Cereal Research Communications 36(4), pp. 571–582 (2008)
DOI: 10.1556/CRC.36.2008.4.6

Effect of Soil Applied Zinc Sulphate on Wheat (*Triticum aestivum* L.) Grown on a Calcareous Soil in Pakistan

†M.A. KHAN[1], M.P. FULLER[2]* and F.S. BALOCH[3]

[1]University College of Agriculture, Bahauddin Zakariya University, Multan 60800, Pakistan
[2]School of Biological Sciences, University of Plymouth, Drake Circus, Plymouth, PL4 8AA, UK
[3]Department of Field Crops, Faculty of Agriculture, University of Cukurova, Adama, 01330, Turkey

(Received 19 December 2007; accepted 17 March 2008)

A field experiment was conducted to investigate the effect of soil application of zinc fertilizer on yield and yield components of wheat (*Triticum aestivum* L. cv. Inqlab 91) grown on calcareous soil in Pakistan. The levels of zinc sulphate were 0 (control), 5, 10, 15, 20, 25 and 30 kg ha^{-2} and the zinc sulphate was combine-drilled at the time of sowing. Zinc sulphate increased the Leaf Area Index, the total number of fertile tillers m^{-2}, number of spikelets $spike^{-2}$, spike length, grain $spike^{-2}$, thousand grain weight, grain yield, straw yield and biological yield and decreased harvest index. Most of the response trends were curvilinear although the decrease in harvest index was linear. All applications of zinc sulphate gave economic increases in margins over costs but the application of 5 kg ha^{-2} gave the highest marginal rate of return. It is recommended that under such calcareous soil conditions growers can expect good returns from the application of 5 kg zinc sulphate ha^{-2} at the time of sowing but if the grain price were to increase or the price of zinc sulphate were reduced economic responses could be expected from higher levels of zinc sulphate.

Keywords: zinc, zinc-deficient calcareous soils, yield and yield components, *Triticum aestivum* L.

Introduction

The importance of nutrients (micro and macro) for the normal growth of crop plants is universally recognized. In under-developed and developing countries however, plant nutrition is not being used in optimal and balanced levels and as a consequence the production potential of soils is frequently not being fully ex-

* Corresponding author; E-mail: M.Fuller@plymouth.ac.uk

0133-3720/$20.00 © 2008 Akadémiai Kiadó, Budapest

ploited and the application of only major plant nutrients (N, P and K) is not adequate to achieve full potential yield of crops in many agricultural systems.

Zinc is an important essential element present in plant enzymatic systems. Genc et al. (2006) reported that zinc has vast numbers of functions in plant metabolism and consequently zinc deficiency has a multitude of effects on plant growth. Zinc deficiency is a worldwide nutritional constraint for crop production in many types of soil in the world (Sillanpää 1982; Rengel and Graham 1995) and particularly in cereals growing on calcareous soil (Graham et al. 1992; Cakmak et al. 1996a; Singh et al. 2005). In Pakistan, zinc deficiency is a widespread micronutrient disorder on calcareous soil (Rafique et al. 2006) and is considered the third most common deficient nutrient after nitrogen and phosphorous (NFDC, 1998).

Cereal crops occupy a prime position in providing food for human consumption and according to Graham and Welch (1996) about 50% of the soil used for cereal production in the world contains a low level of plant available zinc which reduces not only grain yield but also nutritional quality (low in micronutrients essential for good human health). Cereal grains are a major source of zinc intake for persons living in developing countries and zinc deficient cereal food is creating serious health problems. Seed zinc concentrations of wheat grown under zinc deficient conditions are very low (Erdal et al. 2002). The fact that at least 60% of cultivated soils have growth-limiting problems with mineral-nutrient deficiencies and toxicities, and about 50% of the world population suffers from micronutrient deficiencies make plant nutrition research a promising avenue to meeting the global demand for sufficient food production with enhanced nutritional value in this millennium (Cakmak 2002).

Zinc has been found useful in improving yield and yield components of wheat (Cakmak et al. 1996; Modaihsh 1997; Kaya et al. 2002; Singh 2004) and adequately applied zinc has been shown to improve the water use efficiency of wheat plants (Bagci et al. 2007). High temperature during maturation and ripening is a major stress in many wheat production areas (Gibson and Paulsen 1999), including Pakistan, and zinc can help provide thermo-tolerance to the photosynthetic apparatus of wheat (Graham and McDonald, 2001). In general zinc application appears to improve the overall field performance of wheat plants. The study reported here was designed to investigate the effect of soil applied zinc on yield and yield component of wheat grown on a calcareous drought-prone soil in Multan, Pakistan.

Materials and Methods

Experimental design, soil conditions and crop sowing

A field trial was conducted to study the response of wheat *Triticum aestivum* cv. Inqlab 91 to soil applied zinc under silt loam calcareous soil in Multan (Pakistan) during the crop season of 2005. The experiment was laid out in a randomized block design with seven zinc treatments and three replications with a plot size of 2.5 m × 12 m. Zinc sulphate was used as a source of zinc at the following levels 0, 5, 10, 15, 20, 25 and 30 kg ha^{-1}. Before fertilizer application, 30 cm soil samples showed Ece 0.80 dsm^{-1}, pH 8.1, available phosphorus 19 mg kg^{-1}, nitrogen 0.04%, available potassium 121 mg kg^{-1}, zinc (DTPA extractable) 0.6 mg kg^{-1}, manganese 0.8 mg kg^{-1}, iron 5.5 mg kg^{-1} and copper 0.8 mg kg^{-1}. Bansal et al. (1990) reported that the critical level of zinc for wheat in alkaline soils of semi-arid regions of the Punjab, India was 0.75 mg kg^{-1} soil of DTPA extractable zinc. Given these figures it appears that the soil type used in this investigation can be classified as having zinc deficiency.

The crop was sown on 29th of November 2005 into a well-prepared seed bed in rows 22.5 cm apart with a single row hand drill at a seed rate of 150 kg ha^{-1}. Except for zinc application, all other agronomic practices were kept same for all experimental units. The levels of zinc sulphate were independently randomized in each block and combine drilled at the time of sowing.

Crop data, statistical and economic analyses

During crop growth, sequential destructive samples of 10 plants per plot were taken 40, 52, 64 and 76 days post sowing and leaf area measured using a leaf area meter and leaf area index (LAI) computed.

Prior to harvest a one meter row-length of wheat plants was randomly selected from each plot and all tillers were counted and computed to number of tillers m^{-1}. Data on plant height, spike length and grains $spike^{-1}$ were recorded on ten randomly selected tillers from each plot. Plant height was measured from ground level to the tip of the ear. Spikes of all ten tillers were cut and removed and data on spike length and spikelets $spike^{-1}$ were recorded. At maturity, a further 10 spikes were collected threshed and grain number counted and averaged to give the number of grains $spike^{-1}$.

The crop was harvested manually from each plot separately and the harvested plants tied into bundles and stacked for sun drying until constant weight to give the biological yield (above ground). Each plot was then threshed manually and

grain and straw separated by winnowing. Grain yield was obtained by weighing the entire grain portion of each plot and straw yield obtained by subtracting the grain yield from the biological yield. Three samples of 1000 grains were randomly taken from the grain, weighed and averaged to provide the 1000-grain weight. Harvest index was obtained by calculating the ratio between the grain yield and biological yield, expressed as a percentage.

The data were analyzed using the statistical computer based program MSTAT. Differences among treatments were compared using least significant differences (LSD) at 5% level of probability. Response trends were fitted to the data using first or second order polynomials curve fitting (Microsoft Excel) and coefficients of determination (R^2) calculated.

Economic analysis was carried out on a marginal return over costs of inputs CIMMYT (1988) based on a price of 0.686 USD per kg zinc sulphate and 100 USD per tonne of wheat.

Results

Leaf Area Index

The analysis of LAI revealed that significant differences between treatments were established by 40 d post sowing with each of the zinc applications leading to an incremental increase in LAI (Fig. 1). These increases were maintained through to ear emergence but their relative difference did not alter substantially. Maximum LAI's obtained were in the range 2.0 to 2.5 at ear emergence.

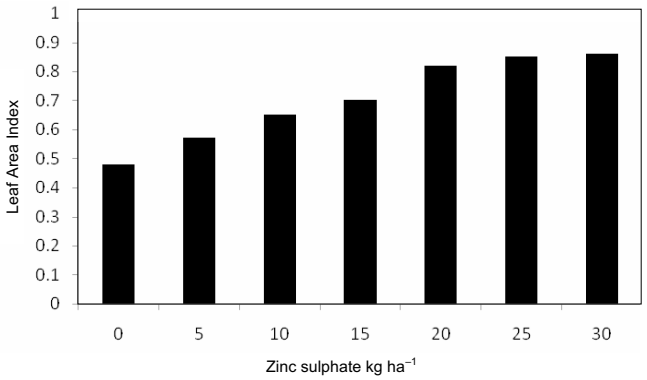

Figure 1. Recorded levels of Leaf Area Index ($LSD_{0.05}$ = 0.11) 40 days post sowing of wheat grown with differing levels of zinc sulphate supplementation

Yield

Yield was significantly improved by the application of zinc sulphate (Fig. 2). Improvements were consistent for both grain and straw components although the increases were greater for straw than for grain. The net effect of these disproportionate increases was that the Harvest Index decreased with increasing applications of zinc (Fig. 3). The increased straw yield was accompanied by significant

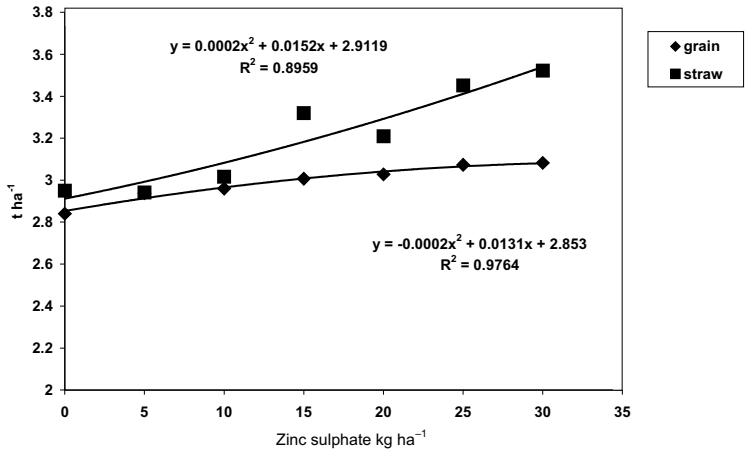

Figure 2. Changes in grain ($LSD_{0.05}$ = 0.0991) and straw yield ($LSD_{0.05}$ = 0.1109) of wheat grown with differing levels of zinc sulphate supplementation

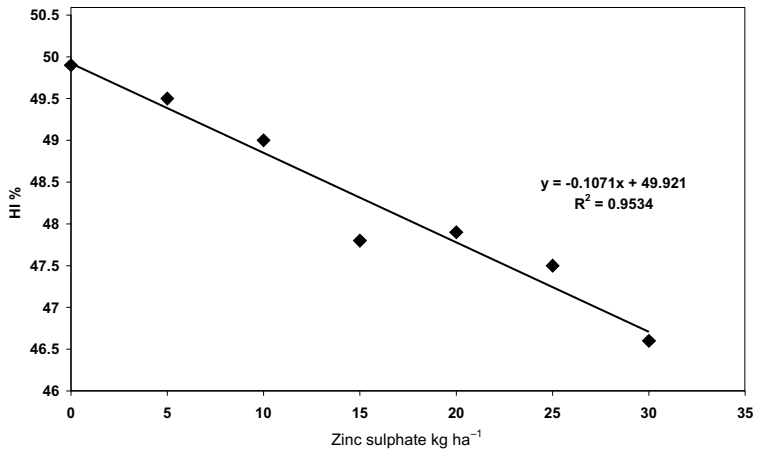

Figure 3. Changes in Harvest Index of wheat grown with differing levels of zinc sulphate supplementation ($LSD_{0.05}$ = 1.27)

and consistent increases in plant height (Fig. 4) and small but consistent increases in straw density (data not shown).

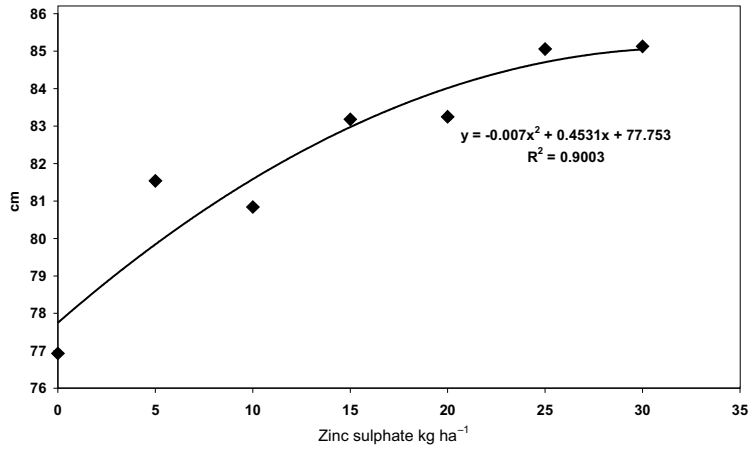

Figure 4. Changes in plant height of wheat grown with differing levels of zinc sulphate supplementation ($LSD_{0.05}$ = 2.52)

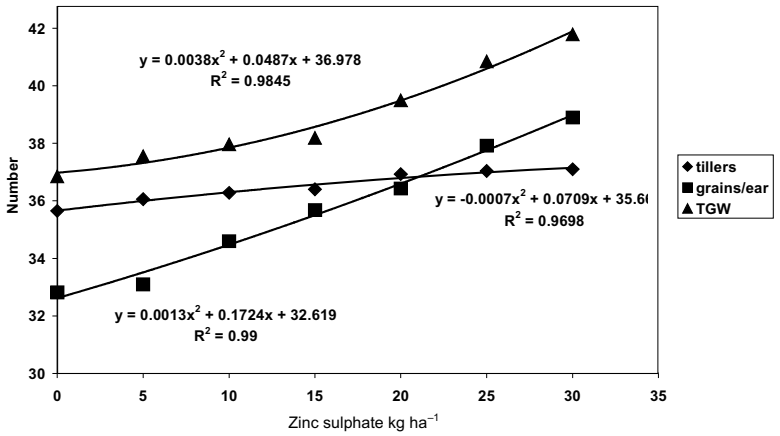

Figure 5. Changes in the components of grain yield (fertile tillers m^{-1} (× 10^{-1}) ($LSD_{0.05}$ = 10.19), grains per ear ($LSD_{0.05}$ = 3.41), TGW ($LSD_{0.05}$ = 3.10)) of wheat grown with differing levels of zinc sulphate supplementation

Components of Grain Yield

The three components of grain yield, fertile tillers m^{-1}, grains ear^{-1} and thousand-grain weight (TGW), all increased with increases in zinc sulphate application (Fig. 5). Proportionately, grains per ear and TGW increased more dramatically than fertile tillers m^{-1} and these components were therefore more responsible than changes in fertile tiller numbers for the changes in grain yield.

Grains per ear is the product of spikelets per ear and grains per spikelet and an analysis of this showed that there were significantly more fertile spikelets per ear but that spikelet fertility remained relatively constant at 1.5 to 1.6 grains per spikelet at increasing levels of zinc application. The increased number of spikelets per ear led to incremental increases in spike length which paralleled that of the increases in straw length.

A theoretical prediction of grain yield can be computed from the measured components of yield in order to determine the relative accuracy of the components and to inform the precision of the sample used to measure the components. This was carried out and plotted against measured grain yield (Fig. 6). Whilst the theoretical grain yield overestimated the actual yield by a factor of 1.75 to 2.0 the relative rankings of the yield were very similar and this lends confidence to the relative values of the measured yield components.

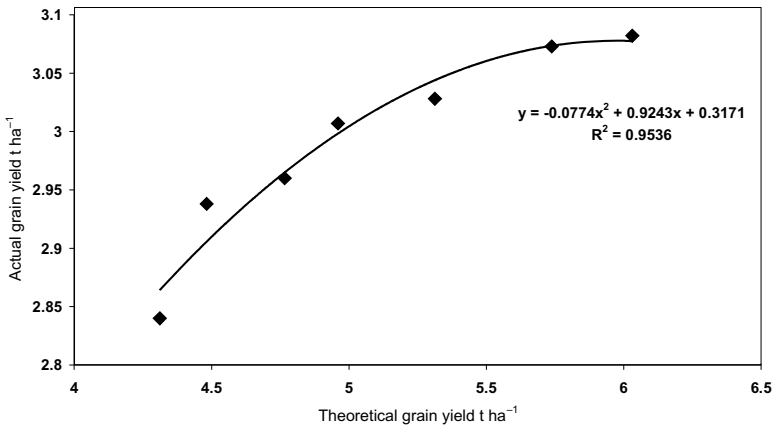

Figure 6. Theoretical grain yield (computed from the measured yield components) versus measured grain yield

Economic analysis

Economic analysis of the results showed that all applications were economic but there was little extra benefit over the first application rate of 5 kg ha^{-1}. This application gave a marginal return over investment in zinc sulphate of 185.8% whereas all further increases in zinc yielded investment improvements less than 100% (Table 1). The marginal rate of return decreased exponentially from the lowest application to the highest.

Table 1. Economic analysis of soil applied zinc sulphate to wheat (*Triticum aestivum* L.)

ZnSO4 (kg ha^{-1})	Cost of $ZnSO_4$ (USD ha^{-1})	Gross Returns (USD ha^{-1}) (grain price = 100 USD t^{-1})	Marginal benefit over Costs and Control (USD ha^{-1})	Marginal rate of return over investment in $ZnSO_4$ (%)
0	0	284	–	–
5	3.43	290.37	6.37	185.8
10	6.86	289.14	5.14	75.0
15	10.29	290.41	6.41	62.4
20	13.71	289.09	5.09	37.1
25	17.14	290.16	6.16	35.9
30	20.57	287.63	3.63	17.6

Discussion

Zinc applications had positive effect on plant growth leading to increased LAI, plant height, number of fertile tillers m^{-2}, number of filled spikelets $spike^{-1}$, spike length, grains $spike^{-1}$, biological and straw yields and 1000-grain weight culminating in improved grain yield. The apparent mechanism for achieving these improvements was the increase in leaf area index, providing an improved resource generating base for the crop, i.e. an improved carbohydrate source. The consequence of this improved source was the improvement in overall biomass and consequently improvements in yield components of the crop. Improvements in fertile tillers m^{-2} and number of filled spikelets $spike^{-1}$ are important aspects to achieve more grains per unit land area. Elsewhere it has been reported that semi-dwarf wheat varieties, due to better exploitation of assimilates to the ear during pre flowering period, resulted in more fertile florets (Calderini et al. 1995; Miralles et al. 1998) but improved floret fertility was not a significant factor. Whilst zinc applications improved biomass production, assimilate partitioning in favour of grain yield actually decreased as evidenced by the depression in harvest index. Increases in grain yield were a result of the disproportionate increase in biomass relative to the drop in harvest index. Other workers have also reported

that zinc application improved spike length and effective tillers plant^{-1} (Islam et al. 1999) and number of grains plant^{-1} (Genc et al. 2006). Both this previous work and the results presented here showed that increased number of grains plant^{-1} were not at the cost of grain weight. Zinc has been reported elsewhere as being effective in increasing dry matter production in wheat plants (Imtiaz et al. 2003; Ozkutlu et al. 2006) and it appears that its application acts like nitrogen addition to nutrient rich soil, stimulating greater biomass productivity at a greater proportion to the decrease in harvest index.

It is of interest to note that the fundamental principles of wheat growth and development apply in this example even when the crop is under severe limitation as evidenced by the relatively low LAI's and modest yields recorded.

The results reported indicate that zinc is a limiting factor in wheat growth in these situations. Zinc deficiency has been reported to cause stunted plant growth (Imtiaz et al. 2003) and as shown here, the impact of zinc stress on wheat growth in zinc-deficient calcareous soil can be mitigated by zinc fertilization. Optimum plant height of semi-dwarf wheat varieties ranges between 70 and 100 cm (Flintham et al. 1997) and zinc application increased plant height from 76.93 to 85.13 cm and this correlated with the increase in grain yield.

Generally, the wheat growing areas of Pakistan including Multan face high temperature stress during reproductive growth of wheat plants. Both the rate of dry matter accumulation and duration of reproductive growth are reduced with high temperature during grain development and filling (Gibson and Paulsen 1999). Zinc application has been reported to increase thermo-tolerance of the photosynthetic apparatus of wheat (Graham and McDonald 2001). It is possible in our experiment that zinc improved thermo-tolerance to the photosynthetic apparatus of wheat throughout the life cycle of the crop since both pre- and post-anthesis yield components of the crop were improved by the applications.

Genetic improvement of the wheat crop in the past has mostly been obtained from increased number of grain m^{-2} and harvest index (Slafer and Andrade 1991; Reynolds et al. 1999; Brancourt-Hulmel et al. 2003) and improvement in grain yield also attributable to improved biomass production particularly through fertilizer additions and crop protection (Siddique et al. 1989; Donmez et al. 2001). Modaihsh (1997) also reported that zinc application improved biological yield as well as grain yield of wheat grown on calcareous soils and this is supported here.

Every agronomic improvement in crop performance must be judged against the costs of the agronomic application if the technology is going to be adopted into current farmers practice. A minimum marginal rate of return as low as 50% on costs may be acceptable (CIMMYT 1988) but returns over 100% are preferred. In this experiment all applications zinc sulphate gave significant financial returns

marginal rates of return but only one, 5 kg ha^{-1}, gave a marginal rate of return in excess of 100%. It would appear therefore that the most economical dose rate is 5 kg ha^{-1} zinc sulphate. Clearly this analysis is dependent on the price of zinc sulphate and the price of grain and could alter if either of these prices altered significantly.

In conclusion, it was observed that zinc sulphate application in zinc deficient calcareous soils improved the efficiency of wheat plants to increase the yield components and grain yield of wheat. The results indicate that this is as a result of improved LAI and biomass. Zinc applications actually decreased harvest index but this marginal reduction was compensated for by a greater biomass increase. It seems probable that the supplied zinc had a mitigation effect of high temperature stress during reproductive growth. It is recommended that under such calcareous soil conditions growers can expect good returns from the application of 5 kg ha^{-1} zinc sulphate at the time of sowing.

References

Bagci, S.A., Ekiz, H., Yilmaz, A., Cakmak, I. 2007. Effect of zinc deficiency and drought on grain yield of field-grown wheat cultivars in Central Anatolia. Journal of Agronomy and Crop Science **193**:198–206.

Bansal, R.L., Takar, P.N., Bhandari, A.L., Rana, D.S. 1990. Critical level of DTPA extractable Zn for wheat in alkaline soils of semiarid region of Punjab, India. Nutrient Cycling in Agroecosystems **21**:163–166.

Brancourt-Hulmel, M., Doussinault, G., Lecomte, C., Bérard, P., Le Buanec, B., Trottet, M. 2003. Genetic improvement of agronomic traits of winter wheat cultivars released in France from 1946 to 1992. Crop Science **43**:37–45.

Cakmak, I. 2002. Plant nutrition research: Priorities to meet human needs for food in sustainable way. Plant and Soil **247**:3–24.

Cakmak, A., Yilmaz, A., Kalayci, M., Ekiz, H., Torun, B., Ereno, B. 1996. Zn deficiency as a critical problem in wheat production in Central Anatolia. Plant and Soil **180**:165–172.

Cakmak., I, Sari, N., Marschner, H., Kalayci, M., Yilmaz, A., Eker, S., Gulut K.Y. 1996a. Dry matter production and distribution of zinc in bread and durum wheat genotypes differing in zinc efficiency. Plant and Soil **180**:173–181.

Calderini, D.F., Dreccer, M.F., Slafer, G.A. 1995. Genetic improvement in wheat yield and associated traits. A re-examination of previous results and latest trends. Plant Breeding **114**:108–112.

CIMMYT, 1988. From Agronomic Data to Farmer Recommendation. An Economic Training Manual, Mexico, D.F, pp. 30–34.

Donmez, E., Sears, R.G., Shroyer, J.P., Paulsen, G.M. 2001. Genetic gains in yield attributes of winter wheat in the Great Plains. Crop Science **41**:412–419.

Erdal, I., Yilmaz, A., Taban, S., Ekar, S., Torun, B., Cakmak, I. 2002. Phytic acid and phosphorus concentrations in seeds of wheat cultivars grown with and without zinc fertilization. Journal of Plant Nutrition **25**:113–127.

Flintham J.E., Angus W.J., Gale, M.D. (1997) Heterosis, overdominance for grain yield, and alpha-amylase activity in Fl hybrids between near-isogenic Rht dwarf and tall wheats. Journal of Agricultural Science **129**:371–378.

Genc, Y., McDonald, G.K., Graham, R.D. 2006. Contribution of different mechanisms to zinc efficiency in bread wheat during early vegetative stage. Plant and Soil **281**:353–367.

Gibson, L.R., Paulsen, G.M. 1999. Yield components of wheat grown under high temperature stress during reproductive growth. Crop Science **39**:1841–1846.

Graham, A.W., McDonald, G.K. 2001. Effect of zinc on photosynthesis and yield of wheat under heat stress. Proceedings of the 10th Australian Agronomy Conference 2001, Australian Society of Agronomy. Hobart, Tasmania, Australia. Available on line at http:/www.regional.org.au/au/asa/2001/2/c/graham.htm.

Graham, R.D., Ascher, J.S., Hynes, S.C. 1992. Selecting zinc-efficient cereal genotypes for soils of low zinc status. Plant and Soil **146**:241–250.

Graham, R.D., Welch, R.M. 1996. Breeding for staple food crops with high micronutrients density. Agricultural strategies for micronutrient working paper no. 3. International Food Policy Research Institute, Washington, D.C.

Imtiaz, M., Alloway, B.J., Shah, K.H., Siddique, S.H., Memon, M.Y., Aslam, M., Khan, P. 2003. Zinc nutritious of wheat: 1: Growth and zinc uptake. Asian Journal of Plant Sciences **2**:152–155.

Islam, M.R., Islam, M.S., Jahirhuddin, M., Hoque, M.S. 1999. Effect of sulphur, zinc and boron on yield, yield components and nutrients uptake of wheat. Pakistan Journal of Science and Industrial Research **42**(3):137–140.

Kaya, Y., Kaya, Y., Arisoy, R.Z., Göcmen, A. 2002. Variation in grain yield and quality traits of bread wheat genotypes by zinc fertilization. Pakistan Journal of Agronomy **1**:142–144.

Miralles, D.J., Katz, S.D., Colloca, A., Slafer, G.A. 1998. Floret development in near isogenic wheat lines differing in plant height. Field Crops Research **59**:21–30.

Modaihsh, A.S. 1997. Foliar application of chelated and non-chelated metals for supplying micronutrients to wheat grown calcareous soils. Experimental Agriculture **33**:237–245.

NFDC. 1998. Micronutrients in Agriculture. Pakistani Perspectives, Status, Rreport No. 4/98. Planning and Development Division, Government of Pakistan. pp. 57.

Ozkutlu, F., Torun, B., Cakmak, I. 2006. Effect of zinc humate on growth of soybean and wheat in zinc-deficient calcareous soils. Communications in Soil Science and Plant Analysis **37**: 2769–2778.

Rafique, E., Rashid, A., Ryan, J., Bhatti, A.U. 2006. Zinc deficiency in rainfed wheat in Pakistan: Magnitude, spatial variability, management, and plant analysis diagnostic norms. Communications in Soil Science and Plant Analysis **37**:181–197.

Rengel, Z, Graham, R.D. 1995. Importance of seed Zn content for wheat growth on Zn-deficient soil. Plant and Soil **173**:259–266.

Reynolds, M.P., Rajaram, S., Sayre, K.D. 1999. Physiological and genetic changes in irrigated wheat in the post-green revolution period and approaches for meeting projected global demand. Crop Science **38**:1611–1621.

Siddique, K.H.M., Belford, R.K., Perry, M.W., Tennant, D. 1989. Growth, development and light interception of old and modern wheat cultivars in a Mediterranean-type environment. Australian Journal of Agricultural Research **40**:473–487.

Singh, Y.P. 2004. Effect of nitrogen and zinc on wheat irrigated with alkali water. Annals of Agricultural Research **25**:233–236.

Singh, B., Kumar, S., Natesan, A., Singh, B.K., Usha, K. 2005. Improving zinc efficiency of cereals under zinc deficiency. Current Science **88**:36–44.

Sillanpää, M. 1982. Micronutrients and Nutrients Status of Soil: A Global Study. FAO Soils Bull No. 48. Rome

Slafer, G.A., Andrade, F.H. 1991. Changes in physiological attributes of the dry matter economy of bread wheat *(Triticum aestivum)* through genetic improvement of grain yield potential at different regions of the world. A review. Euphytica **58**:37–49.