IAC-13, IAC-16, IAC-17, IAC-18, IAC-19, IAC-20, IAC-22, Paraná*, *IAS-5* and *BR-4*. The efficient-responsive soybean cultivars showed the highest values for shoot and total DM and EI, and the lowest shoot P-concentrations.

Soybean cultivar	Properties of uninoculated (**-** = control) and inoculated (**+**) soybeans							
	Nodule number/plant		Above-ground part of plant				Grain yield t/ha	
			Dry matter weight (g)		Nitrogen (% N)			
	-	**+**	**-**	**+**	**-**	**+**	**-**	**+**
OS-1-00	0	44.6	4.29	6.19	1.84	2.65	3.54	4.05
OS-2-00	0	37.8	3.41	4.91	1.69	2.44	3.39	3.85
OS-1-0	0	38.2	3.34	4.80	1.71	2.46	3.53	4.02
OS-2-0	0	35.8	3.21	4.62	1.67	2.40	3.36	3.81
OS-3-0	0	49.2	4.24	6.11	1.84	2.65	3.42	4.00
OS-1-I	0	31.9	2.64	3.80	1.46	2.11	3.57	4.03
OS-2-I	0	36.3	3.24	4.67	1.65	2.38	3.83	4.33
OS-3-I	0	40.2	4.17	6.00	1.82	2.62	3.71	4.23
LSD 5%	4.0		1.13		0.22		0.31	
LSD 1%	5.3		2.02		0.41		0.36	

Table 15. Mean values of nitrogen fixation indicators and grain yield of 8 soybean cultivars (2004-2007; Osijek, Croatia) (Sudaric et al., 2008)

Ojo et al. (2010) tested 55 soybean genotypes under acid soil conditions in area of Umudike, Nigeria for two growing seasons. Highly significant differences in genotypic effects were observed for all the traits (days to 50% flowering, plant height at maturity, number of pods/plant, 100-seed weight and grain yield). Eight acid tolerant varieties were found (*Conqvista, TGX 1896-3F, TGX 1897-17F, TGX 1866-7F, TGX 1805-31F, Milena, Doko* and *TGX 1844-18E*) with a higher grain yield of >1.80tons/ha compared to <1.45tons/ha in the previously recommended varieties (*TGX 1485- 1D* and *TGX 1440-1E*). The result also showed the potential of the EMBRAPA genotypes in upgrading the TGX varieties for higher productivity. The eight identified acid tolerant varieties could therefore be explored in the development of improved high yielding soybean genotypes for production on acid soils of Nigeria.

9. Agronomic management practice and nutritional status of soybean

9.1 Fertilization

In general, mainly fertilization of soybean with nitrogen, phosphorus and potassium are common agronomic practice. Additional using the other nutrients are more exception than rule. In some cases application of the higher P and K rates are needed for achieving of satisfied yields of soybean.

Phosphorus and potassium are limiting factor of field crops yield on some hydromorphic soils in Croatia (Kovacevic, 1993; Kovacevic et al., 2007; 2011; Rastija et al., 2006). By application of the ameliorative rates of NPK fertilizer up to 3748 kg/ha level soybean yields were increased up to 32 %. Protein contents in soybean grain were independent on the fertilization, while oil contents were increased up to 0.66% compared to the control (Rastija, et al., 2006). In the second experiment, P and K applied separately up to 1500 kg/ha either P_2O_5 or K_2O and in their combination (1000 + 1000 kg/ha). Yields of soybean were increased up to 21% (influences of P), 17% (influences of K) and 30% (PK influences). However, protein and oil contents in grain were independent on fertilization (Kovacevic et al., 2007).
Soybean is generally responsive to fertilization with inadequate nutrient supplies. For example, grain yields of soybeans were increased by 40% and 34% as affected by the K and P fertilization, respectively (Table 16). According to status of the uppermost full-developed trifoliate leaf (Jones, 1967, cit. Bergmann and Neubert, 1976; Bergman, 1992) the adequate P, and high Ca and Mg status as well as low K status was found in the soybean leaves when ordinary fertilization was applied (Table 16). However, nutritional status of soybean was considerably improved when affected by the ameliorative fertilization. Calcium uptake by soybean leaves was high and it was practically independent on the fertilization. Also, the K fertilization influenced the Mg status in soybean leaves: it was decreased in relative amount by about 30 % compared to ordinary fertilization. More favorable relationship between K and Mg was associated with K fertilization: 1.13 and 3.20 for ordinary fertilization and the highest rate of added K, respectively (Table 16).
Rastija et al. (2006) applied four rate of ameliorative PK-fertilization on acid soil. As affected by the fertilization grain yields of soybean were increased up to 32%. However, yield differences among three ameliorative treatments were non-significant. Protein contents in soybean grain were independent on the fertilization, while oil contents were increased up to 0.66% compared to the control (Table 17).

Fertilization (March 22, 1990) by P and K rates on equal (kg/ha: 90 N + 137 P_2O_5+ 132 K_2O) NPK fertilization and soybean propreties (the growing season 1990: the uppermost full-developed trifoliate leaf before anthesis)											
K_2O kg/ha	Yield t/ha	Leaf concentrations (% in dry matter)				P_2O_5 kg/ha	Yield t/ha	Leaf concentrations (% in dry matter)			
		P	K	Ca	Mg			P	K	Ca	Mg
132	2.13	0.32	1.17	1.80	1.04	195	2.86	0.33	1.24	1.86	1.05
433	2.69	0.32	1.49	1.82	0.92	325	2.71	0.35	1.39	1.89	1.04
735	2.98	0.32	1.65	1.77	0.83	585	2.57	0.38	1.52	1.94	0.98
1337	2.81	0.33	2.01	1.66	0.79	1105	2.52	0.49	1.80	1.92	0.91
2532	2.82	0.33	2.37	1.85	0.74	585	2.60	0.41	2.01	1.80	0.81
LSD 5% LSD 1%	0.49 0.66	0.01 0.02	0.13 0.17	0.19 0.26	0.08 0.11	LSD 5% LSD 1%	0.49 0.66	0.01 0.02	0.13 0.17	0.19 0.26	0.08 0.11

Table 16. Response of soybean to ameliorative P and K fertilization (Kovacevic, 1993)

Kovacevic et al. (2007) tested response of soybean to ameliorative P and K fertilization alone or in their combination. As affected by applied fertilization soybean yields were increased up to 21% (influences of P), 17% (influences of K) and 30% (PK influences). However, protein and oil contents in grain were indenpendent on fertilization (Table 18).

Fertilization (April 23, 2004)			Soybean properties (the 2005 growing season)				
	kg/ha		(t/ha)	Percent in dry matter			
Treatment	P_2O_5	K_2O	Grain	Grain		Leaves*	
			yield	Protein	Oil	P	K
Control	125	82	3.88	41.92	20.33	0.530	2.67
PK-1	375	248	4.87	40.89	20.80	0.537	2.71
PK-2	625	414	4.73	41.42	20.62	0.571	2.85
PK-3	875	582	4.98	40.64	20.99	0.487	2.73
PK-4	1125	746	5.14	41.94	20.73	0.501	2.69
LSD 5%			0.72	n.s.	n.s.	n.s.	n.s.
			* the uppermost full-developed threefoliate leaf before anthesis				

Table 17. Residual impact of PK-fertilization on soybean properties (Rastija et al., 2006)

Kovacevic et al. (2011) reported residual impacts of increasing rates of PK-fertilization up to 1000 kg P_2O_5/ha and 672 K_2O/ha in spring 2004 and liming by granulated fertdolomite (24.0 % CaO + 16.0 % MgO + 3.0 % N + 2.5 % P_2O_5 + 3.0 % K_2O) in autumn 2007 on soybean status in the growing season 2010. As affected by liming yields of soybean were increased for 18 % (means 3279 and 3854 kg/ha, for unlimed and limed plots, respectively). Also, grain quality parameters were improved by liming (thousand grain weight were 151.8 and 168.3 g; protein contents were 35.24 and 39.06 %, respectively), while oil contents were decreased (23.84 and 22.62 %, respectively). However, impact of P and K fertilization was considerably lower in comparison with liming (Table 19).

Fertilization (April 23, 2004)*				Soybean properties (the 2005 growing season)				
		kg/ha		kg/ha	Percent in dry matter			
Treatment		P_2O_5	K_2O	Grain	Grain		Leaves*	
				yield	Protein	Oil	P	K
a	Control	125	82	3600	41.27	20.74	0.537	2.81
b	P-1	625	82	3580	40.76	20.83	0.513	2.86
c	P-2	1125	82	3460	41.57	20.64	0.593	3.15
d	P-3	1625	82	4360	41.74	20.52	0.603	2.88
e	K-1	125	582	4010	41.13	21.20	0.520	2.87
f	K-2	125	1082	4200	40.21	21.10	0.547	2.95
g	K-3	125	1582	4080	40.59	21.10	0.573	3.29
h	P2K2	1125	1082	4670	40.28	21.14	0.593	3.05
			LSD 5%	370	n.s.	n.s.	0.055	0.30
			LSD 1%	510			n.s.	n.s.
* for next year: 80 N + 125 P_2O_5 + 82 K_2O				* the uppermost full-developed trifoliate leaf before anthesis				

Table 18. Residual influences of NPK-fertilization on soybean properties (Kovacevic et al., 2007)

Residual effects of fertilization and liming on soybean (cultivar *Lucija*) grain yield and grain quality in the 2010 growing season											
Factor B*: Fertilization (April 2004)			Factor A**: Lime(t/ha) (Oct. 2007)		Mean B	Factor A**: Lime t/ha) (Oct. 2007)		Mean B	Factor A**: Lime (t/ha) (Oct. 2007)		Mean B
	kg/ha		0	10		0	10		0	10	
	P_2O_5	K_2O	Grain yield (kg/ha)			Protein contents (%)			Oil contents (%)		
a	0	0	3141	3730	3422	36.12	37.68	37.68	23.70	22.49	23.10
b	250	168	3231	3837	3534	34.92	36.84	36.84	23.58	22.61	23.09
c	500	336	3285	4047	3666	35.73	37.59	37.59	23.58	22.29	22.94
d	750	504	3352	3826	3589	34.59	36.67	36.76	24.32	22.90	23.61
e	1000	672	3387	3860	3624	34.83	36.88	36.88	24.02	22.79	23.41
	Mean A		3279	3854		35.24	37.15		23.84	22.62	
	LSD 5% LSD 1%		A: 209 B: 156 AB: ns 482 ns			A: 0.63 B: ns AB: ns 1.46			A: 0.53 B: ns AB: ns 1.23		
* Ameliorative fertilization by NPK 10:30:20 (a-e) on ordinary fertilization; N added by NPK-fertilizer were equalized with CAN (calcium ammonium nitrate: 27% N); ** ferdolomite (24.0 % CaO + 16.0 % MgO + 3.0 % N + 2.5 % P_2O_5 + 3.0 % K_2O) 10 t/ha											

Table 19. Residual effects of PK-fertilization (April 2004) and liming (Oct. 2007) on soybean (Kovacevic et al., 2011)

Response of soybean to phosphorus and potassium fertilization on yield and at the uppermost trifoliate leaves status									
Impacts of P (triple superphosphate) fertilization					Impacts of K (KCl form) fertilization				
P rate	Soybean yield (kg/ha)		Leaf P (%) at R2 stage		K rate	Soybean yield (kg/ha)		Leaf K (%) at R2 stage	
kg/ha	1997	1998	1997	1998	kg/ha	1997	1998	1997	1998
0	615	700	0.23	0.28	0	914	1180	1.51	2.27
5	814	890	0.26	0.35	9	973	1280	1.58	2.87
10	826	960	0.44	0.35	18	1092	1299	2.34	2.64
20	925	1338	0.44	0.57	36	1188	1320	2.36	2.54
30	1188	1667	0.46	0.51	54	1559	2236	2.66	2.64
40	1585	2433	0.46	0.40	72	2294	2725	2.62	2.62
50	2443	2731	0.44	0.35	90	2246	2773	2.71	2.70
60	2598	2814	0.50	0.35	108	2544	3164	2.25	2.65
70	2713	2938	0.50	0.38	135	2520	2815	2.21	2.61
P treatments received a blanket application of 108 kg K/ha; K treatments received a blanket application of 60 kg P/ha; Sufficiency ranges at the uppermost threefoliate leaves R2 stage: 0.26-0.50 % P and 1.71-2.50 % K									

Table 20. Response of soybean to P and K fertilization (Casanova, 2000)

Casanova (2000) reported that the primary nutritional limitation for successful soybean production under savanna soils in Venezuela (Guarico state) are soil acidity and deficiencies of P, K, N and Ca. Other nutrients as Mg, S and Zn become limiting when the soil is cultivated for several years. Application of triple superphosphate up to 70 kg P/ha and potassium chloride up to 135 kg K/ha on fixed rate of 108 kg K/ha for P plots and 60 kg P/ha for K plots resulted by considerable yield increases. The treatment combination of 60 kg P/ha and 108 kg K/ha produced the best grain yield of 3.16 t/ha (Table 20).

Mottaghian et al. (2008) applied in a silty loam soil in Mazandaran province, Iran, for soybean eight fertilization treatments as follows: 20 and 40 t/ha of organic fertilizers (municipal solid waste compost, vermicompost and sewage sludge) enriched with 50% of anorganic fertilizers need by the soil), only inorganic fertilizers (potassium sulphate and triplephosphate 75 kg/ha) and control (unfertilized). Mixture of 40 t/ha sewage sludge and inorganic fertilizers produced the highest yield and micronutrient (Mn, Cu, Zn and Fe) grain concentrations.

9.2 Liming

Acid soils occupy 3.95 billion ha (about 30 % of the world's ice-free land area (von Uexkull and Mutert, 1995). The poor production of crops grown in acid soils is due to combinations of toxicity (Al, Mn, Fe, H) and deficiencies (N, P, Ca, Mg, K, Fe, Zn). Soil acidity is certainly one of the most damaging soil conditions affecting the growth of most crops. Many factors are involved, but Al toxicity is of outermost significance because of damaging root growth and therefore reduces water and nutrient uptake.

Poor growth of soybean in acid soils as been attributed to a number of factors that include: low pH, high level of Al, Mn, and H, low levels of Ca, Mg, P, K, micronutrients like B, Zn etc. (Fageria, 1994), low population of beneficial micro-organisms like rhizobia, vesicular arbuscular (VAM) fungi and inhibition of root growth (Maddox and Soileux, 1991).

Management practices, such as acidificatying effects of acid-forming N fertilizers, removal of cations by harvested crops, increased leaching and leguminous crops (N_2-fixation), have resulted in the lowering of natural soil pH (Baligar and Fageria, 1997).

Plant growth in mineral acid soils can be restricted by complex of factors. Malnutrition of plants on acid soils is mostly the results of limited soil nutrient availability, often strengthened by impaired uptake capability of the root. Based for over 5000 observations for soybeans worldwide, the optimum pH value for soybeans indicated by this approach lies between ph 5.7 and 6.0 (Sumner, 1997).

An optimum liming regime should achieve the reduction plant available Al and Mn concentrations to levels which allow optimal production of a particular crops, supplying adequate levels of plant available Ca and Mg for optimum root growth and crop performance, creating conditions for optimal performance of beneficial soil fauna and flora particularly int he rhizosfere, and in case of legumes, creating environment which promotes infection and nodulation of root with effective N-fixing rhizobia. (Keltjens, 1997).

For successful soybean production, large quantities of lime and phosphorus fertilizers may be required (Fageria *et al.*, 1995). Liming improves microbiological activities of acid soils, which in turn increases N fixation by legumes, and also promotes mineralization of organic materials. However, over liming may reduce crop yield by inducing P and micronutrient deficiencies (Fageria, 1984).

Unfortunately, over 50% of the world's potential arable land surface is composed of acid soils mostly distributed in developing countries (von Uexküll and Mutert, 1995; Kochian et al., 2005). This restricts the production of soybeans and other legumes due to their sensitivity to acid soil infertility. The growth of leguminous crops and development of symbiosis on acid soils are generally affected by deficiencies of Ca, K, P, Mg, S, Zn and Mo and/or toxicities of Al, Mn and Fe (Foy,1984; Clark et al., 1988).

Liming has been used to ameliorate the problem of aluminium toxicity and low pH in soils. Liming the top soil, however, remains a temporary solution due to subsoil acidity. Restriction in root growth due to subsoil acidity reduces plant nutrient acquisition and access to subsoil water which culminates in the reduction of crop yield (Ferrufino et al., 2000). Moreover, the cost of liming particularly in developing countries is prohibitive and does not justify such huge investment given the return on investment from grain yield of soybeans. The input cost of the recommended quantity of 0.5 to 1.00 tons/ha of liming material (Yusuf and Idowu, 2001), is about the expected total revenue from the current average yield of 0.7 tons/ha in the South-East and South-South regions of Nigeria. The identification of acid stress tolerant cultivars of soybeans, therefore, remains a viable alternative.

Opkara et al., (2007) conducted field experiments in Southeastern Nigeria, in the 2003 and 2004 growing seasons to assess the effect of liming on the performance of four high yielding soybean varieties (early maturing TGX 1485-1D, TGX 1799-8F, TGX 1805-8F and medium maturing TGX 1440-1E). Five lime rates of 0, 0.5, 1.0, 1.5 and 2.0 t/ha were applied to the main plots while the four soybean varieties were planted in the sub-plots. Liming significantly increased soil pH, number of nodules and number of pods per plant and grain yield, especially in 2004 but did not significantly influence plant height, shoot dry matter, days to 50% flowering and 100-seed weight. The 1.0 t/ha lime rate proved to be optimum and is thus recommended for high grain yield in soybean. Mean grain yield at 1.0 t/ha lime rates was higher than the yield in the control (no lime) by 66%. The medium maturing TGX 1440-1E gave, on the average, significantly higher number of leaves and number of pods per plant and grain yield than other varieties.

Kovacevic et al., (1987) tested response of maize, soybean and wheat on liming by hydrated lime to level 20 t/ha. The field experiment was conducted in triplicate for maize- soybean-wheat rotation. Depending on the year grain yield of soybean ranged between 2.59 and 4.03 t/ha. Liming with 10 t of lime increased soybean yield by 17 %. Increased lime rates did not affect grain yield. Low grain yield were obtained under dry and warm weather conditions in 1983 and cold and wet weather conditions in 1984. Liming with 20 tons of lime per hectare increased soil pH from 4.0 to 6.4 at end of the first year of testing (Table 21).

	Hydrated lime (t/ha: autumn 1980)							LSD	
Year	0	1	5	10	15	20	Mean	5%	1%
	Grain yield of soybean in maize-soybean-wheat rotation (t/ha)								
1981	2.67	2.72	2.80	2.81	2.95	2.85	2.80	0.11	0.15
1982	3.48	3.75	4.06	4.28	4.29	4.32	4.03	0.11	0.15
1983	2.24	2.39	2.60	2.72	2.77	2.83	2.59	0.08	0.11
1984	2.27	2.32	2.49	3.08	3.03	3.02	2.70	0.15	0.20
1985	3.37	3.43	3.58	3.61	3.59	3.59	3.53	0.09	0.12
Mean	2.81	2.92	3.11	3.30	3.33	3.32			
	Soil pH (1n KCl) status at end of the growing season								
1981	4.03	4.21	5.03	5.44	5.94	6.42			
1984	4.40	4.36	4.93	5.46	6.02	6.53			

Table 21. Response of soybean to liming on Fericanci acid soil (Kovacevic et al., 1987)

Loncaric et al. (2007) applied liming with carbocalk up to 20 t/ha (spring 2003) and three degrees of fertilization (every year for 4-year period) on Donji Miholjac dystric luvisol. Soybean was grown on the experimental field in the fourth growing season (2006). Depending on the treatment, soybean yields were in range from 2.7 t/ha (unlimed and unfertilized plots) to 4.4 t/ha (treatment kg/ha: 140 N + 300 P_2O_5 + 300 K_2O) and phosphorus removals (P_2O_5/ha) by soybean were 56 and 78, respectively.

9.3 Soil tillage

Different tillage techniques affect the root absorption of nutrients. Lavado et al. (2001) tested effects of conventional and zero tillage (CT and ZT) on nutritional status of soybean, wheat and maize with emphasis on heavy metals. The field experiments were conducted in area far from contaminated sources in Buenos Aires Province, Argentina. The effects of tillage were limited for nutrient concentrations, but significant for heavy metals. Soybean appeared to be more sensitive than cereals to the apparent effect of soil tillage. Grain composition of soybean was independent on soil tillage. Under CT conditions leaves and stem N as well as root Cu were significantly higher, while root -Zn, -Pb and -Ni were significantly lower in comparison with ZT (Table 22).

Soil tillage treatments (ZT = zero tillage; CT = conventional tillage) and soybean nutritional status (G = grain; L+S = leaves and stems; R = root) of soybean under field conditions (mg/kg)*												
	ZT	CT	ZT	CT	ZT	CT	ZT	CT	ZT	CT	ZT	CT
	Nitrogen		*Phosphorus*		*Potassium*		*Sulfur*		*Copper*		*Zinc*	
G	33800a	46900a	4500a	1900a	19800a	18000a	2200a	2600a	17.10a	20.83b	44.85a	43.50a
L+S	9500a	14400b	2100a	1500a	15000a	15000a	900a	800a	10.93a	13.45a	21.48a	18.70a
R	7000a	8600a	2900a	900b	1300a	900a	800a	800a	18.70a	27.98b	64.73a	41.78a
	Boron		*Molybdenum*		*Lead*		*Nickel*		*Cadmium*		*Chromium*	
G	5.77a	6.15a	2.95a	1.71a	0.85a	0.80a	4.30a	4.26a	<0.05a	<0.05a	0.93a	1.20a
L+S	4.03a	4.60a	1.49a	1.70a	0.69a	0.63a	1.55a	2.08a	<0.05a	<0.05a	1.74a	2.36a
R	5.10a	6.00a	1.15a	1.36a	3.51a	2.41b	9.46a	6.77b	<0.05a	<0.05a	10.80a	11.93a
	* Means with different letter in each row are significantly different between treatments at LSD 5 %											

Table 22. Impacts of soil tillage on nutrient and heavy metal status of soybean (Lavado et al., 2001)

Jug et al (2006) reported about soil tillage impacts on nutritional status of soybean on chernozem soil for four growing seasons (stationary field experiment from 2002 to 2005). Three treatment of soil tillage were applied as follows: a) conventional tillage, b) reduced tillage (DH = diskharrowing instead of ploughing) and c) no-till (NT). In general, the characteristics of growing season (the factor „year") were more influencing factor of soybean nutritional status (aerial part in stage of full-developed pods) in comparison with the soil tillage. In this study, low influences of applied soil tillage treatments on nutritional status of soybean were found because significant differences on soybean composition were found only for four (Cu, Cr, Sr and Ba) from total 20 analysed elements. For example, conventional tillage resulted by the higher plant Cu (by 15% and 18% in comparison with DH and NT, respectively), and the lower plant Sr (by 12% and 16%, respectively) and Ba (by 26% and 23%, respectively), while under DH conditions by 22% lower plant Cr was found. Main nutrient status were independent on soil tillage (Table 23). For this reason, usual fertilization practice is recommended for possible application of soil tillage reduction under conditions of calcareous chernozem.

Stipesevic et al. (2009) reported response of winter wheat and soybean to different soil tillage systems on chernosem soil for four years. Three applied soil tillage treatments were applied as follows: a) CT – conventional soil tillage, based on mouldboard ploughing, b) DH – soil tillage based on diskharrowing instead of ploughing; and c) NT – no-tillage. Both crops showed decreasing concentration of Zn within the plant tissue as a result of the soil tillage reduction in the order CT>DH>NT, presumably due to the limited roots growth in lesser disturbed soil at DH and NT treatments. Winter wheat recorded generally lower than optimal Zn concentrations and higher P:Zn ratios at reduced soil tillage treatments, as a result of lower Zn uptake. The recommendation for the winter wheat production by reduced soil tillage is additional Zn fertilization, whose exact amounts and way of application shall follow further research.

The year (the factor A) and soil tillage (ST = the factor B: conventional = CT; diskharrowing = DH; no-till = NT) and composition of soybean (cultivar Tisa)**											
Year (A)	ST (B)	The aerial part of soybean at full-developed pods stage*									
		Percent on dry matter basis					mg/kg on dry matter basis				
		P	**K**	**Ca**	**Mg**	**S**	**Zn**	**Mn**	**Fe**	**Cu**	**B**
2002		0.316	1.85	1.67	0.636	0.171	21.9	38.6	158	9.4	37.6
2003		0.297	1.56	1.91	0.639	0.212	22.4	111.1	385	8.7	46.7
2004		0.407	2.49	1.75	0.470	0.265	34.3	69.2	229	10.3	59.2
2005		0.397	2.66	1.74	0.515	0.223	24.0	84.3	282	9.5	44.2
LSD A 5%		0.047	0.47	n.s.	0.101	0.034	3.7	26.5	127	n.s.	6.0
	CT	0.370	2.18	1.68	0.538	0.226	25.3	71.7	272	10.5	46.8
	DH	0.366	2.31	1.75	0.565	0.215	26.7	75.0	222	9.1	47.3
	NT	0.327	1.93	1.87	0.592	0.212	25.0	80.7	296	8.9	46.7
LSD B 5%		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	1.3	n.s.
Mean		0.354	2.14	1.77	0.565	0.218	25.7	75.8	264	9.5	46.9
		mg/kg on dry matter basis					mg/kg on dry matter basis				
		Mo	**Co**	**Ni**	**Cr**	**Sr**	**Ba**	**Al**	**Pb**	**Cd**	**Na**
2002		0.148	0.055	2.81	0.851	25.0	6.59	112	0.376	0.030	44.6
2003		0.198	0.160	1.83	0.609	21.1	6.64	312	0.336	0.042	29.3
2004		0.126	0.163	1.84	0.406	16.4	5.30	171	0.307	0.028	34.8
2005		0.313	0.174	2.44	0.450	21.3	9.48	215	0.503	0.086	59.2
LSD A 5%		0.090	0.040	n.s.	0.193	4.1	2.52	123	0.097	0.034	9.6
	CT	0.267	0.149	2.56	0.626	19.1	5.75	214	0.374	0.051	39.5
	DH	0.175	0.120	2.14	0.485	21.7	7.80	163	0.394	0.043	41.6
	NT	0.146	0.145	1.99	0.626	22.1	7.46	230	0.374	0.045	44.9
LSD B 5%		n.s	n.s.	n.s.	0.126	2.5	1.70	n.s.	n.s.	n.s.	n.s.
Mean		0.196	0.138	2.23	0.579	21.3	9.48	215	0.381	0.047	42.0
		* under detectable levels (mg/kg): **Se** (<0.60), **Hg** (<0.12), **As** (<0.40)									

Table 23. Influences of the growing season and soil tillage on nutritional status of soybean (Jug et al., 2006)

10. Mineral nutrition in function of diseases and pest control

To control diseases and pest the farmers have several options as follows: genetics (cultivation of less susceptible or even resistant to diseases and pest), biological control (utilization of predators), chemical control (using correspondingly pesticides), plant and soil management practices (creating optimal growth conditions of the cultivated crops and /or to eradicate those conditions, which are favorable for multiplication of diseases and pest) and plant nutrition.

Nutrition of plant has a substantial impact on the predisposition of plants to be attacked or affected by diseases and pests. The ratio between nitrogen and potassium plays obviously a particular role in the host/pathogen relationship. However, unbalanced fertilization is wead spread Developing countries apply nitrogenous and potassic fertilizers at a ratio of 1: 0.2, the situation in developed countries is slightly better with a NK ratio of 1:0.4 (Krauss, 2001).

Generally, potassium tends to improve plant health (Perrenoud, 1990).

Useof potassium decreased the incidence of fungal diseases in 70% of the cases. Simultaneously, K increased yield of plants infested with fungal diseases by 42% (Perrenoud, 1990). Mondal et al. (2001) found a negative correlation between K contents in soybean with incidence and positive correlation with their respective yield.

Insects activately select plants best suited as a food source by, among other factors, appearance, stage of development and composition oft he plant. A precondition for successful infestation is the coincidence of certain developmental stages of both host and pathogen. The use of fertilizers can affect this coincidence by either accelerating or slowing down the development of the host plant relative to that of pathogen. A good example is the control of stem cancer (*Diaporthe phaseolorum*) in soybean by potash use, because the fungus can attack soybean only at a particular phenological stage. Earliness due to balanced fertilization provides the possibility to escape (Ito et al., 2001).

Rodrigues et al., (2009) found that spraying of soybean by potassium silicate (Psi) solutinon reduced the intensity of soybean rust. Soybean rust severity at the highest applied KSi rate in level 60 g/L (pH 5.5) was 70% less than the control (plant spraying with water). This finding may be valuable in areas where soybean is grown as a monoculture, and where high yielding but susceptible cultivars cannot be grown because of occurence of frequent severe epidemics. However, Duarte (2009) reported that there was no effects of KSi on rust control in susceptible soybean cultivar *Monarca*.

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