Agropedology 2011, 21 (1), 28-34

Different forms of boron and sulphur and their effect on B and S contents in mustard *(Brassica juncea L.)* and sunflower *(Helianthus annus L.)*

K. KARTHIKEYAN[1] AND L. M. SHUKLA

Division of Soil Science and Agricultural Chemistry,
Indian Agricultural Research Institute, New Delhi-110 012, India

Abstract : Green-house experiments were conducted involving four levels of boron (0, 1, 2 and 3 mg kg $^{-1}$) and sulphur (0, 20, 40 and 60 mg kg $^{-1}$) in an acid Alfisols collected from Ranchi, Jharkhand with mustard and sunflower as test crops. Organically bound boron, specifically adsorbed and oxide bound increased with increasing levels of boron. Other forms of boron had positive relationships with B in leaf, stem and seed of the crop. Water soluble sulphur, sulphate sulphur and heat soluble sulphur increased with increasing levels of sulphur. At same level of sulphur with increasing levels of boron, the water soluble sulphur and sulphate sulphur were found to decrease, but the heat soluble sulphur did not show significant change in the soils. Water soluble sulphur and sulphate sulphur were found to be positively and significantly correlated with dry-matter yield and S content in plants and seeds of the crops.

Additional key words: *Acid alfisol, fractions of boron and sulphur*

Introduction

Boron exists in different forms and is distinguished in many categories (Evans and Sparks 1983). Soil B, as adsorbed by clay minerals (Goldberg *et al.*1996; Datta and Bhadoria 1999), organic matter (Yermiyaho *et al.* 1988), Al and Fe oxides (Elrashidi and O'Connor 1982), Mn oxyhydroxides (Jin *et al.* 1987) and calcium carbonate (Goldberg and Forster 1991), can be stored or removed depending on changes of boron concentration in soil solution (Keren and Bingham 1985). Thus, knowledge regarding distribution of B in different fractions is essential to understand soil chemistry and B-nutrition.

Similarly, S occurs in soil in a variety of valency states and chemical forms (Blanchar 1986). It exists both in organic and inorganic forms and the availability of sulphur in the soil is determined by the interaction between different forms of S, apart from the soil properties. The information on different fractions of S and B particularly in acid Alfisol of Ranchi Plateau and their influence on B and S contents in mustard and sunflower is virtually lacking and hence the present investigation was carried out.

Material and Methods

Green-house experiments were conducted during 2006 in Division of Soil Science and Agricultural Chemistry, IARI, Delhi, to know the particular fraction of S and B that has larger effect on the availability of S and B. Experimental soils (Alfisols) collected from Ranchi, Jharkhand had pH 5.4, clay 21.5 %, CEC

[1]Present address: National Bureau of Soil Survey and Land Use Planning, Nagpur - 440 033, India

11.18 c mol (p+) kg^{-1}, organic carbon 1.82 g kg^{-1}, available sulphur 4 mg kg^{-1} and boron 0.14 mg kg^{-1}. Five kg of soil was filled up in each polythene-lined earthen pots. Four levels of boron (0, 1, 2 and 3 mg kg^{-1}) and sulphur (0, 20, 40 and 60 mg kg^{-1}) were applied through $(NH_4)_2 SO_4$ and H_3BO_3, respectively. The treatments were replicated thrice following a completely randomized block design.

The N P K was applied @ 65:25:18 mg kg^{-1} and 35:26:18 mg kg^{-1} to mustard (*var* Pusa Bold) and, sunflower (*var* Morden), respectively and were raised under recommended agro-management. The N supplied through $(NH_4)_2 SO_4$ was adjusted in different treatments. At the harvest of the crops, soil samples were also collected, processed and analyzed for various fractions of sulphur (Williams and Steinbergs 1959) and boron by the method outlined by Hou *et al.* (1996), which was later modified by Datta *et al.* (2002). Sulphur content in the plant samples was estimated turbidimetrically after digesting with di-acid mixture (HNO_3:$HClO_4$:5:1) as described by Chesnin and Yien (1951). For B, plant samples were ignited to ash in a muffle furnace at 550° C, after extracting with dilute acid (0.1 *N* HCl)(Jackson 1978), the B in the extracts was estimated by azomethine-H method (John *et al.* 1975).

Results and Discussion

Readily soluble boron

At harvest of mustard and sunflower the readily soluble B varied from 0.17 to 0.97 mg kg^{-1} (mean 0.54 mg kg^{-1}), for mustard crop and 0.32 to 1.12 mg kg^{-1} (mean 0.69 mg kg^{-1}), for sunflower crop (Table 1). The readily soluble boron increased with increasing levels of B and S. The readily soluble B had significant and positive correlation with specifically adsorbed B ($r = 0.75^{**}$, $r = 0.86^{**}$) and organically bound B ($r = 0.83^{**}$, $r = 0.74^{**}$) in mustard and sunflower grown pots, respectively (Table 2). Response to added boron may be due to low available boron in soil under study (Karthikeyan and Shukla 2008). The readily soluble boron includes dissolved plus boron adsorbed non-specifically on edges of clays and other variable charge surfaces (Hou *et al.* 1994) and often considered leachable (Rhoades *et al.* 1970). The readily soluble B had positive correlation with the B in leaf ($r = 0.69^{**}$), stem ($r = 0.71^{**}$) and seeds ($r = 0.64^{**}$) of mustard and B in leaf ($r = 0.62^{**}$), stem ($r = 0.62^{**}$) and seed ($r = 0.83^{**}$) of sunflower crop (Table 3).

Specifically adsorbed boron

The specifically adsorbed boron fraction varied from 0.09 to 0.52 mg kg^{-1} (mean 0.24 mg kg^{-1}) after the harvest of mustard and from 0.16 to 0.61 mg kg^{-1} soil (mean 0.33 mg kg^{-1}) after harvest of sunflower crop (Table 1). In general, increasing levels of boron and sulphur increased their concentration in soils. At the harvest of the crops, the specifically adsorbed boron in soils had significant positive correlation with organically bound B ($r = 0.69^{**}$, for mustard and sunflower ($r = 0.79^{**}$), respectively. Generally, this fraction includes the desorbed boron from the inorganic constituents (Hou *et al.* 1994). Further, B fraction probably originates from weak binding sites of both organic and inorganic constituents, where organic contribution dominates over inorganic ones. The specifically adsorbed boron was significantly correlated with B content in stem ($r = 0.65^{**}$) and seed ($r = 0.51^{*}$) for mustard and B content in stem ($r = 0.51^{**}$) and seed ($r = 0.66^{**}$) in sunflower crop.

Oxide bound boron

Oxide bound boron ranged from 0.16 to 0.45 mg kg^{-1} (mean 0.28 mg kg^{-1}) in mustard grown soil (Table 1), whereas in sunflower-grown soil, it varied from 0.17 to 0.58 mg kg^{-1} (mean 0.38 mg kg^{-1}). The oxide bound boron increased with increasing levels of sulphur and boron. The negative correlation between oxide bound B and B concentration in mustard plants indicated that the availability of B to plants decreased with an increase in oxide bound B in soils, because the oxide bound B fraction included tightly bound B at mineral surfaces as well as B that has isomorphously replaced Al or Fe within the octahedral sheet of the minerals (Hou *et al.* 1994).

Table 1. Different fraction of B (mg kg $^{-1}$) in soil at harvest of mustard and sunflower

Treatment	Readily Soluble		Specifically adsorbed		Oxide bound		Organically bound	
	Mustard	Sunflower	Mustard	Sunflower	Mustard	Sunflower	Mustard	Sunflower
$S_0 B_0$	0.17 (0.68)	0.32 (1.14)	0.14 (0.56)	0.23 (0.82)	0.18 (0.72)	0.17 (0.68)	0.11 (0.44)	0.15 (0.54)
$S_0 B_1$	0.31 (1.10)	0.46 (1.53)	0.19 (0.63)	0.28 (0.91)	0.23 (0.82)	0.26 (0.87)	0.19 (0.68)	0.21 (0.70)
$S_0 B_2$	0.43 (1.31)	0.58 (1.71)	0.23 (0.70)	0.32 (0.94)	0.31 (0.94)	0.44 (1.30)	0.23 (0.70)	0.23 (0.68)
$S_0 B_3$	0.71 (2.10)	0.86 (2.51)	0.52 (1.54)	0.61 (1.78)	0.44 (1.30)	0.52 (1.52)	0.27 (0.80)	0.29 (0.85)
$S_{20} B_0$	0.23 (0.93)	0.38 (1.40)	0.09 (0.36)	0.18 (0.66)	0.16 (0.64)	0.22 (0.81)	0.14 (0.56)	0.12 (0.44)
$S_{20} B_1$	0.46 (1.70)	0.61 (1.98)	0.19 (0.70)	0.28 (0.91)	0.20 (0.74)	0.31 (1.00)	0.18 (0.66)	0.18 (0.58)
$S_{20} B_2$	0.74 (2.36)	0.89 (2.53)	0.25 (0.80)	0.34 (0.97)	0.32 (1.02)	0.48 (1.37)	0.26 (0.83)	0.26 (0.74)
$S_{20} B_3$	0.91 (2.80)	1.06 (2.96)	0.32 (0.98)	0.41 (1.14)	0.41 (1.26)	0.56 (1.56)	0.29 (0.89)	0.30 (0.84)
$S_{40} B_0$	0.26 (1.07)	0.41 (1.60)	0.12 (0.49)	0.21 (0.82)	0.19 (0.78)	0.18 (0.70)	0.17 (0.70)	0.14 (0.55)
$S_{40} B_1$	0.44 (1.52)	0.59 (1.95)	0.15 (0.52)	0.24 (0.79)	0.24 (0.83)	0.33 (1.09)	0.22 (0.76)	0.20 (0.66)
$S_{40} B_2$	0.66 (1.92)	0.81 (2.38)	0.19 (0.55)	0.28 (0.82)	0.28 (0.81)	0.38 (1.12)	0.30 (0.87)	0.25 (0.73)
$S_{40} B_3$	0.79 (2.08)	0.94 (2.66)	0.22 (0.58)	0.31 (0.88)	0.36 (0.95)	0.41 (1.16)	0.32 (0.84)	0.29 (0.82)
$S_{60} B_0$	0.23 (0.90)	0.38 (1.39)	0.12 (0.47)	0.16 (0.59)	0.19 (0.74)	0.22 (0.81)	0.14 (0.56)	0.18 (0.66)
$S_{60} B_1$	0.57 (2.02)	0.72 (2.28)	0.33 (1.17)	0.42 (1.32)	0.26 (0.93)	0.47 (1.49)	0.21 (0.75)	0.22 (0.70)
$S_{60} B_2$	0.71 (2.29)	0.86 (2.65)	0.39 (1.26)	0.48 (1.48)	0.32 (1.03)	0.52 (1.60)	0.32 (1.03)	0.27 (0.83)
$S_{60} B_3$	0.97 (2.94)	1.12 (3.25)	0.43 (1.30)	0.52 (1.51)	0.45 (1.36)	0.58 (1.68)	0.34 (1.05)	0.32 (0.93)
Range	0.17 - 0.97	0.32 – 1.12	0.09 0.52	0.16 – 0.61	0.16 – 0.45	0.17 – 0.58	0.11 0.34	0.12 – 0.32
Mean	0.54	0.69	0.24	0.33	0.28	0.38	0.23	0.23

(Figures in the parenthesis denote the per cent to the total boron)

Table 2. Correlation coefficients (r) among different forms of boron mustard and sunflower grown soils (at harvest)

Form of B	Readily soluble B		Specifically adsorbed B		Oxide bound B	
	Mustard	Sunflower	Mustard	Sunflower	Mustard	Sunflower
Specifically adsorbed B	0.75**	0.86**	-	-	-	
Oxide bound B	-0.10	-0.22	-0.25	0.32	-	
Organically bound B	0.83**	0.74**	0.69**	0.79**	0.26*	0.31

(significant at 5 per cent level; ** significant at 1 per cent level)*

Table 3. Correlation coefficients (r) between different forms of boron and B content in mustard and sunflower (at harvest)

Forms of B	Boron Concentration					
	Leaf		Stem		Seed	
	Mustard	Sunflower	Mustard	Sunflower	Mustard	Sunflower
Readily soluble B	0.69**	0.62**	0.71**	0.62**	0.64**	0.83**
Specifically adsorbed B	0.39	0.25	0.65**	0.51*	0.51*	0.66**
Oxide bound B	0.46	0.48	0.37	0.48	0.32	0.46
Organically bound B	0.47	0.49	0.52*	0.45	0.56*	0.70**

(significant at 5 per cent level; ** significant at 1 per cent level)*

Organically bound boron

The organically bound boron content in mustard-grown soil varied from 0.11 to 0.34 mg kg^{-1} (mean 0.23 mg kg^{-1} soil) and 0.12 to 0.32 mg kg^{-1} (mean 0.23 mg kg^{-1}) in sunflower-grown soil (Table 1). This form of boron increased with increasing levels of boron and sulphur. This fraction solely depended on the organic carbon content of the soil. The organically bound boron had a significant relationship with B content in stem (r = 0.52*) and seed (r = 0.56*) of mustard, and B content of seed (r = 0.70**) of sunflower (Table 3).

Water soluble sulphur

The water soluble sulphur varied from 0.17 to 27.9 mg kg^{-1} (mean 12.3 mg kg^{-1}) in mustard growing soils and 1.24 to 29.4 mg kg^{-1} (mean 14.0 mg kg^{-1}) in sunflower-grown soils (Table.4). The results indicated that at the same level of S, the water soluble S decreased with increasing levels of boron, which may be due to the increased requirement of sulphur by plants. At harvest of mustard and sunflower, the water soluble sulphur was significantly and positively correlated with sulphate sulphur (r = 0.76**, r = 0.85**) and heat soluble sulphur (r = 0.62**, r = 0.81**) respectively. The significant and positive correlations of water soluble sulphur with sulphate sulphur and heat soluble sulphur have been reported by Ram *et al.* (1993), Gowrisankar (1997), Pandey *et al.* (1989) and Brajendra (2003). The interaction effect of boron and sulphur on the S uptake was statistically significant at all levels (S_0B_0 to $S_{60}B_3$) for sunflower and mustard seed (Karthikeyan and Shukla 2008), but maximum sulphur uptake in straw was found in $S_{60}B_2$ level. The water soluble S had highly significant correlation with S content in leaf (r = 0.63**), stem (r = 0.76**) seeds (r = 0.89**) of mustard and leaf (r = 0.78**), stem (r = 0.87**) and seed (r = 0.77**) of sunflower crop. Mishra *et al.* (1990) also reported similar findings in groundnut leaves. In general, Sulphur uptake by plants will increase with increase level of S (Vaiyapuri *et al.* 2008).

Sulphate sulphur

The sulphate sulphur in mustard-grown soil varied from 4.24 to 31.2 mg kg^{-1} (mean 15.9 mg kg^{-1}) and 7.0 to 34.4 mg kg^{-1}, (mean 19.0 mg kg^{-1}) in sunflower grown-soils (Table 4). The sulphate sulphur

Table 4. Different fractions of S (mg kg^{-1}) in soil at harvest of the mustard and sunflower crops

Treatment	Water soluble sulphur		Sulphate sulphur		Heat soluble sulphur	
	Mustard	Sunflower	Mustard	Sunflower	Mustard	Sunflower
$S_0 B_0$	0.66	2.31	4.94	8.16	11.2	12.3
$S_0 B_1$	0.39	2.04	4.52	7.46	12.8	12.6
$S_0 B_2$	0.17	1.82	4.24	7.24	11.9	13.5
$S_0 B_3$	0.21	1.24	4.72	7.00	14.9	12.8
$S_{20} B_0$	10.9	12.5	12.4	15.6	22.8	21.5
$S_{20} B_1$	10.3	12.0	11.6	14.8	23.7	22.8
$S_{20} B_2$	10.0	10.7	10.5	13.7	22.4	21.3
$S_{20} B_3$	7.21	8.86	9.02	12.2	24.9	23.6
$S_{40} B_0$	19.3	21.0	24.4	27.6	32.2	33.4
$S_{40} B_1$	15.8	17.5	21.0	24.2	33.5	35.2
$S_{40} B_2$	15.2	16.8	18.1	21.3	32.8	35.8
$S_{40} B_3$	12.4	14.1	15.4	18.6	32.3	34.6
$S_{60} B_0$	27.9	24.6	29.3	34.4	40.4	38.4
$S_{60} B_1$	24.2	25.9	31.2	32.5	39.6	37.5
$S_{60} B_2$	24.9	23.5	28.3	31.5	38.5	38.1
$S_{60} B_3$	24.8	29.4	25.2	28.4	39.4	38.0
Range	0.17 - 27.9	1.24 – 29.4	4.24 - 31.2	7.00 – 34.4	11.2 - 40.4	12.3 – 38.4
Mean	12.8	14.0	15.9	19.0	27.1	27.0

Table 5. Correlation coefficients (r) among different forms of sulphur in mustard and sunflower grown soils (at harvest)

Form of S	Water soluble S		Sulphate sulphur	
	Mustard	Sunflower	Mustard	Sunflower
Sulphate sulphur	0.76**	0.85**	-	-
Heat soluble sulphur	0.62**	0.81**	0.77**	0.63**

(significant at 5 per cent level; ** significant at 1 per cent level)*

decreased with increasing levels of boron. The sulphate was correlated significantly with heat soluble sulphur for mustard-grown soils (r = 0.77**), and for sunflower grown soils (r = 0.63**). Ram *et al.* (1993) and Gowrisankar and Shukla (1999) reported a significant and positive association of sulphate sulphur with water soluble sulphur. Sulphate-S was also significantly correlated with the fine fraction of the soil (Mishra *et al.* 1990). The sulphate sulphur was found to be highly correlated with the S content of leaf (r = 0.60**), stem (r = 0.69**) and seed (r = 0.84**) of mustard and leaf (r = 0.74**), stem (r = 0.65**) and S content in seed (r = 0.55*) of sunflower.

Heat soluble sulphur

This form of S, commonly referred as mineralizable S ranged from 11.2 to 40.4 mg kg^{-1} (mean 27.0 mg kg^{-1}) in mustard-grown soils and 12.3 to 38.6 mg kg^{-1} (mean 27.0 mg kg^{-1}) in sunflower-grown soils (Table 4). The heat soluble sulphur was relatively higher than the water soluble sulphur and sulphate-S, indicating the release of sulphur by wet and dry heating of the soil during the extraction. There was no change in heat soluble S with the increasing levels of B, but increased with the increasing levels of S. Heat soluble sulphur had a significant and positive correlation (Table 5) with water soluble S (r = 0.62**)

Table 6. Correlation coefficients (r) between different forms of Sulphur and S contents in mustard and sunflower (at harvest)

Form of B	Sulphur concentration					
	Leaf		Stem		Seeds	
	Mustard	Sunflower	Mustard	Sunflower	Mustard	Sunflower
Water soluble S	0.63**	0.78**	0.76**	0.87**	0.89**	0.77**
sulphate S	0.60**	0.74**	0.69**	0.65**	0.84**	0.55*
Heat soluble S	0.51*	0.57*	0.35	0.44	0.41	0.46

(significant at 5 per cent level: ** significant at 1 per cent level)*

and sulphate S (r = 0.77**) in mustard-grown soils and water soluble S (r = 0.81**) and sulphate S (r = 0.63**) in sunflower grown soils. The results are in conformity with the findings of Pandey *et al.* (1989) for alluvial soils of U.P. A significant positive correlation of heat soluble sulphur with sulphate-S has also been reported by Ram *et al.* (1993). The heat soluble sulphur is significantly correlated with the leaf content of mustard (r = 0.51*) and sunflower (r = 0.57*)(Tables 6).

Conclusions

The readily soluble, specifically adsorbed, oxide bound and organically bound forms of boron were found to increase with increasing levels of boron. Excluding the oxide bound boron, all other forms had positive relationships with the plant-B of mustard and sunflower crops. Water soluble sulphur, sulphate sulphur and heat soluble sulphur forms increased with increasing levels of sulphur. At same level of sulphur with increasing levels of boron, the water soluble sulphur and sulphate sulphur forms were found to decrease, but the heat soluble fraction, water soluble sulphur and sulphate sulphur forms were found to be positively and significantly correlated with all the plant parameters of mustard and sunflower. The results indicated that, boron was not influenced by sulphur and *vice-versa*, because both have different adsorbing sites and are non-competing in nature.

Acknowledgment

The senior author thanks Indian Agricultural Research Institute (IARI) and Council of Scientific and Industrial Research (CSIR), New Delhi for facilities and financial assistance, respectively. We also acknowledge the constructive suggestions provided by the reviewers in improving quality of the manuscript.

References

Blanchar, R.W. (1986). Measurement of sulphur in soils and plants. In: sulphur in Agriculture (M.A. Tabatabai, ed.) no. 27. *American Society of Agronomy*, Madison, W.I., pp 465-490.

Brajendra, (2003). Ph.D Thesis. Indian Agricultural Research Institute, New Delhi-12.

Chesnin, L. and Yien, C.H. (1951). Turbidimetric determination of available sulfate. *Proceedings of the Soil Science Society of America* **15**, 149-151.

Datta, S.P. and Bhadoria, P.B.S., (1999). Boron adsorption and desorption in some acid soils of West Bengal, India. *Journal of Plant Nutrition and Soil Science* **162**, 183-191.

Datta, S.P., Rattan, R.K., Suribabu, K. and Datta, S.C. (2002). Fractionation and colorimetric determination of boron in soils. *Journal of Plant Nutrition and Soil Science* **165**, 179-184.

Elrashidi, M.A. and O'Connor, G.A. (1982). Boron sorption and desorption in soils. *Soil Science Society of America Journal* **46**, 27-31.

Evans, C.M. and Sparks, D.L (1983). On the Chemistry and mineralogy of boron in pure and mixed system: a review. *Communication in Soil Science and Plant Analysis* **4**, 827-846.

Goldberg, S. and Forster, H.S. (1991). Boron sorption on calcareous soils and reference calcites. *Soil Science* **152**, 304-310.

Goldberg, S., Forster, H.S., Lesch, S.M. and Heick, E.L. (1996). Influence of anion competition on boron adsorption by clays and soils. *Soil Science* **161**, 99-103.

Gowrisankar, D. and Shukla, L.M. (1999). Kinetics of native sulphate desorption in Inceptisol of Delhi. *Agrochimica* **43**, 1-9.

Gowrisankar. D. (1997). Ph.D. Thesis. Indian Agricultural Research Institute, New Delhi-12.

Hou, J., Evans, L.J. and Spiers, G.A. (1996). Chemical fractionation of soil boron. I. Method development. *Canadian Journal of Soil Science* **76**, 485-491.

Hou, J., Evans, L.J. and Spires, G.A. (1994). Boron fractionation in soils. *Communication in Soil Science and Plant Analysis* **25**, 1841-1853.

Jackson, M.L. (1978). *Soil Chemical Analysis.* Prentice Hall of India, New Delhi.

Jin, J., Martens, D.C. and Zelazny, L.W. (1987). Distribution and plant availability of soil boron fractions. *Soil Science Society of America Journal* **51**, 1228-1231.

John, M.K., Chuah, H.H. and Neufeld, J.H. (1975) Application of improved azomethine-H method to the determination of boron in soils and plants. *Analytical Letters* **8**, 559-568.

Karthikeyan, K., and Shukla, L.M. (2008). Effect of boron – sulphur interaction on their uptake and quality parameters of mustard (*Brassica juncea* L.) and sunflower (*Helianthus annus* L.) *Journal of the Indian Society of Soil Science* **56**, 225-230.

Keren, R., and Bingham, F. T. (1985). Boron adsorption by clay minerals using a phenomenological equation. *Clays and Clay Minerals* **29**, 198-203.

Mishra, U.K., Das, C.P. and Mitra, G.N. (1990). Forms of sulphur in some soils of Orissa in relation to relevant soil properties. *Journal of Indian Society of Soil Science* **38**, 61-69.

Pandey, D.K., Tiwari, K.N. and Tiwari, R.L. (1989). Different forms of sulphur in alluvial soils. *Journal of the Indian Society of Soil Science* **37**, 161-163.

Ram, H., Dixit, V.K. and Khan, T. (1993). Distribution of different form of sulphur in rice growing soils of Uttar Pradesh. *Journal of the Indian Society of Soil Science* **41**, 594-565.

Rhoades, J.D., Invalson, R.D. and Hatcher, J.T. (1970). Laboratory determination of leachable soil B. *Soil Science Society of America Proceeding* **34**, 871-875.

Vaiyapuri, K., Mohamed Amanulla, M. and Rajendran, K. (2010) Influence of sulphur and boron on yield attributes and yield of soybean. *The Madras Agricultural Journal* **97**, 65-67.

Williams, C.H. and Steinbergs. A. (1959). Soil sulphur fractions as chemical indices of available sulphur in some Australian soils. *Australian Journal of Agricultural Research* **10**, 340-352.

Yermiyaho, U., Keren, R. and Chen, Y. (1988). Boron sorption on composted organic matter. *Soil Science Society of America Journal* **52**, 1309-1313.

Received : December 2010 *Accepted : April 2011*