Asian Journal of Chemistry Vol. 22, No. 3 (2010), 2397-2406

Chemical Analysis of Barley Under Different Irrigation and Fertilizing Systems

S. MALEKI FARAHANI, M.R. CHAICHI*, D. MAZAHERI,
R. TAVAKKOL AFSHARI and G. SAVAGHEBI
University College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran
E-mail: rchaichi@ut.ac.ir

The effect of different fertilizing systems and drought stress during grain development on grain minerals of barley (*Hordeum vulgare L.*) was studied in field experiments on a clay-loamy soil during 2007 growing season. The treatments consisted of three irrigation regimes (main plots) of: non-stressed (NS, normal irrigation until the end of the plant physiological maturity), medium stress (MS, ceased irrigation from the beginning of flowering to the initiation of seed filling stage and severe stress (SS, ceased irrigation from the initiation of flowering stage to the end of the physiological maturity) and 6 fertilizing systems consisted of no fertilizing (NF), phosphorous and nitrogen biofertilizers (BF), 100 % chemical fertilizer (NPK) (CF), vermicompost (VC) 5 t/ha, 50 % chemical fertilizer (NPK) + 50 % vermicompost (2.5 t/ha) (CV) and 50 % chemical fertilizer (NPK) + biofertilizer (CB), assigned to the sub plots. Drought stress significantly increased grain minerals of N, P, Zn and Mn by 12 %, 4 %, 27 % and 7 % compared to control (NS), respectively. Average nitrogen content of barley grain in chemical fertilizer (CF) was significantly more than the other treatments followed by integrated fertilizing systems (CB and CV). The P content of barley grain produced in BF fertilizer was significantly higher than other treatments. Iron and zinc content of barley grain increased by vermicompost application. However, Mn content of barley grain was higher in fertilized with chemical fertilizer.

Key Words: Barley, Drought stress, Fertilizing system, Grain mineral.

INTRODUCTION

Barley (*Hordeum vulgare L.*) ranks fifth among all crops in grain production in the world after maize, wheat, rice and soybean[1]. In recent years, about two-third of barley crop has been used for feed, one-third for malting and about 2 % for food directly[2]. In sustainable agriculture grains are expected to have high nutritional value and ability to produce vigorous seedling to compete weeds and increase yield. Grain mineral composition influence both nutritional quality and seed vigour. During seed development on the parent plant, nutrient concentration in seed is dependent on soil type, nutrient availability, crop species, weather condition, growing season and cultivar[3,4]. There is an inconsistency in literature on the quality of organically and conventionally produced crops because of different management practices and environmental conditions. Generally in organic products, vitamin C, Fe, P, Mg, Zn contents were higher compared to conventional products. However, protein, Mn, K, nitrate and heavy metal contents were less[3,5-9]. Organic and inorganic fertilizers change the crop quality according to their different potential abilities. Inorganic fertilizers are generally more soluble and available at the high plant demand, but organic manure releases minerals slowly which may not be fully available during the critical period of plant demand[5]. Micronutrient uptake rate could be changed through inorganic or organic fertilizer application by their influence on soil pH [10] or increasing the organic matter content of the soil[11]. There is a tendency in developed countries to reduce environmental risk and enhancing food nutritional value by using more organic fertilizers, while in developing countries low soil fertility limits the use of organic fertilizers[12]. Thus it is important to apply the best fertilizing systems to overcome the widespread poverty and achieve international grain food security.

Water is the most precious agricultural resource after land in the water-limited environments[13], However few studies have dealt with the effect of limited irrigation on the concentration of minerals in the grains. Different moisture stress treatments during pre and after anthesis on maize did not affect the mineral concentration in grain[10,14]. It is assumed that both water and fertilizer (chemical, organic and biofertilizer) can affect mineral concentration in barley grain. To-date, most biofertilizers have been developed and used primarily for supplying N and P to plants and relatively less is known about their utility for supplying micronutrients. Nevertheless, microorganisms and organic matter supplements may significantly affect the chemistry of micronutrients in soils and in some situations may be manipulated to enhance micronutrient uptake by plants.

This study was conducted to fulfill the information about the effects of different fertilizing and irrigation systems on grain mineral concentration in soils with low organic matter content.

EXPERIMENTAL

Initial barley (cv. Turkman) seed, used in this experiment for seed production, was provided by the Seed and Plant Breeding Research Institute, Karaj, Iran which is a spring malting barley seed.

Field experiments: Field studies were conducted at the Experimental Farm of College of Agronomy and Animal Sciences, University of Tehran, Iran (35º 56' N and 50º 58' E with an altitude of 1312 m) during 2006-2007 cropping season. The soil texture of experimental site was clay loam. Experimental design was a split plot arrangement based on a randomized complete block design with four replications. The barley seeds were sown in 2 m × 5 m plots with 5 m alleys between replications on March 17th, 2007 at a rate of 300 seed m^{-2}. The treatments consisted of three irrigation regimes (main plots) and 6 soil fertilizing systems (sub-plots). The irrigation treatments were applied at different phenological stages of barley according to

Zadoks scale[15] consisted of: non-stressed (NS, normal irrigation until the end of the plant physiological maturity), medium stress (MS, ceased irrigation from the beginning of flowering (Zadoks 65) to the initiation of seed filling stage (Zadoks, 70) and severe stress (SS, ceased irrigation from the initiation of flowering stage to the end of the physiological maturity). Fertilizing systems consisted of no fertilizing (control) (NF), phosphorous and nitrogen biofertilizers (Biofertilizer is a complex of different free living nitrogen fixing and phosphorus solubilizing bacteria) (BF), 100 % chemical fertilizer (NPK) (based on soil chemical analysis) (CF), vermicompost (vermicompost or vcompost, is the heterogeneous mixture of decomposing vegetable or food waste, bedding materials and pure vermicast produced during the course of normal vermiculture operations, it is an excellent, nutrient-rich organic fertilizer and soil conditioner (VC) (applied 5 t/ha), 50 % chemical fertilizer (NPK) + 50 % vermicompost (2.5 t/ha) (CV) and finally 50 % chemical fertilizer (NPK) + 50 % biofertilizer (CB), assigned to the sub plots[16].

Soil and vermicompost chemical characteristics are presented in Tables 1 and 2. Application of chemical fertilizer was performed based on soil analysis. The amounts of N, P and K applied were 105 kg N ha^{-1}, 32 kg P_2O_5 ha^{-1} and 170 kg K_2O ha^{-1}, respectively. All P (triple superphosphate), K (K_2SO_4) and organic fertilizers were applied as basal fertilizers, whereas N (urea) was applied in one third as basal fertilizer and the rest as topdressing. Normal irrigation was performed at weekly intervals when soil moisture reached 50 % available soil water at root growth zone. There was no effective raining during generative growing period (Table-3). At physiological maturity plants were harvested from the two central (eliminating the side rows as border effects) rows of each plot. After harvesting, the barley ears were threshed by hand and were equilibrated to 7-8 % moisture content (by fresh weight). Samples were ground to pass through a 1 mm screen. Total nitrogen contents were determined using the modified kjeldahl method[17] and phosphorus content was measured after dry ashing the vanadad-molybdate method[18]. The concentrations of iron, zinc and magnesium were determined in an air-acetylene flame by atomic absorption spectrometry (AAS) (Shimadzu AA.670, Japan).

TABLE-1
CHARACTERISTICS OF TOP 20 cm OF SOIL AT EXPERIMENTAL SITES AT INITIATION OF EXPERIMENT

Bulk density (g/cm^3)	Organic carbon (%)	pH	EC ds/m	P mg/kg	N % (K mg/kg)	Ca meq/L (Mg meq/L)	Cu mg/kg (Mn mg/kg)	Zn mg/kg (Fe mg/kg)
1.51	0.83	8.5	1.112	17.4	0.09 (191)	7.2 (3)	1.39 (17)	0.63 (6.1)

TABLE-2
CHARACTERISTICS OF APPLIED VERMICOMPOST

Organic carbon % (pH)	EC ds/m (P mg/kg)	N % (K mg/kg)	Ca meq/L (Mg meq/L)	Cu mg/kg (Mn mg/kg)	Zn mg/kg (Fe mg/kg)
17.5 (8.5)	6.21 (1020)	2.24 (9340)	5.2 (11.8)	6.124 (30.50)	37.85 (75)

TABLE-3
TOTAL MONTHLY PRECIPITATION, AVERAGE MONTHLY TEMPERATURE, AVERAGE MONTHLY RELATIVE HUMIDITY AND MAXIMUM AIR TEMPERATURE (T_{max}) FOR THE PERIOD OF OCTOBER 1st TO JULY 31st, KARAJ, IRAN

Month	Precipitation (mm)	Mean Temperature (ºC)	Relative humidity (%)	T_{max} (ºC)
	2006-2007	2006-2007	2006-2007	2006-2007
October	71.2	18.9	51.0	31.0
November	16.0	8.40	61.0	22.2
December	62.9	1.30	70.0	9.60
January	45.9	1.90	58.0	14.0
February	44.0	5.60	61.2	14.6
March	82.2	7.30	60.0	18.2
April	100.4	14.4	52.0	23.6
May	13.1	20.3	45.0	22.4
June	12.6	24.3	38.0	38.0
July	6.80	27.0	37.0	38.4

Statistical analysis: Data were statistically analyzed separately for each production year by analysis of variance (ANOVA) using MSTATC (Michigan State Univ., East Lansing, MS, USA) and SAS (SAS Inst., 1990) programs. Duncan test ($p < 0.05$) was used to compare means within and among treatments and interactions.

RESULTS AND DISCUSSION

Phosphorus: Irrigation system, fertilizing system and their interaction had significant effect on phosphorus concentration in grain (Table-4). Phosphorus content followed an increasing trend as water stress increased except for BF and NF treatments (Fig. 1). Phosphorus decrease in BF can be related to less bacterial activity under water stress. Fertilizing systems significantly affected the phosphorus content in which the highest amount of phosphorus was achieved in BF treatment under normal irrigation (Fig. 1). This result could demonstrate the activity of phosphate solubilizing of *lentus* and *pseudomonas* bacteria available in this biofertilizer.

TABLE-4
ANALYSIS OF VARIANCE FOR IRRIGATION AND FERTILIZING SYSTEM

Source of variation	MSE					
	df	P (%)	N (%)	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)
Rep	2	0.0001^{NS}	0.0003^{NS}	55.49^{NS}	8.91^{NS}	22.47^{NS}
Irrigation system	2	0.001*	0.03**	40.59^{NS}	14.36^{NS}	98.76*
Fertilizing system	5	0.003**	0.17**	1.22*	10.51**	8.87*
Irrigation system *fertilizing system	10	0.001**	0.04**	52.52*	7.52**	10.67**
CV(%)	–	5.65	2.82	9.00	4.66	3.47

NS: Not Significant; **: Significance level, $p < 0.01$; *: Significance level, $p < 0.05$.

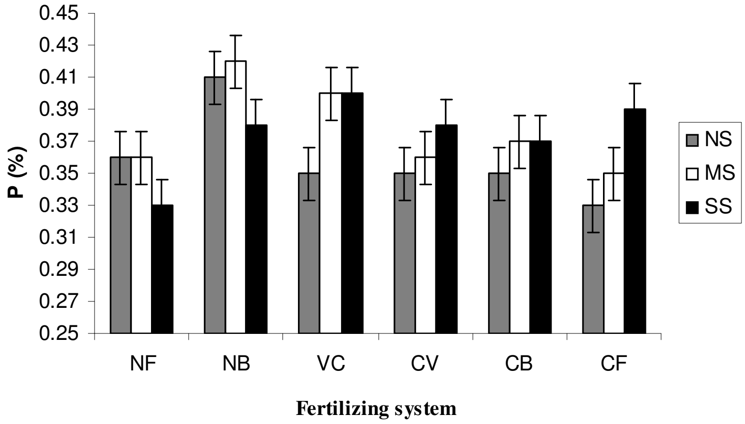

Fig. 1. Interaction effect of irrigation systems and fertilizing systems on P concentration of barley grain. NS = Normal irrigation until the end of the plant physiological maturity; MS = Ceased irrigation from the beginning of flowering (Zadoks, 65) to the initiation of seed filling stage (Zadoks, 70); SS = Ceased irrigation from the initiation of flowering stage (Zadoks, 65) to the end of the physiological maturity; NF = No fertilizing; NB = Phosphatic and nitrogenous biofertilizer; VC = Vermicompost; CV = 50 % chemical fertilizer including NPK + 50 % vermicompost; CB = 50 % chemical fertilizer including NPK + 50 % biofertilizer and CF = 100 % chemical fertilizer

Nitrogen: Irrigation system, fertilizing system and their interaction had significant effect on nitrogen concentration in grain (Table-4). The nitrogen content increased with water stress. In SS treatment the highest N % was achieved. Chemical fertilizer application increased nitrogen content though CF treatment had the highest N % among fertilizing systems in under all irrigation systems (Fig. 2). There are evidences that nitrogen content increases with increase in nitrogen source[19,20].

There was no significant difference in N content between organic fertilizers and control. It can be concluded that *Azetobacter* and *Azosprilum* bactria which are available in this biofertilizer are plant growth promoting because they promoted plant growth without any increase in N content.

Iron: The iron concentration was affected by irrigation and fertilizing systems and their interaction (Table-4). Iron content followed an increasing trend as water stress increased except for BF, NF and CB treatments (Fig. 3). Iron content reached to its highest level in CF and CV, respectively. The iron content in barely grain did not follow any special trend at different fertilizing systems and drought stress treatments.

The zinc content in grain was significantly affected by water stress, fertilizing system and their interaction effect. Increasing in water stress increased zinc in conventional (CF) and integrated (CB and CV) fertilizing systems (Fig. 4). Theses fertilizing systems had less zinc under normal irrigation compared to organic and control treatments.

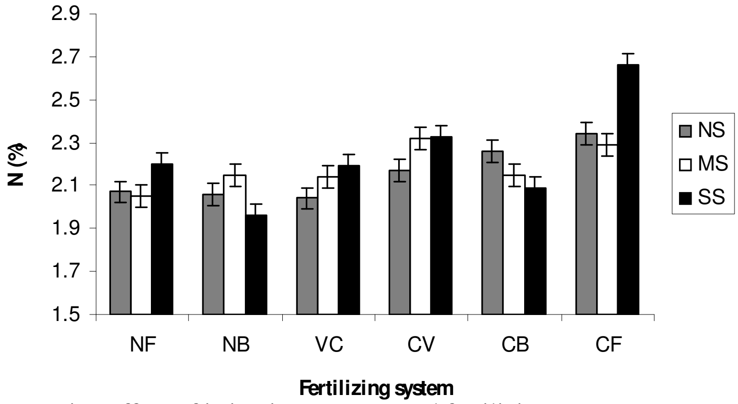

Fig. 2. Interaction effect of irrigation systems and fertilizing systems on N concentration of barley grain. NS = Normal irrigation until the end of the plant physiological maturity; MS = Ceased irrigation from the beginning of flowering (Zadoks, 65) to the initiation of seed filling stage (Zadoks, 70); SS = Ceased irrigation from the initiation of flowering stage (Zadoks, 65) to the end of the physiological maturity; NF = No fertilizing; NB = Phosphatic and nitrogenous biofertilizer; VC = Vermicompost; CV = 50 % chemical fertilizer including NPK + 50 % vermicompost; CB = 50 % chemical fertilizer including NPK + 50 % biofertilizer and CF = 100 % chemical fertilizer

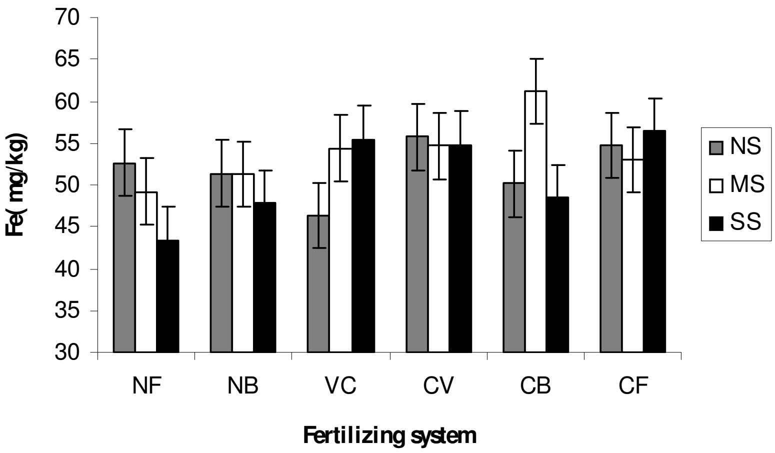

Fig. 3. Interaction effect of irrigation and fertilizing systems on Fe concentration of barley grain. NS = Normal irrigation until the end of the plant physiological maturity; MS = Ceased irrigation from the beginning of flowering (Zadoks, 65) to the initiation of seed filling stage (Zadoks, 70); SS = Ceased irrigation from the initiation of flowering stage (Zadoks, 65) to the end of the physiological maturity; NF = No fertilizing, NB = Phosphatic and nitrogenous biofertilizer; VC = Vermicompost; CV = 50 % chemical fertilizer including NPK + 50 % vermicompost; CB = 50 % chemical fertilizer including NPK + 50 % biofertilizer and CF = 100 % chemical fertilizer

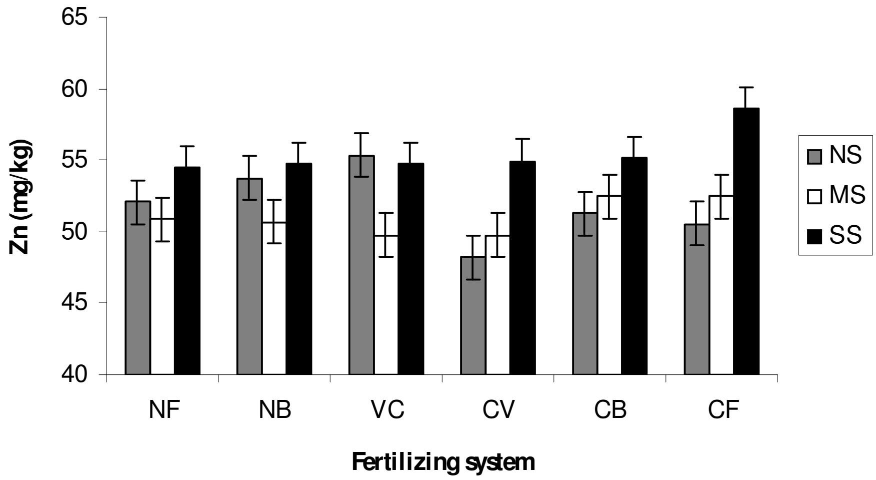

Fig. 4. Interaction effect of irrigation systems and fertilizing systems on Zn concentration of barley grain. NS = Normal irrigation until the end of the plant physiological maturity; MS = Ceased irrigation from the beginning of flowering (Zadoks, 65) to the initiation of seed filling stage (Zadoks, 70); SS = Ceased irrigation from the initiation of flowering stage (Zadoks, 65) to the end of the physiological maturity; NF = No fertilizing; NB = Phosphatic and nitrogenous biofertilizer; VC = Vermicompost; CV = 50 % chemical fertilizer including NPK + 50 % vermicompost; CB = 50 % chemical fertilizer including NPK + 50 % biofertilizer and CF = 100 % chemical fertilizer

Yield reduction in organic and control treatments under severe stress caused increase in Zn content compared to mild stress (MS).

Manganese: Irrigation system, fertilizing system and their interaction had significant effect on Mn concentration in barely grain (Table-4). The manganese concentration increased with water stress intensity in all fertilizing systems except control (NF) (Fig. 5). Chemical fertilizer treatment produced the highest level of Mn content followed by CV and VC treatments (Fig. 4). Under normal irrigation, fertilizing treatments which received chemical fertilizer, had higher amount. Chemical fertilizer increases Mn uptake with reducing soil pH [21]. In treatments with vermicompost Mn concentration increased under severe water stress condition. This increase can be related to high amount of Mn in vermicompost.

Application of organic manure reduces exchangeable Fe and Mn because these nutrient are available in low soil pH [22].

The trend towards less concentration of P, N, Zn and Mn in grain in response to normal irrigation revealed the dilution effect of NS treatment. Grain mineral concentration decreases with high yield[10]. Mobilization of nutrients from vegetative tissues into the grain can also be a significant source of micronutrients[3,20,23]. Plants suffering from nutrient deficiency during reproductive development may rely totally on reserves within the roots, stem and leaves for nutrient content of seeds[24].

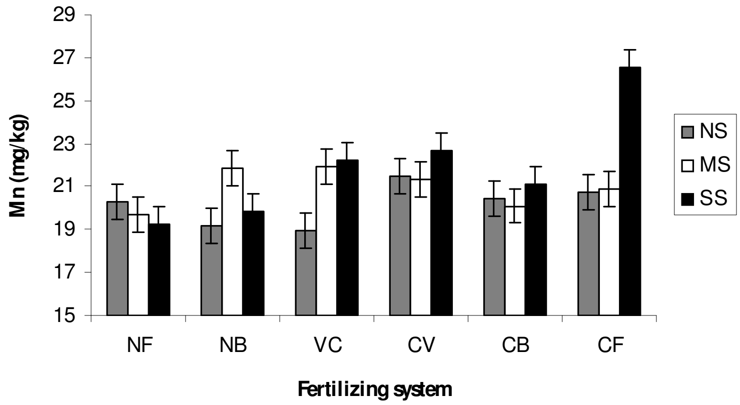

Fig. 5. Interaction effect of irrigation systems and fertilizing systems on Zn concentration of barley grain. NS = Normal irrigation until the end of the plant physiological maturity; MS = Ceased irrigation from the beginning of flowering (Zadoks, 65) to the initiation of seed filling stage (Zadoks, 70); SS = Ceased irrigation from the initiation of flowering stage (Zadoks, 65) to the end of the physiological maturity; NF = No fertilizing; NB = Phosphatic and nitrogenous biofertilizer; VC = Vermicompost; CV = 50 % chemical fertilizer including NPK + 50 % vermicompost; CB = 50 % chemical fertilizer including NPK + 50 % biofertilizer and CF = 100 % chemical fertilizer

Higher P concentration in nitrogen and phosphorus biofertilizer among other fertilizing treatments showed the efficiency of this biofertilizer to use insoluble soil P. This result confirmed the optimum soil P level for efficient utilization of phosphorus by P solubilizing bacteria in the soil (Fig. 1). Otherwise application of this biofertilizer could not have any advantage over other treatments[12]. In full irrigation treatment (NS) the highest P content of 0.43 % was obtained in biofertilizer fertilizing systems. However, at MS drought stress the amount of P decreased. This could happen by the decrease of bacteria population as affected by drought stress in biofertilizer treatment. At drought conditions P solubilizing and N fixing bacteria can not demonstrate their potential ability in P and N utilization in the soil[25]. In the same condition at the other fertilizing treatments, because of the drought stress and the availability of minerals and on the other hand, because of the unsuitable conditions for vegetative growth, the concentration of minerals, especially P, will increase in the plant tissue.

As drought stress increased, the N content of the barley grain followed an increasing trend in all fertilizing treatments (Fig. 2). This phenomenon was more obvious in chemical fertilizer treatment where the highest N content of 2.6 % reached at severe drought stress. The increment of N content at drought stress has been reported by many researchers[20]. The steep slope of N increment in vermicompost containing treatments of VC and CV could be because of higher mineralization rate at drought stress conditions. The mineralization rate would be accelerated at drought stress condition because of higher oxidation rate. Organic fertilizers provide less N to crop compared to chemical fertilizers because of less N input or inconsistency of N supply with crop demand. Integrated fertilizing can provide more N than organic fertilizer[26], though increase in N content in these treatments is attributed to more N input.

High levels of iron and zinc content in vermicompost resulted in more iron and zinc in CV and VC fertilizing systems (both contained vermicompost). Soil organic matter has direct effect on zinc and iron availability[11]. So, higher levels of iron and zinc uptake can be expected in treatments containing vermicompost. Probably, iron uptake increases with microbial activities and release of siderophores[3].

Pearson and Rengel[27] reported that zinc was remobilized from the leaves of wheat and that a greater percentage of zinc was remobilized from leaves in plants with a deficient zinc supply. Also in soybean more than 50 % of zinc is remobilized during pod filling[28]. The high concentration of zinc in treatments under stress (SS and MS) could be resulted from remobilization of zinc to the grain.

Iron has an intermediate mobility within the phloem[29]. According to Miller *et al.*[30], less than 20 % of iron contained in vegetative tissues were mobilized to the grain. Thus, Fe concentration did not change in different irrigation treatments because of low mobility. In NF, CV and CB treatment the iron content in the grain increased at MS and then decreased at SS treatment while at biofertilizer, vermicompost and chemical fertilizer treatments no response was observed at different drought stress levels compared to control (No drought stress). This result can prove genetic control of Fe content rather than environmental effects. Other researchers have also reported the genetical control of Fe content in plants in the previous experiments[31].

Ryan *et al.*[6], described that manganese in barley grain concentrations generally reflect soil exchangeable manganese and pH. It can be concluded that application of superphosphate on soil in chemical fertilizer treatment reduced soil pH and consequently increased manganese availability. The maximum manganese content of 26 mg/kg was achieved at chemical fertilizer treatment when severe drought stress was applied. In other fertilizing systems the fluctuation in manganese content was not significant. When the soil pH reaches to 7 or less because of environmental conditions, the availability of manganese will increase in soil and plant tissue. Thus application of vermicompost because of its organic matter content tends to decrease the pH of the soil and increasing exchangeable manganese and iron and this could explain the results obtained in this experiment[22].

Overall water limited system during seed development increased barley grain protein, phosphorus, nitrogen and micronutrient concentrations except for Fe content[20]. It can be concluded that water deficit condition during grain development was able to enhance nutritional value in barely grain. On the other hand integrated fertilizing systems including vermicompost and biofertilizer along with chemical fertilizers have the capacity to provide enough and healthy food in sustainable agricultural systems in Iran.

ACKNOWLEDGEMENT

The authors wish to express their full appreciations to University of Tehran for their technical, moral and financial supports which made this project possible.

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(*Received*: 14 August 2009; *Accepted*: 3 December 2009) AJC-8136