



International Journal of **Soil Science**

ISSN 1816-4978



Academic
Journals Inc.

www.academicjournals.com

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

¹V. Feiziasl, ¹J. Jafarzadeh, ²M. Pala and ³S.B. Mosavi

¹Dryland Agricultural Research Institute, Maragheh, Iran

²International Center for Agricultural Research in Dryland Areas, Aleppo, Syria

³Faculty of Agriculture, University of Maragheh, Iran

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, Kurdistan 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 (Sillanpää, 1982;

Corresponding Author: V. Feiziasl, Dryland Agricultural Research Institute, Maragheh, Iran

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; Sillanpää, 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, Kurdistan 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; Ziaei 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, Kurdistan 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 $p < 0.05\%$ 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 drawn 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 $p < 0.5\%$. 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).

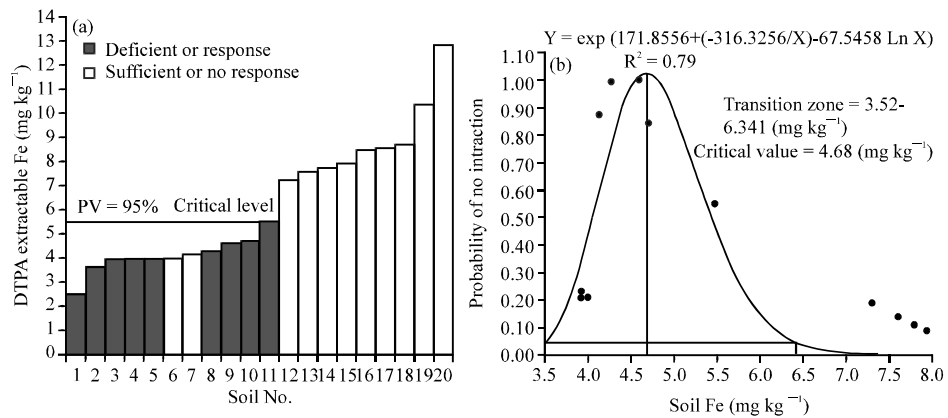


Fig. 1: (a) Relationship between soil iron amounts and dryland wheat response to iron chelate application on 20 locations in north-west of Iran and (b) determining of exact Fe critical level by dependency probability of soil testing groups

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

Plant condition	Sample grouping		Sum
	Trust	Faults	
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

N₁₁ = No. of observation frequencies for trust deficient

N₂₂ = No. of observation frequencies for faults sufficient

N₁₂ = No. of observation frequencies for faults deficient

N₂₁ = No. of observation frequencies for trust sufficient

N₀₀ = Total No. of observation frequencies for both sufficient and deficient

N₁₀ = Sum of observation frequencies for deficient

N₂₀ = Sum of observation frequencies for sufficient

N₀₁ = Sum of observation frequencies for trust

N₀₂ = 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 drawn 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

Soil No.	Plant position				Total observation No.	Soil Fe (mg kg ⁻¹)	χ ² -value	Dependency prob.
	Response (Deficient)		Non-response (Sufficient)					
	Trust	Fault	Trust	Fault				
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<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 { $Y = \exp 171.8556 + (-316.3256/X) - 67.5458 \times \ln X$ } 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<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<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 Kurdistan 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 ≤ 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 ≤ 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 ≤ 0.05% (Fig. 2a). Whereas, calculated critical

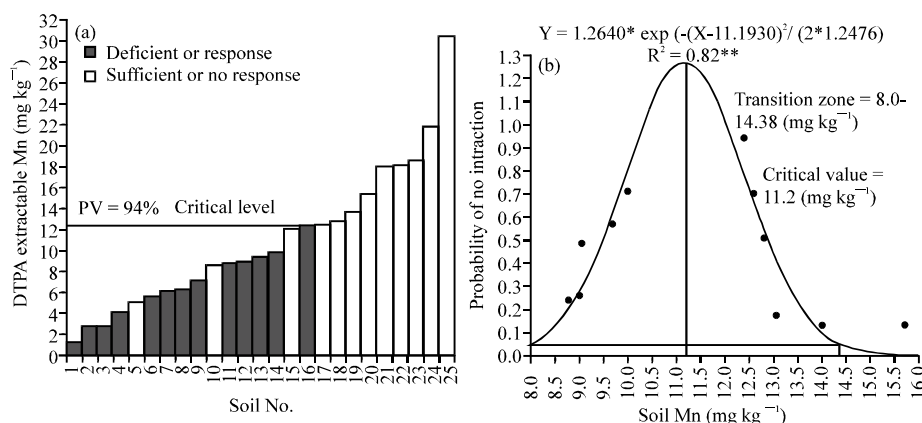


Fig. 2: (a) Relationship between soil Mn and wheat response using of manganese sulfate in 25 locations of Northwestern of Iran and (b) determination of exact critical level of Mn by dependency probability of soil testing groups

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

Soil No.	Response (deficient)		Non-response (sufficient)		Total No. of observation	Soil Mn (mg kg ⁻¹)	χ ² -value	Dependency prob.
	Trust	Fault	Trust	Fault				
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).

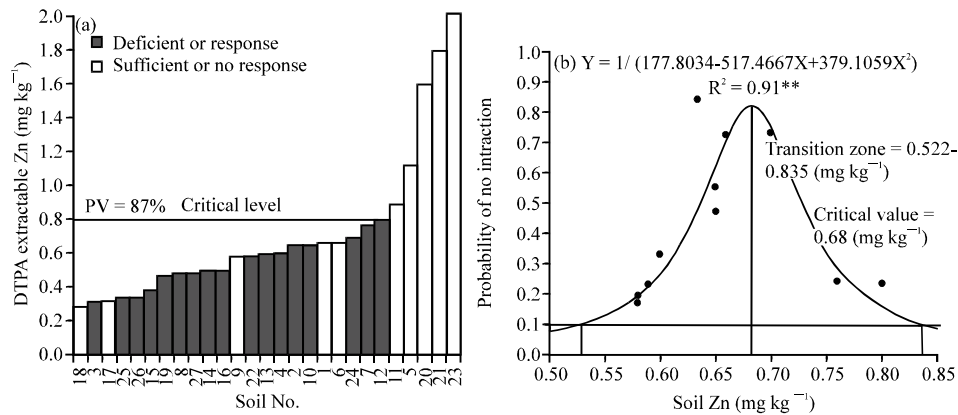


Fig. 3: (a) Relationship between soil Zn and wheat response using of zinc sulfate in 27 locations of Northwestern of Iran and (b) determination of exact critical level of Zn by dependency probability of soil testing groups

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

Soil No.	Plant situation				Total No. of observations	Soil Zn (mg kg ⁻¹)	χ ² -value	Dependency probability
	Response (deficient)		Non-response (sufficient)					
	Truth	Fault	Truth	Fault				
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 (Sillanpää, 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

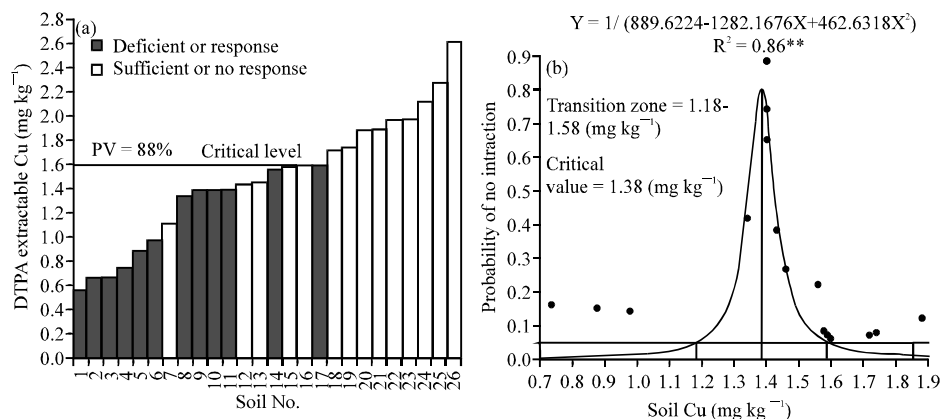


Fig. 4: (a) Relationship between soil copper and wheat response to copper sulfate application in 26 locations of Northwestern of Iran and (b) determination of exact critical level of Cu by dependency probability of soil testing groups

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

Soil No.	Plant position		Trust	Fault	Total No. of Observations	Soil Cu (mg kg ⁻¹)	χ^2 -value	Dependency Prob.
	Response (deficient)	Non-Response (sufficient)						
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).

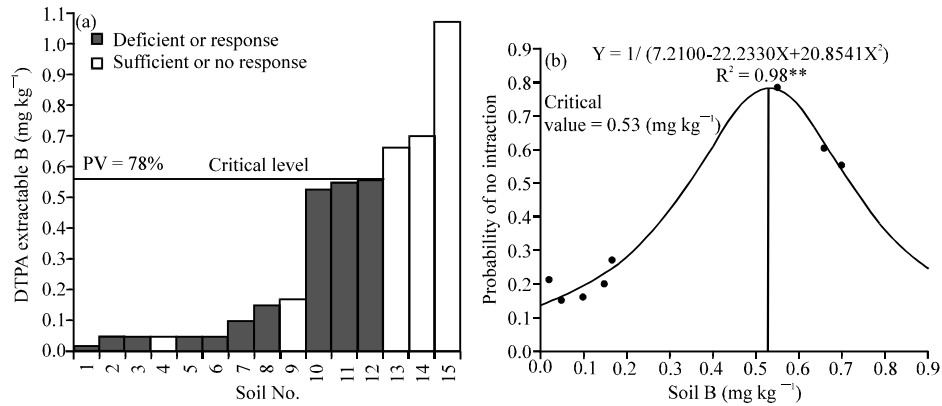


Fig. 5: (a) Relationship between soil B and wheat response using of Boric acid in 15 locations of Northwestern of Iran and (b) determination of exact critical level of B by dependency probability of soil testing groups

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

Soil No.	Plant position				No. of observations	Soil B (mg kg ⁻¹)	χ ² -value	Dependency prob.
	Response (deficient)		Non-response (sufficient)					
	Trust	Fault	Trust	Fault				
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 $\{Y = 1/(7.2100 - 22.2330 * X + 20.8541 * X^2)\}$, 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 ≤ 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.

REFERENCES

- Agrawal, H.P., 1992. Assessing the micronutrient requirement of winter wheat. *Commun. Soil Sci. Plant Anal.*, 23: 2255-2568.
- Ali Ehyaei, M. and A.A. Behbahanizadeh, 1993. Description of soil method analysis. *Soil Water Res. Inst. Bull.*, pp: 129.
- Amer, F.M., 1995. Soil test modifiers for coarse-textured calcareous soils. *Commun. Soil Sci. Plant Anal.*, 26: 3023-3032.
- Ascher-Ellis, J.S., R.D. Graham, G.J. Hollamby, J. Paull and P. Davies *et al.*, 2001. Micronutrients. In: *Application of Physiology in Wheat Breeding*, Reynold, M.P., J.I. Ortiz-Monasterio and A. McNab (Eds.). D.F CIMMYT, Mexico, pp: 219-240.
- Balali, M.R., M.J. Malakouti, H. Mashayekhi and Z. Khademi, 2000. Micronutrients Effects on Yield Increasing and their Critical Level Determination in Irrigated Wheat Soils. In: *Balance Nutrition of Wheat (A complication of Papers)*, Malakouti, M.J. (Ed.). Agricultural Education Publication, Washington, DC, pp: 121-134.
- Bansal, R.L., P.N. Takker, A.L. Bhandari and D.S. Rana, 1990. Critical level of DTPA extractable Zn for wheat in alkaline soils of semiarid region of Punjab, India. *Nutrient Cycl. Agroecosyst.*, 21: 163-166.
- Brennan, R.F., 1992. The effect of zinc fertilizer on take-all the grain yield of wheat grown on zinc-deficient soils of the Esperance region, Western Australia. *Nutrient Cycl. Agroecosyst.*, 3: 215-219.
- Cakmak, I., A. Yilmaz, M. Kalayci, H. Ekiz, B. Torun, B. Erenoglu and H.J. Braun, 1996. Zinc deficiency as a critical problem in wheat production in central Anatolia. *Plant Soil*, 180: 165-172.
- Cate, R. B., Jr. and L.A. Nelson, 1965. A rapid method for correlation of soil test analyses with plant response data. *North Carolina Agric. Exp. Stn. Int. Soil Test. Ser. Tech. Bull.*, No. 1.
- Das, D.K., 1996. *Soil Acidity: Introductory Soil Science*. Kallyani, India, pp: 498.
- Dow, A.I. and S. Roberts, 1982. Critical nutrient ranges for crop diagnosis. *Agron. J.*, 74: 401-403.
- Dwivedi, B.S. and K.N. Tiwari, 1992. Effect of native and fertilizer zinc on dry matter yield and zinc uptake by wheat (*Triticum aestivum*) in Udic Ustochrepts. *Trop. Agric.*, 69: 357-361.
- Fageria, N.K., V.C. Baligar and C.A. Jones, 1991. *Growth and Mineral Nutrition of Field Crops*. 1st Edn., Marcel Dekker, Inc., New York, pp: 476.

- Feiziasl, V., G.H.R. Valizadeh, V. Toshih, A.A. Taliee and V. Belson, 2003. Determination of micronutrients critical level in Northwestern of Iran for Dryland wheat. *Iran. J. Crop Sci.*, 5: 236-249.
- Feiziasl, V. and G.H. Valizadeh, 2004. Soil testing: Interpretation of soil testing results by Cate-Nelson graphical and ANOVA methods. *Dryland Agric. Res. Inst. Bull.*, No. 1658, pp: 123.
- Feiziasl, V., R. Kasraei, M. Moghaddam and G.H.R. Valizadeh, 2004. Investigation on uptake limitation and nutrient deficiency diagnosis at applied phosphorus and zinc fertilizers by different methods in Sardari wheat. *J. Agric. Sci. Nat. Resour.*, 11: 23-33.
- Feiziasl, V., 2006. Determination of Fe, Mn, Zn and Cu critical levels and classification by cate-nelson ANOVA methods for Dryland Wheat (*T. aestivum*. L.) in North Western of Iran. *Iran. J. Agric. Sci.*, 37: 389-401.
- Feiziasl, V., 2007. Soil testing: Interpretation of calibration experiments by mistcherlich-bray, plant response column order procedure (Interaction chi-square) and integrated system. *Dryland Agric. Res. Inst. Bull.*, No. 208, pp: 120.
- Harmsen, K., K.D. Spemherd and A.Y. Allan, 1983. Crop response to nitrogen and phosphorus in rainfed agriculture. *Nutrient Balances and the Need for Fertilizers in Semi-Arid and Arid Regions Proceeding 17th Colloquium International Potash Institute, Bern, Switzerland*, pp: 223-248.
- Havlin, J.L. and P.N. Soltanpour, 1981. Evaluation of the NH_4HCO_3 -DTPA soil test for iron and zinc. *Soil Sci. Soc. Am. J.*, 45: 70-75.
- Havlin, J.L. and P.N. Soltanpour, 1982. Greenhouse and field evaluation of the NH_4HCO_3 -DTPA soil test for Fe. *J. Plant Nutr.*, 5: 769-783.
- Keisling, T.C. and B. Mullinix, 1979. Statistical consideration for evaluating micronutrient test. *Soil Sci. Soc. Am. J.*, 43: 1181-1184.
- Krentos, V.D. and P.I. Orphanos, 1979. Nitrogen and phosphorus fertilizers for wheat and barley in a semi-arid region. *J. Agric. Sci.*, 93: 711-717.
- Lindsey, W.L. and W.A. Norvell, 1978. Development of a DTPA soil test for zinc, iron, manganese and copper. *Soil Sci. Soc. Am. J.*, 42: 421-428.
- Malakouti, M.J. and M.N. Gheybi, 1997. Determination of nutrient critical levels in strategic crops and correct fertilizer recommendation in Iran. *Agricultural Education Publication, Iran Tehran*, pp: 56.
- Marschner, H., 2002. *Mineral Nutrition of Higher Plants*. 2nd Edn., Elsevier Science Ltd, New York.
- Matar, A., J. Torrent and J. Ryan, 1992. Soil and fertilizer phosphorus and crop responses in the dryland Mediterranean zone. *Soil Sci.*, 18: 82-146.
- Matar, A.E., E. Jabbour and K. El Hajj, 1987. Prediction of barley response to fertilizers by means of soil nitrogen and phosphorus tests. *Proceedings of the 2nd Regional Soil Test Calibration Workshop, Soil Test Calibration in West Asia and North Africa, Sept. 1-6, Turkey, ICARDA, Aleppo, Syria*, pp: 12-22.
- Olsen, S.R., C.V. Cole, F.S. Watanabe and L.A. Dean, 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *US Department of Agriculture Circular No. 939*. US Government Printing Office, Washington DC.
- Rezaei, A., 2007. *Understanding of statistic and probability*. Mashhad Nashr Publication.
- Sedri, M.H. and M.J. Malakouti, 1998. Determination of micronutrients critical levels in Kordestan irrigated wheat soils. *Iran. J. Soil Water Sci.*, 12: 19-31.
- Sillanpää, M., 1982. *Micronutrients and the Nutrient Status of Soils: A Global Study*. FAO Soils Bulletin 48 Food and Agriculture Organization of the United Nations, Rome, pp: 75-82.
- Sims, J.T. and G.V. Johnson, 1991. *Micronutrient Soil Tests*. In: *Micronutrients in Agriculture*, Mortvedt, J.J., F.R. Cox, L.M. Shuman and R.M. Walch (Eds.). Soil Science Society of America, Inc., Madison, Wisconsin, USA., pp: 427-477.

- Singh, H.G. and P.N. Takkar, 1981. Evaluation of efficient soil test methods for Zn and their critical values in salt-affected soils for rice. *Commun. Soil Sci. Plant Anal.*, 12: 383-406.
- Singh, J.P., R.E. Karamanos and J.W.B. Stewart, 1987. The zinc fertility of Saskatchewan soils. *Can. J. Soil Sci.*, 67: 103-116.
- Singh, K., 1992. Critical soil level of zinc for wheat grown in alkaline soils. *Nutrient Cycl. Agroecosyst.*, 31: 253-256.
- Soltanpour, P.N., M. El Gharous and A. Azzaoui, 1986. Nitrogen and phosphorus soil test calibration studies in Morocco. *Proceeding of the 1st Soil Test Calibration Workshop*, Jun. 1986, ICARDA, Aleppo, Syria, pp: 85-95.
- Soltanpour, P.N., A. Matar and K. Harmsen, 1988. Program of work for the regional network of soil test calibration study sites in limited rainfall areas. *Proceeding of the 2nd Regional Workshop* Ankara, Turkey, *Soil Test Calibration in West Asia and North Africa*, Sept. 1-6, ICARDA, Aleppo, Syria, pp: 111-116.
- Takker, P.N. and M.S. Mann, 1978. Toxic levels of soil and plant zinc for maize and wheat. *Plant Soil*, 49: 667-669.
- Taliei, A.A. and M.J. Abedi, 1999. Study on the effects of Zn fertilizer amounts and its critical level determination in dryland wheat in Kermanshah province. *Iran. J. Crop Sci.*, 1: 1-14.
- Tandon, H., 1995. *Micronutrients in Soils, Crops and Fertilizers* Fertilizer Development and Consultation Organisation. New Delhi, India, pp: 1-38.
- Trieweiler, J.F. and W.L. Lindsay, 1969. EDTA-ammonium carbonate soils test for zinc. *Soil Sci. Soc. Am. Proc.*, 33: 49-54.
- Welch, R.M., W.H. Allaway, W.A. House and J. Kudata, 1991. Geographic Distribution of Trace Element Problems. In: *Micronutrient in Agriculture*, Mortvet, J.J., F.R. Cox, L.M. Shuman and R.M Welch (Eds.). Soil Science Society Am., Madison, WI, pp: 31-57.
- Zadoks, J.C., T.T. Chang and C.F. Konzak, 1974. A decimal code for the growth stages of cereals. *Weed Res.*, 14: 415-421.
- Ziaecian, A. and M.J. Malakouti, 2000. Manganese Sulfate Application Effects on Wheat Production in Fars Province with Severe Calcareous Soils. In: *Balance Nutrition of Wheat*, Malakouti, M.J. (Ed.). Agricultural Education Publication, USA., pp: 191-212.