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THE ROLE OF MICRONUTRIENTS IN CROP PRODUCTION AND HUMAN HEALTH

MUHAMMAD IMTIAZ[1*], ABDUL RASHID[2], PARVEZ KHAN, M.Y. MEMON AND M. ASLAM

[1]*Soil Science Division, Nuclear Institute of Agriculture, Tando Jam, Sindh, Pakistan*
[2]*Pakistan Atomic Energy Commission, HQ, Islamabad, Pakistan.*
[*]*Corresponding author E-mail: drimtiaz64@yahoo.com*

Abstract

The soils in Pakistan across 22 Mha cultivated area are predominantly alluvial and loessal, alkaline in pH, calcareous and low in organic matter. These factors are mainly responsible for nutrient fixation in soil and low availability to plants. Zinc (Zn) deficiency in Pakistan was the first micronutrient disorder recognised in early 1970s as a cause of *hadda* disease in rice. After identification of Zn deficiency, extensive research has been carried out during last four decades on micronutrient deficiencies in soils and their drastic effects on crops. Subsequently, field-scale deficiencies of zinc (Zn) boron (B) and iron (Fe) have been established in many field and horticultural crops. The most widespread deficiency is of Zn as 70 % of the soils of Pakistan are Zn deficient and observed in rice, wheat, cotton, maize, sunflower, sugarcane, brassica, potato and in many other crops along with citrus and deciduous fruits. Boron deficiency is another major nutritional disorder which severely affects rice, cotton, wheat, sugarbeet, peanut, citrus and deciduous fruits. The third field-scale disorder is Fe chlorosis which has been exhibited in peanut, chickpea, cotton, citrus, ornamentals and many tree species. Copper (Cu) and manganese (Mn) deficiencies are of localized occurrence.

The mineral elements like Zn, Fe and Cu are as crucial for human health as organic compounds such as carbohydrates, fats, protein and vitamins. The daily dietary intake of young adult ranges from 10-60 mg for Fe, 2-3 mg for Cu and 15 mg for Zn. Intake less than these values can cause slow physiological processes. These micronutrients deficiencies in soil are not only hampering the crop productivity but also are deteriorating produce quality. High consumption of cereal based foods with low contents of micronutrients is causing health hazards in humans. The contents of micronutrients in food can be elevated either by supplementation, fortification or by agricultural strategies i.e., biofortification and application of micronutrients containing fertilizers. Food fortification and supplementation are too expensive, not practical to be applied on large scale and not easily accessible to poor masses. The development of micronutrient efficient genotypes can be a successive tool to overcome the micronutrient disorders in soil and for improvement in human health. However, the harvesting of micronutrient enriched grains from field would mine out more micronutrients. The cultivation of these genotypes can be integrated with the application of micronutrients containing fertilizers. Addition of such fertilizers will not only correct the deficiencies but also improve the fruit size and quality of crops. In general, 2-5 kg Zn ha^{-1} may be adequate for improved crop production, however, soil applied Fe is generally ineffective except for Fe-sequestrine. Repeated sprays of Ferrous sulphate ($FeSO_4$) or chelated Fe cure the chlorosis and improve the quality of food stuff. However, despite being highly cost effective, currently micronutrient use is negligible.

Introduction

The elements essential for plants are C, H, O, N, P, K, Ca, Mg, S, Fe, Cu, B, Mn, Mo, Zn, Cl. Out of these 16 elements, 9 essential elements have been classified as “macronutrients” as these are required in relatively large amount by the plants. These elements include C, H, O, N, P, K, Ca, Mg, S. The remaining of the elements (B, Cu, Fe, Mn, Mo and Zn) are called “trace elements” (Alloway, 1990; Brady & Weil, 2002). The group of essential elements includes both macro and trace elements. Essential trace elements are often called “micronutrients” because they are required in small, but in critical concentrations by living organisms. Out of 80 million hectare (Mha) geographical area of Pakistan, 22 Mha are cultivated. The cultivated soils of the country have derived from alluvium and loess, and are low in organic matter and many essential nutrients. The deficiency of Zn, Fe and Cu is the common feature of these soils. Being arid to semi arid area, about 75% of cultivated area is irrigated while the rest is rain-fed. The major cropping systems in the country are cotton- wheat, rice-wheat and mixed cropping like maize based and sugarcane based systems. Popular crops in rain-fed area are wheat, sorghum, peanut, chickpea etc. Usually two crops in a year is the normal routine unless moisture is a serious problem. As a matter of fact whole crop produce is removed from the field, hardly any crop residue is recycled back into the soil. In addition abundant soil moisture particularly during monsoon season may cause micronutrient leaching beyond the root zone (Rashid, 2005) while the soil surface due to dry spell may also retard the root absorption of micronutrients (Shorrocks, 1997). During the era of “Green Revolution” the high yielding crop varieties were introduced and their higher demand for nutrients also contributed to increased amount of micronutrients mining which lead to their deficiencies. Unfortunately, fertilizer application practice in Pakistan is predominantly in favour of nitrogen (N) and phosphorus (P) only, whereas potassium (K) use is limited to a few high K requiring crops like sugarcane and potatoes. Many introduced crop varieties are more susceptible to micronutrient deficiencies than landraces (Rashid & Din, 1992, Imtiaz *et al*., 2006).

According to a survey about 70% of the soils used for growing crops in Pakistan have low levels of available Zn (Rashid, 1996). Zinc deficiency in plants does not only reduce the yield but also the nutritional quality of grains. Hence soil conditions and agronomic practices are conducive to the incidence of micronutrient deficiencies in plants. The production of low micronutrient stuff has created concern about micronutrient-deficiency related health hazards especially in poor masses of society in developing countries of the world (Graham & Welch, 2002). It is imperative to initiate studies on such global problems with due attention. This paper will review the role of micronutrients in crop production and human health.

Micronutrient deficiencies: Deficiency of micronutrient in soil and plants is a global nutritional problem and is prevalent in many countries with different magnitude of severity. The identification of biological role of Zn by Raulin (1869) who observed that common bread mold (*Aspergillus niger*) did not grow in the absence of Zn. This observation introduced a new area for research in crops, and in 1914 first demonstration of Zn deficiency in plants was made by Mazé (1914) while the first identification of Zn deficiency in field conditions was reported by (Chandler, 1937) in the deciduous orchards of California. Deficiency of other micronutrient was established in the same era. The countries affected by micronutrient deficiency include USA, Australia, Turkey, India, Pakistan and other countries.

In Pakistan the first ever micronutrient deficiency was observed by Yashida & Tanaka (1969) who established that the cause of *Hadda* disease of rice in the Punjab was Zn deficiency. Field scale Zn deficiency in rice in Punjab was established in 1970 (Chaudhry *et al.*, 1976, 1977). During 1980, micronutrient deficiencies were recognized in a wide range of soils, crops and fruits in NWFP, Punjab, Balochistan, Sindh and Azad Jammu and Kashmir (Rashid & Qayyum, 1991). A wide spread deficiency of Zn, Fe and B in rainfed soils and crops of Pothowar plateau was also established in the same period (Rashid & Qayyum, 1991).

Diagnosis of micronutrients deficiencies - plant deficiency symptoms: As the micronutrient deficient plants may exhibit characteristic symptoms, plant symptoms can be useful indicator of micronutrient deficiencies. The most common symptoms of Zn deficiency include stunted growth, shortened internodes and petioles and small malformed leaves (little leaf) which result in “rosette” symptom in young growth of dicotyledons (Snowball & Robson, 1986) and “fan shaped” stem in monocotyledons (Grundon, 1987). Deficiency symptoms of Cu are dieback of stems and twigs, yellowing of leaves, stunted growth and pale green leaves that wither easily (Lewis, 1990). In case of iron deficiency chlorosis of young leaves is peculiar in many crops and fruit plants. Other micronutrients have also characteristics symptoms by which their deficiencies can be identified in plants.

Soil testing: It is practical and most widely used technique for predicting micronutrients deficiencies in crops. An ideal soil test is one which is rapid, reproducible and correlates reliably with responses in plant yield, plant specific nutrient concentration or uptake of that nutrient (Brennan *et al*., 1993). However, soil test levels at which micronutrient deficiency in plant can occur may vary to some extent according to soil type and crop species. Soil samples for the analysis can be taken at any time of the year but care is needed to ensure that a representative sample has been taken over the full area of the field. It is also important to avoid contamination of the soil samples by contact with metal equipment. The soil tests most widely used around the world include AB-DTPA (Soltanpour & Workman, 1977) and DTPA (Lindsay & Norvell, 1978). These are multi-element soil tests for alkaline soils and effective as conventional micronutrient tests for Cu, Fe, Zn and Mn (Imtiaz *et al*., 2006). Generalized micronutrient soil test interpretation criteria for determining micronutrient deficiencies in Pakistan are presented in Table 1.

Plant analysis: An alternative to soil testing is to analyse samples of leaves or grain to determine the micronutrient status of both crop and soil on which it is growing. However, it is not often possible to rectify the problem to prevent the losses in the existing crop, but once diagnosed, the deficiency can be treated for future crops in time to prevent further losses of yield. Leaf sampling practices vary with regard to which leaves are sampled and this is the result of local experience. However, in all cases, after sampling the leaves need to be thoroughly washed with distilled water and dried before grinding for analysis, taking care to avoid contact of the sample with external sources of micronutrients at all stages. Critical (or threshold) concentrations in leaf dry matter will also vary according to the species of plant and the position of the leaves on the plant. In general, critical leaf values range from 15 mg Zn kg^{-1} in rice, 20 mg Zn kg^{-1} in wheat, and 22 mg Zn kg^{-1} in maize and groundnut. (Alloway, 2003). Locally developed Zn plant analysis diagnostic criteria for selected crops have been presented in Table 2.

Factors affecting micronutrient bioavailability: Bioavailability of all four metallic micronutrients is significantly affected by soil pH, decreasing with increasing soil pH. Solubility of Fe decreases a thousand fold for each unit increase in soil pH in the range 4 to 9 (Lindsay, 1979), and consequently, most Fe deficiencies occur on calcareous soils. The activity (consequent bioavailability) of Mn, Cu and Zn decreases 100-fold for each unit increase in soil pH. Amounts of exchangeable metals in soil are related to their concentrations in soil solutions, so soil pH affects exchangeable Fe, Mn, Cu and Zn similarly (Table 4).

Table 1. Criteria for interpreting micronutrient soil test data.

Micronutrient	Soil test reagent	Concentrations (μg g^{-1}) considered to be Low
Zn	DTPA	<0.5
	AB-DTPA	<1.0
Fe	DTPA	<0.2
	AB-DTPA	<0.2
Cu	DTPA	<4.5
	AB-DTPA	<2.0
Mn	DTPA	<1.0
	AB-DTPA	<1.8

DTPA = Diethylene triamine pentaacitic acid
AB-DTPA = Ammonium Bicarbonate diethylene triamine pentaacitic acid
Source: Rashid *et al*., (1994), Rafique *et al*., (2002)

Table 2. Locally developed Zn plant analysis diagnostic criteria for selected crops.

Crop species	Critical concentration mg Zn kg^{-1}		
	Whole shoot	Leaves	Seeds
Wheat	16-20	12-16	20-24
Rice	20	19	15
Cotton	18	24	18
Sorghum	27-33	20-22	10-14
Rapeseed	29	33	29

Source: Rashid (2005)

Table 3. Physical and chemical properties of soils.

Soil	pH	P ug g^{-1}	CaCO3 %	Zn ug g^{-1}	CEC cmolc kg^{-1}	Clay %	LOI %
Pindorian	7.7	31.2	0.1	43.9	9.4	15	1.1
Gujranwala	8.0	2.5	0.1	54.0	12.5	22	1.3
Lyallpur	8.4	3.8	2.9	77.9	12.6	20	1.1
Kotli	7.3	5.6	0.1	80.9	28.5	58	2.6
Hafizabad	8.9	8.8	3.0	56.3	13.2	15	0.9
Jhatpat	8.4	4.3	18.7	78.9	29.8	68	1.9
Rajar	8.7	0.9	8.9	55.9	19.3	22	1.1
Shahdra	8.1	7.0	1.9	88.1	9.9	12	0.7
Woodcut 1	7.2	18.2	0.01	30.9	8.2	24	1.9
Woodcut 2	5.2	32.3	0.02	87.7	15.1	71	3.4
Sandhill	4.8	34.5	0.01	24.1	3.0	21	0.9

Source: Imtiaz *et al*., (2006)

Reactions with soil organic matter (SOM) significantly affect the bioavailability of these metallic micronutrients (Stevenson, 1991). Copper reacts with SOM to form very stable complexes with carboxylic and phenolic groups. Due to these stable complexes Cu deficiencies are often associated with organic soils. Reactions of Zn with SOM are also important in providing bioavailable Zn, but the strength of these bonds is not as strong as with Cu.

There are many other factors (Table 3) like calcium carbonate contents, clay contents, concentrations of other nutrients, salt affected soils and water logging which can affect the bioavailability of micronutrients to plants (Table 4).

Table 4. Langmuir equation parameters of different soils.

Soil	b ug g^{-1}	K ug ml^{-1}	r2	Soil	bug g^{-1}	K ml g^{-1}	r2
Pindorian	556	0.90	0.96	Jhatpat	1668	2.99	0.42
Gujranwala	588	1.30	0.91	Shahdra	556	2.25	0.99
Guliana	588	2.83	0.98	Rustam	667	7.5	0.98
Kotli	667	1.36	0.97	Sultanpur	714	4.66	0.99
Hafizabad	625	8.0	0.98	Lyallpur	625	5.33	0.99
Bhalwal	625	3.2	0.98	Woodcut 1	434	0.36	0.97
Matli	625	2.67	0.98	Woodcut2	714	0.19	0.84
Rajar	625	5.33	0.99	Sandhill	500	0.14	0.89

Source: Imtiaz *et al*., (2006)

Table 5. Relative sensitivity of crop species to zinc deficiency.

High	Medium	Low
Bean	Barley	Alfalfa
Citrus	Cotton	Asparagus
Flax	Lettuce	Carrot
Fruit trees	Potato	Clover
Grape	Soybean	Grass
Hops	Sudan grass	Oat
Maize (corn)	Sugar beet	Pea
Onion	Table beet	Rye
Pecan nuts	Tomato	Wheat
Rice		
Sorghum		
Sweet corn		

(Mainly derived from Martens & Westermann, 1991)

Soil types associated with widespread micronutrient deficiencies in crops: Although it is recognised that micronutrients deficiencies in crops can be found on many types of soils in the different bio - climatic zones of the world, there are a relatively small number of widely occurring types of soil which are more frequently associated with micronutrient deficiencies than any other. These are:

1. Calcareous soils
2. Organic soils
3. Sandy soils
4. Saline and Sodic (salt- affected) soils
5. Vertisols,
6. Gleysols (poorly drained/waterlogged soils).

Susceptibility of crops to zinc deficiency: All crops are susceptible to zinc deficiency, but species differ considerably in their ability to tolerate low levels of zinc supply. The relative susceptibilities of different crop species to zinc deficiency are given in Table 5.

From the Table above, it can be seen that the major food staples, rice, maize and sorghum are highly susceptible to deficiency. However, even though wheat has a relatively low susceptibility, it is still affected by deficiency in many parts of the world where the available zinc status of soils is very low. Much of the land in Asia and the Near East and Australia used for wheat production has either calcareous or sandy soils with very low zinc supply capacities and this causes yield losses of 20% or more over vast areas (e.g. 14.5 M ha in Turkey alone) (Malakouti, 2008). Paddy rice production on flooded soils is also very prone to zinc deficiency and it is estimated that up to 50% of all paddy rice production could be affected by zinc deficiency (Scharpenseel *et al*., 1983).

Improving crop yield and quality with micronutrients: Micronutrient deficiency can greatly disturb plant yield and quality, and the health of domestic animals and humans (Malakouti, 2007). Extensive research on the effects of micronutrient fertilizers on crop yield and quality has been conducted during the past decade (Malakouti *et al*., 2005). Results of a broad-based study conducted in 815 irrigated wheat growing regions of Iran to evaluate the effect of micronutrients showed an increase of 4 to 11% in wheat grain yield by the addition of each micronutrient (Fe, Zn, Cu, and B) or a combination of Fe + Zn + Cu + B to NPK fertilizer increased grain yield (Malakouti, 2000).

Appreciable crop yield increases under local conditions have also been observed in a number of crops at the farmers' fields. Average yield increases with Zn application are 22% in potato and sunflower, 18% in maize, 13% in wheat, 12% in rice and 8% in sugarcane (Anon., 1998). Average yield increases with B have been depicted from 7% to 21% in different crops (Anon., 1998, Rashid *et al*., 2006). In Pakistan, the peanut, potato and chickpea are severely affected by Fe deficiency and the yield increased recorded by the use of Fe averaged as 30% for peanut, 16% for potato and 15% for chickpea. Inorganic Fe salts except Sequestrene are generally ineffective in soil application. However, repeated foliar sprays of $FeSO_4$ or chelated Fe cure the chlorosis (Anon., 1998).

Mineral nutrient reserves in seed must also be adequate to sustain plant growth until root system takes over the nutrient supply function. During early establishment phase, the mineral nutrients are partly supplied by the soil. Therefore, information on mineral nutrient reserves in seed should be perfect from agricultural point of view and human requirements as well. It could provide an insight into these genotypes, which are high mineral element accumulators, and can best be utilized for human consumption as well as agricultural production. In the absence of systematic data it would be very difficult to determine the adequacy of our diet with respect to minerals. The seed of a number of wheat genotypes (local and exotic) was analysed for different micronutrients concentrations (Table 6) and it was found that none of these genotypes (except genotype SI-99-65) fulfil the quality standards set by the Harvest Plus. According to Harvest Plus, for improved micronutrient nutrition of humans, cereals grains should contain 50 to 60 mg kg^{-1} Zn and similar amount of Fe. This situation is very alarming and there is a dire need for an alternative and a rapid approach to improve mineral nutrient concentrations in cereals.

Table 6. Concentration of mineral nutrients in seed of different wheat genotypes.

Genotypes	Zn	Fe	Cu	Genotypes	Zn	Fe	Cu
	µg g^{-1}				µg g^{-1}		
SD-4	18.13	17.63	3.63	Indus-66	21.70	39.89	3.30
M-172	17.09	31.30	3.32	CM-24/87	24.40	26.23	3.27
Uqab	14.13	19.47	2.66	Anmole	42.87	30.03	3.27
WL-711	17.22	15.40	3.13	Pavan	31.87	23.50	2.90
7-03	17.40	20.27	3.93	RWM-9313	24.03	17.67	3.20
Zardana	19.01	18.63	3.38	M-233	24.70	27.03	3.40
Sonalika	28.21	16.00	2.95	A-4	24.37	39.93	4.17
Maxipak	12.72	17.57	3.77	A-7	32.53	27.83	3.23
Juhar-78	27.27	18.50	3.30	V-7001	22.80	52.43	3.37
SI- 99-257	21.08	16.27	3.79	V-7002	43.93	33.93	4.07
SI-99-77	22.66	18.40	3.91	V-7003	34.40	32.57	4.33
Soghat-90	18.22	14.03	3.44	V-7004	32.60	30.50	3.43
SI-97-71	31.37	18.17	3.83	V-7005	35.50	29.60	4.27
SI-99-261	42.23	29.23	3.40	V-7010	27.80	23.13	4.30
SI-97-151	40.90	31.03	3.60	V-7012	32.10	24.90	3.67
SI-99-76	43.13	32.30	3.45	V-7014	41.07	18.20	4.43
Abadgar	27.30	13.03	5.80	V-7015	32.30	23.07	3.13
Sindh-81	30.40	18.70	3.20	V-8001	36.07	24.53	3.17
SI-99-15	46.70	38.27	3.63	V-8003	32.97	19.92	3.37
ESW-9525	26.87	14.93	3.20	V-8004	35.13	22.10	3.10
Inqulab-91	25.37	14.23	4.00	V-8006	35.93	23.47	3.10
ESW-9639	25.67	25.43	4.30	IBW-96079	29.37	21.07	3.27
T.J-83	41.33	17.50	3.87	IBW-97170	22.47	17.37	3.00
15-10	41.73	37.50	2.93	CT-99186	31.83	25.37	3.23
Bakhtawar	33.20	18.27	4.20	CT-00054	28.33	21.03	3.37
SI-99-85	24.50	13.03	5.20	CT-97177	27.87	40.87	3.23
SI-99-50	26.50	15.60	4.17	IDA-97107	25.33	19.27	3.37
SI-99-239	45.30	20.47	3.40	Fakhr-e-Sarhad	28.53	26.20	3.63
SI-99-65	55.50	28.23	6.10	CT-0067	30.97	30.93	3.80
Iqbal	38.50	24.93	4.47	WS10	31.13	27.77	3.83
Kiran-95	28.07	23.10	4.67	IDA-97082	15.50	15.50	3.53
Khirman	26.07	21.80	4.07	IBW99110	24.97	25.67	3.47
SD-1200/1	28.45	16.60	4.07	IBW97249	25.67	21.74	3.90
ZA-77	31.93	32.67	3.07	CT-00231	23.73	30.50	3.57
Mangla	34.33	17.27	4.13	CT-00108	27.80	34.93	4.10
Sarsabz	29.07	15.33	3.13	IBW-97057	14.20	23.93	3.70
SI-99-50	28.47	13.47	5.10	IBW-96390	26.70	34.33	4.23
Yecora	24.57	13.27	4.27	IBW-96405	25.47	15.17	4.27
ESW-9650	29.33	24.33	3.33	CT-00019	29.80	38.93	3.90
CV (%)	11.37	11.25	10.92				
LSD	5.33	4.36	0.654				

Source: Imtiaz *et al*., 2005

Human health: Micronutrient malnutrition, the so-called hidden hunger, affects more than one-half of the world's population, especially women and preschool children in developing countries (Welch & Graham, 2004). The role of micronutrients such as vitamin A, iodine, iron and zinc in human nutrition has increasingly been recognized over the last decade. This has led to a change of paradigms in nutrition research and policy, away from the 'traditional' protein-energy-malnutrition (PEM) focus. The physiological impacts of micronutrients are complex, relating to many bodily functions. Zinc deficiency has serious consequences for human health including: impairment of the immune system and as a result, increased prevalence of childhood infections, such as diarrhoea and pneumonia; impaired growth and development of infants, children and adolescents; impaired maternal health and pregnancy outcome (Michael Martin, 2004). Not least the impact of zinc deficiency on immune system defects is of interest in South Asia where as much as 95% of the population is at risk, due to poverty and rice-pulse diets (Brown & Wuehler 2000). Trials conducted in several countries indicate that duration and severity of major baby-killers such as diarrhoea and pneumonia can be reduced by 30-50 % by supplying adequate amounts of vitamin A and zinc (Bhargava *et al*., 2001). In developing countries, zinc deficiency ranks 5th among the leading 10 risk factors. Even on a global scale, taking developed and developing countries together, zinc deficiency ranks 11th out of the 20 leading risk factors. WHO attributes 800,000 deaths worldwide each year to zinc deficiency and over 28 million healthy life years lost (Anon., 2002). It is estimated that zinc deficiency affects one-third of the world's population, with estimates ranging from 4 to 73% according to region and it is 5th leading risk factor (Table 7) alongwith the Fe deficiency which is at 6th position globally (Anon., 2002).

Pakistan has also been affected by the malnutrition of both these elements. Iron and Zn deficiencies are extremely high in pregnant/lactating women as well as in very young children (Anon., 2000). This confirms the high levels of anaemia and other Zn related diseases in these groups. It has been estimated that extent of Zn deficiency in population ranges from 36 to 49% and that of Fe deficiency from 45 to 65% (Table 8). There is a dire need for a rapid approach to improve mineral nutrient concentrations in cereals. Different strategies listed below can be helpful in enhancing the micronutrient densities in staple foods.

Supplementation: Providing Zn or other micronutrients in tablets, syrups etc., to vulnerable groups through health care is possible (Strand, 2003), but may not be a practical solution in socially or geographically marginal populations.

Food fortification: The addition of nutrients to commonly eaten foods, beverages or condiments. It has played a major role in eliminating micronutrient deficiencies in industrialized countries. Infant formulas, infant cereals and ready-to-eat breakfast cereals are often fortified with Zn. Mexico is presently conducting a national, voluntary zinc fortification program, where Zn and other micronutrients are added to wheat and corn flours used for preparing bread and tortilla. Fortification of wheat flour with Fe is an option which also being carried out at NIFA, Peshawar in Pakistan. In Thailand, Zn and Fe enriched noodles are being marketed. With regards to Zn supplies to the poorer parts of the population in South Asia, there has not yet been identified a good food vector. Despite past progress in controlling micronutrient deficiencies through supplementation and food fortification, new approaches are needed to expand the research of food-based interventions possibly through agricultural strategies (Anon., 2007).

Table 7. Leading 10 risk factors in developing countries as percentage causes of disease burden.

Under weight	14.9%
Unsafe sex	10.2%
Unsafe water	5.5%
Indoor smoke	3.7%
Zinc deficiency	3.2%
Iron deficiency	3.1%
Vitamin A deficiency	3.0%
Blood pressure	2.5%
Tobacco	2.0%
Cholesterol	1.9%

Source: (Anon., 2002)

Table 8. Human Zn and Fe deficiency in Pakistan.

	Zinc deficient %	Iron deficient %
Children		45%
Male	36	
Female	38	
Women		65%
Pregnant	49	
Non-pregnant	40	

Source: (Anon., 2000).

Biofortification: Biofortification, a new approach that relies on conventional plant breeding and modern biotechnology to increase the micronutrient density of staple crops, holds great promise for improving the nutritional status and health of poor populations in both rural and urban areas of the developing world (Graham & Welch, 1996). Biofortification provides a sustainable solution to Fe and Zn deficiencies in food around the world as it is the process of enriching the nutrient contents of staple crops. Biofortification of staple food crops with micronutrients by either breeding for higher uptake efficiency or fertilization can be an effective strategy to address widespread dietary deficiency in human populations (Bouis *et al.*, 1999). The lack of micronutrients such as Fe and Zn is a widespread nutrition and health problem in developing countries. Reports have highlighted the current strategies for the biofortification of crops, including mineral fertilization, conventional breeding and transgenic approaches. Any approach which could increase root growth and result in a high transfer of Fe and Zn from the soil to the plant is crucial for biofortification (Graham, 1984).

Genotypic differences in micronutrient use efficiency: Micronutrient efficiency is the ability of a crop to grow and yield well when the availability of the micronutrient is low. Field and growth room screening has shown significant genetic variation in Zn and manganese (Mn) efficiency in winter cereals, which indicates that selection for improved micronutrient efficiency is possible.

When grown on soils with low micronutrient availability due to either chemical or biological fixation, or spatial or temporal unavailability, micronutrient-efficient genotypes have a greater yield in comparison to inefficient ones (Imtiaz *et al.*, 2006), even when fertilized with smaller amounts of fertilizers or less frequently. Generally, micronutrient-efficient genotypes are capable of increasing available soil micronutrient pools through changing chemical and microbiological properties of the rhizosphere as well as by growing thinner and longer roots and having more efficient uptake and transport systems. For Zn-efficient genotypes, more efficient utilization of Zn in tissue also contributes to overall Zn efficiency. Understanding micronutrient efficiency mechanisms is important for designing suitable screening techniques for breeding micronutrient-efficient genotypes. Growing micronutrient-efficient genotypes contributes to environmentally-benign agriculture by lowering the input of chemicals and energy. These genotypes also offer a potential for producing grain for human consumption with higher concentration of Fe, Zn and Cu, the three micronutrients that about a third of the world population is deficient. Such studies have been conducted in Pakistan with many domestic and exotic wheat genotypes for Zn efficiency (Imtiaz *et al*., 2006) which show that these genotypes have different Zn efficiencies which can be exploited for biofortification strategies (Table 9).

Breeding strategy is however, a long term process requiring different types of efforts and resources and it is uncertain whether the breeding strategy will work or not after these long term efforts over many years and huge investments. Apart from these constraints, harvesting of micronutrient-enriched grains from the field through bio-fortified genotypes can remove more these from land and cause rapid depletion of available soil micronutrients, further aggravating deficiencies in soil. A successful breeding program for bio-fortifying cereals is very much dependent on the amount of plant available micronutrients in the soil.

Table 9. Zinc efficiency (%) of various wheat genotypes.

Cultivar	**Country**	**Efficiency %**
Excalibur	Australia	16
Songlen	Australia	20
Gatcher-S61	Australia	59
Wilgoyne	Australia	47
Gatcher-S62	Australia	33
Durati	Australia	10
CBWF-96-49	Turkey	33
CBWF-96-50	Turkey	37
CBWF-96-46	Turkey	35
CBWF-96-108	Turkey	33
Kunduru	Turkey	41
Consort	England	32
Riband	England	29
Hereward	England	33
Charger	England	33
Encore	England	31
Chakwal-86	Pakistan	23
Inqulab	Pakistan	34
Pasban	Pakistan	28
Rawal-87	Pakistan	39
Pothwar	Pakistan	55
Rohtas	Pakistan	35
Bakhtawar	Pakistan	63
Pak-81	Pakistan	36
Pirsabak	Pakistan	48

Source: Imtiaz *et al*., (2006)

Fertilizer strategies: Micronutrient deficiency is widespread in many Asian countries including Pakistan due to the calcareous nature of soils, high pH, low organic matter, salt stress, continuous drought, high bicarbonate content in irrigation water, and imbalanced application of fertilizers. Some of the adverse effects of micronutrient deficiency-induced stress in plants include low crop yield and quality, imperfect plant morphological structure (such as fewer xylem vessels of small size), widespread infestation of various diseases and pests, low activation of phytosiderophores, and lower fertilizer use efficiency (Alloway, 2003). The absence of micronutrient fertilizers results in inadequate absorption of trace elements by plants, which causes substantial yield losses in different crops and forages, and eventually results in poor health for domestic animals and humans (Anon., 2007). Calcareous soil research results of the last decade show that at the present time, among micronutrients, Zn deficiency is the most detrimental to effect crop yield. Other important micronutrients that increase crop yield (most to least effect) are Fe, B, Mn, Cu, and Mo. In the case of calcareous soils, the conventional notion that micronutrients increase crop yield by 15-30% is an underestimated range. In fact, in some cases, especially with inefficient cultivars such as durum wheat (*Triticum durum* L.), micronutrients can increase grain yield up to 50%, as well as increase macronutrient use efficiency (Malakouti, 2007). By supplying plants with micronutrients, either through soil application, foliar spray, or seed treatment, increased yield and higher quality, as well as macronutrient use efficiency, could be achieved (Imtiaz *et al*., 2006), (Fig. 1).

The application of micronutrient fertilizers not only increase the yield of the crop but also increase the density of nutrients in the grain (Fig. 2), which is now prerequisite for the human health. Adding regular fertilizer to soil for crop production can be a better strategy along with the biofortification as it is simple, requires less efforts and provides substantial benefits as mentioned above. In our local soil conditions, following rates of micronutrients application have been recommended for better harvest (Table 10).

Conclusion

Micronutrients nutrition of crops has immense economic importance since an adequate supply of micronutrients can help to ensure that optimum yields are obtained with the given inputs of other crop requirements. It is essential that the available micronutrients status of arable soils is checked on a regular basis to ensure that easily preventable deficiency is not adversely affecting crop productivity and quality. As the deficiency of Zn is widespread in our country, the farmers and agronomists need to always think about Zn.

Table 10. Zinc and Fe use recommendations for different crops.

Species	Dose and method of application
Zinc	
Field crops and vegetables	*2–5 kg ha^{-1}
Rice	20 kg Zn ha^{-1} Nursery area
Fruit orchards	3 Foliar sprays (0.1% Zn Solution)
IRON	
Field crops and fruits	3–4 Foliar sprays (0.5% $FeSO_4$ OR 1% *Sequestrene* solution)

* Lasts 3–4 Crop seasons

Source: Rashid, 2005 , 2006

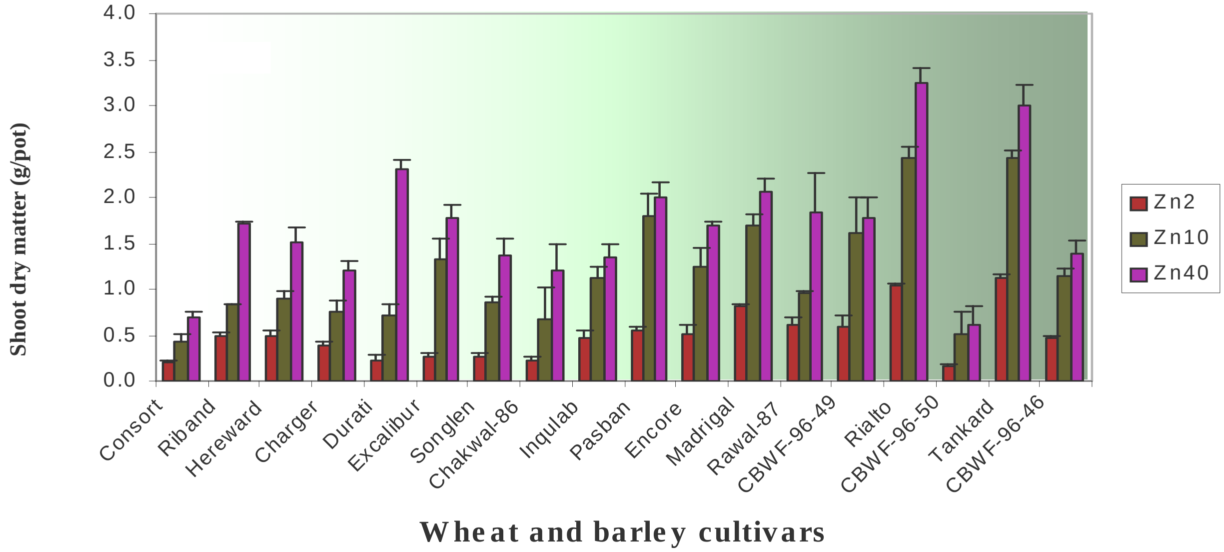

Fig. 1. Effect of Zn activities on wheat and barley shoot dry matter.

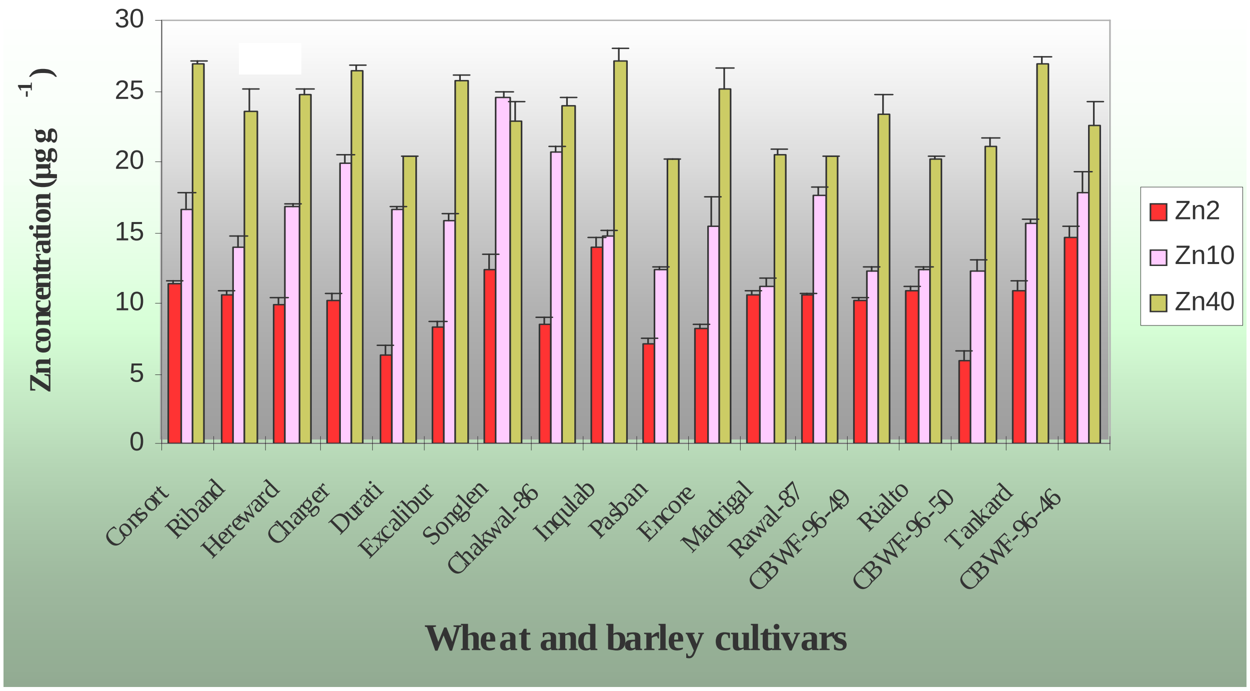

Fig. 2. Effect of Zn activities on Zn concentrations in wheat and barley grain.

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