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Evaluation of different soil extractants for assessing B availability to maize (*Zea mays* L.)

Evaluación de diferentes agentes de extracción del suelo para estimar la disponibilidad de B para maíz (Zea mays L.)
Avaliação de diferentes extractantes de solo para avaliar a disponibilidade de B para o milho (Zea mays L.)

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ABSTRACT

A greenhouse experiment was conducted with twenty surface (0-15 cm) soil samples using maize (cv. Pragati) as a test crop to estimate the critical limits of B in soil and plant. Five soil extractants used in the study varied in their B extraction capacity and could be arranged in the order: Mehlich 3 (pH 2.0) > 0.005 M DTPA + 1 M ammonium bicarbonate (pH 7.6) > 1 M $MgCl_2$ (pH 6.0) > 0.01 M $CaCl_2$ > Hot water. All B extractants employed in the present investigation showed highly significant relationships with Bray's percent yield of maize. The critical limits of B in soil for maize were 0.61 mg hot water soluble B, 2.06 mg AB-DTPA extractable B, 1.03 mg 0.01 M $CaCl_2$ extractable B, 2.20 mg 1 M $MgCl_2$ extractable B and 2.56 mg Mehlich 3 extractable B kg^{-1} soil. The critical limit of B in maize (cv. Pragati) plants of 30 d age was found to be 11.2 mg B kg^{-1} dry plant tissue. The dry matter yields and total B uptake of maize plants related significantly to B extracted by AB-DTPA (pH 7.6), 0.01 M $CaCl_2$, 1 M $MgCl_2$ (pH 6.0) and Mehlich 3 (pH 2.0). Boron concentration of maize plants related significantly to B extracted by AB-DTPA (pH 7.6), 1 M $MgCl_2$ (pH 6.0) and Mehlich 3 (pH 2.0). Among soil extractants examined in the present study, Mehlich 3, a multi-nutrient extractant, appeared to be more suitable for predicting B deficiency in soils as this method had easy adoptability in soil testing laboratories owing short extraction time requirement.

RESUMEN

Se llevó a cabo un experimento de invernadero con veinte muestras de suelo superficiales (0-15 cm) utilizando maíz (cv. Pragati) como cultivo de prueba para estimar los límites críticos de B en el suelo y la planta. Se utilizaron cinco extractantes del suelo que variaban en su capacidad de extracción de B y podrían estar dispuestos en el orden: Mehlich 3 (pH 2,0) > 0,005 M DTPA + 1 M bicarbonato de amonio (pH 7,6) > 1 M $MgCl_2$ (pH 6,0) > 0,01 M $CaCl_2$ > agua caliente. Todos los extractantes de B utilizados en este estudio mostraron una correlación altamente significativa con el rendimiento del maíz de Bray por ciento. Los límites críticos de B en el suelo para el maíz fueron 0,61 mg de B soluble en agua caliente, 2,06 mg de B extraíble con AB-DTPA, 1,03 mg de B extraíble con 0,01 $CaCl_2$, 2,20 mg de B extraíble con 1 $MgCl_2$ y 2,56 mg de B extraíble con Mehlich 3 por kg del suelo. Se encontró que el límite crítico de B en plantas de maíz (cv. Pragati) de 30 días fue de 11,2 mg de B por kg de tejido de planta seca. El rendimiento de la materia seca y la asimilación total de B por las plantas de maíz se correlacionaron significativamente con el B extraido en el suelo con AB-DTPA (pH 7,6), 0,01 M $CaCl_2$, 1 M $MgCl_2$ (pH 6,0) y Mehlich 3 (pH 2,0). La concentración de boro en las plantas de maíz también se correlacionó significativamente con el B extraíble del suelo B solo mediante AB-DTPA, 1 M $MgCl_2$ (pH 6,0) y Mehlich 3 (pH 2,0). Entre los agentes de extracción de B del suelo analizados en el presente estudio, la extracción Mehlich 3, un extractante multinutriente, parece ser más adecuada para predecir la deficiencia de vitamina B en suelos, ya que este método tiene fácil adaptabilidad en los laboratorios de análisis de suelos dado el corto periodo de tiempo requerido para realizar la extracción.

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RESUMO

Realizou-se um ensaio em estufa com vinte de amostras de solo superficiais (0-15 cm), utilizando milho (cv. Pragati) como cultura teste para estimar os limites críticos de B no solo e na planta. Os cinco extractantes do solo utilizados no estudo variaram na sua capacidade de extracção de B de acordo com a seguinte ordem: Mehlich 3 (pH 2,0) > 0,005 M DTPA + 1 M de bicarbonato de amónio (pH 7,6) > 1 M de $MgCl_2$ (pH 6,0) > 0,01 M $CaCl_2$ > água quente. Todos os extractantes de B no presente estudo apresentaram uma correlação altamente significativa com o rendimento percentual de Bray do milho. Os limites críticos de B no solo para o milho foram de 0,61 mg B solúvel em água quente, 2,06 mg de B extraível com AB- DTPA, 1,03 mg de B extraível com 0,01 M $CaCl_2$, 2,20 mg de B extraível com 1 M $MgCl_2$ e 2,56 mg de B extraível com Mehlich 3 por kilo de solo. O limite crítico de B encontrado para plantas de milho (cv. Pragati), de 30 d de idade foi de 11,2 mg de B por kilo de tecido vegetal seco. A produção de matérica seca e a absorção total de B por plantas de milho apresentaram-se significativamente correlacionadas com o B extraível do solo, estimado por AB-DTPA (pH 7,6), 0,01 M $CaCl_2$, 1 M $MgCl_2$ (pH 6,0) e Mehlich 3 (pH 2,0). A concentração de boro pelas plantas de milho também se correlacionou significativamente com o B extraível do solo estimado apenas por AB-DTPA, 1 M $MgCl_2$ (pH 6,0) e Mehlich 3 (pH 2,0). Entre os extractantes de solo usados no presente estudo, a extração Mehlich 3 parece ser a mais adequada para previsão da deficiência de B nos solos podendo este método ser facilmente adoptado em laboratórios de análise de terras dado o curto tempo de extração exigido e o recurso a um extractante do solo multinutriente.

KEY WORDS
Boron uptake, Bray's percent yield, critical limits in soil and plant, dry matter yield, Mehlich 3, soil analysis

PALABRAS CLAVE
Asimilación de Boro, rendimiento de Bray, límites críticos en suelo y planta, rendimiento de la materia seca, Mehlich 3, análisis del suelo

PALAVRAS-CHAVE
Absorção de boro, rendimento de Bray, limites críticos de B no solo e na planta, produção de matéria seca, Mehlich 3, análise de terras

1. Introduction

Maize is one of the most important food grain crops of the world. In India, it ranks as the third most important food grain crop grown in 8.11 M ha area in India with production of 19.77 MT, with an average yield of 2,435 kg/ha (Directorate of Maize Research 2008). Among nutrient deficiencies, B deficiency has been identified as a serious agricultural issue in more than 100 crops in 80 countries (Shorrocks 1997). Singh (2001) explored that out of 36,825 soil samples of India, about 33% were deficient in B. The possible roles of B in crops include sugar transport, cell wall synthesis, lignification, cell wall structure integrity, carbohydrate metabolism, ribose nucleic acid (RNA) metabolism, respiration, indole acetic acid (IAA) metabolism, phenol metabolism, and as part of the cell membranes (Srivastava and Gupta 1996; Gupta et al. 2011). Boron is known to influence the reproductive phase of the plants and therefore, influence pollen viability and seed setting (Mozafar 1993). The decision on B fertilization is dependent on the reliability of the soil test performed to judge the availability of B in soils. Soil test based diagnosis commonly involves estimation of hot water soluble B in soils (Farrar 1975). However, several researchers have noted some problems of significance with hot water soluble B as an index of B availability in soils, such as the problematic comparability of the basic soil parameters determined routinely, precision, time consumption etc. (Deabreu et al. 1994; Shiffler et al. 2005). Besides this, a single method such as hot water soluble B cannot suit all types soils. Ideally, the selection of an extractant must be based on the comparative evaluation of different methods for their suitability to predict B availability. In the present study, an attempt was made to screen some multinutrient extractants for predicting the availability of B in soils collected from different places in India, as this exercise could help in saving time and expenditure involved in routine soil testing. The critical limits of B in soils and maize plants were also determined.

2. Materials and Methods

Bulk surface (0-15 cm) samples of soils were collected from twenty different locations in the Uttarakhand state of India. The soil samples were dried in shade, crushed with a wooden roller and passed through a 2 mm sieve. Processed soil samples were stored in polythene bags until pot filling. Soil samples were analyzed for general soil properties like mechanical analysis by Bouyoucous Hydrometer method (Black 1965), soil pH and electrical conductivity in 1:2 soil water suspension and readily oxidizable C by the modified Walkley and Black method as outlined by Jackson (1967). Soil samples were also analyzed for extractable B by the hot water (Bingham 1982), Mehlich 3 (Mehlich 1984), AB-DTPA (Soltanpour and Workman 1979), 0.01 M $CaCl_2$ (Aitken et al. 1987) and 1 M $MgCl_2$ (Tiller et al. 1972) methods. The concentration of B in soil extracts was estimated by a spectrophotometric method in which the intensity of yellow colour produced by the Azomethine-H reagent was estimated at 420 nm on a visible range spectrophotometer (Wolf 1974). Some general properties of soil samples and extractable B concentrations as determined by different extractants are presented in **Table 1**.

2.1. Greenhouse experiment

Two and a half kilograms of each soil on an oven dry weight basis were placed in ten plastic pots. A basal dose of 30 mg N, 10.8 mg P and 20.8 mg K kg^{-1} soil through urea, potassium dihydrogen phosphate and potassium chloride was applied in solution form. Five B levels: 0, 0.25, 0.50, 1.0, 2.5 mg B kg^{-1} soil as borax in solution form were applied to each soil in duplicate. Soil contained in each pot was thoroughly mixed after the addition of B on a polythene sheet and transferred back to the plastic pot. All the pots were irrigated with tap water (0.008 mg B L^{-1}) and left for equilibration for a week. When the soil filled in the pots was near to its field capacity moisture content, six healthy surface sterilized maize seeds (*Zea mays* L., cv. Pragati) were sown in each pot. After emergence, plants were thinned to four in each pot. All the pots were regularly watered and maintained at field capacity. The plants were harvested at 30 d after emergence close to the soil surface.

After harvesting, plants were sequentially washed in tap water, 0.1 N HCl and finally in distilled water. Plants were kept in paper bags, oven dried at 60 ºC for 48 h and dry matter yield was recorded. Bray's percent yield (Bray 1948) of maize, which indicates percent of the maximum yield obtained for soils of varying inherent B supply but of varying productive potentials, was calculated as:

$$\text{Bray's percent yield} = \frac{\text{Dry matter yield in control (0 mg B kg}^{-1}\text{ soil) (g pot}^{-1}\text{)}}{\text{Dry matter yield at optimum B level (g pot}^{-1}\text{)}} \times 100$$

Dried plant samples were ground in a stainless steel grinder. One gram of finally ground plant sample was weighed, carefully transferred to a silica crucible and ashed in a muffle furnace at 550 ºC for 3 h. After ashing, the ash was dissolved in 2 mL of 6 N HCl. The contents were diluted to 15 mL and filtered in a polypropylene tube. Plant extracts were analyzed for B by colorimetry following Azomethine -H method (Wolf 1974) as mentioned in the preceding section. The content of B in plant material was expressed in terms of µg g^{-1} plant tissue. Boron uptake was calculated as the product of B concentration in maize tissues and dry matter yield pot^{-1} and expressed as µg B pot^{-1}.

2.2. Statistical Analysis

The experimental data on dry matter yields of maize were statistically analyzed using a two factorial completely randomized design using a computer program (STPR) developed by the Department of Mathematics and Statistic of the University. Simple linear correlation and regression analyses were performed following the standard statistical procedures outlined by Snedecor and Cochran (1967). The test of significance (F-test) was conducted at $p \leq 0.01$ and $p \leq 0.5$.

3. Results and Discussion

The general properties of soil samples and extractable B contents as determined by different extraction methods are presented in Table 1. Soil textures of the samples under study ranged from sand to sandy clay. Soil pH and electrical conductivity values determined in 1:2 soil water suspensions varied from 5.6 to 8.6 and from 0.03 to 0.101 dS m^{-1}, respectively. The content of readily oxidizable soil C also varied from 0.6 to 12.0 g kg^{-1} soil.

The ranges noted for extractable soil B were 0.24 to 0.89 mg hot water soluble B, 1.13 to 3.04 mg AB-DTPA (pH 7.6) extractable B, 0.26 to 1.48 mg 0.01M $CaCl_2$ extractable B, 0.93 to 2.67 mg 1M $MgCl_2$ (pH 6.0) extractable B and 0.91 to 3.35 mg Mehlich 3 (pH 2.0) extractable B kg^{-1} soil. The range reported here for water soluble B was well under the concentration limits reported for Indian soils by Singh and Sinha (1987) and Sakal and Singh (1995). On the basis of mean extractable B content in soils, the extractants employed in the study could be arranged in the following order of their B extraction capacity: Mehlich 3 (pH 2.0) > 0.005 M diethylene triamine pentaacetic acid (DTPA) + 1 M ammonium bicarbonate (pH 7.6) > 1 M $MgCl_2$ (pH 6.0) > 0.01 M $CaCl_2$ > Hot water. Matula (2009) also observed that the extraction strength of Mehlich 3 test for B was roughly five times higher than the ammonium acetate and water extractions. The highest soil extractable B content noted in the case of Mehlich 3 extractant could be attributed to the presence of acetate and fluoride anions in Mehlich 3 extractant which could displace B from specific sorption sites (Diana and Beni 2006).

Table 1. Some general properties of soil samples and extractable B content

Soil No.	Soil Properties							Extractable soil B (mg kg^{-1})				
	Sand (%)	Silt (%)	Clay (%)	Texture	pH	EC (dS m^{-1})	Organic C (g kg^{-1})	HWS-B	AB-DTPA	0.01M $CaCl_2$	1M $MgCl_2$	Mehlich 3
1	46	10	44	Sandy clay	8.4	0.09	1.9	0.51	1.80	0.65	1.73	1.73
2	8	56	36	Silty clay loam	8.2	0.08	1.6	0.40	1.54	0.45	1.33	1.32
3	35	48	17	Loam	6.7	0.04	2.5	0.29	1.70	1.03	1.67	1.63
4	37	40	23	Loam	6.0	0.02	3.4	0.38	1.60	0.52	1.47	1.26
5	36	44	20	Loam	5.9	0.03	5.0	0.61	2.10	0.71	2.27	2.70
6	16	50	34	Silty clay loam	7.6	0.08	12.0	0.27	1.29	0.32	1.07	1.17
7	58	24	18	Sandy loam	7.4	0.04	2.7	0.24	1.13	0.26	0.93	0.91
8	62	24	14	Sandy loam	5.9	0.03	5.3	0.40	1.80	0.77	2.00	1.80
9	48	34	18	loam	6.3	0.06	6.4	0.42	1.96	0.65	1.93	2.02
10	63	24	13	Sandy loam	5.6	0.02	3.9	0.45	2.00	0.58	2.07	2.14
11	40	38	22	loam	8.5	0.06	1.9	0.38	1.34	0.39	1.27	1.33
12	30	47	23	loam	8.3	0.10	2.7	0.46	1.65	0.71	1.60	1.60
13	27	58	15	Silt loam	8.3	0.06	6.8	0.48	1.85	0.84	1.87	1.89
14	34	34	32	Clay loam	7.5	0.09	7.8	0.50	2.11	0.97	2.20	2.56
15	62	23	15	Sandy loam	8.2	0.08	1.9	0.37	1.54	0.84	1.40	1.19
16	73	12	15	Sandy loam	8.3	0.08	1.8	0.89	3.04	1.48	2.67	3.35
17	27	36	37	Clay loam	8.1	0.09	3.3	0.45	2.06	0.90	2.13	2.22
18	20	46	34	Clay loam	8.2	0.10	3.0	0.43	2.62	1.16	2.40	3.24
19	86	8	6	Loamy sand	8.6	0.03	0.9	0.42	1.65	0.65	1.53	1.50
20	92	1	7	Sand	8.6	0.03	0.6	0.46	2.16	1.29	2.33	3.04

3.1. Relationships between soil properties and extractable soil B content and among soil extractants

Simple correlation analyses were performed between soil properties and extractable B contents and also among different extractants. No statistically significant correlation was recorded between any examined soil property and B extracted by different soil extractants, possibly due to the relatively limited number of soils chosen for the study and the complex influence of different soil properties on the extractable B content in these soils (The data on correlation coefficient values are not presented here). However, the simple correlation coefficients among different soil extractants were highly significant ($p \leq 0.01$) as shown in **Table 2**. Highly significant correlation coefficient values among different soil extractants indicated that all the examined soil extractants extracted B from the similar chemical fractions of B in these soils. Zbíral and Němec (2009) also reported a linear relationship between hot water and Mehlich 3 extractable B in soils of Czech Republic.

Table 2. Simple correlation coefficients (r) among different soil extractants

Soil Extractant	AB-DTPA	0.01M $CaCl_2$	1M $MgCl_2$	Mehlich 3
HWS-B	0.813**	0.623**	0.750**	0.721**
AB-DTPA	1	0.850**	0.946**	0.945**
0.01M $CaCl_2$		1	0.829**	0.822**
1M $MgCl_2$			1	0.954**
Mehlich 3				1

** Significant at $p \leq 0.01$, * Significant at $p \leq 0.05$.

3.2. Effect of B levels on dry matter yield of maize

The deficiency symptoms of B on upper leaves appeared as white necrotic lesions on leaves. The apical portion of the affected leaves was shriveled and necrotic as earlier noted by Sakal and Singh (1995). The data on dry matter yields of maize were statistically analyzed using a two factorial completely randomized design, and analysis of variance indicated that soil type, B levels and the interaction effect of soil and B levels influenced dry matter yields of maize significantly. In general, wide variations in the dry matter yield of maize were noted among the investigated soils, and application of B improved the dry matter yield of maize in some soils (**Figure 1**). A comparison of dry matter yields obtained at different B levels in soils indicated that in soils no. 2, 8, 12 and 19, application of 0.25 mg B kg^{-1} soil brought the highest and statistically significant dry matter yield of maize over the 0 mg B kg^{-1} soil level. In soils no. 11 and 13, the highest and statistically significant dry matter yields of maize over 0 mg B kg^{-1} soil levels were noted at the 0.5 mg B kg^{-1} soil level. In soil no. 17, application of 1 mg B kg^{-1} soil gave the highest and statistically significant increase in the dry matter yield of maize over the 0 mg B kg^{-1} soil level. In soil no. 4, the highest and statistically significant dry matter yield of maize was noted at the B level of 2.5 mg B kg^{-1} soil over 0 mg B kg^{-1} soil. A statistically significant decrease in the dry matter yield of maize was recorded especially at higher B levels in soils no. 2, 8, 11, 12, 18 and 19.

In general, acidic soils with low clay contents (soils no. 8 and 10) or alkaline soils with low hot

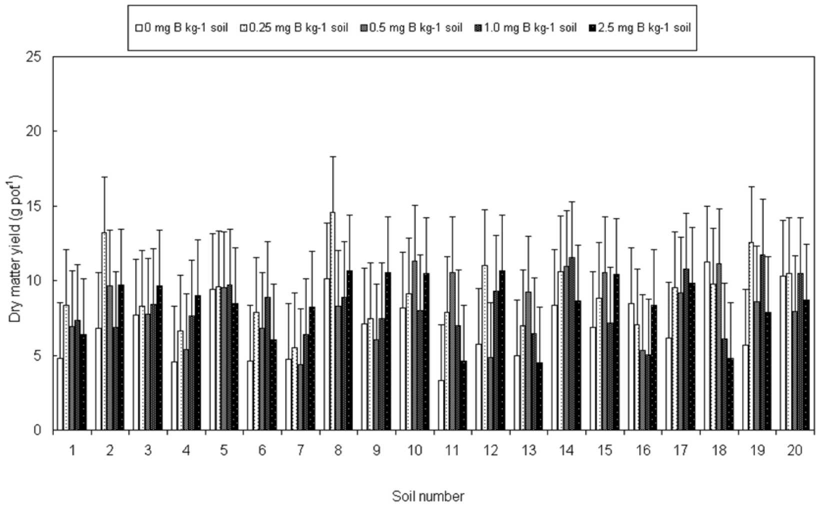

Figure 1. Effect of different B levels on dry matter yield of maize (cv. Pragati) in different soils. The vertical bar indicates the LSD for soil × B levels interaction effect at $p \leq 0.05$.

water soluble B contents (soils no. 1, 2, 11, 12, 13 and 19) appeared to be more responsive to B application. The response of B application in maize was reported earlier by Singh and Sinha (1987) in acid red loam soil, by Sakal et al. (1989) in calcareous soils of Bihar (India) and also by Sujatha (2005) in an Inceptisol. On the other hand, the alkaline soils with high sand contents and low organic C contents (soils no. 19 and 20) showed a declining trend in dry matter accumulation of maize, especially at higher B levels (2.5 mg B kg^{-1} soil), indicating their proneness to B toxicity problems. The relationships between sand content and soil organic C ($r = -0.444^*$, significant at $p \leq 0.05$), between sand content and soil electrical conductance ($r = -0.508^*$, significant at $p \leq 0.05$) and between clay content and soil electrical conductance ($r = 0.688^{**}$, significant at $p \leq 0.01$) were significant. These relationships indicated that sandy soils which usually contain low soil organic C and soluble salts were likely to have poor B sorption capacities and could readily show up B toxicity at higher levels of added B. Evans (1987) recorded a significant correlation between B adsorption maximum and soil organic C content for twenty Canadian soils. Secor and Radke (1985) also showed that low levels of indifferent electrolyte concentrations could reduce B sorption by preventing borate ions from approaching adsorption sites at the edges of clay particles.

3.3. Relationship between Bray's percent yields and soil extractable B

The computed values of Bray's percent yields varied from 31.3 to 120.2 percent (**Figure 2**). Singh and Sinha (1987) also reported that Bray's percent yield for B ranged from 75.0 to 134.6 percent in maize (cv. BAU-804). To estimate the critical limits (the threshold concentration below which the probability of finding economic response to the application of a nutrient in a crop is greater) of B in terms of soil extractable B for maize, Bray's percent yield of maize was plotted against soil extractable B estimated by different soil extractants. The critical limits of B were estimated following the statistical procedure (R^2-technique) of Cate and Nelson (1971). This statistical procedure was adopted to separate the group of responsive soils from the group of non-responsive soils and both these groups were likely to maintain different slopes. Hence, the critical limit could be worked out by estimating the point of intersection of two distinct straight lines representing the sub-populations of responsive and non-responsive soils. For each group of soils, the best fitting line could be the one in which the sum of squares of deviations of observed percent yields from their mean would be at minimum. In the statistical procedure, soils were arranged in the increasing order of their extractable B content with their respective Bray's percent yields values. At successive increasing values of soil extractable B, Bray's percent yields were divided into two sub-populations and cumulative sum of squares (CSS) of both the sub-population were computed and the coefficient of determination (R^2) was calculated as: $R^2 = (TSS-(CSS_I + CSS_{II}))/TSS)$, where TSS represented the total sum of squares of the whole population, and CSS_I and CSS_{II} the cumulative sum of squares for sub-populations I and II, respectively. The statistical significance was examined by F-test both at $p \leq 0.05$ and ≤ 0.01. The relative suitability of different soil extractants could be judged by the statistical significance and the magnitude of R^2-value. As shown in **Figure 2**, the critical limits of B in soil, below which the response of maize to applied B could be expected, were 0.61 mg hot water soluble B, 2.06 mg AB-DTPA extractable B, 1.03 mg 0.01 M $CaCl_2$ extractable B, 2.20 mg 1 M $MgCl_2$ extractable B and 2.56 mg Mehlich 3 extractable B kg^{-1} soil. All R^2 values were significant at $p \leq 0.01$ except for hot water soluble B for which R^2 value was significant at $p \leq 0.05$. Singh and Sinha (1987) reported 0.45 mg hot water soluble B in soils as the lower critical limit of B for maize (cv. BAU-8041). The observed variation in the critical limit of B in soil in terms of hot water soluble B could be attributed partly to the variations in soil properties and also to differential intraspecific responses to B application within a crop (Srivastava and Gupta 1996). Considering the magnitude of R^2-values (coefficient of determination for delineation of B responsive soils from B non-responsive soils), different soil extractants could be arranged in the following order of reliability: 1 M $MgCl_2$ > Mehlich 3 > AB-DTPA > 0.01 M $CaCl_2$ > Hot-water. However, keeping in view the rapidity of the extraction procedure with Mehlich 3 extractant and also the fact that Mehlich 3 extractable B could account for 78.3 percent of the variation in Bray's percent yields ($R'^2 = 0.738$, significant at $p \leq 0.01$), it would certainly be a better method for soil testing laboratories as compared to the hot water soluble B or 1M $MgCl_2$ procedures.

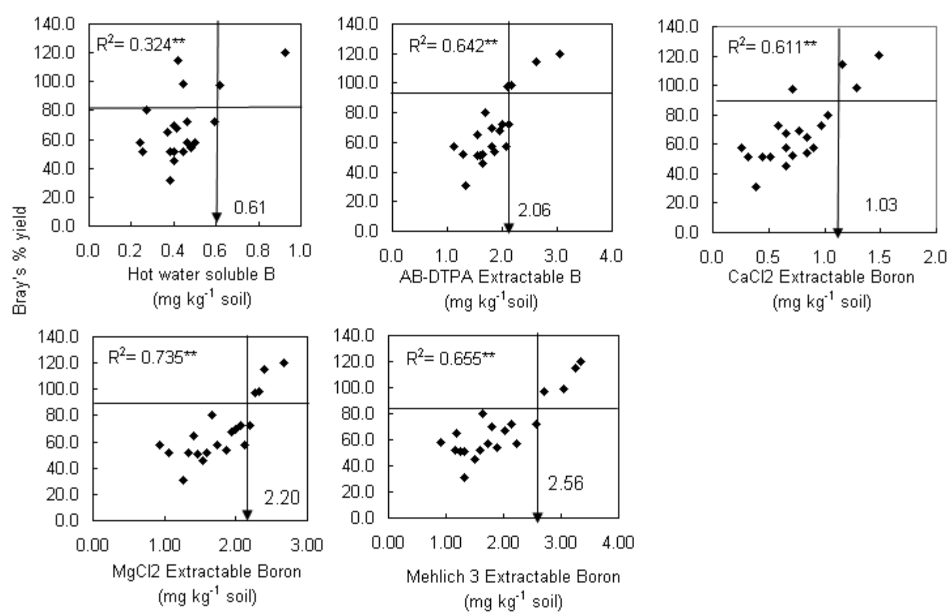

Figure 2. Scatter diagrams plotted between extractable soil B versus Bray's percent yield of maize. R^2 indicated in the figure are coefficients of determination for delineation of responsive soils from non-responsive soils. Simple regression equations between soil extractable B (X) and Bray's percent yield of maize (Y) with their respective coefficient of determination indicating the percent variation in Bray's percent yields which could be accounted by B extracted by a particular extractant (R'^2) were: Y= 24.9 + 98.7 (HWS extr. B); R'^2 = 0.332**, Y = -13.2 + 44.2 (AB-DTPA extr. B); R'^2 = 0.709**, Y = 24.3 + 58.1 ($CaCl_2$ extr. B); R'^2 = 0.623**, Y = -2.1 + 39.3 ($MgCl_2$ extr. B); 0.627**, Y = 14.7 + 27.8 (Mehlich 3 extr. B); R'^2 = 0.738. ** Significant at $p \leq 0.01$ and * Significant at $p \leq 0.05$.

3.4. Relationship between Bray's percent yields and B concentration in maize

Boron concentration in maize tissue at 30 d after emergence varied from 7.6 to 16.2 mg B kg^{-1} plant tissue and accounted 48.4 percent variation in Bray's percent yields (R'^2 = 0.484, significant at ≤ 0.01, Figure 3). The critical limit of B in maize determined by the R^2-technique was found to be 11.2 mg B kg^{-1} tissue, which was quite close to the earlier reported value (10.0 mg B kg^{-1} plant tissue) for maize (Sakal and Singh 1995). Singh and Sinha (1987) noted 7.6 mg B kg^{-1} plant tissue as the critical limit of B in maize (cv. BAU-8041). The variation in the critical limit of B in maize reported in the present investigation as compared to earlier works could be attributed to the variation in genetic makeup of the variety and agro-climatic conditions (Shorrocks 1997). The coefficient of determination for the delineation of B responsive soils from B non-responsive soils based on B concentration in maize tissue (R^2 value) was also significant at $p \leq 0.01$.

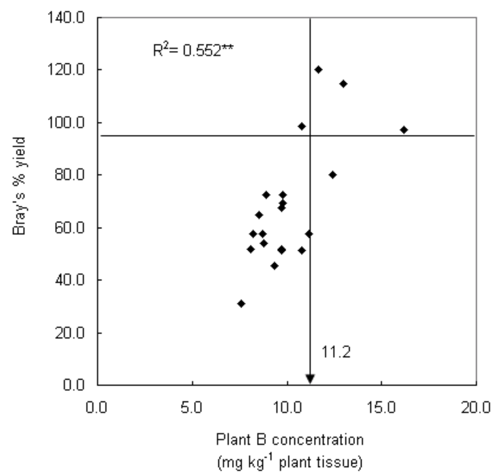

Figure 3. Scatter diagrams plotted between B conc. versus Bray's percent yield of maize. R^2 indicated in the figure is the coefficient of determination for delineation of responsive soils from non-responsive soils. Simple regression equations between B concentration in plants (X) and Bray's percent yield of maize (Y) with the coefficient of determination indicating the percent variation in Bray's percent yields which could be accounted by B concentration in plants (R'^2) was: Y = -12.9 + 8.0 (B conc. in plants); R'^2 = 0.484**. ** Significant at $p \leq 0.01$ and * Significant at $p \leq 0.05$.

3.5. Relationship between extractable soil B content and dry matter yield, B concentration and B uptake of maize

The dry matter yields, B concentration and B uptake of maize under 0 mg B kg^{-1} soil were regressed on soil extractable B contents estimated by different soil extractants (Table 3). Among different soil extractants examined in the present investigation, B extracted by AB-DTPA; 0.01M $CaCl_2$; 1M $MgCl_2$; and Mehlich 3 accounted 47.2, 45.3, 57.5 and 57.7 percent variations in the dry matter yield of maize (R'^2 = 0.453 to 0.577, all significant at $p \leq 0.01$), however, hot water soluble

B failed to account for significant variations in dry matter yields of maize in these soils ($R^{'2}$ = 0.112, non-significant at $p \leq 0.05$). As regards the relationship between B extracted by different soil extractants and B concentration in maize tissue, B extracted by AB-DTPA; 1M $MgCl_2$; and Mehlich 3 accounted 24.6, 24.6 and 29.5 percent variations in the concentration of B in maize tissues ($R^{'2}$ = 0.246 to 0.295, all significant at p ≤ 0.05) while the hot water soluble B and 0.01M $CaCl_2$ extractable B failed to account significant variations in B concentration in maize plants grown in these soils ($R^{'2}$ = 0.127 to 0.145, non-significant at $p \leq 0.05$). Thus, it appeared that hot water or 0.01M $CaCl_2$, which could displace only a limited amount of B sorbed on soils, could not explain the variations in B concentration in maize plants. These findings corroborated with those reported earlier by Parker and Gardner (1982), who examined B availability in fifteen Western Oregon soils using white clover as the test crop and reported a statistically non-significant correlation between hot water soluble B and plant B concentration in three successive harvests. A highly significant relationship between hot water soluble B and the concentration of B in maize plants (correlation coefficient, r = 0.826, significant at $p \leq 0.01$) had been shown only in acid red loam soils by Singh and Sinha (1987). The regression analysis between B extracted by different soil extractants and the B uptake by maize plants showed that the B extracted by AB-DTPA, 0.01M $CaCl_2$, 1M $MgCl_2$, and Mehlich 3 accounted 44.7, 34.2, 50.8 and 56.5 percent variations in B uptake by maize plants ($R^{'2}$ = 0.342 to 0.565, all significant at $p \leq 0.01$) while the hot water soluble B failed to account significant variations in B uptake by maize plants grown in these soils ($R^{'2}$ = 0.151, non-significant at $p \leq 0.05$). Redd et al. (2008) also noted that Mehlich 3 extractable B correlated significantly to B concentration and total B uptake in alfalfa.

Table 3. Regressions between extractable soil B concentration and dry matter yield, B concentration and B uptake of maize

Soil extractant (X)	Dry matter yield (Y, g pot^{-1}) Regression equation	R^2 value	B conc. in plant (Y, mg kg^{-1}) Regression equation	R^2 value	B uptake (Y, mg pot^{-1}) Regression equation	R^2 value
Hot Water	Y = 4.56 + 5.47X	0.112	Y = 7.65 + 5.66 X	0.145	Y = 29.63 + 99.41 X	0.151
AB-DTPA	Y = 0.63 + 3.43X	0.472**	Y = 5.98 + 2.26 X	0.246*	Y = 23.50 + 52.45 X	0.447**
0.01 M $CaCl_2$	Y = 3.39 + 4.71X	0.453**	Y = 8.42 + 2.28 X	0.127	Y = 24.60 + 64.31 X	0.342**
1 M $MgCl_2$	Y = 0.55 + 3.58 X	0.575**	Y = 6.32 + 2.13 X	0.246*	Y = -21.34 + 52.81 X	0.508**
Mehlich 3	Y = 2.45 + 2.34 X	0.577**	Y = 7.20 + 1.52 X	0.295*	Y = 3.16 + 36.37 X	0.565**

** Significant at $p \leq 0.01$, * Significant at $p \leq 0.05$.

4. Conclusions

The multinutrient extractants like AB-DTPA (pH 7.6), Mehlich 3, 0.01 M $CaCl_2$, and 1M $MgCl_2$ can be used to predict the response of maize to B application. The critical limits of B in soil for maize were 0.61 mg hot water soluble B-, 2.06 mg AB-DTPA extractable B-, 1.03 mg 0.01 M $CaCl_2$ extractable B-, 2.20 mg 1M $MgCl_2$ extractable B- and 2.56 mg Mehlich 3 extractable B- kg^{-1} soil. The critical limit of B in maize at 30 d after emergence was 11.2 mg B kg^{-1} plant tissue. Considering the time requirement of these extractants, the Mehlich 3 extraction procedure appeared to be more suitable as a routine method for assessing B fertility status of soils in soil testing laboratories as B extracted by this extractant had a close relationship with dry matter yield, tissue B concentration and B uptake by maize.

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