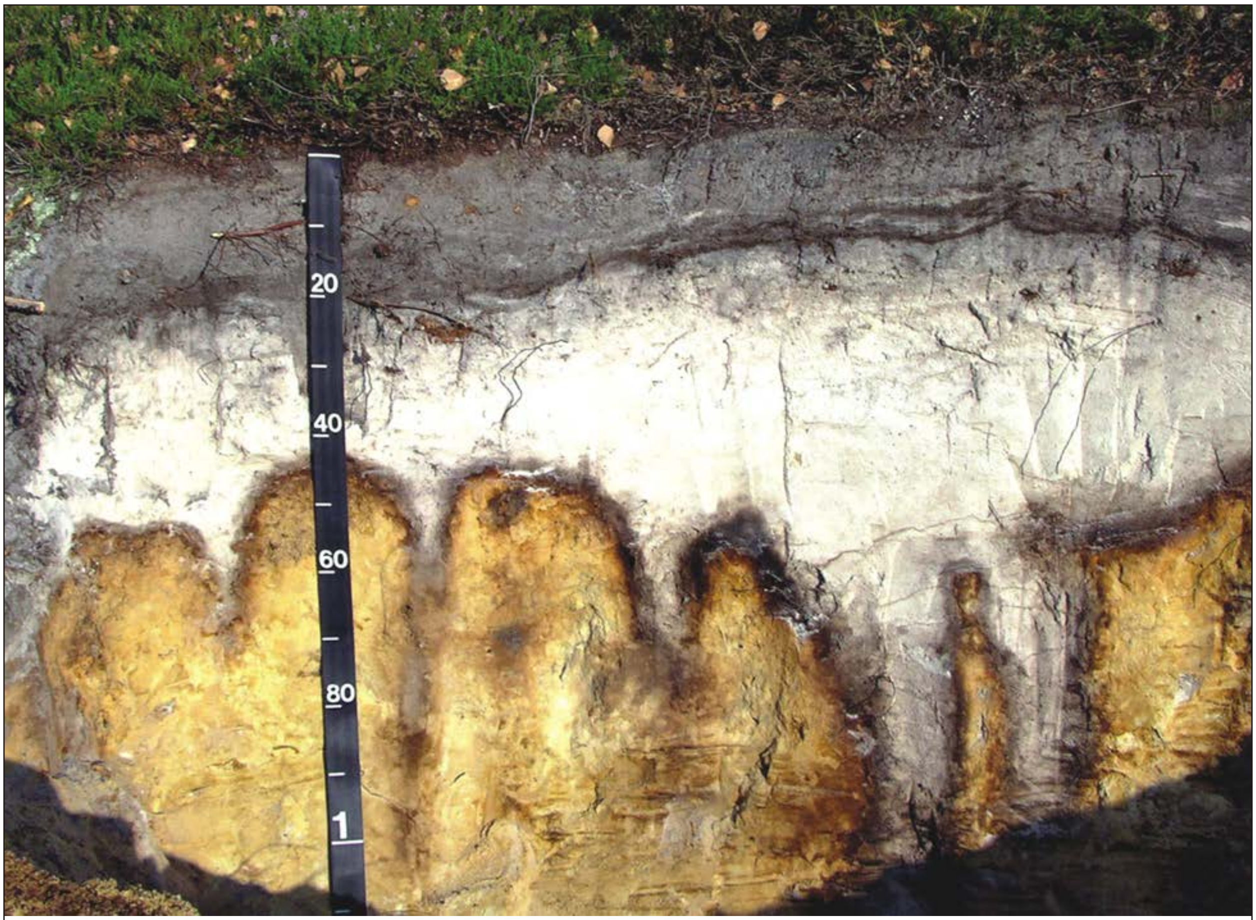

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Determination of Critical Levels of Micronutrients by Plant Response Column Order Procedure for Dryland Wheat (*T. aestivum* L.) in Northwest of Iran

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Abstract: Plant response column order procedure was used to determine critical levels of Fe, Mn, Zn, Cu and B for dryland wheat in West Azarbaijan, East Azarbaijan, Kurdestan and Kermanshah Provinces of Iran. Series of experiments were conducted in randomized complete block design with 4 treatments of each micronutrients (0, 5, 10 and 15 kg ha^{-1} Fe as iron chelate (NaFeEDDHA); 0, 5, 10 and 15 kg ha^{-1} Mn as manganese sulfate; 0, 5, 10 and 15 kg ha^{-1} Zn as zinc sulfate; 0, 2.5, 5 and 7.5 kg ha^{-1} Cu as copper sulfate and 0, 1.5, 3 and 4.5 kg ha^{-1} B as boric acid) with three replications for four years (1998-2002). The collected data were used in plant response column order procedure and interaction chi-square (probability of no interaction between soil classes) models. The results for boundary of between soil deficient and sufficient classes or critical levels by plant response column order procedure and interaction chi-square model for Fe, Mn, Zn, Cu and B critical values were determined as 4.7, 11.2, 0.7, 1.4 and 0.5 mg kg^{-1} soil, respectively; predictable values for critical levels of micronutrients were also calculated as 99.5, 94, 87, 88 and 78%, respectively. From the results, it can be concluded that soil Fe, Mn, Zn, Cu and B requirements and dryland wheat response relationships can be determined by plant response column order procedure and interaction chi-square methods. These methods can be applicable for classifying and prediction of soil micronutrient needs in dryland wheat cultivation in Northwest region of Iran.

Key words: Soil testing, iron, manganese, zinc, copper, boron, interaction chi-square, dryland wheat

INTRODUCTION

One of the important factors in increasing wheat yield is supply of sufficient amount of nutrients. Among them, it can be pointed out to provide micronutrients such as Fe, Mn, Zn, Cu and B, which are not less important than macronutrients in plant nutrition (Dwivedi and Tiwari, 1992; Tandon, 1995; Marschner, 2002). Plants absorb these elements from soil, thus, we can make a relationship between soil nutrient levels and plant response. This relationship was often made through soil testing and calibration experiments, as the latter is a more current method for fertilizer recommendation in annual crops like wheat in the world (Cate and Nelson, 1965; Dow and Roberts, 1982; Das, 1996). Suitable fertilizer recommendation can be presented by calibration experiments with crop response results for each crop and determining of critical level of these elements is necessary for particular crop (Krentos and Orphanos, 1979; Harmsen *et al*., 1983; Soltanpour *et al*., 1986; Matar *et al*., 1987; Amer, 1995). On the other hand, many researchers have reported insufficiency of micronutrients and crop production in soils of different regions of the world (Sillanpä, 1982;

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Welch *et al*., 1991; Brennan, 1992). Also, the dryland areas in Northwest of Iran, often under wheat cultivation, were affected by arid and semi-arid climate with erratic distribution of precipitation in space and time, drought and cold stresses, high carbonate calcium and high pH, low organic matter and micronutrients deficiencies of Fe, Mn, Zn, B, Cu and etc., which result to appear decrease of yield to reach production potential (Krentos and Orphanos, 1979; Harmsen *et al*., 1983; Soltanpour *et al*., 1986; Matar *et al*., 1987; Amer, 1995). Therefore, micronutrients applications can be beneficial to improve wheat grain quality and quantity under such conditions. Determination of critical level of micronutrients in the soil is most principle basis for fertilizer recommendation for wheat cultivation in these areas (Feiziasl and Valizadeh, 2004). Several researchers have studied the micronutrients and determination of their critical level for crops, particularly, wheat in different soils of the world. Results of these researches detected that optimum levels of Fe, Mn, Zn, Cu (DTAP method) and B (Hot water method) in soil for wheat crop are: 11-16, 10-15, 0.4-0.8, 0.1-2.5 and 0.1-2 mg kg^{-1} soil, respectively, (Lindsay and Norvell, 1978; Takker and Mann, 1978; Sillanpä, 1982; Singh *et al*., 1987; Fageria *et al*., 1991; Sims and Johnson, 1991; Agrawal, 1992; Bansal *et al*., 1990; Dwivedi and Tiwari, 1992; Singh, 1992; Tandon, 1995; Cakmak *et al*., 1996; Ascher-Ellis *et al*., 2001). Whereas results of different researches in Iran (particularly in Northwest provinces such as East and West Azarbaijan, Kurdestan and Kermanshah) show that critical levels of Fe, Mn, Zn, Cu (DTAP method) and B (Hot water method) are 4-4.5, 3.6-4.6, 0.75-2, 0.87-1.1 and 0.65 mg kg^{-1} soil, respectively, for wheat (Sedri and Malakout, 1998; Talliei and Abedi, 1999; Balali *et al*., 2000; Ziaeian and Malakouti, 2000; Feiziasl *et al*., 2003).

Therefore, the objective of this study was finding a scientific basic for micronutrients utilization of dryland wheat in Iran and achieve optimum yield with high quantity and quality.

MATERIALS AND METHODS

In order to determine the critical levels of Fe, Mn, Zn, Cu and B for wheat cultivation, this study was conducted in Randomized Complete Block Design (RCBD) with 4 treatments of each micronutrients (0, 5, 10 and 15 kg ha^{-1} Fe as iron chelate (NaFeEDDHA); 0, 5, 10 and 15 kg ha^{-1} Mn as manganese sulfate; 0, 5, 10 and 15 kg ha^{-1} Zn as zinc sulfate; 0, 2.5, 5 and 7.5 kg ha^{-1} Cu as copper sulfate and 0, 1.5, 3 and 4.5 kg ha^{-1} B as boric acid) in 3 replications and 4 years (1998-2002) in Northwest of Iran (East and West Azarbaijan, Kurdestan and Kermanshah provinces). In each region, nitrogen fertilizer used from urea based on regional fertilizer recommendation and phosphorus fertilizer applied from triple superphosphate based on its critical level 9 mg kg^{-1} in soil with (Olsen method; Olsen *et al*., 1954), where, these fertilizers were applied as uniformly for all treatment in the studied regions (Feiziasl *et al*., 2004). Critical level of K for dryland wheat was considered as 250 mg kg^{-1} soil with Acetate ammonium method, thus, soil testing results of these regions did not show any K deficiency (Malakuoti and Gheybi, 1997). Before the experiments, 200 soil samples were taken from 0-25 cm depth in wheat production farms by compositing method in the 4 provinces and amounts of Fe, Mn, Zn, Cu and B were measured by DATP and Hot water methods (Ali Ehyaei and Behbahanizadeh, 1993). In order to save time and expenses and achieve desirable results in this study, principles given by Fageria *et al*. (1991) and Soltanpour *et al*. (1988) was used in the calibration experiments.

Sardari local wheat variety was used in this study. Seeds were disinfected by Vitavax with the ratio of 0.2% and were seeded at the density of 350 seeds m^{-2} (about 140 kg ha^{-1}). Plots width and length were 2.1 and 8 m, respectively, (12 rows in each plot with 17.5 cm apart). 2-4-D herbicide was used at the rate of 2 L ha^{-1} when the plants were at the growth stage of tillering, GS21 (Zadoks *et al*., 1974).

In overcome the border effects, 2 rows from both side and 0.5 m from first and end of plots were omitted and the rest of plots was harvested to determine wheat grain yield and then homogeneity of regional experiments was tested. On the basis of soil testing and plant response, amount of Fe, Mn, Zn, Cu and B for dryland wheat was classified into 2 groups as sufficient and deficient by plant response column order and interaction Chi-square statistical procedures (Keisling and Mullinix, 1979; Havlin and Soltanpour, 1981). In plant response column order procedure, soil numbers or experimental locations and soil micronutrient amount (before applying of fertilizer treatments) was drawn in column figure in X and Y axis, respectively (Example Fig. 1a). In Fig. 1, columns of X axis were ordered upon rising order of soil micronutrient amount in Y axis. In this condition, columns in X axis were divided two main parts (Trieweiler and Lindsay, 1969; Havlin and Soltanpour, 1981; Singh and Takkar, 1981) as given below:

- First part of Fig. (columns) included the soils which wheat in compare to check was shown positive and significant response to applied micronutrient at $p<0.5\%$ and this part was named as Response or Deficient part
- Second part of Fig. 1a included the soils that which wheat crop did not show any significant response to applied micronutrient at $p\leq 0.05\%$ and also in these soils, the crop did not show any micronutrient deficiency symptom. This part of figure was named as Non-response or Sufficient part

In order to separate the deficient and sufficient parts or determining micronutrient critical level in the soil, a line from end of response (deficient) part was drown to Y axis and critical level was detected in cross point of line with X axis. In this study response and non-response of dryland wheat to micronutrient fertilizers was the base on classifying them to deficient and sufficient groups at $p\leq 0.5\%$. But existing of marginal region between deficient and sufficient groups caused that boundary between deficient and sufficient groups was in doubt, thus interaction Chi-square statistical procedure or contingency tables was used to solve this problem, which determined independency of soil testing groups (Rezaei, 2007; Keisling and Mullinix, 1979; Feiziasl, 2006). For this purpose, grouping of data and calculation of chi-square value by contingency table based on observation number related to deficient and sufficient part (fault and trust) was done by using soils of end part of deficient zone which has characteristic of deficient soils (response to applied fertilizer) continually. Contingency table (Table 1) was written to each grouping of data (Rezaei, 2007).

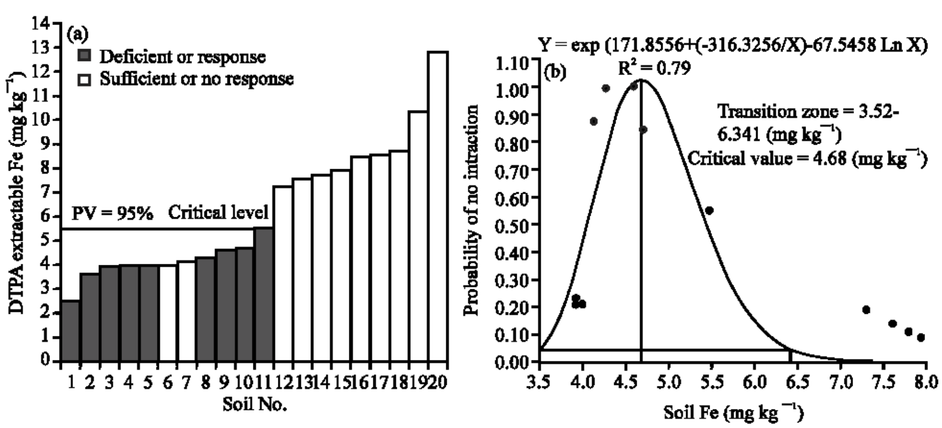

Fig.1: (a) Relationship between soil iron amounts and dryland wheat response to iron chelate application on 20 locations in north-west of Iran and (b) determining of exact Fe critical level by dependency probability of soil testing groups

Table 1: Observation number and interaction chi–square statistical procedure factors by contingency table

	Sample grouping		
Plant condition	Trust	Faults	Sum
Response (deficient)	N_{11}	N_{12}	N_{10}
Non-response (sufficient)	N_{21}	N_{22}	N_{20}
Sum	N_{01}	N_{02}	N_{00}

Interaction Chi-square statistical procedure value for each established contingency Table for proposed groupings was calculated by the following formula (Keisling and Mullinix, 1979; Rezaei, 2007):

$$\chi^2 = \frac{(N_{11} \times N_{22} - N_{12} \times N_{21})^2 \times N_{00}}{N_{10} \times N_{20} \times N_{01} \times N_{02}}$$

Where:
χ^2 = Chi-square value
N_{11} = No. of observation frequencies for trust deficient
N_{22} = No. of observation frequencies for faults sufficient
N_{12} = No. of observation frequencies for faults deficient
N_{21} = No. of observation frequencies for trust sufficient
N_{00} = Total No. of observation frequencies for both sufficient and deficient
N_{10} = Sum of observation frequencies for deficient
N_{20} = Sum of observation frequencies for sufficient
N_{01} = Sum of observation frequencies for trust
N_{02} = Sum of observation frequencies for faults

Then, significant probability value of calculated chi-square was determined with one degree of freedom by chi-square table that, values show the dependency of soil testing groups (Feiziasl, 2006). Finally, a relationship was fitted between micronutrient amounts in studied soils (X-axis) and significant probability of calculated Chi-square for transition zone (in Y-axis) then a line was drown from maximum amount of curve, which show maximum dependency of deficient and sufficient groups, to X-axis (amount of soil micronutrient) (Example Fig. 1b). Cross point of this line with X-axis was defined as boundary line of deficient and sufficient groups or micronutrient critical level. Also, cross point of 5% significant of curve with X-axis was determined as transition zone (Keisling and Mullinix, 1979; Feiziasl, 2007). MSTATC, Excel and Curve expert software were used for statistical analysis, column figure drawing and fitting suitable curve between micronutrient amounts and Chi-square probability levels, respectively.

RESULTS AND DISCUSSION

Iron

Based on the significant response and non-response of crop to Fe application, its amount was ordered by plant response column order procedure. Results showed that dryland wheat grain yield had significant ($p \leq 0.5\%$) response for Fe application to 5.5 mg kg^{-1} Fe in the soil. So, dryland wheat at two locations of 20 studied sites did not differ significantly response to Fe application in less than 5.5 mg kg^{-1} Fe in soil (Fig. 1a). However, results like this are expected in farmers' fields conditions and with less degree in greenhouse experiments because of many other limiting factors for plant growth (Trieweiler and Lindsay, 1969; Havlin and Soltanpour, 1982; Singh and Takkar, 1981).

Table 2: Observation frequency, soil Fe and significant probability level of transition zone chi-square (dependency prob. of groups) in groupings

	Plant position							
	Response (Deficient)		Non-response (Sufficient)		Total observation	Soil Fe		Dependency
Soil No.	Trust	Fault	Trust	Fault	No.	(mg kg^{-1})	χ^2-value	prob.
4	4	0	11	5	20	3.9	1.5126	0.230
5	5	0	11	4	20	3.95	1.667	0.210
6	5	1	10	4	20	4.00	1.6667	0.210
7	5	2	9	4	20	4.14	0.3175	0.870
8	6	2	9	3	20	4.28	0.0105	0.992
9	7	2	9	2	20	4.60	0.0000	0.995
10	8	2	9	1	20	4.70	0.0505	0.840
11	9	2	9	0	20	5.48	0.3922	0.550
12	9	3	8	0	20	7.30	1.8182	0.190
13	9	4	7	0	20	7.60	2.3529	0.140

Interaction Chi-square statistical procedure or contingency table was used to determine exact separation of Fe sufficient and deficient groups (Fig. 1a). Another way is to use groups dependency probability from true and fault of distinguish method by proposed grouping to determine exact separation of marginal zone (Table 2). Keisling and Mullinix (1979) believed that soil nutrient amount will have maximum significant probability of chi-square in the boundary line between two groups (critical level). According to them, critical level of Fe sufficient and deficient groups will be 4.6 mg kg^{-1} (soil No.9) with 99.5% of probability dependency ($p \leq 0.995$) as shown in Table 2. But maximum estimated dependency probability will not always confirm to maximum of soil nutrient curve and groups dependency probability. Therefore, the relationship between nutrient amounts and groups dependency probability (Fig.1b) should be used to determine the exact separation of groups or Fe critical level and distinguish of transition zone (Feiziasl, 2007).

Results of relationship between soil nutrient amounts and groups dependency $\{Y = \exp 171.8556+(-316.3256/X)-67.5458\times \mathrm{Ln}X\}$ showed that maximum probability of soil testing groups equal to curve maximum or 4.7 mg kg^{-1} soil (critical level). Also, transition zone were from 3.25 to 6.34 mg kg^{-1} at $p \leq 0.5\%$ probability, which the minimum and maximum level of this zone indicate confident deficient and excessive of Fe in soil, respectively (Fig. 1b) (Keisling and Mullinix, 1979). Results showed that probability value of estimated critical level was 99.5% by method. Two soils from 20 studied soils, where, Fe was less than estimated critical level, wheat did not show any significant response to Fe application, where, only in one soil it showed significant response to Fe application, where Fe was more than critical level ($p \leq 0.5\%$) (Fig. 1a). But critical level of this data was estimated as 8.5 mg kg^{-1} by Cate-Nelson ANOVA method and by Mistcherlich-Bray equation this value was 6 mg kg^{-1} for obtaining 80% of maximum grain yield (Feiziasl *et al*., 2003; Feiziasl, 2006). Comparison of these methods revealed that estimated critical level by plant response column order procedure is 45 and 22% less than results of Cate-Nelson ANOVA method and Mistcherlich-Bray equation, respectively. Balali *et al*. (2000) determined the average of Fe critical level, 4.03 mg kg^{-1} by Cate-Nelson graphical method for irrigated wheat in northwest provinces of Iran as also used in this study, which Kermanshah had maximum (7.3 mg kg^{-1}) and West Azarbaijan had minimum amount (2 mg kg^{-1}). Sedri and Malakout (1998) reported that critical level of Fe is 4.5 mg kg^{-1} for irrigated wheat in Kurdestan province. Also, Tandon (1995) mentioned that, critical level of Fe is 4.4 mg kg^{-1} for irrigated wheat in Indian soils and Agrawal (1992) reported it as 5 mg kg^{-1}. Comparing of these research results with our study showed that reported critical levels of irrigated wheat by different interpretation methods are nearly similar to this research results presented in this study.

Manganese

Results of the plant response column order procedure method show that dryland wheat grain yield has significantly responded to manganese sulfate fertilizer application to 12.6 mg kg^{-1}($p \leq 0.05\%$). Despite less than 12.6 mg kg^{-1} Mn in 3 locations of 25 experimental locations, it did not show any significant response to Mn application (Fig. 2a).

Results of contingency Tables of Mn proposed grouping showed that groups separation place, based on Mn sufficient and deficient in the studied soils, is 12.4 mg kg^{-1}(Soil No. 15). This value is exactly confirmed to maximum dependency probability of groups at $p \leq 94\%$ (Table 3) and it was named predictability value of critical level (Singh and Takkar, 1981).

According to Keisling and Mullinix (1979) method, determining of critical level on the base on maximum probability of groups dependency, Mn critical level was determined as 12.4 mg kg^{-1} (Table 3). But by considering maximum of the better curve between Mn amounts and probability of group's dependency {$Y=1.2640*\exp(-(X-11.1930)^2/(2*1.2476)$}, exact separation place of Mn sufficient and deficient groups (critical level) was determined as 11.2 mg kg^{-1} with 94% predictability value. This value is 10% less than previous critical value (12.4 mg kg^{-1}) (Fig. 2b). Two soils from 25 studied soils, which Mn was less than 11.2 mg kg^{-1}, dryland wheat grain yield did not show any significant response to manganese sulfate fertilizer application, but only in one soil with above 11.2 mg kg^{-1}Mn, there was a significant response at $p \leq 0.05\%$ (Fig. 2a). Whereas, calculated critical

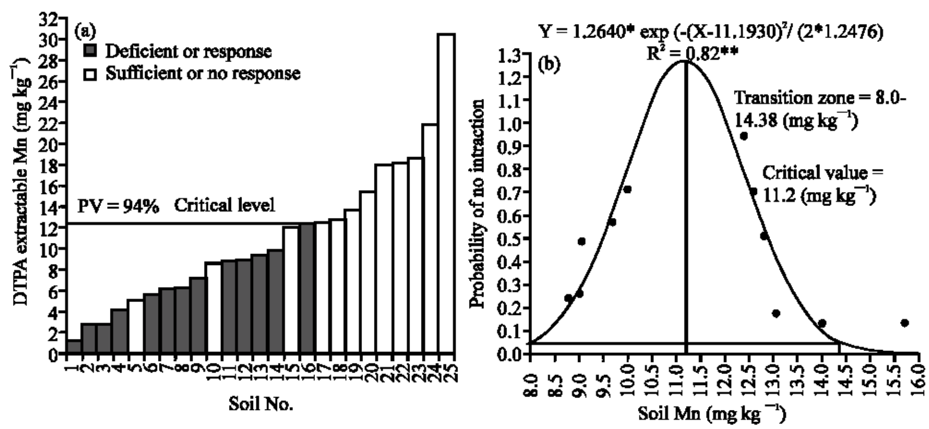

Fig. 2: (a) Relationship between soil Mn and wheat response using of manganese sulfate in 25 locations of Northwestern of Iran and (b) determination of exact critical level of Mn by dependency probability of soil testing groups

Table 3: Observation frequency, soil Mn and significant probability level of Chi-square of transition zone (dependency prob. of groups) in proposed grouping

	Plant position							
	Response (deficient)		Non-response (sufficient)		Total			
Soil No.	Trust	Fault	Trust	Fault	No. of observation	Soil Mn (mg kg^{-1})	χ^2-value	Dependency prob.
11	9	2	10	4	25	9.00	1.2808	0.260
12	10	2	10	3	25	9.10	0.5291	0.480
13	11	2	10	2	25	9.70	0.3645	0.570
14	12	2	10	1	25	10.00	0.1603	0.710
15	12	3	9	1	25	12.40	0.0076	0.940
16	13	3	9	0	25	12.60	0.1574	0.710
17	14	4	8	0	25	12.80	0.4464	0.510
18	14	5	7	0	25	13.10	1.9176	0.180
19	14	6	6	0	25	14.00	2.2409	0.140

value of Mn was 8 mg kg^{-1} for this data by Cate-Nelson ANOVA method and Mistcherlich-Bray equation for obtaining 80% of maximum grain yield. This value is 40% less than critical level of the present study. But estimated critical level of Mn by Mistcherlich-Bray equation for obtaining of 90% of maximum grain yield was exactly similar to critical level of this study (Feiziasl *et al*., 2003; Feiziasl, 2006). Balali *et al*. (2000) determined Mn critical value as 4.3 mg kg^{-1} by Cate-Nelson graphical method for irrigated wheat in Northwestern of Iran (in the same provinces of this study), which Kermanshah province had maximum Mn critical level (4.6 mg kg^{-1}). Ziaeian and Malakouti (2000) estimated Mn critical level as 3.6 mg kg^{-1} by Cate-Nelson graphical method for obtaining of 85% of maximum grain yield for irrigated wheat in Farce province, where, calcareous soils are dominant. Lindsay and Norvell (1978) and Agrawal (1992) expressed that Mn critical level was 5.0 and 5.5 mg kg^{-1} for irrigated wheat, respectively. Comparison of the estimated critical level of dryland wheat in this study with reported critical levels for irrigated wheat by above mentioned researchers shows that Mn critical level for dryland wheat is more than that of irrigated wheat. Because many limiting factors (water, heat and cold stress etc.) have negative influence on nutrient absorption in dryland compare to irrigated conditions, in addition to dryland wheat grain yield less than grain yield of irrigated wheat. Feiziasl *et al*. (2004) reported by using liner correlation coefficients between nutrient ratios in plant and grain yield that, for making nutrient balance in plant, dryland wheat requires more Mn than other micronutrients (Fe, Zn, Cu and B) and this showed that soil Mn critical level for dryland wheat is high in this area. However, critical level of nutrients is not fixed and were affected by precipitation amounts, soil type and climate conditions. It is often believed that critical level of nutrients increase by decreasing of precipitation and soil temperature. The same conditions are often found in north west high-land of Iran and they cause nutrients absorption problems in these areas (Krentos and Orphanos, 1979; Harmsen *et al*., 1983; Matar *et al*., 1992).

Zinc

Results of the plant response column order procedure method show that dryland wheat grain yield has significant response to zinc sulfate fertilizer application to 0.8 mg kg^{-1}($p \leq 0.05$%). Five locations from 25 experimental locations, where, Zn was less than 0.8 mg kg^{-1}, the crop did not show any significant response (Fig. 3a).

Results of contingency Tables of Zn proposed grouping for dryland wheat showed that group's separation place on the base on Zn sufficient and deficient in the studied soils is 0.66 mg kg^{-1} (Soil No. 6) with 87% groups dependency probability or predictability value (Table 4).

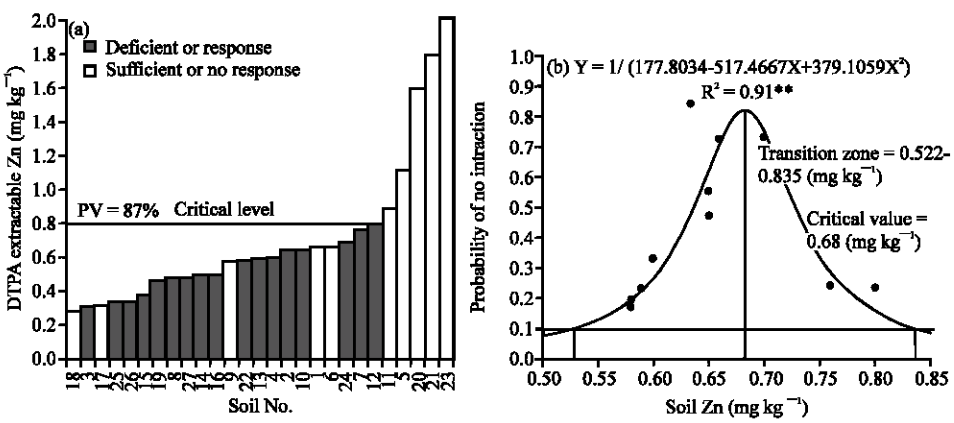

Fig. 3: (a) Relationship between soil Zn and wheat response using of zinc sulfate in 27 locations of Northwestern of Iran and (b) determination of exact critical level of Zn by dependency probability of soil testing groups

Table 4: Observation frequency, soil Zn and significant probability level of chi-square of transition zone (dependency prob. of groups) in proposed grouping

	Plant situation							
	Response (deficient)		Non-response (sufficient)		Total No. of	Soil Zn		Dependency
Soil No.	Truth	Fault	Truth	Fault	observations	(mg kg^{-1})	χ^2-value	probability
22	10	3	7	7	27	0.59	0.5843	0.19
13	11	3	7	6	27	0.59	1.5010	0.23
4	12	3	7	5	27	0.60	1.0530	0.33
10	14	3	7	3	27	0.65	0.5559	0.47
6	14	5	5	3	27	0.66	0.1474	0.87
24	15	5	5	2	27	0.70	0.1378	0.73
7	16	5	5	1	27	0.76	1.3946	0.24
12	17	5	5	0	27	0.80	1.3416	0.23

According to maximum of the better curve between soils Zn amounts and groups dependency probability [$Y = 1/(177.8034-517.4667*X+379.1056*X^2)$], exact separation place of deficient and sufficient groups (Critical level) was determined a 0.68 mg kg^{-1}. This amount was approximately similar to estimated critical level by maximum group's dependency probability. Contrary to Fe and Mn, levels of transition zone was not predictable for Zn at $p\leq 0.05\%$, therefore, these levels were determined at $p\leq 10\%$ which were from 0.52 to 0.84 mg kg^{-1} (Fig. 3b). Whereas, critical levels of this data for obtaining of 80% of maximum grain yield was estimated as 0.55 and 0.61 mg kg^{-1} by Cate-Nelson ANOVA method and Mistcherlich-Bray equation, respectively. Above mentioned critical levels are 19 and 10% less than estimated critical level of this study, respectively (Feiziasl *et al*., 2003; Feiziasl, 2006). Taliei and Abedi (1999) estimated 0.75 mg kg^{-1} for Zn critical level of Sardari variety in Kermanshah Province and Belali *et al*. (2000) determined it as 7.4 mg kg^{-1} for irrigated wheat by DATP and Cate-Nelson graphical methods in Northwestern provinces of Iran (in the provinces of this study). Also, they expressed that, the range of Zn critical level is from 0.4 to 1 mg kg^{-1} in Iran. Sedri and Malakout (1998) reported that, it is 0.87 mg kg^{-1} for irrigated wheat in Kurdistan province. Many researchers also believe that, the Zn critical level of wheat is 0.4-0.8 mg kg^{-1} in arid and semiarid calcareous soils (Sillanpä, 1982; Singh *et al*., 1987; Bansal *et al*., 1990; Agrawal, 1992; Dwivedi and Tiwari, 1992; Singh, 1992; Tandon, 1995; Cakmak *et al*., 1996). Therefore, calculated critical level of Zn in this study is similar to results of above mentioned studies.

Copper

Cu critical level was determined as 1.6 mg kg^{-1} for grain yield of dryland wheat by plant response column order procedure at $p\leq 0.05\%$. Despite less than 1.6 mg kg^{-1} Cu in 5 locations of 26 experimental locations, wheat did not show any significant response to copper sulfate fertilizer application (Fig. 4a).

Results of contingency Tables of Cu proposed grouping show that group's separation on the based on Cu sufficient and deficient in the studied soils, is 1.4 mg kg^{-1} (Soil No. 21) with 88% groups dependency probability or predictability value (Table 5).

Based on maximum of the better curve between Cu amounts and groups dependency probability [$Y = 1/(889.622-1282.168*X+462.632*X^2)$], exact separation of deficient and sufficient groups (Critical level) was determined as 1.38 mg kg^{-1}. This value was exactly similar to estimated critical level by maximum group's dependency probability. Also Cu transition zone levels were determined as 1.2-1.6 mg kg^{-1} at $p\leq 0.05\%$ (Fig. 4b). Dryland wheat at one location of 26 studied locations didn't show significant response for Cu fertilizer application in less than 1.38 mg kg^{-1} Cu in soil, but 2 locations where Cu was above 1.38 mg kg^{-1}, there was significant response at $p\leq 0.05\%$. Whereas, calculated critical levels of Cu were 1.7 and 1.3 mg kg^{-1} by Cate-Nelson ANOVA method and Mistcherlich-Bray equation for obtaining 80% of maximum grain yield, respectively. Result of

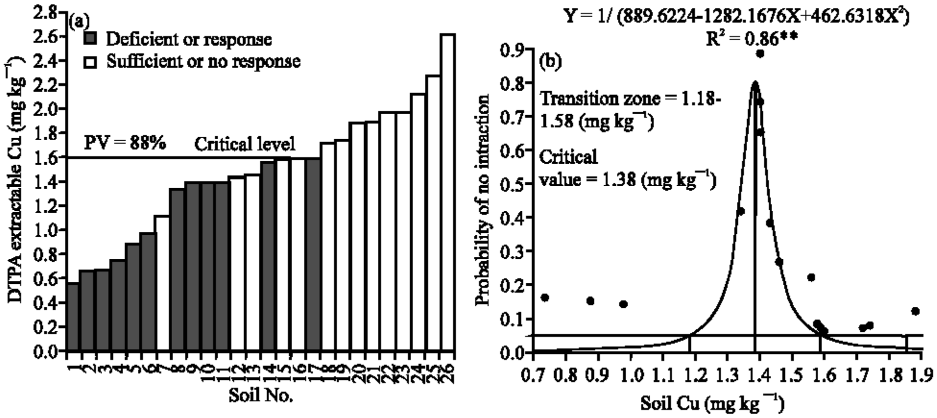

Fig. 4: (a) Relationship between soil copper and wheat response to copper sulfate application in 26 locations of Northwestern of Iran and (b) determination of exact critical level of Cu by dependency probability of soil testing groups

Table 5: Observation frequency, soil Cu and significant probability levels of transition zone chi-square (dependency prob. of groups) in proposed grouping

	Plant position							
	Response (deficient)		Non-Response (sufficient)		Total			
Soil No.	Trust	Fault	Trust	Fault	No. of Observations	Soil Cu (mg kg^{-1})	χ^2-value	Dependency Prob.
6	6	0	14	6	26	0.88	2.2807	0.15
7	6	1	14	6	26	0.98	2.3400	0.14
8	7	1	13	5	26	1.34	0.7775	0.42
11	10	1	13	2	26	1.40	0.1119	0.88
12	10	2	12	2	26	1.43	0.2476	0.38
13	10	3	11	2	26	1.46	0.8512	0.27
14	11	3	11	1	26	1.56	1.2621	0.22
15	11	4	10	1	26	1.58	1.5654	0.08
16	11	5	9	1	26	1.60	3.2773	0.07

Mistcherlich-Bray equation was approximately similar to estimated critical level of this research (Feiziasl *et al*., 2003; Feiziasl, 2006). Average Cu critical level was determined as 1.1 mg kg^{-1} by Cate-Nelson graphical methods for irrigated wheat in Northwestern provinces of Iran (this study provinces), where, there was no significant differences among them (Belali *et al*., 2000). Sedri and Malakout (1998) determined Cu critical value of irrigated wheat as 0.87 mg kg^{-1} in soils of Kurdistan province. Agrawal (1992) and Tandon (1995) reported that Cu critical levels for wheat are 0.6 and 0.78 mg kg^{-1}, respectively in Indian soils. But Sims and Johnson (1991) reported that Cu critical levels of crop plants are 0.1-2.5 mg kg^{-1}. Comparing the results of this study with results of above mentioned researchers shows that Cu critical level of dryland wheat is more than that for irrigated wheat.

Boron

Critical level of B was determined as 0.56 mg kg^{-1} for grain yield of dryland wheat by plant response column order procedure at $p\leq 0.05\%$. Two locations from 26 experimental locations, where, Cu amounts were less than critical level, wheat did not show any significant response to boron fertilizer application (Fig. 5a).

Results of contingency Tables of B proposed grouping indicated that group's separation, based on B sufficient and deficient, is 0.55 mg kg^{-1} (Soil No. 11) with 78% group's dependency probability (Table 6).

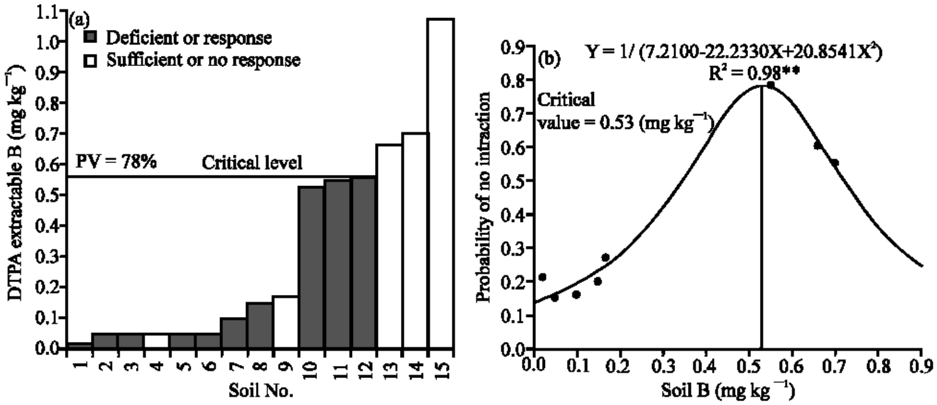

Fig. 5: (a) Relationship between soil B and wheat response using of Boric acid in 15 locations of Northwestern of Iran and (b) determination of exact critical level of B by dependency probability of soil testing groups

Table 6: Observation frequency, soil B and significant probability level of chi-square of transition zone (dependency prob. of groups) in proposed grouping

	Plant position							
	Response (deficient)		Non-response (sufficient)		Total			
Soil No.	Trust	Fault	Trust	Fault	No. of observations	Soil B (mg kg^{-1})	χ^2-value	Dependency prob.
6	5	1	4	5	15	0.05	2.2685	0.15
7	6	1	4	4	15	0.10	2.1429	0.16
8	7	1	4	3	15	0.15	1.7593	0.20
9	7	2	3	3	15	0.17	1.2500	0.27
10	8	2	3	2	15	0.53	0.6818	0.43
11	9	2	3	1	15	0.55	0.0825	0.78
12	10	2	3	0	15	0.56	0.5769	0.47
13	10	3	2	0	15	0.66	0.5769	0.47
14	10	4	1	0	15	0.70	0.3896	0.55

Based on the maximum of the better curve between B amounts and groups dependency probability {$Y = 1/(7.2100\text{-}22.2330^*X+20.8541^*X^2)$}, exact separation of deficient and sufficient groups (Critical level) was determined as 0.53 mg kg^{-1}. This amount was approximately similar to estimated amount by maximum group's dependency probability (Fig. 5b; Table 6). Dryland wheat at 2 locations from 26 studied location, where B amount was less than 0.53 mg kg^{-1}, did not show significant response to boric acid fertilizer application, but in 2 locations with above critical level it showed significant response at $p \leq 5\%$. Whereas, critical level of this data was estimated as 0.23 mg kg^{-1} by Mistcherlich-Bray equation for obtaining 80% of maximum grain yield. This value was approximately half of calculated critical level of this study (Feiziasl *et al*., 2003). Critical level of B was reported as 0.65 mg kg^{-1} for irrigated wheat in soils of Kurdistan province, where, it is nearly similar to critical level of this research (Sedri and Malakout, 1998). Sims and Johnson (1991) expressed that B critical levels are 0.1-2.0 mg kg^{-1} for different crop plants. Ascher-Ellis *et al*. (2001) reported that if the amount of B is less than 0.5 mg kg^{-1}, symptoms of B deficiency will appear in wheat and toxicity symptoms will appear if the amount of B is more than 15-20 mg kg^{-1}.

CONCLUSIONS

Using of Chi-square method for determination of nutrient critical values in soil was appeared by contingency table for first time.

Recommended critical levels of Fe, Mn, Zn, Cu and B are 4.7, 11.2, 0.7, 1.4 and 0.5 mg kg^{-1}, respectively, using plant response column order procedure and Interaction Chi-square statistical procedure.

Critical levels determined for Fe, Mn, Zn, Cu and B are useable in other Mediterranean countries with similar soil and climate condition of Northwest region of Iran.

Predictable values for critical levels of Fe, Mn, Zn, Cu and B calculated as 99.5, 94, 87, 88 and 78%, respectively, which these values is not calculate in other soil testing interpretation methods.

Estimated critical levels of Mn, Zn and B by these methods are more and Fe critical level is less than that of Cate-Nelson ANOVA method and Mistcherlich-Bray equation. But Cu critical levels are between Cate-Nelson ANOVA method and Mistcherlich-Bray equation (Feiziasl *et al*., 2003; Feiziasl, 2006).

In some instances, estimated critical levels of micronutrients for dryland wheat are approximately similar to reported critical levels for irrigated wheat (Fe, B, Zn) or more than those (Mn, Cu).

Plant response column order procedure and interaction chi-square methods can be applicable for classifying and prediction of soil micronutrient needs in dryland wheat cultivation in Northwest region of Iran and other same Mediterranean regions.

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