Zentrum für Entwicklungsforschung (ZEFc)

Comparison of DRIS and critical level approach for evaluating nutrition status of wheat in District Hyderabad, Pakistan

Inaugural-Dissertation
zur
Erlangung des Grades
Doktor der Agrarwissenschaften
(Dr. agr.)

der Hohen Landwirtschaftlichen Fakultät
der
Rheinischen Friedrich-Wilhelms-Universität
zu Bonn

vorgelegt am 20.06.11

von
NAHEED AKHTER

aus
SINDH, PAKISTAN

1. Referent: Prof. Dr. Heiner Goldbach

2. Referent: Prof. Dr. Paul L.G. Vlek

Tag der Promotion: 31.08.2011

Erscheinungsjahr: 2012

Diese Dissertation ist auf dem Hochschulschriftenserver der ULB Bonn
http://hss.ulb.uni-bonn.de/diss_online elektronisch publiziert

To my late mother and father

and to my family

ABSTRACT

Intensive cropping systems, improper use of fertilizers or no fertilizer application, and unreliable and poor quality of irrigation water have led to declining soil fertility in the district of Hyderabad, Pakistan. To date, no comprehensive overview exists on the nutrient status of the soils in the region and on yield constraints due to mineral nutrient deficiencies or imbalances. The objectives of this study were to a) determine the nutritional factors limiting productivity of wheat in Hyderabad, Pakistan, b) compare the DRIS and critical level approach for evaluating nutrient deficiencies in wheat, and c) identify the most limiting nutrient(s) that should be applied to increase and stabilize the yield of wheat in the region. Farmers' fields (181) were selected on the basis of a survey of wheat-growing areas. Low- and high-yielding areas for two vegetation seasons (2007-08 and 2008-09) with different crop production management were selected. Plant sampling of wheat was done for shoot material at GS-29 (tillering stage) and for leaf tissue at GS-39 (emergence of flag leaf; Zadok et al. 1974). Sample analysis included the determination of macronutrients (N, P, K) and micronutrients (Zn, Cu, Fe, Mn, and B). For yield estimates at harvest, data on grains per spike, number of spikelets and thousand-grain weight were collected. Yield data were divided into low-and high-yielding populations according to the Cate and Nelson (1971) procedure for partitioning. The mean value and coefficient of variance were calculated for DRIS norms. The selected DRIS norms were: N/P, N/K, N/Cu, N/Fe, N/Mn, N/Zn, N/B, P/K, P/Cu, P/Fe, P/Mn, P/Zn, P/B, K/Cu, K/Fe, K/Mn, K/Zn, K/B, Cu/Fe, Cu/Mn, Cu/Zn, Cu/B, Fe/Mn, Fe/Zn, Fe/B, Mn/Zn, Mn/B and Zn/B. The DRIS indices were established for N, P, K, Zn, Fe, Cu, and B of the low- and high-yielding populations. These indices were compared with the developed norms. The interpretation of the wheat nutrients was done using the nutritional balance index (NBI) approach.

The average index value for N at GS-39 is +47.04, which indicates that N is sufficient in the leaf tissue. The values of P and K are 58.49 and 21.67, respectively. These positive values show that N, P and K are sufficient in the leaf tissue, and that the wheat plants do not require any additional fertilization. The micronutrients are almost in good balance, i.e., neither sufficient nor deficient except for Fe. The index value of Fe is -93, whereas the index values for Mn, Zn, Cu, and B are -21.88, +17.77, -1.38 and -28.68, respectively. The NBI is 56.45, which shows that there is no high nutritional imbalance. The interpretation of the data with respect to deficiency and adequate and moderate supply shows that all nutrients are adequately supplied with exception of Zn and B, which show high values. However, the average index values of the shoot material at GS-29 are different; here the value for N is -54.27, which indicates that N is deficient at this growth stage. The same applies to P and K. The micronutrient values, however, are positive. This indicates that these nutrients are not in short supply compared to the macronutrients. The NBI is 75.23, which shows some nutritional imbalance.

According the results of the critical level approach, the average concentration of N in the leaf tissue at GS-39 is deficient (which is in contrast to the DRIS evaluation), whereas all other nutrients are adequate. The average nutrient concentration in the shoot material at GS-29 is similar to that in the leaf at GS 39. The DRIS calculation also indicates that N is in short supply at the early growth stage, whereas Mn and B are present in high concentrations. Statistically, the values in the critical level approach are non-significant compared to those of the DRIS. However, DRIS has an advantage, as the DRIS norms for the study area are similar at both studied growth stages, which makes the interpretation easier. It has to be stressed, though, that the DRIS only indicates nutrient supply in relation to the other nutrients. According to the DRIS evaluation, if the N supply is improved during early development, other nutrients may become yield limiting, e.g., P and K. The DRIS norms can provide guidelines for the policy makers in the region regarding recommendations for appropriate fertilizer application.

Vergleich von DRIS und der Methode der kritischen Konzentration für die Bewertung des Nährstoffstatus von Weizen im Distrikt Hyderabad, Pakistan

KURZFASSUNG

Intensive Anbausysteme, falscher bzw. kein Einsatz von Düngemitteln sowie unzuverlässige Bereitstellung und schlechte Qualität des für die Bewässerung eingesetzten Wassers haben zu einer abnehmenden Bodenfruchtbarkeit im Distrikt Hyderabad, Pakistan, geführt. Es gibt keinen umfassenden Überblick über den Nährstoffstatus der Böden in der Region oder über ertragsbegrenzenden Mangel oder Nährstoffungleichgewicht. Die Ziele dieser Studie waren a) die Nährstoff-Faktoren zu bestimmen, welche die Weizenproduktivität in Hyderabad, Pakistan, begrenzen, b) die DRIS Methode bzw. die „critical nutrient level Methode" („CNL") (kritische Konzentration) für die Bewertung von Nährstoffmangel bei Weizen zu vergleichen, und c) die am meisten begrenzenden Nährstoffe zu bestimmen, welche die Weizenerträge in der Region am meisten limitieren. 181 Praxisschläge wurden für eine Bestandsaufnahme in Weizenanbaugebieten ausgewählt. Die Schläge wurden unterteilt in Hoch- bzw. Niedrigertragsflächen für zwei Anbauperioden (2007-08 und 2008-09). Sprossproben wurden zum Wachstumsstadium GS-29 (Bestockung) und vom Blattgewebe zum Wachstumsstadium GS-39 (Erscheinen des Fahnenblatts; nach Zadoks et al. 1975) genommen. Die Proben wurden auf Makronährstoffe (N, P, K) und Mikronährstoffe (Zn, Cu, Fe, Mn, B) analysiert. Für die Ertragsbestimmung wurden zur Ernte die Anzahl an Körnern pro Ähre, die Anzahl der Ährchen und das 1000-Körnergewicht bestimmt. Die Ertragsdaten wurden vwerendet, um die Gesamtpopulation in Hochertrags- bzw. Niedrigertragspopulationen zu unterteilen nach der Methode von Cate und Nelson (1971). Mittelwert und Variationskoeffizient wurden für die DRIS-Normen berechnet. Die ausgewählten DRIS Normen waren: N/P, N/K, N/Cu, N/Fe, N/Mn, N/Zn, N/B, P/K, P/Cu, P/Fe, P/Mn, P/Zn, P/B, K/Cu, K/Fe, K/Mn, K/Zn, K/B, Cu/Fe, Cu/Mn, Cu/Zn, Cu/B, Fe/Mn, Fe/Zn, Fe/B, Mn/Zn, Mn/B und Zn/B. Die DRIS-Indizes wurden für N, P, K, Zn, Fe, Cu, und B für beide Populationen berechnet und mit den DRIS-Normen verglichen. Die Interpretation der Weizennährstoffe wurde auf der Grundlage des nutritional balance index (NBI) durchgeführt.

Der durchschnittliche Index für N bei GS-39 ist +47.04; dies deutet daraufhin, dass N im Blattgewebe zu diesem Zeitpunkt ausreichend vorhanden ist. Die P- bzw. K-Werte betrugen 58.49 bzw. 21.67. Daraus folgt, dass N, P und K im Blattgewebe ausreichend vorhanden sind, und dass die Weizenpflanzen keine zusätzlichen Düngemittelgaben benötigen. Die Mikronährstoffe sind fast ausgewogen vorhandenmit Ausnahme von Fe. Der Index für Fe ist -93, während die Werte Mn, Zn, Cu, bzw. B -21.88, +17.77, -1.38 bzw. -28.68 betragen. Der NBI beträgt 56.45; dies weist auf eine noch weitgehend ausgewogene Nährstoffversorgung zum Zeitpunkt der Bestockunghin. Die Interpretation der Daten nach der CNL Methode weist auf hohe Zn und B Werte hin. Jedoch unterscheiden sich die durchschnittlichen Indizes zum zweiten Probenahmezeitpunkt; hier beträgt der N-Wert -54.27, das heißt, dass N in diesem Wachstumsstadium nicht mehr ausreichend vorhanden ist, ebenso P und K. Die Werte der Mikronährstoffe sind jedoch positiv. Dies deutet darauf hin, dass diese Nährstoffe im Verhältnis zur Makronährstoffversorgung ausreichend vorhanden sind. Der NBI beträgt 75.23, was auf ein Nährstoffungleichgewicht hindeutet.

Die Ergebnisse der CNL Analyse ergaben (im Gegensatz zur DRIS Evaluierung), dass die durchschnittliche N-Konzentration im Blattgewebe zum Zeitpunkt GS-39 nicht ausreichend war, während alle anderen Nährstoffe ausreichend vorhanden sind. Die durchschnittliche Nährstoffkonzentration im Spross bei GS-29 ähnelt der des Blattgewebes zum Zeitpunkt GS-39. Die DRIS-Berechnung zeigt außerdem, dass N zum diesem Zeitpunkt nicht ausreichend vorhanden ist, während die Mn- und B-Konzentrationen hoch sind. Statistisch gesehen, sind die CNL Werte verglichen mit den DRIS-Werten nicht signifikant voneinander unterschieden. Jedoch hat der DRIS-Ansatz den Vorteil, dass die DRIS-Normen im zu beiden untersuchten Wachstumsstadien ähnlich

sind. Dies erleichtert die Interpretation. Jedoch muss betont werden, dass das DRIS lediglich die Nährstoffversorgung im Verhältnis zu anderen Nährstoffen aufzeigt. Auf der Grundlage der DRIS-Auswertungen kann angenommen werden, dass die Verbesserung der N-Versorgungzu GS-39 zu einer Limitierung des Ertrags durch andere Nährstoffe führen könnte, wie zum Beispiel P und K. Die DRIS-Normen können Richtlinien für die politischen Entscheidungsträger in der Region hinsichtlich sachgerechter Düngung zur Verfügung stellen.

TABLE OF CONTENTS

Acronyms/Abbreviations

% DM	Dry-matter Percentage
AAS	Atomic Absorption Spectrophotometer
AEZs	Agro-Ecological Zones
ANOVA	Analysis of Variance
APO	Asian Productivity Organization
CDL	Critical Deficient Level
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo
CLN	Critical Leaf Nutrient level
CV	Coefficient of Variation
CVA	Critical Value Approach
DAP	Di- ammonium Phosphate
DRIS	Diagnosis and Recommendation Integrated System
FAO	Food and Agriculture Organization
FBS	Federal Bureau of Statistics
FFBL	Fauji Fertilizer Bin Qasim Limited
FFC	Fauji Fertilizer Company
GDP	Gross Domestic Production
GIS	Geographic Information System
GPS	Global Positioning System
GS	Growth Stage
IFA	International Fertilizer Agency
NARC	National Agricultural Center
NBI	Nutritional Balance Index
NDFC	National Development Finance Corporation
NP	Nitrophos
NSR	Nutrient Sufficiency Range
PARC	Pakistan Agriculture Research Council
PDS	Pakistan Demographic Survey
PTFE	Polytetrafluoroethylene
SD	Standard Deviation

Ton ha−1	Tons per Hectare
UNDP	United Nations Population Division
USDA	United States Department of Agriculture
VDLUFA	Verband Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten

1 GENERAL INTRODUCTION

1.1 Food production for increasing population

According to the United Nations Population Division, World Population Prospects, the world's population increased from 2.3 billion in 1965 to 6.8 billion in 2008. The population will further grow to 9 billion by year 2050 (UN's Population Division, World Population Prospects: The 2008 Revision). World food projection models show that to meet the food demand of the global population in 2020, annual cereal production needs to increase by 40 %, which would then be nearly 2.5 billion tons (Rosegrant et al., 1999, 2001). Dyson (1999) estimated that the total world cereal production needs to rise to 2.7 billion tons whereas Wild (2003) modeled 4 billion tons by 2025 to match food requirements of the world population. Of this increase in demand, 85 % has to come from the developing countries. It is predicted (e.g., Byrnes and Bumb, 1998) that most of the anticipated increase in world population will occur in developing countries. Thus, agricultural production in the developing countries needs to be intensified. However, these regions are already suffering from serious problems related to food production, access to food, water availability, malnutrition, and soil degradation (Bos et al., 2005).

Although the grain stock is never able to meet the demand of the growing population, historically the difference between grain production and the consumption is almost zero (U.S. Department of Agriculture, Production Supply and Distribution:, (Figure 1.1).

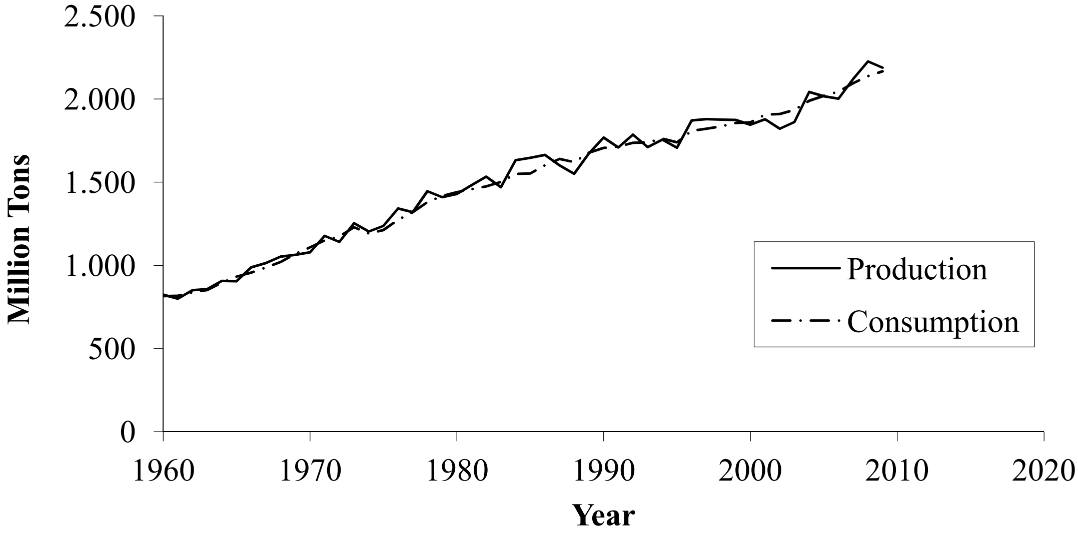

Figure 1.1 World grain production and consumption, 1960-2009

Source: U.S. Department of Agriculture, *Production Supply and Distribution*, electronic database at www.fas.usda.gov/psdonline, updated 10 July 2009.

This department further reported the time that the grain stock can meet the demand of the population dropped from 130 days in 1986 to 77 days in 2009. The grain stock was 61 days in 2006 which has improved in 2009 to 77 days but still lies below the long-term average (Figure 1.2).

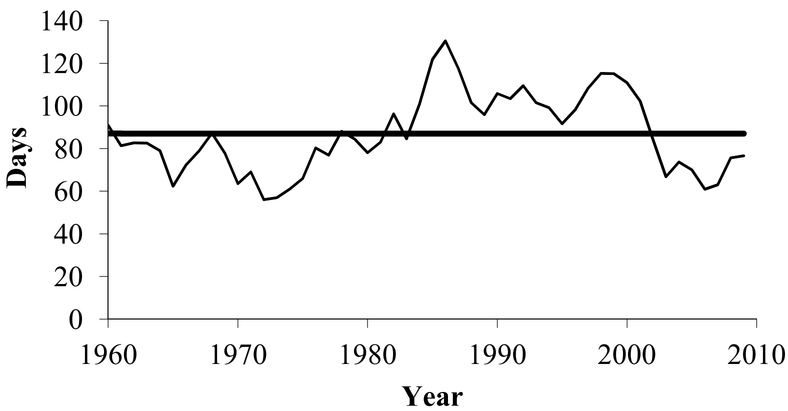

Figure 1.2 World grain stocks as days of consumption, 1960-2009

Source: U.S. Department of Agriculture, *Production, Supply and Distribution,* electronic database, at www.fas.usda.gov/psdonline, updated 10 July 2009

In the absence of an available stock and to meet the challenges of overall food security, one option is to increase the world`s existing irrigated area.. Although this area increased from 94 million ha in 1950 to 287 million ha in 2007, during the last 10 years, the rated expansion of the irrigated area actually decreased by 6 % (Figure 1.3) due to environmental issues, urbanization and increasing water scarcity. In addition, salinization of many irrigated soils reduces the availability of productive land.

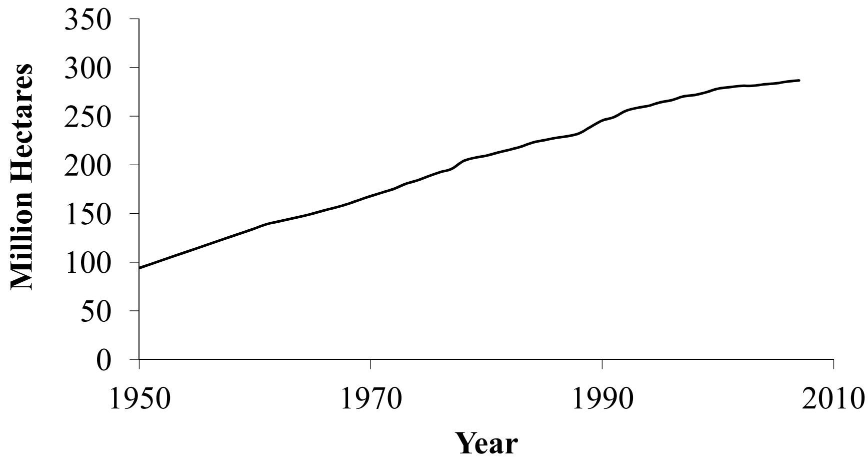

Figure 1.3 World irrigated area, 1950-2007

Source: 1950-60 data compiled by Lester R. Brown for "Eradicating Hunger: A Growing Challenge," in World watch Institute, *State of the World 2001* (New York: W.W. Norton and Company, 2001), pp. 52-53; 1961-2007 data from U.N. Food and Agriculture Organization, *Resource STAT*, electronic database at http://faostat.fao.org/site/405/default.aspx, updated April 2009; population from U.N. Population Division, *World Population Prospects: The 2008 Revision Population Database*, at esa.un.org/unpp, updated 11 March 2009.

This increase in irrigated area is small compared to the recent growth in population. In 1979, the irrigated area per thousand people was 47.6 ha, which reduced to 37.2 ha in 2007 (Figure 1.4). The downward trend is an alarming situation.

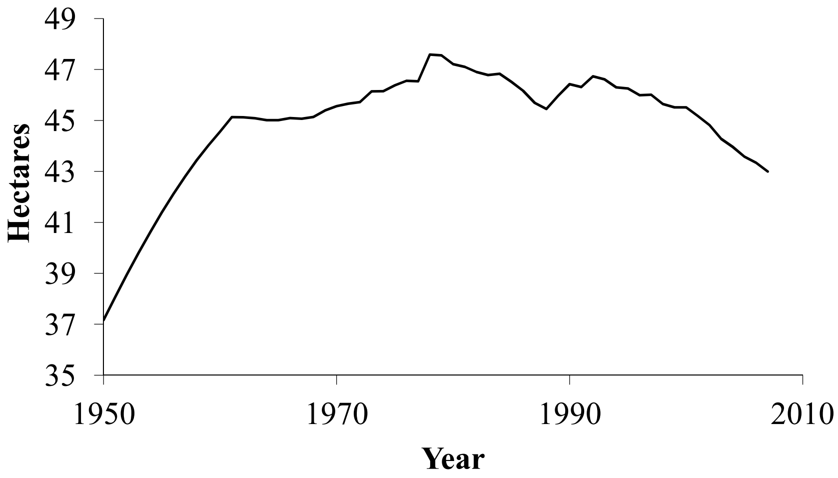

Figure 1.4 World irrigated area per thousand people, 1950-2007

Source: 1950-60 data compiled by Lester R. Brown for "Eradicating Hunger: A Growing Challenge," in World watch Institute, State of the World 2001 (New York: W.W. Norton and Company, 2001), pp. 52-53; 1961-2007 data from U.N. Food and Agriculture Organization, Resource STAT, electronic database at http://faostat.fao.org/site/405/default.aspx, updated April 2009; population from U.N. Population Division, World Population Prospects: The 2008 Revision Population Database, at esa.un.org/unpp, updated 11 March 2009.

In addition, the grain production area per person decreased by more than 50 % compared to 1950.The trend of decline is less pronounced in Australia but tends to be quite high in most other countries (Table 1.1).

Table 1.1 Grain- Harvested areas per person in selected countries and the world in 1950 and 2000, with projection to 2050.

Country	Area (ha per person)		
	1950	2000	2050
Australia	0.73	0.90	0.60
Canada	1.42	0.59	0.41
United States	0.51	0.20	0.14
Nigeria	0.26	0.14	0.06
India	0.22	0.10	0.06
China	0.17	0.07	0.06
World Average	**0.23**	**0.11**	**0.07**

Source: Grain area for 1950 from U.S. Department of Agriculture (USDA), Production, Supply, and Distribution (PS&D), Country Reports, October 1990; 2000 data from USDA, PS&D, electronic database, updated 10 July 2009; population data and projections from U.N. Population Division, World Population Prospects: The 2008 Revision Population Database, electronic database, at http://esa.un.org/unpp, updated 11 March 2009.

In short, the world population is increasing whereas the area for grain production per person is decreasing. Due to ecological constraints and lack of land resources, this area cannot be increased without severe ecological damage (e.g., slashing remaining rainforests). So the only solution to cope with this situation is to increase grain production per unit available area.

The number of undernourished people in the world increased from 800 million in 1999 (Pinstrup-Andersen et al., 1999) to 1020 million people in 2009 (FAO, 2009). Of this number, 98.5 % live in developing countries of which 65 % are located in Asia and on the Pacific islands (Figure 1.5).

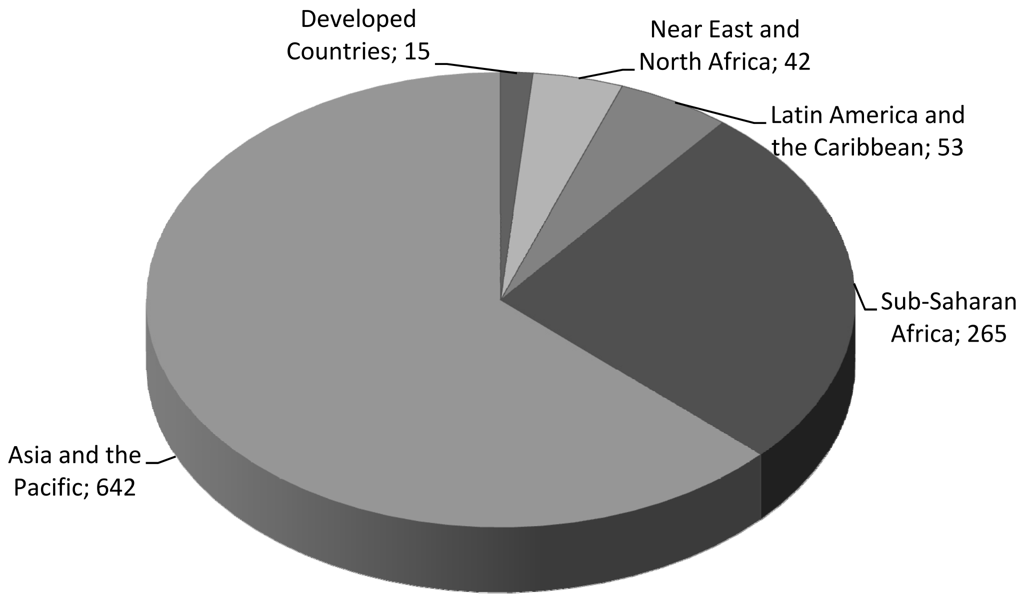

Figure1.5 Undernourishment in the world and in selected regions (in %), 1996

In South Asia, children under the age of 5 years are particularly at risk. Worldwide, 30 % of the children are underweight, and low birth weight is becoming a major factor in child malnutrition and premature death (Pinstrup-Andersen, 1999; UNDP, 1999). Micronutrient deficiencies, e.g., in iron (Fe), zinc (Zn) and iodine, are critical in the developing countries, and result in a reduction of physical growth, reduce the function of the immune system, and enhance maternal mortality (Welch and Graham, 2000). Approximately 3 billion people in the world suffer from Fe and Zn deficiencies (Graham et al., 2001). These deficiencies need to be met preferably by micronutrient enrichment in crops.

Thus further significant increases in demand for food are to be expected even if population growth slows down, and this food has to be produced under the limited land resources through intensified cropping.

For a sustainable soil management, inputs and outputs need to be balanced; otherwise increases in crop production will lead to continuous depletion of nutrients from fertile and low fertile soils.

1.2 Worldwide role of fertilizer use in nutrient management

Soil productivity is decreasing in most of the irrigated areas of the world due to soil degradation and nutrient mining through intensive and high yielding crops. Almost 40 % of the agricultural land is affected by soil degradation (Reynolds et al., 2007). The factors affecting soil fertility include soil erosion, nutrient depletion, water scarcity, salinization, and low organic matter contents. Among all these factors, reduction in soil productivity due to nutrient mining has threatened the food security in many parts of the world (Li et al., 2007).

The required nutrients may come from various sources, such as the atmosphere, soil, irrigation water, mineral fertilizers, green manures and bio-fertilizers. In order to supplement plant nutrients in less fertile soils, the use of mineral fertilizers is common. Improvement of the nutritional status of plants by applying mineral fertilizers and maintaining soil fertility has been a critical step in doubling the food production since the beginning of the 'Green Revolution' (Loneragan, 1997). In 1950, the global fertilizer consumption was 14 million tons, which increased to 160 million tons in 2008 (IFA, 2009). The average world grain yield also increased from 1.06 t ha^{-1} in 1950 to 3.15 t ha^{-1} in 2009 (Figure 1.6; USDA, 2009).

Although nutrient recycling through organic substances is one of the options, mineral fertilizers will be of central importance for meeting future food demands. However, recent trends indicate that the growth rate (ton ha^{-1}) in crop production has begun to decline in the last 10 years, and possibly cannot keep pace with the projected increase in global food demand in the coming decades (Figure 1.6; Rosegrant et al., 2001). This situation is especially dramatic in many developing countries in Africa and

Asia where population pressure on agriculture is already very high. For example, in Sub-Saharan Africa the annual growth of total cereal production dropped from 1.9 % in the 1970s to 0.66 % in the 1990s. These decreases were attributed to falling cereal prices, decreases in use of fertilizers, growing water shortages and impairments in soil fertility and management practices (Gruhn et al., 2000; Pinstrup-Andersen et al., 1999; Rosegrant et al., 2001). This trend must be reversed; otherwise very serious food deficits will occur resulting in a significant threat to human nutrition and health.

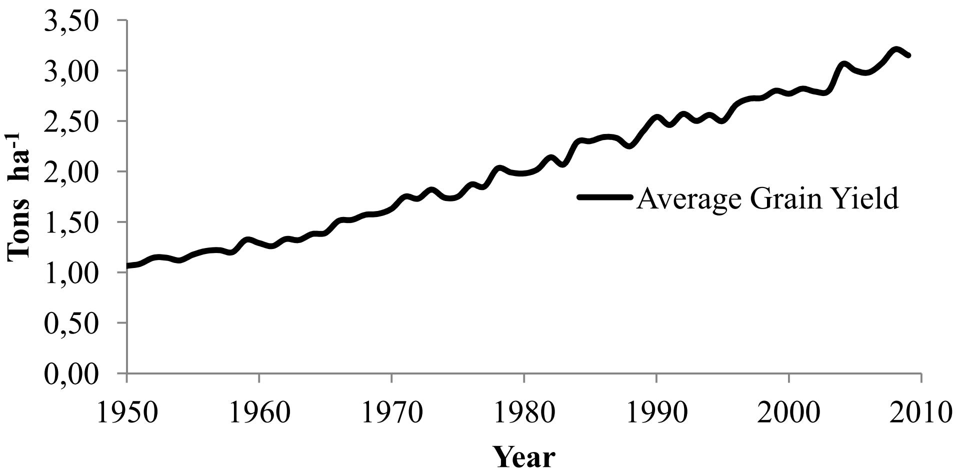

Figure 1.6 Average worldwide grain yields, 1950-2008

White and Zasoski (1998) reported that a soil is considered deficient in a given nutrient when addition of that nutrient as fertilizer produces increased growth, even though the quantity of added nutrients may be small compared with the total amount in the soil. Nutrient deficiencies can be the result of inherently low nutrient status of the soils, low mobility or poor solubility of the given chemical composition of the nutrient. The solubility and mobility of nutrients is a result of number of factors such as irrigation amounts, adsorption capacity of the soil, soil pH (Jungk 2001, Shuman 1991), the chemical composition of nutrients (Crowley and Rengel 1999) and plant-induced changes in the rhizosphere)(Rengel and Marschner 2005). Meynard (1984) reported that the supply and availability of nutrients is an important factor that can influence the yield potential of field crops. Results of this experiment showed that the growth rate in wheat is directly related to the rate of fertilizer application. But there is no linear relationship, Asia where population pressure on agriculture is already very high. For example, in Sub-Saharan Africa the annual growth of total cereal production dropped from 1.9 % in the 1970s to 0.66 % in the 1990s. These decreases were attributed to falling cereal prices, decreases in use of fertilizers, growing water shortages and impairments in soil fertility and management practices (Gruhn et al., 2000; Pinstrup-Andersen et al., 1999; Rosegrant et al., 2001). This trend must be reversed; otherwise very serious food deficits will occur resulting in a significant threat to human nutrition and health.

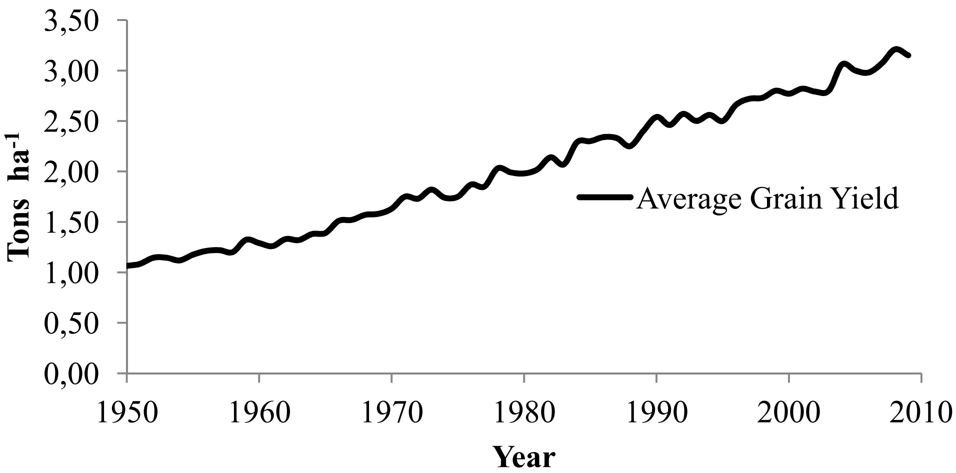

Figure 1.6 Average worldwide grain yields, 1950-2008

White and Zasoski (1998) reported that a soil is considered deficient in a given nutrient when addition of that nutrient as fertilizer produces increased growth, even though the quantity of added nutrients may be small compared with the total amount in the soil. Nutrient deficiencies can be the result of inherently low nutrient status of the soils, low mobility or poor solubility of the given chemical composition of the nutrient. The solubility and mobility of nutrients is a result of number of factors such as irrigation amounts, adsorption capacity of the soil, soil pH (Jungk 2001, Shuman 1991), the chemical composition of nutrients (Crowley and Rengel 1999) and plant-induced changes in the rhizosphere)(Rengel and Marschner 2005). Meynard (1984) reported that the supply and availability of nutrients is an important factor that can influence the yield potential of field crops. Results of this experiment showed that the growth rate in wheat is directly related to the rate of fertilizer application. But there is no linear relationship, i.e., there is a saturation point and excess of fertilizer application may cause toxic effects. The balance between the quantity and appropriate fertilizer is also important. For example, Shuman (1988) and Kaushik et al. (1993) reported that different fertilization treatments can disturb the overall balance of the soil macronutrients and their available concentrations, which in turn affects soil micronutrient level. They found that excessive application of phosphorous (P) inhibited the transfer of soil Zn and resulted in a shortage of Zn in maize, due to possible precipitation of $Zn_3(PO4)_2$. However, when P was applied at the optimum level, it significantly reduced the content of carbonate-, organic- and Fe oxide-bound soil Zn, and increased the content of exchangeable and amorphous iron oxide-bound soil Zn, similar to soil manganese (Mn). Similar effects were found by Agbenin (1998) and Bierman and Rosen (1994). They reported that the application of appropriate rates of nitrogen (N), phosphorus (P) and potassium (K) fertilizers can increase soil copper (Cu), Zn, and Mn availability and the concentrations of Cu, Zn, Fe and Mn in wheat. Larson (1964) concluded that combined application of nitrophos (NP) at a ratio of 2:1 or 3:1 increase each other's utilization efficiency. Hagras (1987) also reported an increased grain yield with the application of NP. Shafi (1971) obtained best results when N and P were applied in a 2:1 ratio (168 kg N + 81 kg P ha^{-1}). Drinkwater and Snapp (2007), and Kayser and Isselstein (2005) reported that plentiful amounts of fertilizers (especially in developing countries) result in excessive inorganic nutrients in the system that cause disturbance in normal biogeochemical cycles of nutrients.

The micronutrients Cu, Zn, Fe and Mn in grain directly affect food quality and are important for human and livestock nutrition. Deficiency of micronutrients will result in anemia, decreased immunity, slow growth, and nyctalopia. However, little attention has been paid to micronutrients in response to different fertilization practices, and how soil fertility impacts on the uptake of micronutrients from soil, and their transfer from tissues to grains. Borlaug (1983) reported that global cereal grain yields have increased manifold since the green revolution, but global food systems are not providing sufficient micronutrients to consumers (Welch, 2002). Over 40% of the world's population is currently micronutrient deficient, resulting in numerous health problems, inflated economic costs borne by society, and learning disabilities for children (Sanchez and Swaminathan, 2005). Though a diversification of diets to include micronutrient-rich traditional foods is a preferred solution to these challenges, staple cereal grains are the primary dietary source of micronutrients for that part of the world's population that has no access to varied food crops (Bouis, 2003).

1.3 Approaches to assess the nutritional status of plant tissues

1.3.1 Current status of tissue analysis

A pre-requisite to properly meet the nutrient demands in crops to optimize production and eventually fortify the products with micronutrients is the proper assessment of the nutrient status of a crop plant (Haase and Rose, 1995). Plant analysis is thus important to learn about the nutritional needs of crops, but requires careful interpretation when using the most common critical level approach (i.e., the tissue level of a nutrient at which the crop is most productive, Rosell et al., 1992). Another approach is the so-called "diagnosis and recommendation integrated system" (DRIS) (Beaufils, 1973). These approaches are tools to estimate the nutrient supply of a plant that can be then considered for fertilizer application rates.

Although to determine the amount of fertilizer needed by tissue analysis is a diagnostic tool to assess the nutrient status of a plant (Timmer and Stone, 1978), for calculating fertilizer rates, information about the productivity and nutrient export from the soil in addition to information about eventually fixation of nutrients in the soil is required.

1.3.2 Plant interpretation methods

The use of plant analyses for determining the nutrient status of plants is of paramount importance. Since many decades, a great deal of work has been done on the use of chemical plant analyses for diagnosing the nutrient requirements of plants. The interpretation, which sometimes is also referred to as evaluation of the analytical results, however, is of decisive importance. There are still difficulties in the interpretation of plant analyses despite the fact that relationships have been revealed between absorbed nutrients and growth.

Relationships between maximum yield and concentrations of essential elements have been assessed by many researchers (Steenbjerg, 1951; Prevot and

Ollagnier, 1956; Smith, 1962; Ulrich and Hills, 1967; Brow, 1970; Dow and Roberts, 1982; Reuter et al., 1997). Some of these approaches are summarized below.

Steenbjerg (1951) proposed two different methods for the interpretation of chemical plant analyses. Method-1 illustrates the relationship between the increases in yield after application of a certain amount of plant nutrients and the nutrient concentration in a certain plant tissue (Figure 1.7).

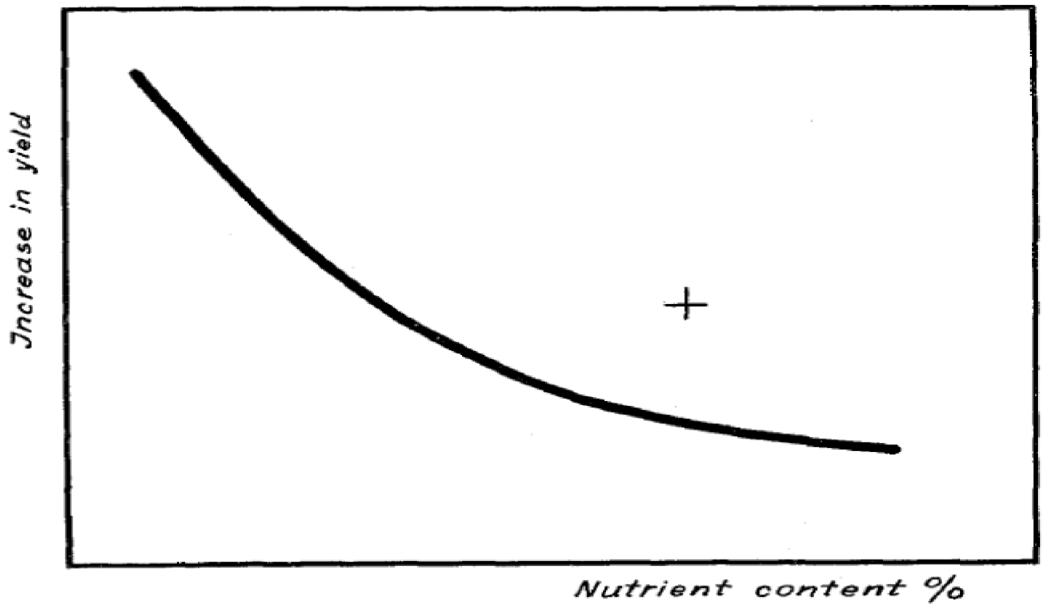

Figure 1.7 Relationship between increases in yield and nutrient content after the application of plant nutrients.

Note: Original graph taken directly from Steenbjerg (1951), where sign "+" does not mean anything. X-axis scale is from right to left.

With this method, standard values for the plant nutrients in the crop were found. During the development of these standard values (limiting values) for three level (high, medium and low content), developmental stages were defined at which the samples have to be taken.

In Method 2 for nutrient level interpretation, relationships between dry matter (DM; total yield) and the percentage of the nutrient content of the dry matter are plotted, (Figure 1.8), and it can be seen that with an increase in yield, the nutrient content (% in DM) rises (full line).

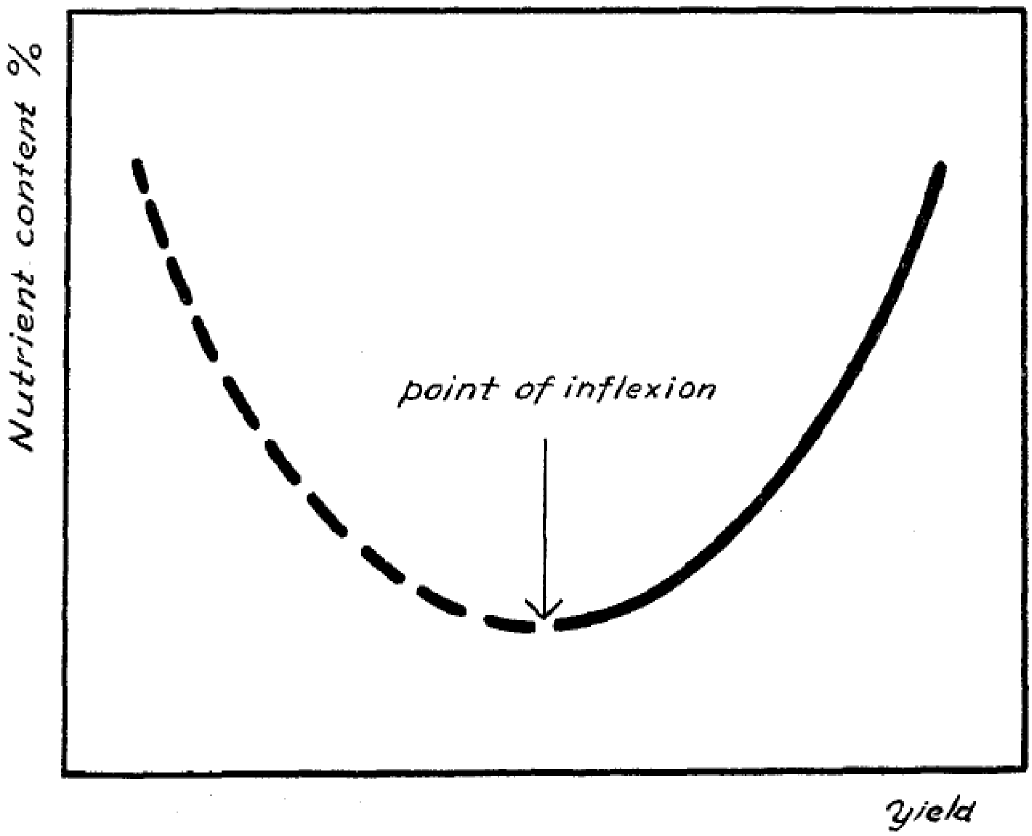

Figure 1.8 Relationship between dry matter (total yield) and percentage of nutrient content.

Note: Original graph taken directly from Steenbjerg (1951). X-axis scale is from right to left.

The graph indicates severe deficiency in the particular plant nutrient concerned where the dry matter production is lowest. This point of inflexion means that increasing relative nutrient contents are found with an increase in dry matter production. Prevot and Ollagnier (1956) observed an association between plant growth and nutrient concentration of a selected plant part (Figure 1.9). The objective was to develop a reliable interpretation for a number of crops, especially during the initial stages of growth, and whether nutrient concentrations are near or at toxic level. As the response curve showed a fairly large slope especially in the deficiency range, Ulrich (1961) later developed a new approach.

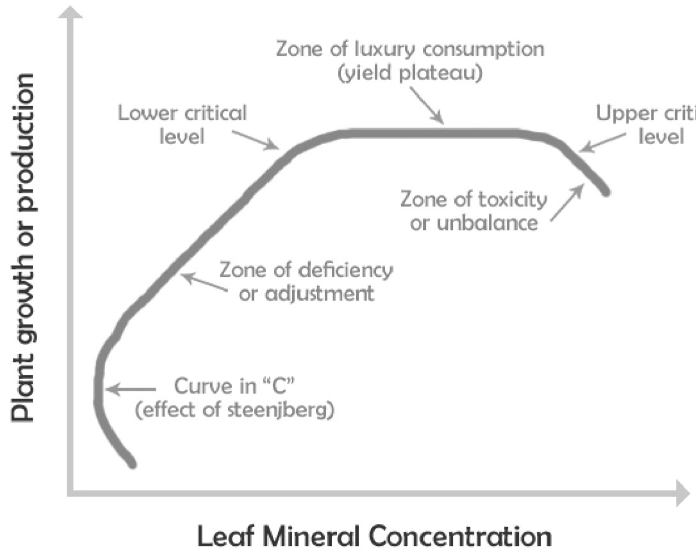

Figure 1.9 Relation of mineral concentration in leaf tissue to growth (Prevot and Ollagnier, 1956).

Source: http://www.sugarcanecrops.com/agronomic_practices/fertigation/

Ulrich (1961) presented a response curve in which the slope of the curve in the deficiency range was very small (Figure 1.10). Later this curve was used for plant analysis.

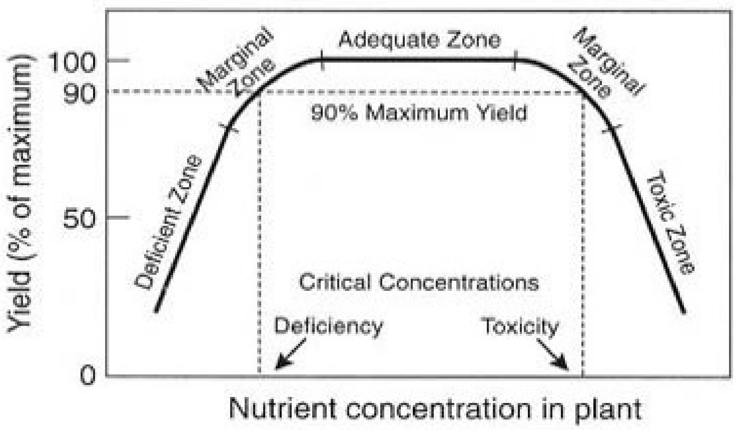

Figure 1.10 Relation of nutrients of plant tissue to growth. (Ulrich, 1961)

Source:http://www.sesl.com.au/fertileminds/200711/Plant%20analysis%20for%20turf%20species.php

The range between deficiency and the critical concentration is very small. However, for some elements and plants, this small change in concentration needs to be adequately defined. Later, one suggested solution was to determine the total amount of a nutrient per plant, thus minimizing the dilution effect. However, this technique is not applicable when dry-matter differences are very large for reasons not related to the nutrient under investigation. The large differences in dry matter accumulation are due to a deficiency of a particular nutrient which is growth limiting.

Both figures show the general relationship between nutrient concentration in plant tissue and dry-matter yield, and also define the point where toxicity occurs. Brady and Wei (2004) and Havlin et al. (2004) revealed that the element absorbed in excessive quantities can reduce plant yield directly through toxicity or indirectly by reducing the concentration of other nutrients to below their critical level or reducing their activity in the physiologically relevant processes resp. cell organelles.

Many researchers have based plant analysis interpretations on "critical" or "standard values." A critical value in the literature is defined as that concentration below which deficiency of the specific nutrient occurs. Critical values of several plants have been widely published despite the fact that this critical level may not be applicable at different growth stages.

The critical level approach is one of the first methods proposed by Ulrich and Hills (1967) for assessing the nutrient status of a plant by foliar analysis. It is the most widely used diagnostic method. Before use of this approach, single concentration values or critical or standard concentrations were used (Smith, 1962). But in order to interpret plant analysis results for diagnostic purposes, the full concentration range from deficiency to excess is needed (Benton, 1993). Critical level is successful in identifying the deficient and sufficient nutrient concentrations for a variety of plant and tree species. The critical level is in that portion of curve where plant-nutrient concentration changes from deficient to adequate; therefore, the critical nutrient concentration (CNC) is the level of a nutrient below which crop yield, quality, or performance is unsatisfactory. However, considerable variation exists in the transition zone between deficient and adequate nutrient concentrations, which makes it difficult to determine actual critical ranges. Consequently, it is more reliable to use a critical nutrient range that is defined as that range of nutrient concentration at a specified growth stage above which the crop is amply supplied with nutrients and below which the crop is deficient in specific nutrients (Kelling et al., 2000; Tisdale et al., 2002; Brady and Wei, 2004; Havlin et al., 2004; Rashid, 2005).

In an interpretation concept developed by Okhi (1987), the critical nutrient level is that nutrient concentration level at which a 10% reduction in yield occurs; this level is also defined as the critical deficient level (CDL).

The adequate nutrient concentration has been defined in several ways. For example, Fageria and Baligar (2005) defined it as 1) the concentration that is just deficient for maximum growth, 2) the point where the growth is 10% less than the maximum, 3) the concentration where plant growth begins to decrease, and 4) the lowest amount of the element in the plant accompanying the highest yield.

Critical nutrient level have been defined for a variety of crops: sugar beet (Ulrich 1961), corn, soybean and alfalfa (Jones 1967), pecan (Sparks 1978), flowers and ornamental plants (Criley and Carlson 1970, Mastalerz 1977), deciduous trees, fruits and nuts (Faust 1980) and for several agronomical crops (Sedberry 1987).

The diagnosis and recommendation integrated system (DRIS) is a comprehensive diagnostic approach that considers the nutrient balance instead of concentrations alone. Unlike the critical level approach, this approach provides an interpretation of plant nutrients irrespective of their age or tissue origin. The advantage is that nutrient ratios (or products) change less over development then its concentrations. This approach was first developed by Beaufils (1971) and was applied to rubber trees in Vietnam. Later, DRIS went through several phases of improvement (e.g., Jones and Bowen, 1981; Walworth and Sumner, 1987). DRIS compares elemental ratio indices of elements with the established norms from an optimum high-yielding population. Walworth et al. (1986) reported that for determining DRIS norms there should be several thousand entries, which are randomly selected. Benton (1993) reported that 10 % of the total samples should be selected for the high yielding group. Further, the DRIS ranks the nutrients according to the degree of limitation (or excess), thus emphasizing the importance of balanced crop nutrition (Benton, 1993). International norms for the DRIS have been obtained by several authors (Sumner, 1981; Beverly, 1993), but some researchers have suggested that norms calculated from a local data base may improve DRIS diagnosis (Dara et al., 1992).

Beaufils and Sumner (1977) studied the effect of the time of sampling on the diagnosis of the N, P, K, Ca, and Mg requirements of sugarcane by the DRIS approach. They used a NPK+lime factorial experiment for testing both soil and leaf norms for sugarcane obtained by DRIS (Beaufils, 1973). The results of their experiments show that the developed norms could be validly used in the diagnosis of the N, P, K, Ca and Mg requirements of sugarcane at the four sampling times. Further, they reported that the diagnoses by the DRIS approach have the advantage over the threshold value approach in that they can be made over a wide range of ages of sampled material.

Hanson (1981) conducted an experiment on DRIS evaluation of the N, P, and K status for soybeans in Brazil. He evaluated the DRIS method utilizing 3 datasets of foliar analyses for N, P, and K. The results of their experiments show that the DRIS method proved useful as an analytical tool to diagnose the soybean response to P.

Gregoire and Fisherb (2004) investigated the relative benefits of different approaches for diagnosing nutrient deficiencies from a dataset of loblolly pine (*Pinus taeda* L.). They compared the vector analysis, DRIS and critical level approaches for identifying deficiencies in N and P by means of foliar analysis in 60 managed stands in southeast Texas. The results of their study reveal that the diagnostic efficacies differed in predicting the response to fertilization, and no method alone was accurate enough for precisely predicting the response across soil groups. Further, they reported that the three methods of interpretation have their advantages and work best when used together. However, it is vital to understand the limitations of foliar diagnosis regardless of the accuracy of the diagnostic technique employed.

Soltanpour et al. (1995) reported that DR1S is a potential method for interpreting plant nutrient composition and compared DRIS with the nutrient sufficiency range (NSR) for corn *(Zea mays* L.). They identified the following flaws in DRIS: (i) very high levels of one nutrient can cause false relative deficiency diagnosis of other nutrients, and (ii) an optimal ratio between two nutrients produces maximum yields only when both nutrients are in their respective sufficiency ranges. They recommend using the NSR technique in combination with a soil test to avoid the misdiagnosis of Zn and Cu deficiencies in corn when N is extremely deficient.

Galantini et al. (2000) conducted a study to formulate the initial values of DRIS Norms for artichoke cv. "Violeta de Provenza" (*Cynara scolymus* L.) in the southeast provinces of Alicante and Murcia of Spain. They established leaf diagnosis standards for the first time for the varieties under the framework of the normality ranks and using DRIS. Among the several farms, with almost 300 ha of irrigated area, they selected the three best plots for the collection of samples, every fifteen days for three months in a row, and for a total of 108 samples. Thereafter, the DRIS norms were developed for the elements N, P, K, Ca, Mg, Zn, Fe, Cu, Mn and for all their mutual relations through the respective statistic analysis.

Bailey (1997) conducted a study to diagnose the nutrient status of grassland using DRIS. They reported that determining the N, P, K and S status of perennial ryegrass *(Lolium perenne)* swards by the 'critical' approach has disadvantages, as the concentration of a nutrient in plant tissue for optimum growth varies both with crop age and with changes in the concentrations of other nutrients. For that reason, they recommended the use of DRIS, which is based on relative rather than on absolute concentrations of nutrients in plant tissue. They stated, however, that without an internal reference, plant growth could be limited by multiple nutrient deficiencies even if N, P, K and S indices are all close to, or equal, to zero (i.e., the optimum), simply because the absolute concentrations of each nutrient (while low) are in the correct state of balance.

Teixeira et al. (2009) conducted a study to form the preliminary DRIS norms and critical leaf nutrient level (CLN) for the 'Smooth Cayenne' pineapple growing in plantations of São Paulo State (Brazil). To develop the DRIS norms, they created a data base of leaf nutrient concentrations (N, P, K, Ca and Mg) and fruit yields for 104 samples. They divided the data into high-yielding (>65 t/ha) and low-yielding (<65 t/ha) sub-populations, and norms were computed using standard DRIS procedures.

Silveira et al. (2005) conducted a study to evaluate three procedures (methods of Beaufils (1973), Jones (1981), and Elwali & Gascho (1984)) for the calculation of DRIS indices, and to verify the efficiency of DRIS as interpretation method. They selected *Brachiaria decumbens* (signal grass) for the study and the concentrations of N, P, K, Ca, Mg, S, Cu, Fe, Mn, and Zn were taken from the expanded leaf laminae of the grass. Subsequently, they calculated the nutritional balance index according to the generated norms, presented negative and significant correlation coefficients with the productivity in the combinations of methods tested. DRIS as proposed by Beaufils

(1973), Jones (1981) and Elwali & Gascho (1984) which were efficient in detecting concentrations that show nutrient deficiency or excess.

Meyer (1981) conducted a study on sugarcane yield data and third leaf analysis from 96 fertilizer trials to establish whether DRlS can be used to improve the quality of the fertilizer advisory service. He reported that in general predictions of a yield response to applied N, P and K were more reliable when DRlS was used than when the nutrient threshold approach was used at an early stage of crop development. The results of his experiments show that imbalances of N, P and K can be detected four to six weeks earlier by using DRlS than by the threshold approach. He further reported that DRlS can be used fairly reliably to indicate N, P and K deficiencies in order of decreasing importance.

1.4 Problem statement

According to the Pakistan Demographic Survey (PDS), in 2007 the total population of Pakistan was about 150 million out of which 65 % was settled in rural areas and closely linked to agriculture production. Agriculture is the mainstay of Pakistan's economy contributing 24 % of the GDP (FBS, 2007). It employs nearly 50 % of the total population. As GDP growth continues to depend on crop production, key attention is given to the agricultural sector.

According to the United Nations Population Division (2010), the population growth rate in Pakistan in 2005 was 2.26 % and 2.16 % at the end of 2010, i.e., a net addition of 1.89 million people till 2010. The population increased after independence more than 4.5 times (United Nations Population Division, 2010), but production of cereal crops did not increase at the same pace (PARC, 2006).

The total cropped area of Pakistan is 21.2 million ha (PAD, 2008) out of which 80 % is irrigated land. Wheat plays an important role to fulfill the food requirements of both urban and rural population of country. According to PAD (2008), wheat has the largest share and is being grown on more than 39 % of the total cropped area followed by cotton, rice, sugarcane, maize and gram (Figure 1.11).

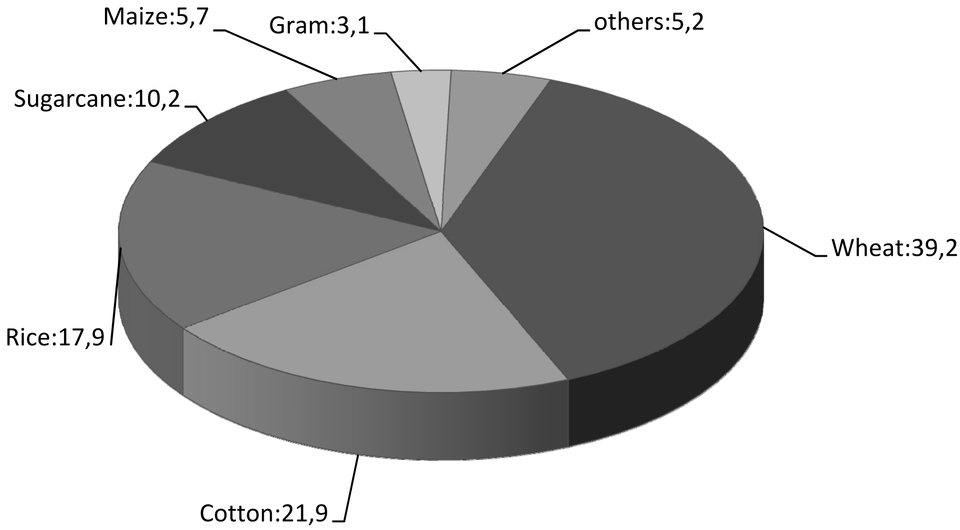

Figure 1.11 Percentage of cropped area under selected crops during the 2008 cropping season in Pakistan (PAD, 2008)

Total wheat production in Pakistan was approximately 10 million tons in 1970 and increased to about 21 million tons in 2008. This twofold increase in production was made possible by a concomitant 17 times increase in fertilizer application (NDFC, 2008).

1.4.1 Wheat production in Pakistan

Wheat (*Triticum aestivum* L.) is the major staple food crop of Pakistan with regard to its area of cultivation and production (Shuaib et al., 2007). Production increased from 3.8 million tons in 1961 to 21 million tons in 2008 (Figure 1.12). For the same period, the wheat production area increased by 184 %.

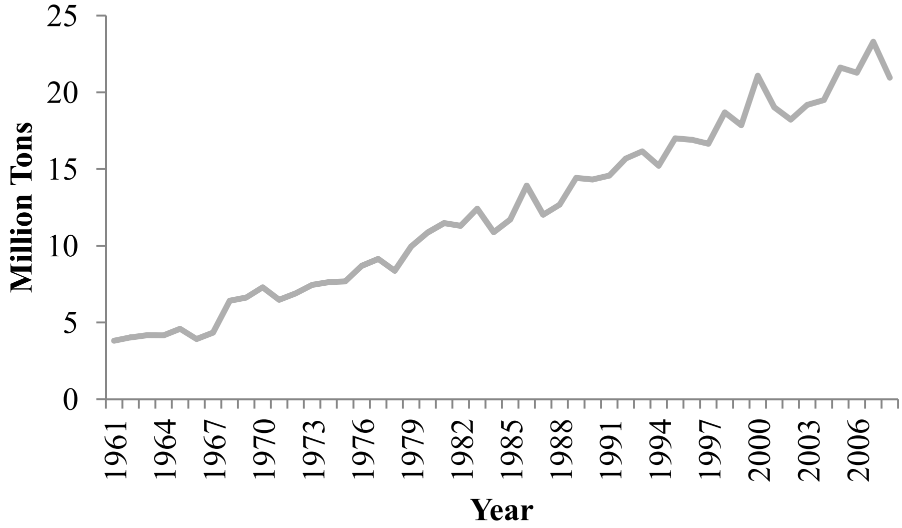

Figure 1.12 Wheat productions (million tons) in Pakistan, 1961-2008

Although the increase in wheat yield during the last two decades in Pakistan is impressive, i.e., from 1.83 tons ha^{-1} in 1990 to 2.72 tons ha^{-1} in 2007 (FAO, 2007; Figure 1.13), it is by far lower than that of many countries such as North America (5.1 tons ha^{-1}). It is unfortunate that though Pakistan is the seventh largest wheat growing country of the world, it ranks 59 in terms of yield per hectare and still imports wheat from other countries to meet the demand of a fast growing population (FAO, 2010).

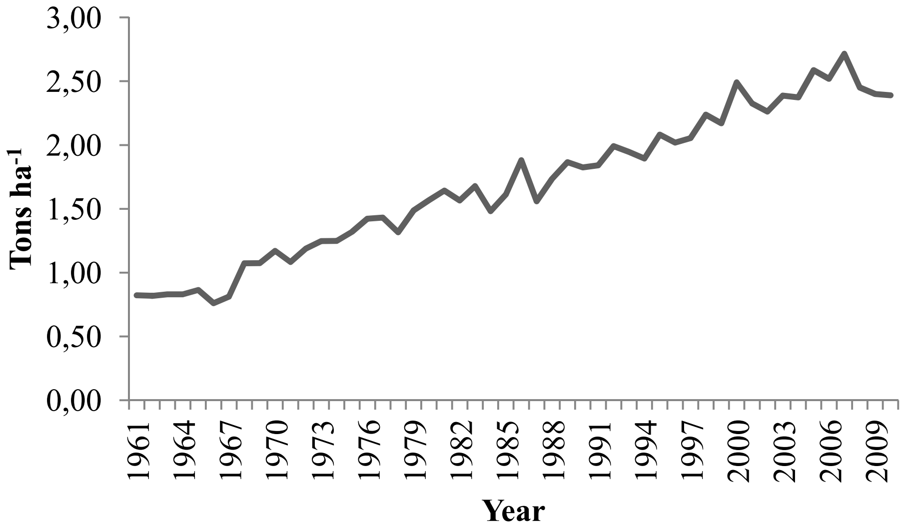

Figure 1.13 Wheat yield per hectare in Pakistan, 1960-2010

The NARC (2009) reported that major reasons for the low productivity in wheat production in Pakistan includes among others delayed harvesting of *kharif* (summer) crops (e.g., cotton, sugarcane and rice) and late planting of wheat, unavailability of improved inputs like certified seeds, imbalance fertilizer use, water scarcity, soil degradation, and inefficient extension services.

Wheat in Pakistan by far is the leading food grain and occupies a central position in agriculture and its economy (Shuaib et al., 2007). For example, Shuaib et al. (2007) reported that the average household spends 9.4% of its income on wheat, whereas wheat product expenditures are 18.4 %. They further reported that there are progressive farmers in irrigated areas who are harvesting 6-7 tons yield ha^{-1} wheat, whereas in rainfed areas yield ranges only from 0.5-1.3 tons ha^{-1} depending on the amount of rainfall. Yields in irrigated areas depend on many factors and range on average between 2.5 and 2.8 tons ha^{-1} depending upon the amount of water available and other factors necessary for high crop yields.

Adsule and Kadam (1986) reported that wheat is one of the most important domesticated food sources in Pakistan, largely due to the fact that its grain contains protein with unique chemical and physical properties. They further reported that beside wheat being a rich source of carbohydrates, it contains other valuable components such as protein, minerals (P, Fe, Mg, Cu and Zn) and vitamins like niacin and vitamin E. Chowdhry et al. (1995) reported that as Pakistani wheat varieties are grown over a wide agro-climatic range they are expected to exhibit yield and quality differences.

1.4.2 Wheat production in the Sindh province of Pakistan

Wheat cultivation in the Sindh province of Pakistan started during the Neolithic period, i.e., 6,000 to 7,000 years ago with emmer or durum wheat types. Local names for wheat are ‘kanak’ and ‘gandum’. It is cultivated on most of the irrigated area of Sindh (35 %). Cotton and rice are the other major crops in the province (Figure 1.14).

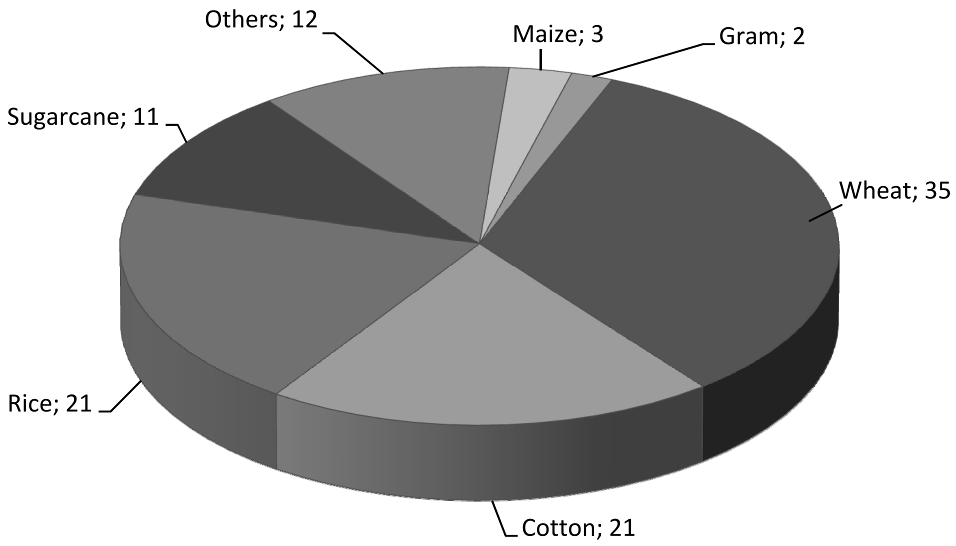

Figure 1.14 Percentage of cropped area in Sindh province of Pakistan, 2008

In 2008, wheat was cultivated on approximately 1 million ha of the irrigated area of the province. Although there has been no substantial reduction or increase in the wheat area during the last 10 years, there are many factors that force the farmers to grow other crops than wheat, e.g., high prices of inorganic fertilizers and other inputs, lack of improved inputs like seeds, low government purchasing rate, and water scarcity.

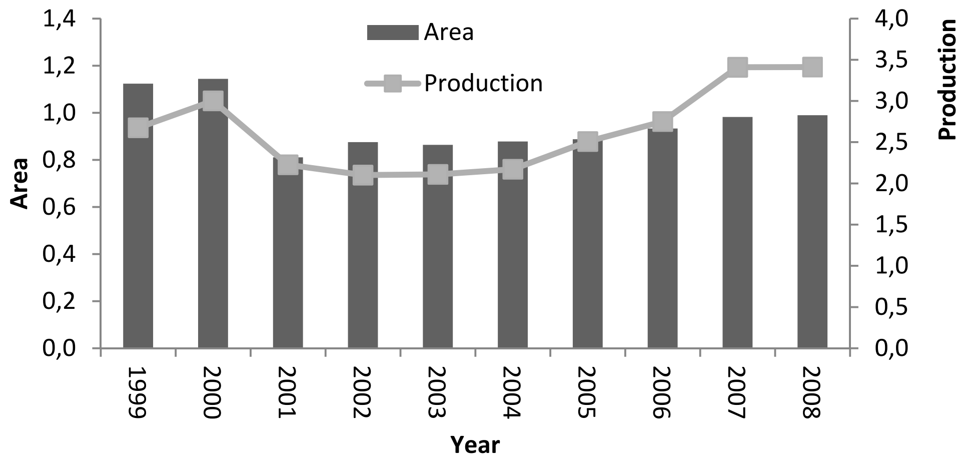

Figure 1.15 Wheat production (tons ha^{-1}) and area under cultivation (ha) in Sindh province of Pakistan, 1999 - 2008

In recent years, it has been observed that wheat production has increased in the province. For example in 2008, the increase in wheat production was 3.4 tons ha^{-1} and in that year was the highest since 1999 (Figure 1.15). This increase is mainly attributed to improved cultivars.

Sowing time for the wheat crop in southern Sindh is from 1 November to 15 of December whereas in northern Sindh it ranges from 7 November to 21 December.

Three sowing methods are applied, i.e., drilling, broadcasting and broadcasting in standing water (ghurbi). Each of these methods has different seed rate applications. For example, a seed rate of 50 (early sowing) - 60 (late sowing) kg $acre^{-1}$ (124 – 142 kg ha^{-1}) is recommended for the drilling method. For broadcasting, the recommendation is 55 (early sowing) - 65 (late sowing) kg $acre^{-1}$ (136 and 161 kg ha^{-1}). With the ghrubi method, the recommendation is 60 (early sowing) - 70 (late sowing) kg $acre^{-1}$ (148 and 173 seed kg ha^{-1}).

Normally wheat is followed by green manure crops such as green gram (moong), cluster-bean (guar), black-eyed pea (lobia), or hubam clover, which are sown immediately after the wheat crop to enrich the soil. Cotton, gram, linseed, barley, and mustard are included in rotations.

1.4.3 Mineral nutrient management through inorganic fertilizer use for wheat in Pakistan

Balanced fertilization supplies N, P, K and/or other nutrients to enhance crop yield, crop quality, and farm income. It corrects soil nutrient deficiencies and maintains soil fertility. According to FAO statistics, NPK fertilizer consumption in Pakistan has increased manifold between 1961 and 2007 (Figure 2.3). For example, in 1990, the NPK fertilizer use was 1.9 million tons and rose to 3.6 million tons in 2007 (Figure 1.16). The recent increase in fertilizer costs has, however, led to a reduction from 3.9 million tons in 2004 to the 3.6 million tons in 2007.

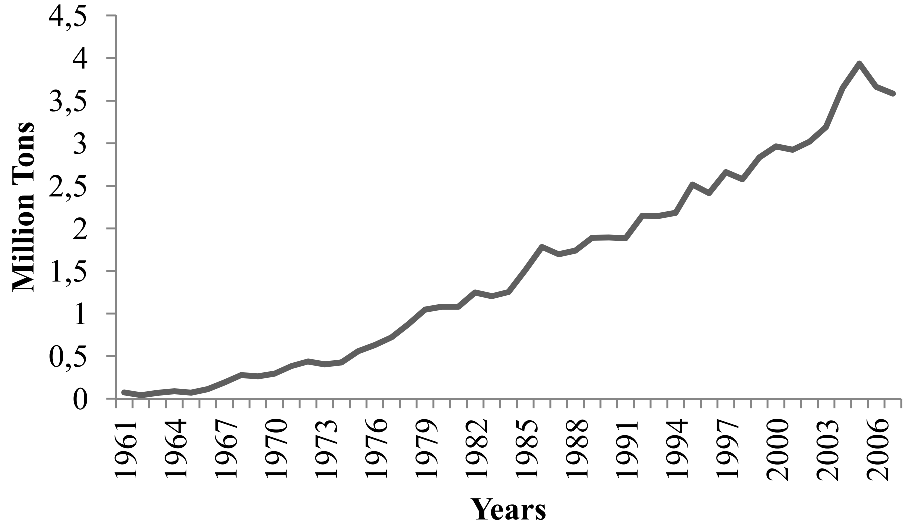

Figure 1.16 NPK fertilizer use (million tons) in Pakistan, 1960-2007

The total fertilizer use in Pakistan is approximately 3.6 million tons (NDFC, 2008), of which most is used for wheat production (50 %) followed by cotton, sugarcane, rice and maize (Figure 1.17). However, the use of nutrients is not balanced. Growth in food production and hence of fertilizer use will continue due to increased food demand. There are recommendations for fertilizer application, but these are not being implemented by farmers. Rashid (2006) reported several reasons for this. For example, most of the research information is documented and published through scientific conferences and seminars, but the transmission to the stakeholders is rather slow and ineffective. They further reported that farmers are not willing to adopt micronutrient-enriched fertilizers. Moreover there is also inadequate availability of such micronutrient-enriched fertilizers. Due to the low fertilizer quality and the lack of adequate methods for its application (especially foliar application), the farmers do not make adequate use of fertilizers to compensate for losses and imbalances. The lack of appropriate technology also leads to uneven random application. Fertilization practices are far from the recommendations with consequent loss of yield, financial waste and environmental contamination.

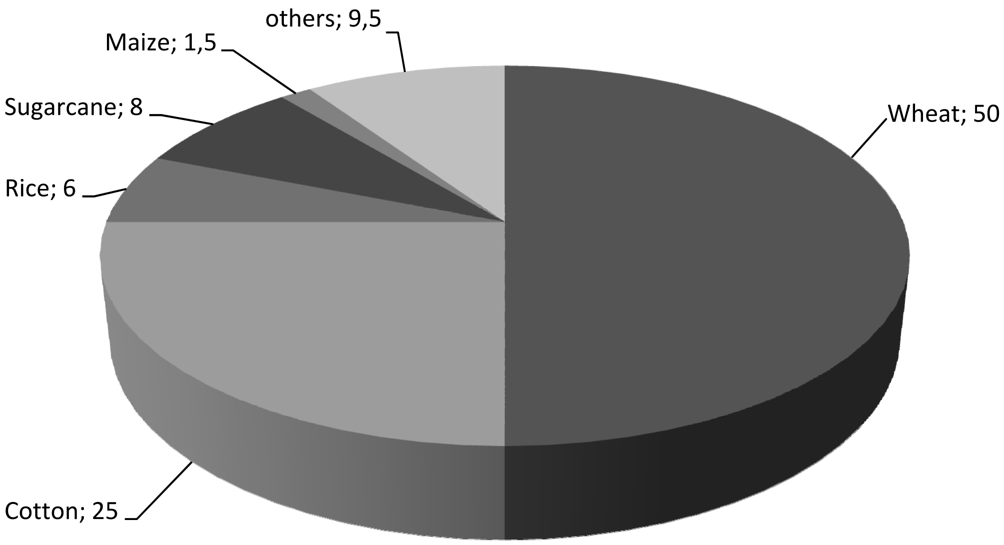

Figure 1.17 Fertilizer use by crop (percentage) in Pakistan. Total consumption 3.6 million tons in 2008 (NFDC)

Urea and di-ammonium phosphate (DAP) are the two major fertilizers (sources of N and P) used in Pakistan. Afzall and Ahmad (2009) reported that the demand for urea and DAP is increasing at an average rate of 6 and 8%, respectively; 82% of the fertilizers are produced within the country. The Fauji Fertilizer Company has a 51.5% share, Engro Chemicals a 20%, and FFBL a 10.5% share in the total production of urea in the country.

Saleem (1983, 1992) reported that fertilizer efficiency is quite low in Pakistan. Selection of suitable fertilizers and their appropriate combination, application method and time can increase their efficiency even with poor quality water. He further reported that management of irrigation is necessary for improving fertilizer use efficiency. There is a positive interaction between fertilizer and irrigation water.

According to the NDFC (2008), the total consumption of fertilizer use in Pakistan was approximately 3.6 tons in 2008. Wheat occupies that largest area because of food security, whereas cotton is a cash crop with a smaller area and using smaller amount of fertilizers but a large amount of pesticides. Wheat uses about 50 % of the total fertilizers followed by cotton, sugarcane, rice and maize (Figure 1.8). Returns on wheat are not very high because of low water productivity and nutrient use efficiency

(FAO 2004). According to Krauss (1997), the USA was produced more than double the amount of food grain per ha than Pakistan with the same amount of nutrients per ha. Unfortunately, Pakistan's soils are deficient in N (100 %), P (90%), Zn (70%) and B (55%). Potassium is generally adequate in irrigated areas, but it is becoming deficient, and only 1-2% of farmers apply potash to fruits, vegetables and sugarcane (APO 2002).

Ahmed and Rashid (2004) reported that the low yields wheat in Pakistan may be attributed to many genetic, environmental and agronomical factors. Among agronomical factors, fertilizer plays a prominent role in increasing the production per unit area. The average yield of 58 trials of irrigated wheat in Sind showed that application of 150-100-60 NPK kg ha^{-1} increased yield (4218 kg ha^{-1}) by 224% over the control (1302 kg ha^{-1}) (NFDC, 2001). The recommended fertilizer doses for irrigated wheat in Sind are 130-170 N, 60-90 P and 50 K kg ha^{-1}.

Amjad (2004) reported that the fertilizer application methods in Pakistan are inefficient. Phosphate fertilizer in wheat is conventionally applied broadcast before sowing the crop by which only 15-25% of the applied P is directly utilized by the wheat crop. The seed-cum-fertilizer drills are also inefficient as these drills place fertilizer either too far from the seed or in direct contact with it. In both cases, the fertilizer use efficiency is hampered. Currently, fertilizer band-placement drills are used. This drill places fertilizer about 5 cm away from and 5 cm deeper than the seed. Alam et al (2002b) emphasized balanced proportion of P fertilizer at proper time and by a suitable method has significant impact on crop yield.. Results of experiments conducted by the Pakistan Agriculture Research Council showed that 60-70% of the applied P is utilized by the wheat crop. Field experiments have confirmed that this drill saves 50% P fertilizer compared to the broadcast method. In addition, a 10% higher grain yield was obtained in plots where a 50% fertilizer dose (99 kg DAP ha^{-1}) was band-applied using this drill compared to the broadcast-applied recommended dose (198 kg DAP ha^{-1}). Thus, a farmer may get a benefit of Rs. 3211 ha^{-1} using this technology as compared to conventional broadcast method. But the situation is different in reality where, farmers use their old fertilization method and consequently get very low yields, although inputs are high.

Ahmad et al. (2005) observed a significant increase in the use of P fertilizer for wheat crops in 1999-2000. This was made possible by improving the fertilizer distribution system and its timely availability to the wheat growers. Furthermore, implementation of strict quality control measures improved the quality of fertilizers. About 38% of the farmers recognized that they had received fertilizers of improved quality. The remaining farmers reported that the quality was either same (55%) or poor (7 %) as compared with the previous year. The soils in the study area in Sindh vary in texture from light sandy soils to moderately fine and fine clayey soils. Medium-textured soils, i.e., loams of different composition, constitute 39 % of the total. The soils are calcareous to varying degrees because of the presence of free calcium carbonate. Soil pH generally ranges from 7.5 to 8.5. Higher pH values are found in sodic soils where sodium dominates in relation to calcium and magnesium (Memon, 2004).

Sindh soils, like most soils of Pakistan, are invariably deficient in N. Phosphorous is deficient in 80-90 % of the soils despite the use of P fertilizers in the last four decades. Levels are generally adequate in the majority (60 %) of soils, and some 40 % soils are marginal to deficient. Organic matter level are very low (<1.0 %), and in 75-80% of the soils even below 0.5 %.

As for the micronutrients, numerous soil samples obtained from various districts of Sindh indicate that Cu, Fe, and Mn levels are generally adequate for crop nutrition. However, Zn is the most deficient micronutrient in Sindh soils, and on average, more than 50% of the soils are deficient in Zn. Boron and Fe are also deficient (Memon 1986). In another study by Memon (1985), soil samples from Hyderabad district were reported to be adequate in Cu, Fe, and Mn.

Due to population and economic growth and because of the importance of soil nutrients for food quality, nutrient mining is expected to be the main hindrance for crop growth in the region. Therefore, guidelines should be provided to the farmers on when to apply nutrients and how much.

It is hypothesized that imbalanced and non-judicious use of fertilizers and other sources of plant nutrition limits productivity in the cropping systems in Hyderabad. The above-mentioned literature clearly shows that good quality and balanced use of fertilizers is very important for good yields. However, in the study area, the farmers do not focus on proper fertilizer use for sustainable crop management.

According to the survey in the Hyderabad fields, the farmers use N fertilizers but do not keep to the recommended fertilizer dose and apply heavy doses throughout the growing season. Therefore, crop lodging and leaching of N from the soil frequently occurs, and in the long run the soil fertility declines. To improve the limited possibilities of dryland farming, it is essential to apply sustainable management practices. Use of crop rotations with legumes improves soil physical (Andriulo et al., 1990a, b), chemical (Miglierina et al., 1995) and biological conditions, thereby enhancing nutrient availability and soil water contents.

1.5 Objectives of the study

Considering the aforementioned situation, the objectives of the present study were:

- To determine the nutritional factors limiting productivity of wheat in the district Hyderabad, Pakistan.
- To compare DRIS and the critical level approach for evaluating nutrient deficiencies in wheat.
- To identify the most limiting nutrient(s) that should be applied to improve and stabilize the yield of wheat in Hyderabad.

1.6 Working hypotheses

It is hypothesized that DRIS evaluation and/or critical level approach are able to identify the most limiting nutrients in the district Hyderabad, Pakistan, and provide a tool to improve crop management in this area by correcting nutrient deficiencies in the most appropriate manner.

2 STUDY AREA

2.1 Location

The study was conducted in Hyderabad, one of the southern districts in Sindh province, Pakistan (Figure 2.1). It is located between latitude 25° 22' 0" N and longitude 68° 22' 0" E at an elevation of 40 m a.s.l. The lands are known to be the most fertile irrigated plains in the region. The Indus River flows on the northwest side of the district, and the desert Rann of Kach is located in the southeast. The total area of Hyderabad is 3,198 km^2 with an irrigated area of 2,620 km^2.

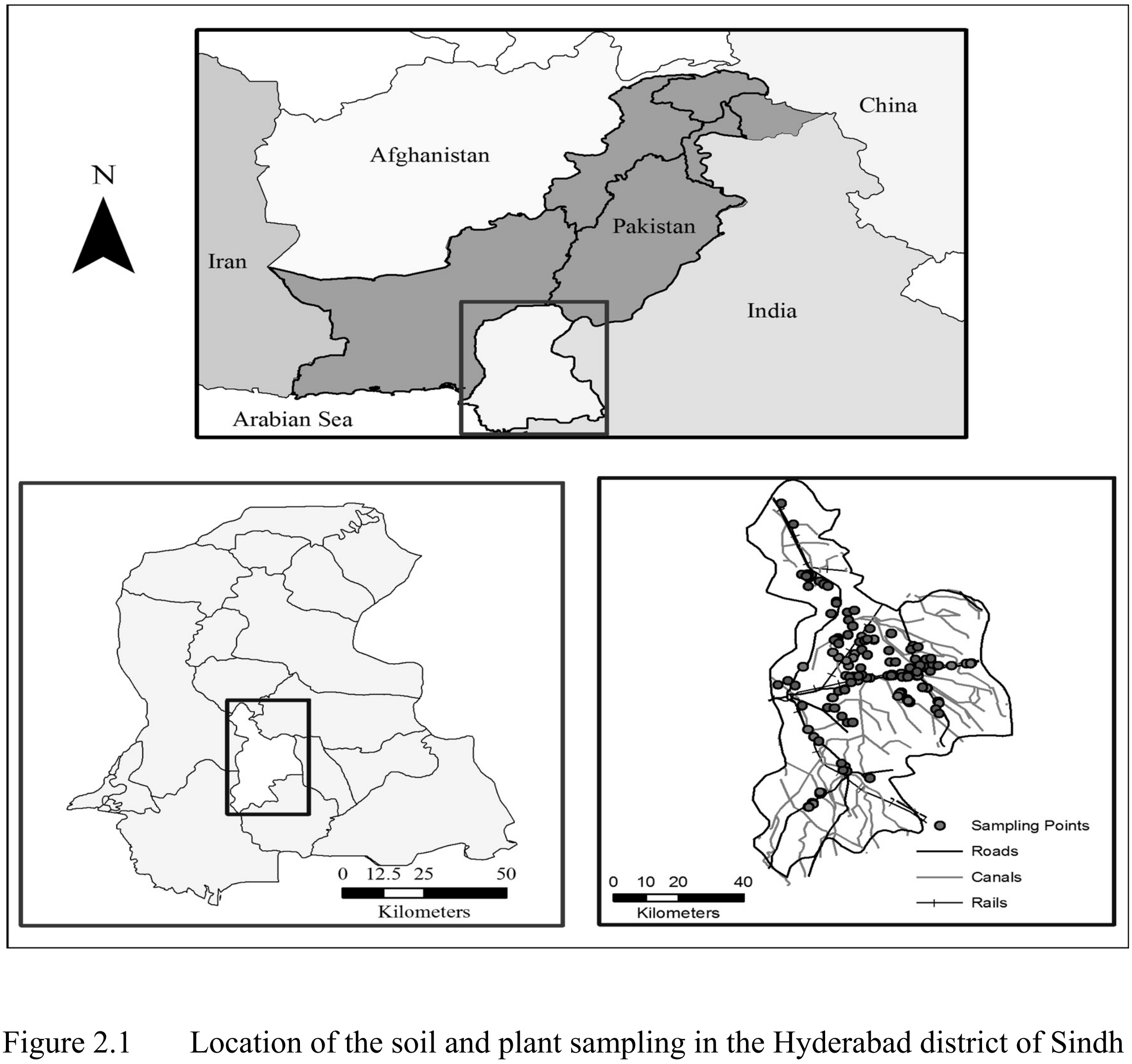

Figure 2.1 Location of the soil and plant sampling in the Hyderabad district of Sindh province, Pakistan

2.2 Meteorological data

Climatically, the study area is arid to semi-arid and receives a long- term average annual rainfall of about 178 mm (PAS, 2009). The average maximum temperature reaches 41.ºĊ in May and the minimum 11.°C in January. The four seasons in Pakistan are, winter (December to February), spring (March to April), summer (May to September) and autumn (October to November). July, August and September receive monsoon rainfall, which is more than 70 % of the total annual precipitation (Figure 2.2).

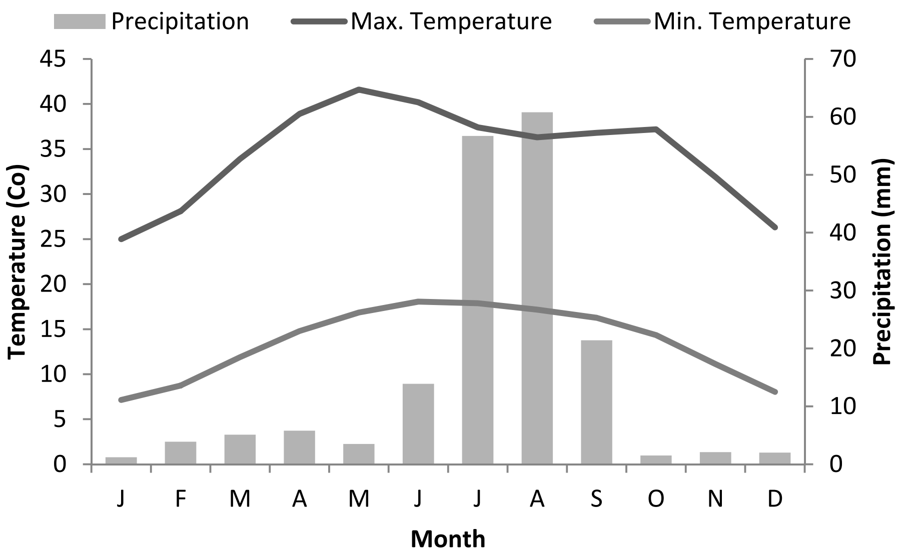

Figure 2.2 Mean monthly precipitation, minimum (min.) temperature and maximum (max.) temperature, 1999 -2008

2.3 Agro-ecological zones (AEZs) in Pakistan

Based upon the climatic conditions, Pakistan is divided into 10 agro-ecological zones (Figure 2.3). These zones are: Indus delta, southern irrigated plain, sandy desert, northern irrigated plains, Barani areas, wet mountains, northern dry mountains, western dry mountains, dry western plateau and the Sulaiman Piedmont (PARC 1980).

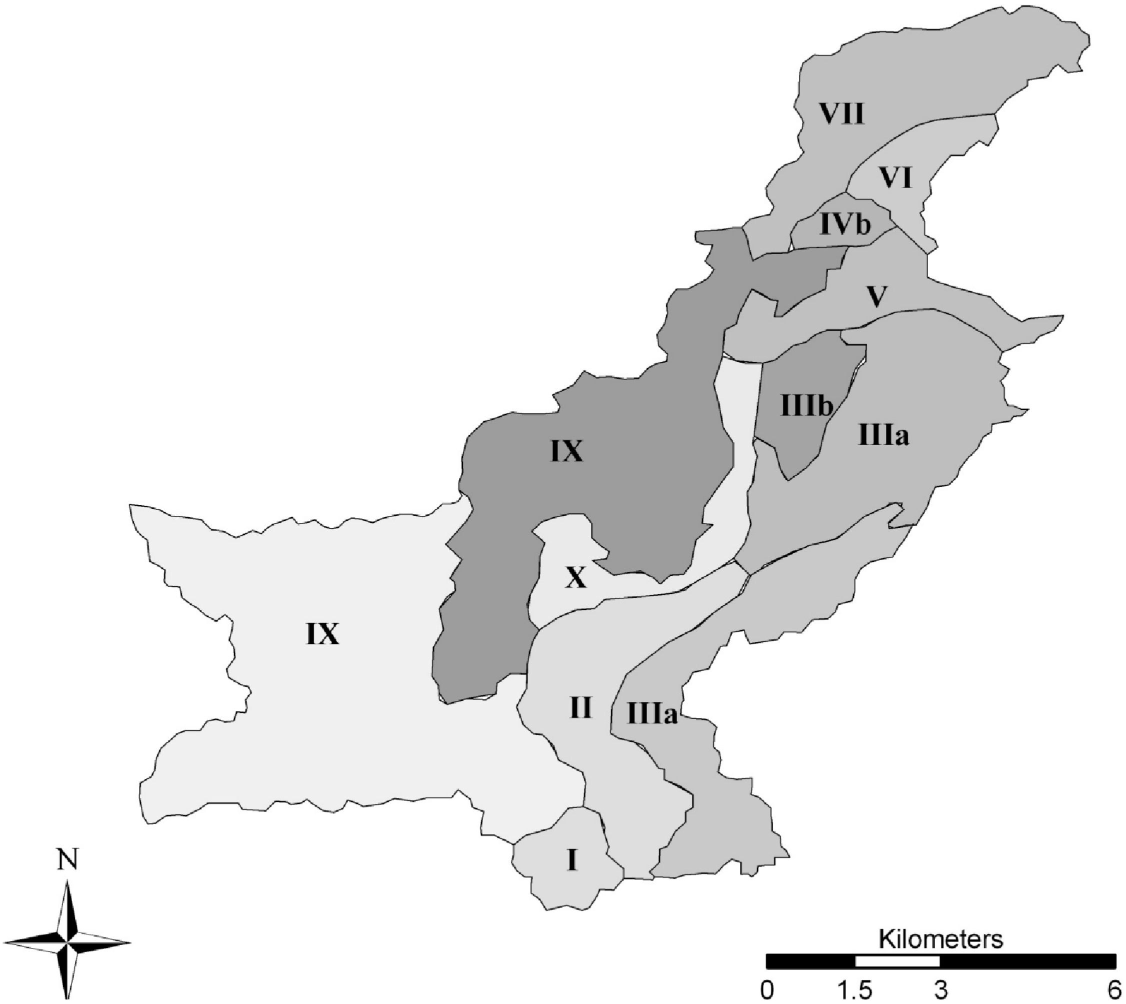

Figure 2.3 Agro-ecological zones of Pakistan (Redrawn in Arc-GIS; PARC 1980)

The study area is located in the agro-ecological zone II. In this zone, the irrigated area is arid with maximum temperatures from 30–50 °C and a minimum temperature of 12 °C. The annual rainfall is 136 mm and the mean monthly summer rainfall is 18 mm in the north and 45 - 55 mm in the south. Cotton, wheat, sugarcane, rice, sorghum, berseem, and clover are the major crops in this area.

Overall there are two cropping seasons in Pakistan, namely “Kharif”, and “Rabi”. For the Kharif season, sowing of the crops begins in April while harvesting is between October and December. For Rabi crops, the sowing starts at the beginning of October and ends in April. The main Kharif crops include rice, sugarcane and cotton, while wheat and barley are the main Rabi crops.

2.4 Cropping pattern

Due to low rainfall and high evapotranspiration, canal and groundwater is used for irrigating the crops in the region. The study area is mainly cultivated with wheat-cotton and wheat-sugarcane rotation. It is divided into two belts of cropping systems, the sugarcane and the cotton belt, respectively. Cotton-wheat rotation is the most common practice in the region. Wheat-sugarcane is also practiced where some fields are used for intercropping of sugarcane with wheat. The other field crops include vegetables and maize as fodder crop, while banana and rose farming are for commercial purposes. Mango gardening is also quite popular in the region.

2.5 Irrigation sources

The surface irrigation system in Pakistan is the world's largest contiguous irrigation system. In Sindh, an extensive network of irrigation canals established mainly after the construction of the Sukkur Barrage on the Indus River. The Indus River is the sole source for surface irrigation in the area and begins in the Himalayan Mountains and the Hindu Kush. However, due to shortage of water and intensive irrigation, the surface water is insufficient for irrigation. Therefore, many farmers install tube wells for pumping the groundwater. The farmers with land at the tail end of the canals suffer from a lack of freshwater supply. Thus, crop production level there are much lower than those in the head area. Therefore, crop selection depends on the availability and the reliability of the irrigation water supply. The crops with high water requirements, such as sugarcane, are hardly found in the tail area.

2.6 Soils

A total of eight soil series varying in parent material and pedagogical development exists in the study area (Figure 3.4). These soil series are Sultanpur, Shahdra, Pacca, Sarhad, Matli, Bagh, Garhi, and Rustam (Table 2.1).

Table 2.1 Soil series in the study region

	Local name	Order	Sub-order	Great group	Sub-group
1	Sultanpur	Ardisols	Orthids	Camborthids	Typic camborthids
2	Shahdra	Entisols	Fluvents	Torri fluvents	Typic torri fluvents
3	Pacca	Ardisols	Orthids	Camborthids	Typic camborthids
4	Sarhad	Entisols	Psamments	Torri psamments	Typic torri psamments
5	Matli	Ardisols	Orthids	Camborthids	Typiccamborthids
6	Bagh	Ardisols	Orthids	Camborthids	Fluventic camborthids
7	Garhi	Entisols	Orthents	Torri orthents	Halic torri orthents
8	Rustum	Entisols	Orthents	Torri orthents	Halic torri orthents

The Sultanpur soils consist of deep and well drained calcareous soils with a pH 8.0-8.2. They consist of a Cambic B horizon, which is about 50 cm thick and has a dark greyish brown colour. The silty clay loam topsoil is underlain by brown\dark brown and friable calcareous silt loam.

Shahdra soils are stratified and moderately calcareous with different textural grades such as silty loam, sandy loam, loamy sand, and clay texture. These are found in recent flood plains. A few mottles are present in the subsoil under arid and semiarid conditions.

Pacca soils have a B-horizon, which is 56-60 cm thick. It has a sub-angular blocky structure with a silty clay to clay texture. They are moderately calcareous with pH 8.0-8.5. Some mottles with some cutans are present in the B horizon.

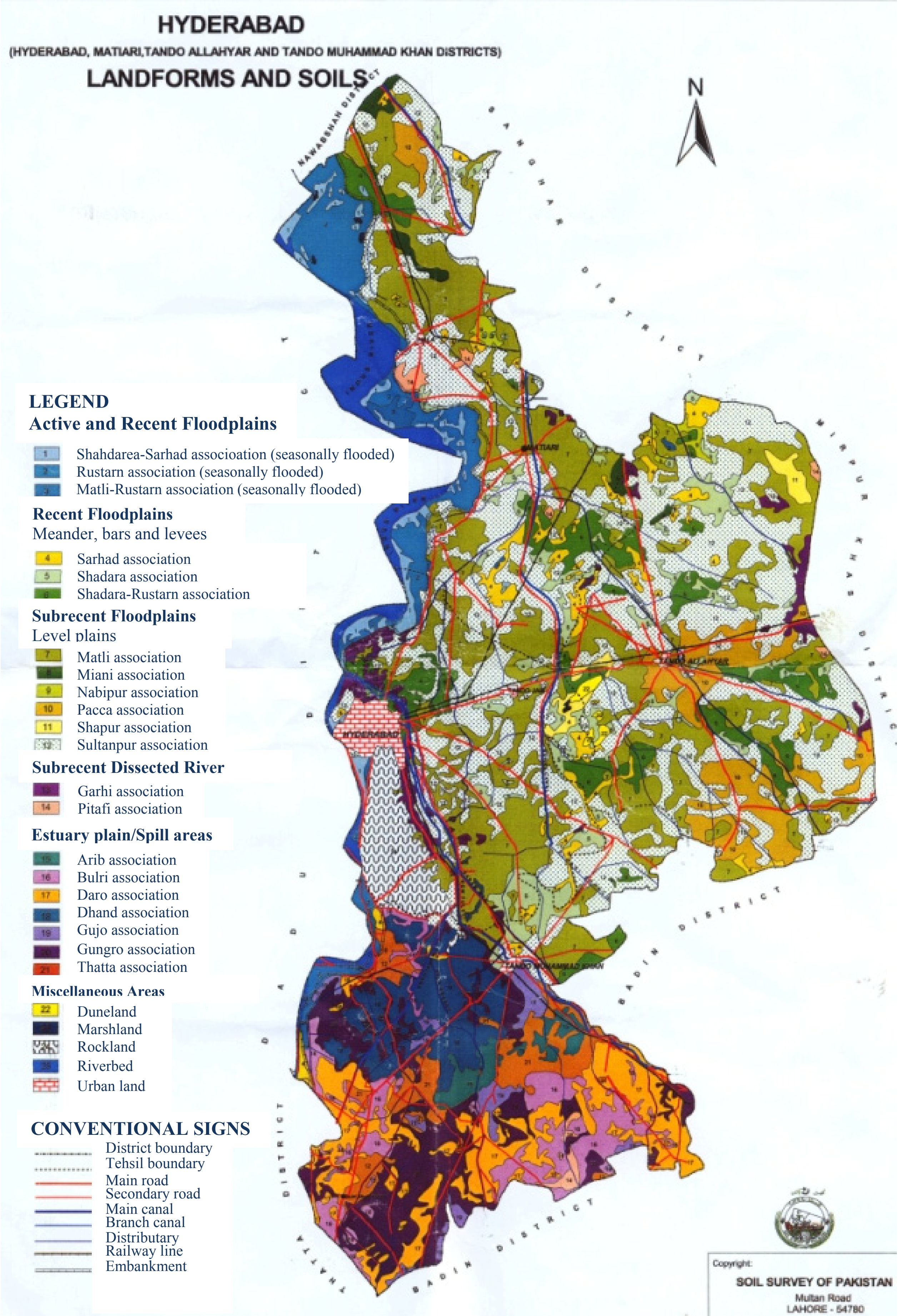

Figure 2.4 Soil map of Hyderabad district (Soil Survey of Pakistan, 2007)

Sarhad soil series are formed from recent alluvium under an arid climate. These soils are loamy sand to sandy in texture with massive, and in few places with a stratified sand structure. They are moderately calcareous with pH 7.8-8.2 in A and C horizons.

Matli soil series are formed in basins and are moderately calcareous with a silty clay to clay texture. B horizons with a weak subangular blocky structure develop in arid and semi- arid climates.

Bagh soil series are formed on level or nearly level areas, mottled on recent alluvium in arid and semi -arid climate. These soils have B a horizon with a subangular blocky structure, and are loamy to sandy loam in texture, and moderately calcareous.

Garhi soils have sandy loam, fine loamy sand, silty clay and loam stratified structures at various depths. Gypsum is present at various depths, notably below the sandy loam to loamy sand layer. These soils are moderately calcareous with pH 8.0-8.5 and are saline in nature.

Rustum soil series have a silty clay and clay texture with massive structures and weak platy structures at various depths. These soils are moderately calcareous with pH 8.2 - 8.5. The soil profile was formed in recent alluvium. Some faint (light colour) or clay mottle is found in the subsoil.

3 METHODS

3.1 Site selection

The farmer's fields were selected on the basis of a survey of wheat growing areas in the district of Hyderabad. Both low- and high-yielding areas with different crop production management were chosen. DRIS implementation requires over one hundred tissue samples for a successful diagnosis of the plant nutrition status in a region. Therefore, a comprehensive wheat plant sampling was conducted in famers' fields in the district of Hyderabad at different development stages during the wheat cropping seasons 2007-2008 (80 samples) and 2008-2009 (101 samples). All samples were collected randomly in places representative of the area (Figure 3.1)

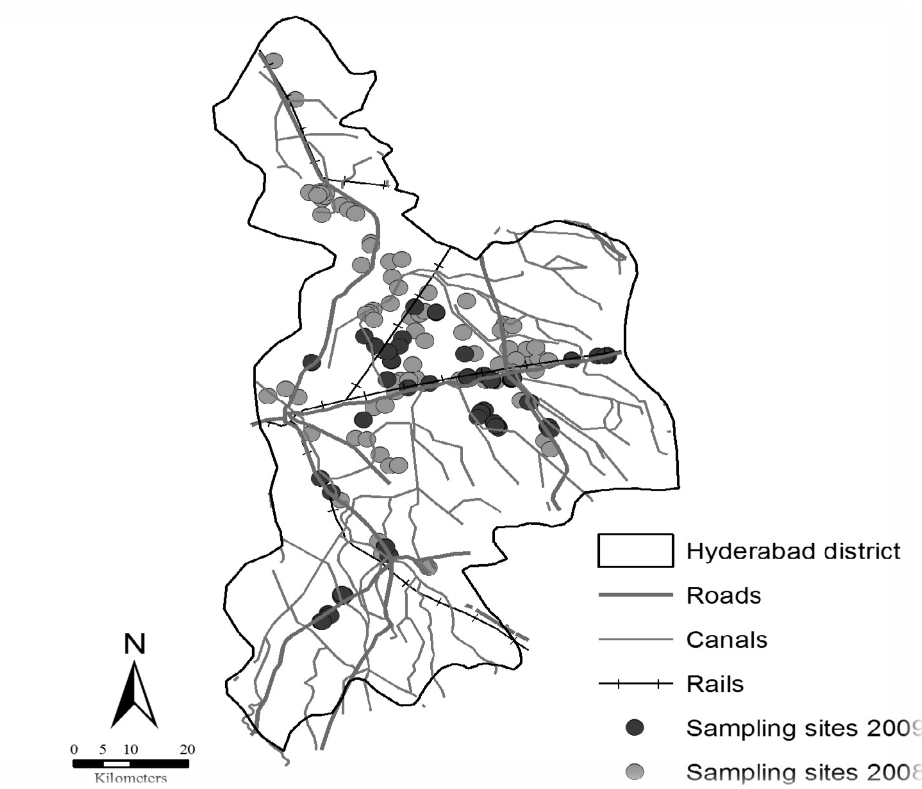

Figure 3.1 Plant sampling locations in district Hyderabad, Sindh, Pakistan

Sampling sites were marked using GPS. The soil survey map of Pakistan (Soil Survey of Pakistan, 2007) was used to digitize the Hyderabad district. To geo-reference this map, GPS points during the field survey were taken from known places e.g., canals crossings and road crossings. The map was then geo-referenced and digitized with the

ARC GIS software. GPS points taken from the 181 sampling sites were then imported (Figure 3.1).

For the sampling sites, along with plant data collection, a short survey was conducted. For this purpose, a questionnaire was generated (Table 3.1) to collect basic information from the farmers.

Table 3.1 Basic information collected in the survey area

S.No.	GPS Point	Soil Series	Cultivar	Name of Farmer	Name of Village	Area	Previous Crop	Fertilizer amount	Source of Irrigation

The soil series map was used to determine the location of a farmer's field from where the plant samples were taken. As different varieties of wheat are grown in the region, data on the variety of the wheat were also collected. To determine the cropping patterns, data on the previous crop and its schedule were also collected from the farmers. . Farmers were also asked which type of fertilizer they used and the amount in kilogram per hectare applied for a specific crop. Some of the farmers in the region apply water directly to their fields from canals whereas the others use underground tube wells for irrigation. However, some use both; data on the irrigation source were included in the questionnaire.

3.2 Sampling strategy

For sampling, the different growth stages of the wheat crop for determination of mineral nutrients and the assessment by the diagnosis and recommendation integrated system (DRIS) were selected according to recommendations of Reuter and Robinson (1986) (Figure 3.3). The first sampling was done at development stage of plant based on the Zadok scale of growth stages (Zadok et al., 1974). The whole shoot material was taken above the ground level at end of the tillering stage (GS-29) from every plot. Four samples were taken from every plot and subsequently pooled. The second sampling was conducted at the emergence of the flag leaf (GS-39). Here the youngest leaf (not flag leaf) was taken from 20 different plants that were randomly selected in the field. These samples were homogenized to make one representative sample of the field. The third sampling was done at harvesting. Plants were counted on one meter square for yield calculation. Twenty plants were selected randomly, and the ears were used to assess the number of grains per spike, number of spikelets and thousand-grains weight.

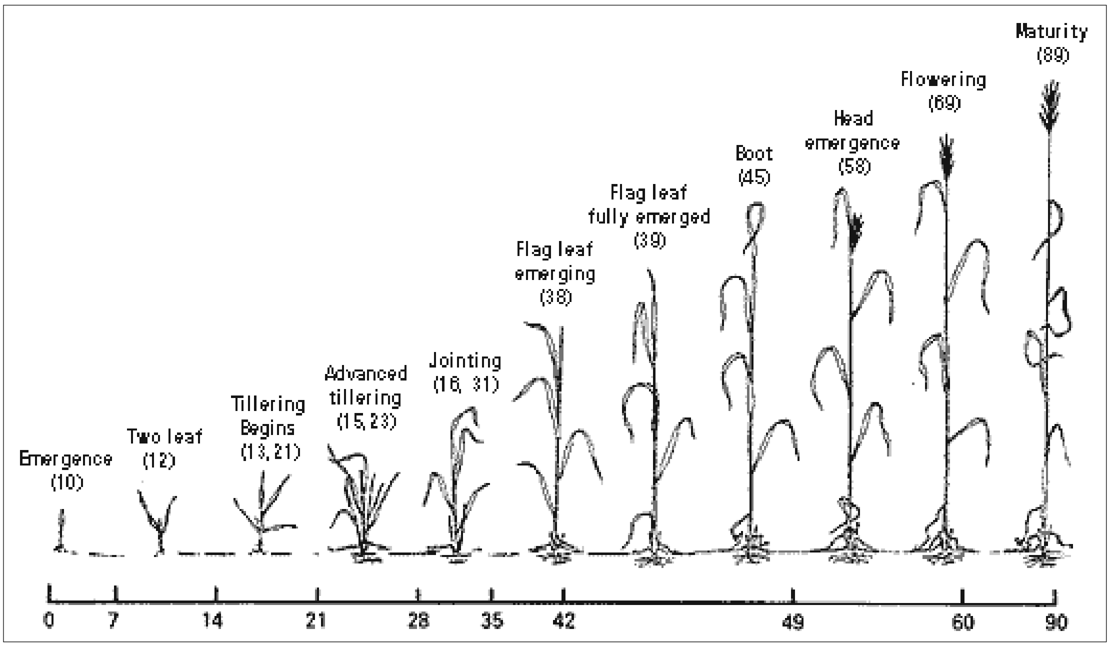

Figure 3.2 Zadok scale of wheat growth stages (Zadok et al., 1974) with days after sowing in parenthesis.

3.3 Plant analysis

3.3.1 Drying of wheat plant material

Before oven drying the samples at 80 °C, the tissues were air dried and placed in paper bags. After drying, the tissues were homogenised and ground and then stored in, airtight plastic bags. .

From the composite samples, sub-samples were taken for analysis of macronutrients (N, P, K) and micronutrients (Zn, Cu, Fe, Mn, and B). The analysis was carried out in the laboratory of the Institute of Plant Nutrition at Bonn University, Germany, in accordance with methods of the Association of German Agricultural Analytical and Research Institutes (VDLUFA). The samples were analysed in duplicate for each nutrient to reduce analytical error.

Figure 3.3 Plant analyses in the laboratory of the Institute of Plant Nutrition at Bonn University, Germany.

3.3.2 Digestion of Plant material

Material was wet digested in PTFE bombs according to Vigler et al. (1980) and Okamoto and Fuwa (1984).

Dried plant material was subject to pressure digestion in duplicate: 0.5g plant material was weighed in Teflon digesting cups, and 4ml of 65% nitric acid (analytical grade) was added for digestion. The PTFE cups were kept in a heating oven at constant temperature (180°C) for one hour. After digestion, the samples were kept overnight for cooling. Then the cups were opened and several rinses were done with ultra pure water (Millipore-Q GmbH, Eschborn) and a constant volume was made in duplicate by the addition of ultra pure water in micro tubes (Eppendorf) for the elemental analysis.

3.3.3 Nitrogen analysis by the Kjeldahl digestion method

Total N was determined in both shoot dry matter and leaf tissue by the Kjeldahl method. The analysis was done by using Vapodest Kjeldahl by Gerhardt GmbH and Co., Bonn. With this method, 0.5 g of plant material in duplicate was taken in the 100 mL glass digestion tubes including a blank without plant material in each set of samples. The plants were digested with 10 mL of concentrated sulphuric acid with a catalyst mixture by Kjeldahl. The mixture was then placed on a heated block digester Gallagher et al. (1975) and Tucker (1974) reported that block digestion is useful for proper heating in a given time period. It shortens digestion time and allows very uniform temperature control. The samples were digested for 60 min at 280°C. After digestion, samples were allowed to cool. The tubes were connected with the, using the auto distillation equipment. The reagents needed for distillation are sodium hydroxide solution, boric acid and deionised water. Ammonia (NH_3) was forced into a 4% boric acid solution by distillation, after NaOH had been added to the solution. Care had to be taken to immediately attach the flask for distillation to the distillation unit after adding the (10N) NaOH concentration to avoid N losses before the distillation process.

All tubes were connected to the distillation unit and the solutions were dispensed in each tube of digested plant material. The distillation period was 4 minutes. Then titration was done using 0.01N sulphuric acid at pH 5.0 with an autotitrator, which recorded the volume of acid used for titration.

3.3.4 Phosphorous determination by molybdenum blue color method

Phosphate in the digest was measured by the reaction of phosphate with ammonium molybdate in an acid medium to form molybdophosphoric acid. The molybdophosphoric acid is reduced to a blue colored complex through reaction with ascorbic acid (Murphy and Riley 1962).

With this method, a spectrophotometer (ECOM 6122 (Eppendorf)) was used where the samples were analysed at 660 nm wave length. A set of different working standards was applied for the calibration curve. A standard curve constructed from absorbance reading of standards is used to convert absorbance value of samples to phosphate concentration.

3.3.5 Potassium determination

The samples of leaf tissue and wheat shoot dry matter were analysed for potassium by a flame photometer (ELEX 6361; Eppendorf) using the digested plant material directly or after dilution according to the concentration.

3.3.6 Boron determination by miniaturized curcumin method

For boron determination, the modified and miniaturized spectrophotometric curcumin method developed by Wimmer and Goldbach (1998) was used. This method allows the determination of boron in sample volumes of 50 - 150 µl with a detection limit of 0.010 mgB l^{-1}.

To avoid contamination from glass, high grade plastic ware was used for analysis. The analysis was done by taking 100 µl of aliquot in micro tubes (Eppendorf). In these tubes, 100µl of 0.1N hydrochloric acid and 50µl of Diol\chloroform extracted solution (2-Ethyl-1,3-hexanediol 10% (v/v) in chloroform) were added. The tubes were closed with air tight lids, shaken for 30 seconds and then centrifuged to yield a clear solution. After centrifugation, the separation of two phases was complete. 20 µl of the organic phase of the sample were taken from the bottom of the tube and then transferred to microtubes. To this phase was then added 200 µl of an acid mixture (concentrated acetic acid and sulphuric acid, 1:1 v/v). For the color reaction, 250 µl of curcumin solution (curcumin and isobutylmethyl ketone) was added, shaken again on a shaker for 30 seconds and then centrifuged. Then the sample was left to stand for one hour for completing the colour reaction. After one hour, the reaction was stopped by the addition of 500 µl B-free water. After complete separation of the two phases, 120 µl of the upper organic phase were transferred into quartz micro cuvette and measurements were done with a Lambda 20 UV/VIS spectrophotometer (Perkin Elmer) at 550 nm. Blanks were run as analytical controls for each set of samples. B concentrations were calculated according to a calibration curve that was prepared with defined B concentrations.

3.3.7 Micronutrient (Zn, Fe, Cu and Mn) determination

The wheat plant shoots and leaf tissue were analysed for micronutrients (Zn, Fe, Cu and Mn) by atomic absorption spectrometry from the acid digested plant material as described above. Values were computed against standard curves prepared freshly each day.

The atomic absorption spectrophotometer (AAS) Perkin-Elmer Model 1100B was used with an air-acetylene flame.

3.4 Yield calculation

In order to develop the DRIS norms for high-yielding populations, yield was estimated using the following formula (CIMMYT website):

$$\begin{gathered} Estimated\ yield\ (t\ ha^{-1}) = \\ (spikes\ per\ sq\ m) \times (average\ no. of\ grains\ per\ spike) \times \\ \big(estimated\ grain\ weight\ (mg\ per\ 10{,}000)\big) \end{gathered} \tag{3.1}$$

During the field work, the data on the required variables, i.e., spikes per square meter, average number of grains per spike and 1000-grains weight, were collected from each site.

For determining the number of spikes per square meter, a wooden frame of 1 m^2 was constructed and from the 20 plants, ear heads were collected and the number of grains per spike counted. Using a "Numagrain" seed counter, 1000 healthy grains were counted and weighed.

3.5 Diagnosis and Recommendation Integrated System (DRIS)

The diagnosis and recommendation integrated system (DRIS) method was applied for the determination of N, P, K, Cu, Fe, Mn, Zn and B nutritional balances of the wheat at two different growth stages. DRIS indices were obtained by the methodology proposed by Beaufils (1973) in which the optimum ratios (norms) for all nutrient combinations are determined and used as a diagnostic criterion. Therefore, the first step for the application of DRIS is to establish the norms. A norm is reckoned as a standard value that is used to evaluate nutrient status/relationships in a plant tissue to be diagnosed. The procedure used to establish norms for a wheat crop is given below.

3.5.1 Establishment of HYDERABAD DRIS norms for wheat crop

Sumner (1979) suggested a survey -type approach for collecting the crop production data from the random experimental or farmer fields to develop the DRIS norms. These crop production data are used to differentiate between low yielding and high yielding populations. The high yielding population data sets are used to develop the norms. Adopting this approach, yield and nutrient data were collected randomly from 181 sites to represent the wheat production area. This population of observations was then divided into two subpopulations, i.e., high-yielding and low-yielding population, on the basis of yield data. To divide the population, a simple statistical approach was used as described below.

3.5.2 Partitioning data into high- and low-yielding sub-populations

The Cate and Nelson (1971) procedure, which is often referred to as statistical Critical Value Approach (CVA), was used to derive the cut-off value between the high-yielding and low-yielding populations (Table 3.2). First, the yield data were arranged in descending order. Starting with the initial yield value (I), the corrected sums of squares of the two populations that result from moving to each successive yield value were calculated. Then the total sum of squares was calculated. This total sum of squares was subtracted from the corrected sum of squares for each population. The difference between the total sum of squares and the corrected sum of squares was then expressed as the percentage of the total corrected sum of squares, which is also referred to as R^2. By this simple iterative process, a series of R^2 values was obtained from which the maximum R^2 value was selected as a cut-off point, i.e., the yield value where R^2 maximum is a cut-off value between the high-yielding and low-yielding sub-populations

Table 3.2 Mathematical expression for determining the cut-off value using the Cate and Nelson (1971) procedure

Total Samples	181					
TSS[a]	$(Yn-1)^2+(Yn)^2 - (Yn-1 + Yn)^2/$ 181					
I	Y	TX1[b]	CSS1[d]	TX2[c]	CSS2[e]	R^2
1	Y1	Y1	$(Y1)^2$			
2	Y2	Y1+Y2	$((Y1)^2+(Y2)^2)-(Y1+Y2)^2/2$	(Yn-1+Yn)-Y2	$((Yn-1)^2+(Yn)^2)-((Y1)^2+(Y2)^2-(Yn-1+Yn - Y2)^2/(181-2)$	TSS-(CSS1,2+CSS2,2)/TSS *100
3	Y3	Y2+Y3	$((Y2)^2+(Y3)^2)-(Y2 + Y3)^2/3$	(Yn-1+Yn)-Y3	$((Yn-1)^2 + (Yn)^2)-((Y2)^2+(Y3)^2 - (Yn-1 + Yn - Y3)^2/(181-3)$	TSS-(CSS1,3+CSS2,3)/TSS *100
-	-	-	-	-	-	-
-	-	-	-	-	-	MAX
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-
n	Yn	Yn-1+Yn	$(Yn-1)^2+(Yn)^2-(Y3)^2/n$	(Yn-1 + Yn)-Yn	$((Yn-1)^2 + (Yn)^2)-((Yn-1)^2+(Yn)^2- (Yn-1 + Yn - Yn)^2/(181-n)$	TSS-(CSS1n + CSS2n)/ TSS ·100

[a] *TSS is total sum of square*
[b] *TX1 is yield of subgroup-1 and*
[c] *TX2 is yield of subgroup-2*
[d] *CSS1 is corrected sum of squares for sub-population-1, and*
[e] *CSS2 is corrected sum of squares for sub-population-2.*

3.5.3 Partitioning the data into low- and high-yielding populations

From the high-yielding population, the mean and coefficient of variance were calculated as proposed by Sumner (1977) for each expression. The expressions representing the norms selected for this study were: N/P, N/K, N/Cu, N/Fe, N/Mn, N/Zn, N/B, P/K, P/Cu, P/Fe, P/Mn, P/Zn, P/B, K/Cu, K/Fe, K/Mn, K/Zn, K/B, Cu/Fe, Cu/Mn, Cu/Zn, Cu/B, Fe/Mn, Fe/Zn, Fe/B, Mn/Zn, Mn/B and Zn/B.

3.5.4 Function value estimates

After establishing the norms, the next step in DRIS calculation is to determine the so-called "function value". The function values determine the variation of the observed ratio, i.e., the tissue samples to be diagnosed, against the norms.

Different scientists have proposed different formulae to determine the function values. For example, according to Jones (1981), the function value can be determined by the following formula:

$$f\left(\frac{A}{B}\right) = (A/B - a/b) \times \frac{1000}{S} \tag{3.2}$$

where A/B is the value of the ratio of the two elements in the tissue under diagnosis, a/b is the value of the corresponding norms, and S is the standard deviation associated with each nutrient ratio norm.

Elwali & Gascho (1984) suggested using the following formula:

$$f\left(\frac{A}{B}\right) = \begin{cases} \left(\frac{A/B}{a/b} - 1\right) \times \frac{1000}{CV} & \text{when A/B > a/b - S} \\ 0, & \text{when A/B = a/b} \\ \left(1 - \frac{n/p}{N/P}\right) \times \frac{1000}{CV} & \text{when A/B < a/ b + S} \end{cases}$$

where A/B is the value of the ratio of the two element in the tissue under diagnosis, a/b is the value of the corresponding norms, and S is the standard deviation associated with each nutrient ratio norm.

However, in this study, DRIS function values for nutrients were calculated using the original procedures proposed by Beaufils (1973), which have been used in many studies (e.g., Silveira et al., 2005). This procedure involves two formulae, depending on the ratio of the two nutrients under study is smaller or larger than their corresponding norm values. These formulae are explained below:

Formula 1:

If the ratio between the two elements is greater than their corresponding norm, i.e., when A / B > a / b, then following formula is applicable:

$$f\left(\frac{A}{B}\right) = \left(\frac{A/B}{a/b} - 1\right) \times \frac{1000}{CV} \qquad (3.3)$$

where A/B is the value of the ratio of the two element in the tissue under diagnosis, a/b is the value of the corresponding norms, and CV is the coefficient of variation associated with each nutrient ratio norm.

Formula 2:

If the ratio between the two elements is less than their corresponding norms, i.e., when A / B < a / b then the following formula is applicable:

$$f\left(\frac{A}{B}\right) = \left(1 - \frac{a/b}{A/B}\right) \times \frac{1000}{CV} \qquad (3.4)$$

The function value, for example of N and P, thus will be derived from the general formula as below:

$$f\left(\frac{N}{P}\right) = \begin{cases} \left(\frac{N/P}{n/p} - 1\right) \times \frac{1000}{CV} & \text{when N/P > n/p} \\ 0, & \text{when N/P = n/p} \\ \left(1 - \frac{n/p}{N/P}\right) \times \frac{1000}{CV} & \text{when N/P < n/ p} \end{cases}$$

where N/P is the value of the ratio of the N and P in the tissue under diagnosis, n/p is the value of the corresponding norm, and CV is the coefficient of variation. The other functions were calculated similarly using appropriate values of A/B and a/b.

3.5.5 Coefficient of variance

The coefficient of variance (CV) is a measure of the variability among different individuals in a group as a percentage of the group mean. The CV is determined by calculating the standard deviation in a group and dividing by the group mean and can be expressed as:

$$CV = \frac{SD}{\overline{X}} \times 100 \quad (3.5)$$

where SD is standard deviation, and $\bar{X}$ is mean of the group.

The standard deviation is a square root of the variance in a group and is expressed as:

$$SD = \sqrt{\sum_{i=1}^{n} \frac{(X_i - \overline{X})^2}{n-1}} \quad (3.6)$$

where $\overline{X}$ is the value of the mean, n is the sample size, and X_i represents each data value from i=1 to i = n.

3.5.6 Index value estimates

The index value for each nutrient represents an integrated measure of its sufficiency as compared to all other nutrients. The index is the mean of all the function values involving the particular nutrient. However, the function value will be added to determine the index for the nutrient in numerator and will be subtracted if the required nutrient index is in the denominator. The DRIS indices were obtained using the methodology proposed by Beaufils (1973), which is explained below for N.

It is important to know that a nutrient may seem to be either in the numerator or denominator of any ratio, and that function values may be either positive or negative in sign. The function value is added in calculating the index for the nutrient in the numerator. However, the function value is subtracted in calculating the index for the nutrient in the denominator.

Below is an example of the N index. As N is in the numerator in all function values, all function values will be added and then divided by the total number of functions involved, i.e., 8 in this study. The following formula was used:

$$I_N = \frac{\left(f\left(\frac{N}{P}\right) + f\left(\frac{N}{K}\right) + f\left(\frac{N}{Cu}\right) + f\left(\frac{N}{Fe}\right) + f\left(\frac{N}{Mn}\right) + f\left(\frac{N}{Zn}\right) + f\left(\frac{N}{B}\right)\right)}{7} \quad (3.7)$$

3.5.6.1 Interpretation of index values

The values of the DRIS indices (I_N, I_P, $I_{K,}$ $I_{Cu,}$ $I_{Fe,}$ $I_{Mn,}$ $I_{Zn,}$ I_B) are not independent. However the sum of the index values should be equal to zero and can be expressed by the following equation:

$$I_N + I_P + I_K + I_{Cu} + I_{Fe} + I_{Mn} + I_{Zn} + I_B = 0 \quad (3.8)$$

For the interpretation of the DRIS indices, the methodology proposed by Wadt (1996) was used in this study. According to this methodology, first of all the Nutritional Balance Index (NBI) was calculated based on the sum of the absolute values of the DRIS indices for all 7 nutrients irrespective of their sign by the following equation:

$$NBI = |I_N| + |I_P| + |I_K| + |I_{Cu}| + |I_{Fe}| + |I_{Mn}| + |I_{Zn}| + |I_B| \quad (3.9)$$

In a second step, the Average Nutritional Balance Index (NBIa) was calculated. The NBI calculated in the first step was divided by the 7 nutrients concerned according to the equation:

$$NBI_a = \frac{NBI}{7} \quad (3.10)$$

In the final step, three ranges were established that indicate deficiency, adequacy, and excess of the nutrients in the plant tissues. The following relationships well describe the nutrient balance:

Relation 1 (Deficiency)

If the index value of a nutrient (I_A) is less than zero but greater than the Average Nutritional Balance Index (NBIa) that nutrient is considered as deficient in plant tissue.

$$\text{Deficient} = I_A < 0 \text{ and } |I_A| > \text{NBIa}$$

Relation 2 (Adequacy)

If the index value of a nutrient (I_A) is less than or equal to the NBIa, that nutrient is considered as adequately supplied.

$$\text{Adequate} = |I_A| \leq \text{NBIa}$$

Relation 3 (High)

If the index value of a nutrient (I_A) is greater than zero and also greater than the NBIa, that nutrient is considered as oversupplied in relation to the other nutrients.

$$\text{Excess} = I_A > 0 \text{ and } |I_A| > \text{NBIa}$$

4 RESULTS AND DISCUSSION

The following section describes 1) Diagnosis and Recommendation Integrated System (DRIS) norms of wheat developed for the Hyderabad district of Pakistan for the shoot material and leaf tissue for the data set of two vegetation seasons (2007-08 and 2008-09), 2) nutrient status determined by DRIS for shoot material and leaf tissue at different two growth stages (GS-29 and GS-39) from different farms for the 2007-08 and 2008-09 vegetation seasons, 3) nutrient status as determined by the critical level approach and 4) the comparison of the two methods.

4.1 Development of DRIS norms for wheat for Hyderabad district of Pakistan

4.1.1 Dividing the dataset into high-yielding and low-yielding populations

Previous studies have shown that that the selection of the reference population has a significant impact on the effectiveness and success of DRIS. There are several ways to select the reference population. For example, Walworth & Sumner (1987) suggested that the reference limit to separate two populations should be arbitrarily selected, as each population is supposed to present the normal distribution. Letzsch & Sumner (1984) recommended that the reference population should contain at least 10% of the overall database observations. Malavolta (1989) recommended that the reference population should be obtained with 80 % maximum yield observations. However, in this study, the critical level was determined by the most sophisticated statistical method proposed by Cate and Nelson (1969). The maximum R^2 value obtained from the yield data was 54.68 (Appendix 1). The samples with higher values were referred to as the high-yield or reference population. Using this R^2 value, 86 out of 181 samples were referred to as the high-yielding or reference population.

Literature shows that there are no specific limits to the selection of the size of a high-yielding population for developing the norms. A large variation in the database size for DRIS norms definition is given from just 24 observations (Leite, 1992) up to about 2,800 (Sumner, 1977) or even more. Sumner (1977) suggested that despite the large population quantity, the quality of the collected data should be the goal for database choice. According to Letzsch & Sumner (1984), the only criteria for the validated norms are that they should represent all the soil types, climates, and cultivars. Previous studies reported that the norms should be considered as representative just if they include all the population variability. Walworth et al. (1988) reported that the database size might not be directly related to norms quantity but the database quality is an important factor. For example, the authors reported that the DRIS norms for corn developed from just 10 corn field observations, with yields exceeding 18t ha^{-1}, were more representative and efficient than norms deriving from larger databases. In the current study, these attributes was given the main emphasis. For example, Figure 3.4 represents the soil types in the district Hyderabad. While selecting the sampling points, this map was used so that all the soil types should be represented by the sampling points. Although there is not a great variability in the selection of the cultivars in the region, as most of the farmers used the local varieties named as TJ-83 and Sarsabz, all the grown cultivars were included in the data collection (TD-1, Momal, Marvi, Inqlab, Kiran-95, Imdad, Heera). Based upon the results of the Cate and Nelson (1977) method, 48 % of the total dataset was used to develop the DRIS norms.

4.1.2 Descriptive statistics for the nutrients in high-yielding and low-yielding population

After dividing the nutrient concentrations for all the elements N, P, K, Ca, Mg, Zn, Fe, Cu and Mn into two subgroups, the means and standard deviations of the high and low yielding populations for GS-29 (Table 4.1) and for GS-39 (Table 4.2) were compared. Based upon the results of the standard deviations, the sufficiency level with coefficient of variance were also developed (Table 4.3 and Table 4.4).

Table 4.1 Comparison of nutrient concentrations in shoot material (dry weight) at growth stage GS-29; mean and standard deviation (SD) between the high-and low-yielding populations of irrigated wheat 2007-2009

Nutrient	High-yielding population		Low-yielding population		Univariate one-way ANOVA	
	Mean	SD	Mean	SD	F-value	p-value
N (%)	3.76	0.79	2.80	0.78	67.09319	<.05*
P (%)	0.37	0.11	0.22	0.07	124.7834	<.05*
K (%)	5.49	0.79	4.21	0.82	115.0557	<.05*
Fe (mg/kg)	296	70.41	260	73.66	11.16904	0.001*
Mn (mg/kg)	46.43	11.95	44.62	11.97	1.036494	0.31
Zn (mg/kg)	24.82	6.18	21.79	5.56	12.08809	0.001*
Cu (mg/kg)	11.63	2.28	9.20	2.45	47.59187	<.05*
B (mg/kg)	12.07	6.63	11.11	5.36	1.165241	0.28

Table 4.2 Comparison of nutrient concentrations in leaf tissue (dry weight) at growth stage GS-39; mean and coefficient of variation (CV) between the high- and low-yielding populations in irrigated wheat 2007-2009

Nutrient	High-yielding population		Low-yielding population		Univariate one-way ANOVA	
	Mean	SD	Mean	SD	F-value	p-value
N (%)	3.80	0.61	3.91	0.59	1.62	0.21
P (%)	0.30	0.11	0.28	0.10	0.67	0.41
K (%)	4.29	0.72	3.99	0.61	9.44	<.05*
Fe (mg/kg)	411	59.96	288	50.50	223	<.05*
Mn (mg/kg)	52.44	15.47	43.95	12.44	16.68	<.05*
Zn (mg/kg)	20.86	5.80	19.14	4.98	4.58	0.03*
Cu (mg/kg)	10.66	2.24	9.32	2.02	18.03	<.05*
B (mg/kg)	11.55	5.04	8.84	5.04	13.04	<.05*

Table 4.3 Statistical parameters of nutrients in shoot material (dry weight) at growth stage GS-29 for high-yielding population in irrigated wheat 2007-2009

Nutrient	Mean	Sufficiency level	Coefficient of Variance (%)
N (%)	3.76±0.79	2.96-4.55	0.21
P (%)	0.37±0.11	0.25-0.47	0.31
K (%)	5.49±0.79	4.71-6.28	0.14
Fe (mg/kg)	296±70	226-366	0.24
Mn (mg/kg)	46.43±11.95	34.48-58.38	0.26
Zn (mg/kg)	24.82±6.18	18.64-31	0.25
Cu (mg/kg)	11.63±2.28	9.35-13.91	0.20
B (mg/kg)	12.07±6.63	5.44-18.70	0.55

Table 4.4 Statistical parameters of nutrients of leaf tissue (dry weight) at growth stage GS-39 for high-yielding population in irrigated wheat 2007-2009

Nutrients	Mean	Sufficiency level	Coefficient of Variance (%)
N (%)	3.80±0.61	3.19-4.41	0.16
P (%)	0.3±0.11	0.19-0.40	0.37
K (%)	4.27±0.72	3.58-5.01	0.17
Fe (mg/kg)	411±59	351-471	0.15
Mn (mg/kg)	52.44±15.47	36.97-67.91	0.30
Zn (mg/kg)	20.86±5.8	15.06-26.65	0.28
Cu (mg/kg)	10.66±2.24	8.42-12.91	0.21
B (mg/kg)	11.55±5.04	6.51-16.59	0.44

Results show that the means of the nutrients of the low-yielding population are mostly lower than those of the high-yielding population at the end of the tillering stage.

These differences are more visible in the shoot material (GS-29), where all nutrients of the low -yielding population have a lower concentration than the high-yielding population. The results of the one way univariate analysis of variance (ANOVA) using *F* and *p*-values show that the concentrations of almost all elements differ significantly at the 5 % confidence interval except for Mn and B (Table 4.1). The statistical analysis of the nutrients in leaf tissue at growth stage GS-39 yielded almost the same results as for the earlier sampling at growth stage GS-29. The *p-value* is below 0.05 for almost all nutrients except P. This is the first indication that high- and low -yielding populations differ significantly. Although this analysis does not have any influence on developing the DRIS norms for the interpretation of the nutrient availability, this analysis gives a first impression on the nutrient concentrations at both plant-growth stages.

4.1.3 DRIS norms for Hyderabad district of Pakistan

DRIS norms are defined as the average value of foliar nutrient ratio pairs for high yielding stands. Using the nutrient concentrations of N, P, K, Ca, Mg, Zn, Fe, Cu and Mn of the reference population, in accordance with the Sumner's (1987) recommendations, quotients for the pairs of elements for both GS-29 (Appendix 2 and Appendix 3) and GS-39 (Appendix 4 and Appendix 5) were developed. The coefficient of variance for each ratio was calculated to analyse the variability within each norm (Walworth and Sumner, 1987). The standard deviation, according to the same authors, permits determination of the rank above and below the standard in which the nutrient is considered to be in balanced supply.

4.1.4 Developing the ratio for the high-yielding and low-yielding population

Nutrient ratios for the high-yielding and low-yielding population were developed for the shoot material collected at the growth stage GS-29 (Appendix 2 and Appendix3) and for the leaf tissue collected at the growth stage GS- 39 (Appendix 4 and Appendix 5), respectively. The 28 nutrient ratios considered for this study are N/P, N/K, Fe/N, Mn/N, N/Zn, N/Cu, N/B, K/P, Fe/P, Mn/P, Zn/P, Cu/P, B/P, Fe/K, Mn/K, K/Zn, K/Cu, K/B, Fe/Mn, Fe/Zn, Fe/Cu, Fe/B, Mn/Zn, Mn/Cu, Mn/B, Zn/Cu, Zn/B, and Cu/B. Beaufils (1971) suggested to not including the ratios that differ significantly between the high- and low-yielding populations. For this purpose, the descriptive statistics were calculated for every pair of ratios. For each sub-population the mean, standard deviation (SD), and coefficient of variation (CV) values were calculated. Similarly, one way univariate analyses of variance (ANOVA) using *F* and *p*-values were conducted at 5 % confidence interval to determine the statistical difference between the high- and the low-yielding population. A ratio with a greater variability in the low population class (i.e., a significant *F* and *p*-value) indicated that the parameter had discriminatory ability.

The ANOVA (*F* and *p*-test) for the comparison of the means of the nutrient ratios between the high- and low-yielding populations for shoot material showed that 17 out of 28 ratios differed significantly at the 0.05 confidence interval (Table 4.5). the results were almost the same when the analysis was conducted for leaf tissue (Table 4.6). The ratios in the leaf tissue were also 17, but 9 of these ratios were different from the shoot tissue. The ratios with significant differences between the high- and low-yielding populations for shoot material include N/P, Fe/N, Mn/N, N/Zn, K/P, Fe/P, Mn/P, Zn/P, Cu/P, B/P, Fe/K, Mn/K, K/Zn, Fe/Cu, Mn/Zn, Mn/Cu, and Zn/Cu. The ratios with significant differences between the high- and low-yielding populations for leaf tissue are N/K, Fe/N, Mn/N, N/Zn, N/Cu, N/B, Fe/P, B/P, Fe/K, Mn/K, K/B, Fe/Mn, Fe/Zn, Fe/Cu, Mn/B, Zn/B, and Cu/B.

Table 4.5 Comparison of individual nutrients, nutrient ratio means and coefficient of variation (CV) between the high- and low-yielding populations for shoot material (GS-29)

	High-yielding population		Low-yielding population		Univariate one-way ANOVA	
Ratio	Mean	Coefficient of variance (%)	Mean	Coefficient of variance (%)	F-value	p-value
N/P	11.47±5.35	47	14.18±6.22	44	1.68	0.002*
N/K	0.7±0.19	27	0.71±0.28	39	7.87	0.95
Fe/N	83.61±31.69	38	110.15±85.5	78	123.33	0.007*
Mn/N	13.32±7.04	53	18.65±14.14	76	15.01	0.002*
N/Zn	0.16±0.05	32	0.14±0.06	43	4.64	0.0043*
N/Cu	0.33±0.09	26	0.33±0.14	42	8.05	0.86
N/B	0.4±0.23	56	0.39±0.42	108	10.14	0.93
K/P	16.66±7.21	43	21.3±7.84	37	0.076	<0.05*
Fe/P	898.19±426.33	47	1322.69±559.5	42	19.53	<0.05*
Mn/P	141.36±67.03	47	227.34±95.66	42	3.06	<0.05*

Table 4.5 continued

	High-yielding population		Low-yielding population		Univariate one-way ANOVA	
Ratio	Mean	Coefficient of variance (%)	Mean	Coefficient of variance (%)	F-value	p-value
Zn/P	76.49±38.36	50	110.67±44.94	41	0.041	<0.05*
Cu/P	35.12±14.68	42	46.91±20.74	44	1.25	<0.05*
B/P	37.1±27.34	74	56.79±33.72	59	5.53	<0.05*
Fe/K	55.01±15.26	28	63.68±19.65	31	55.28	0.002*
Mn/K	8.53±2.19	26	10.96±3.59	33	4.62	<0.05*
K/Zn	0.23±0.06	26	0.2±0.06	30	.0003	0.002*
K/Cu	0.48±0.08	16	0.47±0.09	19	1.185	0.46
K/B	0.61±0.41	67	0.57±0.57	100	7.695	0.56
Fe/Mn	6.92±2.78	40	6.34±2.78	44	10.345	0.16
Fe/Zn	12.55±3.89	31	12.64±4.38	35	35.282	0.89
Fe/Cu	26.26±7.48	28	29.52±8.95	30	11.864	0.0089*
Fe/B	32.67±21.76	67	34.49±34.12	99	0.142	0.67
Mn/Zn	1.97±0.73	37	2.2±0.87	40	2.646	0.06*
Mn/Cu	4.07±1.07	26	5.21±2.05	39	0.285	<0.05*
Mn/B	5.12±3.53	69	6.23±6.62	106	3.273	0.17
Zn/Cu	2.18±0.54	25	2.5±0.8	32	0.231	0.0024*
Zn/B	2.76±2.08	75	2.84±2.54	89	7.305	0.82
Cu/B	1.26±0.79	63	1.18±1.01	86	5.483	0.54

* *Significant at 5 % level of probability.*

Table 4.6 Comparison of individual nutrients, nutrient ratio means and coefficient of variation (CV) between the high- and low-yielding populations for leaf tissue (GS-39)

	High-yielding population		Low-yielding population		Univariate one-way ANOVA	
Ratio	Mean	Coefficient of variance (%)	Mean	Coefficient of variance (%)	F-value	p-value
N/P	14.64±6.53	45	15.91±6.61	42	1.68	0.197
N/K	0.91±0.21	24	1.01±0.26	26	7.87	0.006*
Fe/N	111.72±27.41	25	75.18±15.86	21	123.33	<0.05*
Mn/N	14.28±4.98	35	11.62±4.25	37	15.01	0.000*
N/Zn	0.2±0.07	34	0.22±0.06	27	4.64	0.033*
N/Cu	0.38±0.15	40	0.44±0.15	34	8.05	0.005*
N/B	0.45±0.39	87	0.68±0.56	82	10.14	0.002*
K/P	16.37±6.49	40	16.11±6.27	39	0.076	0.784
Fe/P	1565.83±606.7	39	1191.57±532.5	45	19.53	0.000*

Table 4.6 continued

Ratio	High-yielding population		Low-yielding population		Univariate one-way ANOVA	
	Mean	Coefficient of variance (%)	Mean	Coefficient of variance (%)	F-value	p-value
Mn/P	203.03±105.48	52	178.26±84.75	48	3.06	0.082
Zn/P	79±34.14	43	77.88±39.68	51	0.041	0.839
Cu/P	41.08±19.04	46	38.03±17.64	46	1.25	0.266
B/P	45.09±27.38	61	36.11±23.98	66	5.53	0.020*
Fe/K	98.53±21.85	22	74.65±21.33	29	55.28	<0.05*
Mn/K	12.32±3.39	27	11.22±3.5	31	4.62	0.033*
K/Zn	0.22±0.08	37	0.22±0.07	32	0.0003	0.986
K/Cu	0.43±0.20	46	0.46±0.21	46	1.185	0.278
K/B	0.49±0.40	81	0.71±0.61	86	7.695	0.006*
Fe/Mn	8.55±2.77	32	7.21±2.82	39	10.345	0.002*
Fe/Zn	21.23±6.45	30	16.1±5.17	32	35.282	<0.05*
Fe/Cu	41.96±23.47	56	32.61±11.64	36	11.864	0.001*
Fe/B	47.64±40.11	84	49.86±39.4	79	0.142	0.707
Mn/Zn	2.78±1.50	54	2.47±1.07	43	2.646	0.106
Mn/Cu	5.47±4.35	79	5.18±2.89	56	0.285	0.594
Mn/B	6.05±5.13	85	7.85±7.86	100	3.273	0.072
Zn/Cu	2.1±1.27	61	2.18±1.03	47	0.231	0.631
Zn/B	2.33±1.78	76	3.25±2.63	81	7.305	0.008*
Cu/B	1.22±0.99	81	1.62±1.31	81	5.483	0.020*

*: *Significant at 5 % level of probability.*

4.1.5 Norms for shoot material and leaf tissue

All ratios with a significant difference between the high and low-yielding populations were considered as DRIS norms (Table 4.7). However, ratios that yielded non-significant variance relations between the low and high-yielding population were included in the analysis according to Beaufils and Sumner (1977) that retained the highest variance relation in order to be sure to take into consideration the interaction with other elements.

Table 4.7 Statistical parameters of nutrients norms for high yielding population in irrigated wheat (2007-2009) for shoot and leaf tissue.

	Norms for leaf tissue			Norms for shoot material	
expression	Mean	Coefficient of variance (%)	Expression	Mean	Coefficient of variance (%)
N/K	0.91±0.21	24	N/P	11.47±5.35	47
Fe/N	111.72±27.41	25	Fe/N	83.61±31.69	38
Mn/N	14.28±4.98	35	Mn/N	13.32±7.04	53
N/Zn	0.2±0.07	34	N/Zn	0.16±0.05	32
N/Cu	0.38±0.15	40	K/P	16.66±7.21	43
N/B	0.45±0.39	87	Fe/P	898.19±426.33	47
Fe/P	1565.83±606.73	39	Mn/P	141.36±67.03	47
B/P	45.09±27.38	61	Zn/P	76.49±38.36	50
Fe/K	98.53±21.85	22	Cu/P	35.12±14.68	42
Mn/K	12.32±3.39	27	B/P	37.1±27.34	74
K/B	0.49±0.40	81	Fe/K	55.01±15.26	28
Fe/Mn	8.55±2.77	32	Mn/K	8.53±2.19	26
Fe/Zn	21.23±6.45	30	K/Zn	0.23±0.06	26
Fe/Cu	41.96±23.47	56	Fe/Cu	26.26±7.48	28
Mn/B	6.05±5.13	85	Mn/Zn	1.97±0.73	37
Zn/B	2.33±1.78	76	Mn/Cu	4.07±1.07	26
Cu/B	1.22±0.99	81	Zn/Cu	2.18±0.54	25

According to the original concept of the DRIS, the system should be applicable irrespective of variety and age of the sampled plants Sumner (1981). The author also rated this capacity of the DRIS as a major advantage over the critical value approach. Keeping this advantage in mind, the norms of leaf tissue (sampled at GS-39) and shoot material (sampled at GS-29) should be similar. To test the validity of this approach, an analysis of variance (ANOVA) was performed (Table 4.8). The ANOVA was applied for the ratios that were similar in both samples (GS-29 and GS-39) and significantly different from the low-yielding population: Fe/N, Mn/N, N/Zn, Fe/P, B/P, Fe/K, Mn/K, and Fe/Cu. It can be seen that the norms for leaf tissue and shoot material differ slightly. Often, slightly higher values can be observed for leaf tissue than for shoot material. However, these differences are non-significant at $p = 5$ %.

Table 4.8 ANOVA between GS-29 and GS-39 norms for irrigated wheat (2007-2009)

Source of Variation	SS	df	MS	F	P-value	F crit.
Between populations	36840	1	36840	0.191494	0.668352	4.60011
Within populations	2693350	14	192382.2			

From the above results, it can be concluded that the developed DRIS norms can be universally applied in the Hyderabad district. Originally DRIS was developed by Beaufils (1973) for the interpretation of leaf or plant analyses. This comprehensive system identifies all nutritional factors limiting crop yield. It was also developed by different researcher for a many horticultural, fruit and ornamentals plant species. Among the main horticultural species already diagnosed by this method are lettuce (Sanchez et al., 1991), tomato (Car on et al., 1991; Hartz et al., 1998; Parent et al., 1993; Mayfield et al., 2002), potato (Mac Kay et al., 1987; Parent et al., 1994a), onion (Caldwell et al., 1994), cucumber (Mayfield et al., 2002), and carrot (Parent et al., 1994b). There are only few references about the application of the DRIS method for irrigated crops.

The only available DRIS norms for wheat in literature were only developed for macronutrients by Sumner et al. (1977b) and Sumner (1981) for Washington and Florida, USA. There cannot be a direct comparison between the DRIS norms developed for Hyderabad district and the norms for Washington. First, these norms are only for macronutrients and secondly, they are for different agro-climatic conditions. Although different researchers argue that the DRIS norms developed within one region can also be used for another, the experiment by Sumner (1981) clearly showed that the universality of the norms is misleading, as they can lead to a wrong interpretation of the results. Reis (2002) took four different norms developed for corn by Sumner (1977), Dara et al. (1992), Escano et al. (1981), and Elwali et al. (1985). Using these norms, the order of nutrient requirement was different in all interpretations. Reis (2002) reported that changes of the index signal for the same nutrient among the different standards were observed, e.g., the Mg index was negative when using the DRIS norms of Sumner (1977) and Dara et al. (1992), while it was positive when using those of Escano et al. (1981) and Elwali et al. (1985). Reis (2002) reported that the difference in norms is not because they were not reliable but because they were developed for different regions.

Therefore, these norms can be useful in the geographic region where they were derived, but the universal application of these four DRIS norms should not be recommended to evaluate (corn) nutritional status.

Several factors make the universal use of DRIS norms unsuitable, such as climate, soil, variety, etc. It can be stated that the nutrient concentrations of the high-yielding (or desirable) group used by Sumner (1977), Escano et al. (1981), and Elwali et al. (1985) to derive their DRIS norms were different, leading to a different optimum nutrient balance.

The farmers need to know the nutrient concentrations normally found in their high-yielding crops and to adopt those DRIS standards with nutrient ratio values similar to those found in their high-yielding crops before using the DRIS to evaluate the crop nutritional status. Therefore, in the absence of DRIS norms locally calibrated, norms developed under one set of conditions should only be applied to another if the nutrient concentrations of high-yielding plants from these different sets of conditions are similar.

4.2 DRIS to evaluate the nutritional status of wheat in Hyderabad

After developing the DRIS norms for irrigated wheat in Hyderabad, DRIS was applied to diagnose the nutrient status in the low -yielding population. The results are presented in the following sections.

4.2.1 Function values

After establishing the norms, the DRIS function values for nutrients were calculated using the original procedures proposed by Beaufils (1973; see section 3.5.4). The function values for the leaf tissue (GS-39) and for the shoot material (GS-29) are shown in Appendix 6 and Appendix 7, respectively. After knowing the function values, the index values were calculated for each nutrient.

4.2.2 Index values for interpretation of the nutrient concentrations in leaf tissue and shoot material

After calculating the function values, the methodology presented in section 3.5.3 was used to determine the index values for leaf tissue and shoot material. The index value shows requirement of that particular nutrient at the two different growth stages, i.e., GS-

29 and GS-39. For example, I_N indicates the N requirements in the leaf tissue or shoots material. There are both positive and negative values of the indices in the entire dataset (Appendix 8 and Appendix 9), and the sum of all indices is zero. This shows the correct implementation of the DRIS method.

The average index values at GS-39 are different to those at the GS-29 (Figure 4.1). The average index value for N is +47.04, which indicates that N is sufficient in the leaf tissue. The values of P and K are 58.49 and 21.67, respectively. These positive values show that N P and K are sufficient in the leaf tissue, and that the wheat plants do not require any fertilization. The micronutrients are almost in good balance, i.e., neither sufficient nor deficient except Fe. The index value of Fe is -93, whereas the index values for Mn, Zn, Cu, and B are -21.88, +17.77, -1.38 and -28.68, respectively. The Nutritional Balance Index was 56.45, which means that the there is no high nutritional imbalance. The interpretation of the data according to the three standards deficient, adequate and medium shows the mixed results. Appendix 10 shows that all the nutrients are adequate except Zn and B, which are in high concentrations.

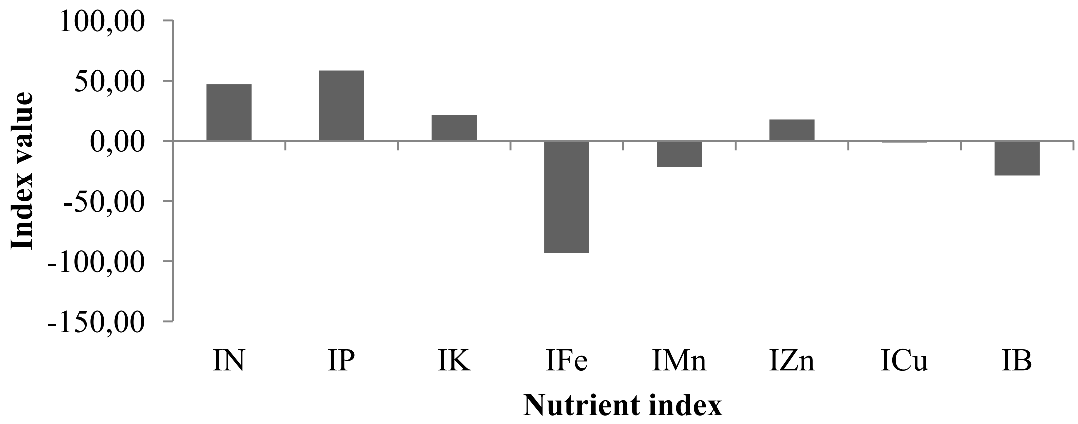

Figure 4.1 Nutrient index values for leaf tissue at GS-39

The average index values of the shoot material are different for different nutrients (Figure 4.2). The average index value for N is -54.27 at GS-29, which indicates that N was deficient in plants at this growth stage of development. The values of P and K are also negative, indicating deficiency of these nutrients. The micr-nutrients, however, are positive, which indicates that these nutrients were not in short supply (see Appendix 9). The interpretation for the nutrients for this dataset is based on the methodology described in section 3.5.1.1. The NBI averaged around 75.23, which indicates some nutritional imbalance. Santos (1997) and Mourão Filho & Azevedo (2003) also suggested that the lower the NBI, the better the nutritional balance. The three criteria, namely deficient, adequate and high nutrient concentrations were then determined (Appendix 11).

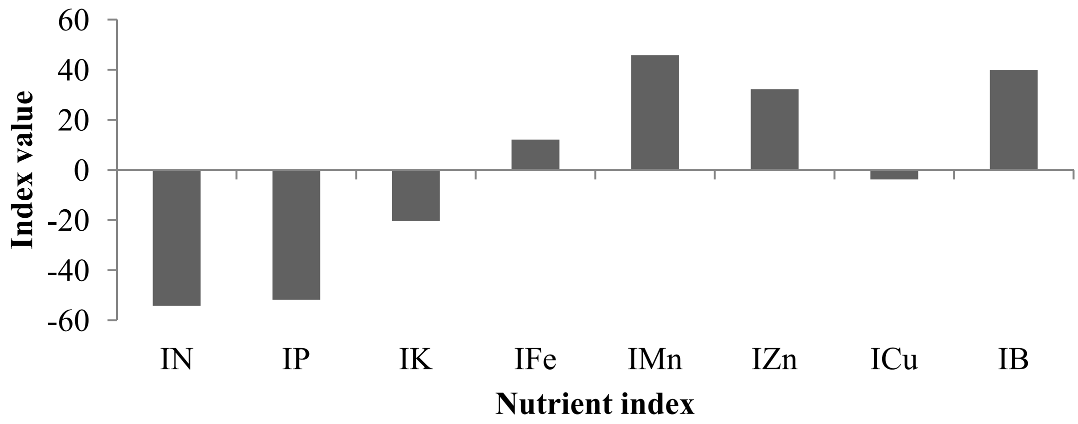

Figure 4.2 Nutrient index values for whole shoot material at GS-29

4.3 Comparing the critical level approach and the DRIS

Critical levels for irrigated wheat are taken from the guidelines provided by Reuter and Robinson (1997) (Table 4.9 and Table 4.10). These guidelines were used for interpretation of the nutrient concentrations in leaf tissue and shoot material. The average concentrations of the leaf tissue showed N to be deficient, whereas all other nutrients were adequate. These results coincide with the results of the DRIS. DRIS always gives relative information; therefore, according to DRIS, the concentrations of B and Zn are relatively higher compared to the other nutrients according to Reuter and Robinson (1997), which are adequate (Table 4.9)

Table 4.9 Critical levels for irrigated wheat for leaf tissue according to Reuter and Robinson, (1997)

Nutrient	Deficient	critical	Marginal	Adequate	High	Toxic
N (%)	<3.4	3.7-4.2	-	4.0-6.5	5.5-6.5	>6.5
P (%)	0.16-0.2	0.44-47	-	0.2	>0.2	-
K (%)	<2.5	-	-	2.5-6.0	>6.0	-
Zn (mg\kg)	4.0-6.0	-	-	17.0-25.0	-	-
Fe (mg\kg)	<10	-	-	10-300	301-500	>10
Cu (mg\kg)	-	-	2.0-4.0	5.0-50	-	-
Mn (mg\kg)	<10	10-13	-	20-100	>400	>10
B (mg\kg)	<3	-	-	3.0-25	>30	<3

The average concentration of nutrients in the shoot material GS-29 is similar to that in the leaf tissue. In the shoot material as well N is deficient whereas all the other nutrients are adequate. The DRIS calculation also showed N to be in short supply, whereas Mn and B are present in high concentrations.

Table 4.10 Critical level for irrigated wheat for shoot material according to Reuter and Robinson, (1997)

Nutrient	Deficient	Critical	Marginal	Adequate	High	Toxic
N (%)	<3.4	3.7-4.2	-	3.25-5.4	5.5-6.5	>6.5
P (%)	<0.2	0.3	-	0.3.0.5	-	-
K (%)	<1.5	-	1.5-2.3	1.5-2.3	4.1-5.5	>6.0
Zn (mg\kg)	<13	-	13-21	19-84	-	-
Cu (mg\kg)	-	5.6	-		-	-
Mn (mg\kg)	<12	-	-	25-300	300-600	700
B (mg\kg)	<3	-	-	3-4.5	4.5	-

5 CONCLUSIONS

As outlined earlier, soils in the study area are considered as deficient in N, P, Zn and B, whereas K, Cu, Fe and Mn contents are adequate. However, the results of the plant analysis at both growth stages, i.e., GS-29 and GS-39, show that the nutrient concentrations in the plant tissues did not correspond to this observation. To which extent nutrient interactions are an important factor possibly affecting affect the nutrient availability of plants is discussed below.

Other than hypothesized, Zn and B in the plant tissues were sufficient. Generally, relatively high doses of N fertilizer had been applied to the study plots. This was also reflected by the total nutrient levels and DRIS indices. It has been shown that ammonium from N fertilizers can indirectly acidify the soil solution via nitrification and physiologically by decreasing the pH of the rhizosphere. In neutral or alkaline soils, acidification of the rhizosphere of plants fed with ammonium can enhance the uptake of Zn and B (Jurkowska et al. 1996; Fageria and Baligar 2005; Diatta and Grzebisz 2006). Furthermore, the form of N fertilizer can affect B accumulation in plants. Wójcik (2000) reported that in B-deficient soils, N added as Ca $(NO_3)_2$ and NH_4NO_3 increased the availability and uptake of B by the roots. This increase was attributed to the fact that NO_3 inhibited B sorption on Fe and aluminum oxides and increased B in the soil solution. Studies show that N fertilizers such as ammonium sulphate ($(NH_4)_2SO_4$) can have a marked acidifying effect on soils and so lead to an increase in the availability of Zn to crops in soils of relatively high pH status. In alkaline soils, rhizosphere acidification in plants fed with ammonium can enhance mobilization of sparingly soluble $Ca_3PO_4$and thereby favor the uptake of P (Gahoonia et al. 1992), as well as the uptake of micronutrients such as B (Reynolds et al., 1987), Fe, Mn and Zn. Cakmak et al. (2000) demonstrated that phytosiderophores released from cereal roots enhanced the solubility and mobility of Zn by chelation from sparingly soluble Zn compounds in calcareous soils.

Sufficient Zn can also be attributed to P fertilizer application. Alloway (2008) reported that application of P fertilizers can lead to an increase in the Zn concentration in plants. This can be explained by an increase in acidity in the root environment (and enhanced uptake of Zn) or by Zn impurities in the P fertilizer. Commercial fertilizers, such as superphosphate, may contain appreciable amounts of Zn and also acidify the soil due to their high sulphate content. The author further mentioned that N can affect Zn availability in two possible ways. Firstly, increased protein formation following N fertilizer additions can lead to Zn being retained in the root as a Zn-protein complex and not translocated to the shoot. Secondly, acidifying N fertilizers, such as ammonium nitrate and ammonium sulphate can lead to a decrease in the rhizosphere soil pH and an increase in Zn availability. In the study area, farmers apply heavy doses of N and P fertilizers, which thus subsequently may lead to relatively higher Zn and B concentrations in plant tissues.

The data in this study reveals a deficiency of N during an early growth stage of wheat (visible in the field), i.e., GS-29, whereas sufficiency was found later at GS-39. This trend was consistent, i.e., low availability of soil N during the early growth stage, and was due to the subsequent fertilizer application and internal recycling of N at stage GS-39. Improved new growth after nutrient loading may be attributed to an increased net N retranslocation (Grime, 1979; Malik and Timmer, 1998; Salifu and Timmer, 2001). One possible reason for the contradictions (no trace element deficiency found in contrast to what has been hypothesised and what is reported for this area) is the irrigation. In case of drought, nutrient levels could be high due to an inhibited growth (concentration effect), but they would probably be too low to sustain higher yields even if more water were available. Based on the results of this study in the district Hyderabad, Pakistan, it is recommended that fertilization of wheat needs more attention specifically regarding application of N fertilizers at earlier growth stages, which ultimately may affect the uptake of micronutrients and the crop yield. The results of the critical level approach and the Diagnosis and Recommendation Integrated System (DRIS) are in close agreement. The results of DRIS greatly depend on the selection of the cut-off value. The Cate and Nelson (1979) procedure applied to compare the cut-off value between the high-yielding and low-yielding population was satisfactory. However, changing the cut-off value affects the DRIS norms and hence the DRIS interpretation. Therefore, it can be concluded that the cut-off value between high- and low-yielding populations is of significant importance and that application of the Cate and Nelson (1979) procedure provides a reliable interpretation.

6 REFERENCES

Adsule RN and Kadam SS (1986) Quality of wheat. Salunkhe DK, (eds) Quality of Wheat and Wheat Products. New Delhi India, Metropolitan Book Co, pp 1–6

Agbenin JO (1998) Quantifying soil fertility changes and degradation induced by cultivation techniques in the Nigerian savanna. Advances in Geoecology 31:435-441

Ahmad N and Rashid M (2004) Fertilizer and their use in Pakistan. Government of Pakistan, Planning and Development Division NFDC, Islamabad

Ahmad Z et al (1988) Weed management strategies for wheat in the irrigated Punjab. Farmers Knowledge Adoption and Economics, Pakistan Agricultural Research Council, Islamabad (PARC/ CIMMYT Paper No 88-3)

Ahmed N and Rashid M (2003) Fertilizer use in Pakistan. NFDC Planning and development division, Islamabad, pp: 94

Alloway, BJ (2008) Zinc in soils and crop nutrition. IZA Publications, International Zinc Association, Brussels

Alexandratos N (1995) World Agriculture: Towards 2010 an FAO Study, Jhon Wiley, New York

Amjad M Anjum MA and Akhtar N (2004) Influence of phosphorous and potassium supply to the mother plant on seed yield quality and vigor in pea. Asian Journal of Plant Science 3(1): 108-113

Anderson OE and Harrison RM (1970) Micronutrient variation within cotton leaf tissue as related to variety and soil location. Commun. Soil Sci. Plant Anal 1:163-172

Andriulo AE et al (1990[a]) Sistemas de producción con trigo en el Sudoeste bonaerense. II Algunas propiedades fisicas edáficas ligadas al agua Actas II Congreso Nacional de Trigo, Pergamino, Argentina, I: 219–225

Andriulo AE (1990b) Sistemas de producción con trigo en el Sudoeste bonaerense I Propiedades fisicomecánicas del suelo Actas II. Congreso Nacional de Trigo, Pergamino, Argentina, I: 209–218

Arshad LA (1976) Effect of NP and their methods of application on the growth and yield of wheat. Dissertation, University of Faisalabad

Aslam Muhammad (1991) Zero tillage wheat pilot production programme for the Punjab rice-wheat system. Coordinated Wheat Barley and Triticale Programme, National Agricultural Research Center (NARC), Islamabad

Bailey JS (1997) The diagnosis and recommendation integrated system (DRIS) for diagnosing the nutrient status of grassland swards: I Model establishment. Plant Soil 197:109–117

Bailey JS (1997) The diagnosis and recommendation integrated system (DRIS) for diagnosing the nutrient status of grassland swards: I Model establishment. Plant and Soil 197:127-135

Beaufils ER (1973) Diagnosis and recommendation integrated system (DRIS) A general scheme for experimentation and calibration based on principles developed from research in plant nutrition. Soil Sci Bul Univ 1 Natal Pietermaritzburg, South Africa

Beaufils ER and Surnner ME (1976) Application of the DRIS approach for calibrating soil and plant factors in their effects on yield of sugarcane - SASTA Proc, 50:118-124

Beaufils ER (1971) Physiological Diagnosis, a guide for improving maize production based on principles developed for rubber trees. J. Fert. Soc. S. Afr. 1:1-31

Beaufils ER (1972) A contribution to plant physiological diagnosis Analysis of a long term factorial fertilizer experiment with maize on acid Hutton soil series. J.Fert. Soc SAfr, 1:23-28

Beaufils ER (1976) Plant/soil/environment calibration (DRIS) 4th International Colloquium on the control of plant nutrition. Vol 1 , Ghent, Belgium, pp21-36

Beaufils, ER and Sumner ME (1977) Effect of time of sampling on the diagnosis of the N, P, K, Ca, and Mg requirements of sugarcane by the DRIS approach. Proc. South Afr.Sugar Technol. Assoc. 51: 62–67

Beaufils ER (1971) Physiological diagnosis - a guide for improving maize production based on principles developed for rubber trees. Fertilizer Society of South African Journal 1:1-30

Bergmann W (ed) (1992) Nutritional disorders of plants colour Atlas Gustav. Fischer Verlag, Jena, Stuttgart, p386

Beverly RB (1993) Re-evaluation reveals weaknesses of DRIS and sufficiency range diagnoses for wheat corn and alfalfa. Comm. Soil Sci. Plant Anal. 24:487-501

Benton Jones , Wolf B and Mills HA (1991) Plant Analysis, Handbook. Micro-Macro Publishing, Athens Georgia, p 213

Bierman PM and Rosen CJ (1994) Phosphate and trace metal availability from sewage-sludge incinerator ash. Journal of Environmental Quality 23:822-830

Borlaug NE and Dows well CR (1993) To nourish infertile soil that feeds a fertile population that crowds a fragile world. Fertilizer News 38:11–20

Borlaug NE (1983) Contributions of conventional plant breeding to food production. Science 219:689-693

Bouis HE (2003) Micronutrient fortification of plants through plant breeding: can it improve nutrition in man at low cost? Proc. Nutr. Soc 62:403-411

Bremner JM Mulvaney CS (1982) Nitrogen-total. Methods of Soil Analysis. Mille RH, (eds) Soil. Sci Soc. Am. Madison WI: 9(2):595-624

Byrnes BH and Bumb BL (1998) Population growth, food production and nutrient requirements. In Journal of Crop Production. Ed. Z. Rengel. The Haworth Press, New York, pp 1–27

Cakmak I, Ozkan H, Braun HJ, Welch RM and Romheld V (2000) Zinc and iron concentrations in seeds of wild, primitive and modern wheats. Food Nutr. Bull. 21: 401–403

Caldwell JO et al (1994) Development and testing of preliminary foliar DRIS norms for onions. Hort Science 29:1501-1504

Campbell CA (1992) Comparative effects of grain lentil-wheat and monoculture wheat on crop production N economy and N fertility in a Brown Chernozem. Can J Plant Sci 72:1091-1107

Caron J Parent LE and Gosselin A (1991) Effect of nitrogen and salinity levels in the nutrient solution on the DRIS diagnosis of greenhouse tomato. Communications in Soil Science and Plant Analysis 22:879-892

Cate RB and Nelsen LA (1971) A simple statistical procedure for partitioning soil test correlation data into two classes. Soil Sci .Soc. Amer. Proc 35:658–660

Cate RB Jr and Nelson LA (1971) A simple statistical procedure for partitioning soil test correlation data into two classes. Soil Sci Soc Am Proc 35:658-659

Cate RB Jr and Nelson LA (1965) A rapid method for correlation of soil test analysis with plant response data North Carolina. Agric Exp Stn International soil Testing Series Bull No 1

Chapman SB (1967) Nutrient budgets for a dry heath ecosystem in south of England. J Ecol. 55:677-89

Chaudhry TM and Qureshi SM (1982) Review of work. Agricultural chemistry section, Agriculture research institute, Tandojam, government of Sindh: (19):26-80.

Chowdhry MA et al (1995) Correlation analysis for grain yield and quality traits in wheat. *J Agric Res*; **33**(2):71–74

Chowdhury FA and Hore KC (1995) Effect of zinc and phosphorus on the yield of wheat. J Bangladesh Agril Sci 23(1):125-128

Criley RA and Carlson WH (1970) Tissue analysis standards for various floricultural crops. Florist's Rev 146:19-20, 70-73

Dara ST, Fixen PE and Gelderman RH (1992) Sufficiency level and diagnosis and recommendation integrated system approaches for evaluating the nitrogen status of corn. Agron J.84:1006-1010

Diatta JB and Grzebisz W (2006) Influence of mineral nitrogen forms on heavy metals mobility in two soils. Part I. Pol. J. Environ. Stud. 15 (2a), 56-62.

Dyson T (1999) World food trends and prospects to 2025. Proc Natl Acad Sci USA 96 :5929–5936

Elwali AMO and Gascho GJ (1984) Soil testing foliar analysis and DRIS as guides for sugarcane fertilization. Agron J. 76: 466-470

Elwali AMO, Gascho GJ and Sumner ME (1985) DRIS norms for 11 nutrients in corn leaves. Agron. J. 77: 506–508

Escano CR, Jones CA and Uehara G (1981) Nutrient diagnosis in corn on hydric dystrandepts: II comparison of two systems of tissue diagnosis. Soil. Sci Soc. Am. J. 45: 1140–1144

Evans FE and Wennerström H (1994) The colloidal domain – where physics chemistry biology and technology meet. Cambridge,VCH

Evans (1959) Elements other than N P and K in the mineral nutrition of sugarcane. ISSCT Proc 10: 473-508

Fageria NK and Baligar VC (2005) Enhancing nitrogen use efficiency in crop plants. Advances in Agronomy 88: 97–185

FAO (1999) FAOSTAT database gateway Disponível em: http://wwwfaoorg Acesso em: fev (Rome Italy)

FAO (2004) The State of Food Insecurity in the World: Monitoring progress towards the World Food Summit and Millennium, Development Goals Food and Agricultural Organisation of the United Nations, Rome

FAO (2004) Impact of climate change on agriculture in Asia and the Pacific. Twenty-seventh FAO regional conference for Asia and the Pacific Beijing, China 17–21 May 2004

Galantini JA (2000) The effects of crop rotation and fertilization on wheat productivity in the Pampean semi-arid region of Argentina 2 Nutrient balance yield and grain quality. Soil. Till Res 53:137–144

Galantini JA (1992) RotacioÂn y fertilizacioÂn en sistemas deproduccioÂn de la regioÂn semiaÂrida bonaerense IProductividad (calidad y rendimiento) del trigo Rev Facultad de AgronomõÂa 13: 67-75

Galantini JM (1984) Statistical procedures for agricultural research. 2nd Edition Wiley, New York: 680

Gahoonia, TS Nielsen NE (1992) Control of pH at soil-root interfaces. Plant and Soil 140: 49–54.

Gorsline GW, Baker DE and Thomas WI (1965) Accumulation of eleven elements by field corn (Zea mays L).Penn State. Univ. Exp. Sta Bull 725: 30

Graham J R and Campbell RH (2001) The theory and practice of corporate finance: evidence from the field. Journal of Financial Economy 60: 187–243

Graham R (1999) Breeding for micronutrient density in edible portions of staple food crops: conventional approaches. Field Crops Research 60: 57–80

Grime, JP (1979) Plant strategies and vegetation processes. John Wiley and Sons, London, UK

Gruhn P, Goletti F and Yudelman M (2000) Integrated nutrient management soil fertility and sustainable agriculture: Current issues and future challenges Food Agriculture and the Environment Discussion Paper 32, International Food Policy Research Institute, Washington DC

Haase DL and Rose R (1995) Vector analysis and its use for interpreting plant nutrient shifts in response to silvicultural treatments. For Sci 41:54–66

Hagras AM (1987) Influence of seed rates and nitrogen fertilization on yield of durum wheat. Wheat, Barley and Tropical Absts 4(1):322

Hanson RG (1981) DRIS Evaluation of N P K status of determinant soybeans in Brazil. Commun. Soil Sci. Plant Nutr. 12: 933–948

Hartz TK, Miyao EM and Valencia JG (1998) DRIS evaluation of the nutritional status of processing tomato. HortScience. Alexandria 33:830-832

Hussain F and Yasin M (2003) Soil fertility monitoring and management in rice-wheat system: Annual Report LRRP, NARC, Islamabad: 1-14

Hussain F and Yasin M (2004) Soil fertility monitoring and management in rice-wheat system: Annual Report LRRP, NARC, Islamabad: 1–33

Hussain N (1973) Effect of different NP levels on the growth and yield of two wheat varieties Maxipak-65 and Ch-70. Dissertation, University of Agriculture, Faisalabad

IFADATA (2009) Accessed at http://wwwfertilizerorg/ifa/ifadata/search between February and April 2009

IUCN (2004) Agriculture: The Chitral conservation strategy. IUCN, Pakistan Sector paper, IUCN Chitral Office, Pakistan

Jones JB jr and Mederski HJ (1964) Effect of time and soil moisture level on the mineral composition of field grown soybean plants. Agron. Abst. Am Soc. Agron. Madison, Wisconsin: 32

Jones CA and Bowen JE (1981) Comparative DRIS and crop log diagnosis of sugar cane tissue analysis. Agron. J. **73**: 941–944

Jones JB jr (1993) Modern interpretation systems for soil and plant analysis in the United States of America. Aust. J. Exp Agric. 33:1039–1043

Jones Wolf B and Mills HA (1991) Plant Analysis, Handbook. Micro-Macro Publishing, Athens Georgia, p 213

Jones JB jr (1967) Interpretation of plant analysis for several agronomic crops. Soil Testing and Plant Analysis, Shuman GW and Welch RM (Ed), Soil Science Society America, Book Series 4 (2):371-426

Jones CA and Bowen JE (1981) Comparative DRIS and crop log diagnosis of sugarcane tissue. Agron. J.73:941-944

Jones CA (1981) Proposed modifications of the diagnosis and recommendation integrated system (DRIS) for interpreting plant analysis. Communications in Soil Science and Plant Analysis 12:785-794

Jurkowska H, Rogo A and Wojciechowicz T (1996) Fitotoksycznoœæ Cu, Zn, Pb i Cb w zale¿noœciod rodzaju nawozu azotowego. [Phytotoxicity of Cu, Zn, Pb and Cd depending on the type of a nitrogen fertilizer]. Zesz. Probl. Post. Nauk Rol., 434:955. (in Polish)

Kaushik RD, Gupta VK and Singh JP (1993) Distribution of zinc cadmium and copper forms in soils as influenced by phosphorus application. Arid Soil Res Rehabil 7: 163–171

Kenworthy AL (1961) Plant analysis and fertilizer problems. Publication 8 Am Inst of Biological Sciences, Washington DC: 28-43

Khan BR et al (1986) Effect of different tillage implements on the yield of wheat Pakistan. Journal of Agricultural Research 7:3 141–147

Khokhar MA (1981) Growth and yield of two wheat genotypes as influenced by different plant populations and fertilizer levels. Dissertation, University of Agriculture, Faisalabad

Kirilav Yu I (1986) Phosphorus rate and yield structure of spring wheat. Wheat, barley and tropical Absts. 3(5):42-52

Larson CA (1964) Production of five varieties of wheat with seven fertility increments and four water treatments at Lyallpur. Pak. J. Agri Sci I: 12-16

Leite R de (1992) A Avaliação do estado do cafeeiro conilon no estado do Espírito Santo utilizando diferentes métodos de interpretação de análise foliar Viçosa: Universidade Federal de Viçosa, (Tese de Doutorado) p,87

Letzsch WS and Sumner ME (1984) Effect of population size and yield level in selection of Diagnosis and Recommendation Integrated System (DRIS) norms. Communications in Soil Science and Plant Analysis15: 997-1006

Loneragen JP (1997) Plant nutrition in 20th and perspectives for the 21 century. Plant soil 196:163-174

Mackay DC, Carefoot JM and Entz T (1987) Evaluation of the DRIS procedure for assessing the nutritional status of potato (Solanum tuberosum L). Commun. Soil Sci. Plant Ana.l18:1331–1353

Malik V and Timmer VR (1995) Interaction of nutrient-loaded black spruce seedlings with neighbouring vegetation in greenhouse environments. Can. J. For. Res. 25:1017–1023.

Mastalerz JW (1977) The greenhouse environment. John Wiley and Sons, New York, pp510-516

Mayfield JL (2002) Effect of current fertilization practices on nutritional status of double-cropped tomato and cucumber produced with plasticulture. Journal of Plant Nutrition 25:1-15

Mead DJ (1984) Diagnosis of nutrient deficiencies in plantation. Nutrition of Plantation Forests, Bowen GD Nambiar EKS (eds). (Academic Press London): 250–291

Memon KS (1984–85, 1985–86) Cooperative research program on micronutrient status of Pakistan–soils. 2nd Annual Report Department of Agriculture Chemistry, Sindh Agriculture University, Tandojam

Meynard MJ (1984) Relationship between growth and development of winter wheat during shoot elongation: effect of nutrition field crop. Absts 35(4): 2920

Miglierina AM (1995) Rotación y fertilización en sistemas de producción de la región semiárida bonaerense II Cambios en algunas propiedades químicas del suelo Rev Facultad Agronomía 15: 9–14

Miller TD (1992) Growth stages of wheat. Better crops with plant food. Potash Phosphorus Institute. 76:12-17

Mourão Filho (2004) FAA DRIS: Concepts and applications on nutritional diagnosis in fruit crops. Scientia Agricola.61:550-560

Munson RD (1969) Plant analysis, varietal and other considerations. Proceeding symposium on plant analysis, Greer F (ed), International Min. & Chem. Corp., Skokie, I(ll):85-104

Murphy J and Riley JP (1962) A modifed single solution method for the determination of phosphate in natural waters. Anal Chim Acta 27:31-36

NFDC (2001) Balanced fertilization through phosphate promotion. Terminal report, NFDC Planning and development division, Islamabad

PARC (2002) Effect of boron ob rice productivity. Annual Report 2002, Pakistan Agriculture Research Council, Islamabad p, 97

Parent LE, Cambouris AN and Muhawenimana A (1994a) Multivariate diagnosis of nutrient imbalance in potato crops. Soil Science Society of America Journal 58:1432-1438

Parent LE, Karam A and Visser SA (1993) Compositional nutrient diagnosis of the greenhouse tomato. Hort Science 28:1041-1042

Pinstrup-Andersen P (1999) Selected aspects of the future global food situation. In: 25th International Fertilizer Industry Association Enlarged Council Meeting, Rome Italy

Pinstrup-Andersen P, Pandya-Lorch R and Rosegrant MW (1999) World food propects: critical issues for the early twenty-first century 2020, Vision Food Policy Report. International Food Policy Research Institute, Washington DC

Prevot P and Ollagnier M (1956) Méthode d'utilisation du diagnostic foliaire (Analyses de Plantes et Problèmes des fumures minerals. Vle. Congr. Intern. Sci. du Sol, Paris, II:177 - 192

Prevot P and Ollangnier M (1961) Law of the minimium and balanced nutrition. In 'Plant Analysis and Fertilizer Problems, Reuther W (Ed) American Institute of Biological Sciences: Washington DC 8:257-77

Rashid A (1996) Secondary and Micronutrients, Soil Science. Rashid A (eds) National Book Foundation, Islamabad: pp, 341-386

Rashid AE, Rafique E and Ryan J (2002) Establishment and management of boron deficiency in crops in Pakistan: A country report In: Goldbach HE et al (eds) Boron in Plant and Animal Nutrition Kluwer Acad Publication, New York, pp 339-340

Rashid A and Fox RL (1992) Evaluating internal zinc requirements of grain crops by seed analysis. Agronomy Journal 84: 469-474

Reuter DJ and Robinson JB (eds) (1986) Plant Analysis: An Interpretation Manual. Inkata Press, Melbourne

Reuter DJ et al (1983) Intra specific variation in the external and internal copper requirements of subterranean clover. Agronomy Journal 75: 45–49

Reuter DJ, Edwards DG and Wilhelm NS (1997) Temperate and sub-tropical crops. Plant analyses, An Interpretation Manual edited by DJ Reuter and JB Robinson (CSIRO Publishing Australia), 2: 81-284

Reynolds SB, Scaife A and Turner MK (1987) Effect of nitrogen form on boron uptake by cauliflower. Commun. Soil Sci. Plant Anal. 18:1143-1154

Rosegrant MW et al (2001) Global food projections to 2020: Emerging trends and alternative futures. International Food Policy Research Institute, Washington DC

Rosell RA et al (1992) Effect of sorghum residues on wheat productivity in semi-arid Argentina I Stover decomposition and N distribution. Crop. Sci. Total Environ 117/118: 253-261

Rosell (2000) The effects of crop rotation and fertilization on wheat productivity in the Pampean semiarid region of Argentina 2 Nutrient balance yield and grain quality. Soil and Till Res 53:137-144

Saleem M (1983) Water and fertilizer management in Pakistan. Proc 17th Coll Intern Potash Inst Morcco: 359-385

Saleem M (1992) Efficient use of plant nutrients. Proc 4th National Congress of Soil Science, Islamabad May 24-26, p, 5

Salifu KF and Timmer VR (2001) Nutrient retranslocation response of Picea mariana seedlings to nitrogen supply. Soil Sci. Soc. Am. J. 65(3):905–913

Sanchez PA and Swaminathan MS (2005) Cutting world hunger in half. Science 307:357–359

Sanchez CA, Snyder GH and Burdine HW (1991) DRIS evaluation of the nutritional status of crisphead lettuce. Journal of Horticulture Science 26:274- 276

Scherr SJ (1999) Soil degradation a threat to developing country food security by 2020? Food Agriculture and the Environmental Discussion Paper 27. International Food Policy Research Institute, Washington DC

Sedberry JE et al (1987) Plant-tissue analysis as a diagnostic aid in crop production. La Agric Expt Sta Bull 783:15

Shahid M, Mohammad F and Tahir M (2002) Path coefficient analysis. Sarhad Journal of Agriculture 18(4):383- 388

Shear CB and Faust M (1980) Nutritional ranges in deciduous tree fruits and nuts. Horticulture Review 2:142–163

Shuman LM et al., (1992) Comparison of Mehlich-1 and Mehlich-3 extractable soil boron with hot water-water extractable boron. Commun. Soil Sci. Plant Anal 23:1–14

Shuman LM (1988) Effect of phosphorus level on extractable micronutrients and their distribution among soil fractions. Soil Science Society American Journal 52: 136–141

Sillanpaa M (1982) Micronutrients and the Nutrient Status of Soils. Soils Bull 48, FAO (Rome)

Smith PF (1962) Mineral analysis of plant tissues. Annual Review Plant Physiology 13:81–108

Soltanpour PN, Malakouti MJ and Ronaghi A (1995) Comparison of DRIS and nutrient sufficient range of corn. Soil Science Society of America Journal Madison 59:133-139

Sparks D (1978) Nutrient concentrations of pecan leaves with deficiency symptoms and normal growth. Horticulture Science 13(3):256-257

Sumner ME (1981) Diagnosing the sulfur requirements of corn and wheat using the DRIS approach. Soil Science Society America Journal 45: 87-90

Sumner ME (1977a) Use of the DRIS system in foliar diagnostic of crops at high yield levels. Soil Science Plant Analyses 8:251–268

Sumner ME (1977) Application of Beaufils' diagnostic indices to maize data published in the literature irrespective of age and conditions. Plant and Soil 46, 1

Sumner ME (1977) Preliminary N P and K foliar diagnostic norms for soybeans. Agronomy Journal: 69

Sumner ME (1977) Preliminary NPK foliar diagnostic norms for wheat. Comm. Soil Sci. Plant Anal. 8(2)

Sumner ME and Beaufils ER (1975) Diagnosis of the NPK requirements of sugarcane irrespective of plant age and season using Beaufils' system (DRIS) Preliminary observations. SASTA Proc 49:147-141

Sumner ME (1977) Use of the DRIS system in foliar diagnosis of crops at high yield levels. Commun. Soil Sci. Plant Anal. 8:251-268

Sumner ME (1977a) Use of the DRIS system in foliar diagnostic of crops at high yield levels. Soil. Sci Plant. Anal.8:251–268

Sumner ME (1981) Diagnosing the sulfur requirement of corn and wheat using foliar analysis. Journal of Agronomy 45:87-90

Sumner ME (1982) The diagnosis and recommendation integrated system (DRIS) as a guide to orchard fertilization. International Seminar on Leaf Diagnosis as a Guide to Orchard Fertilization. Food Fertil. Technol Center for Asia and Pac Reg Suweon, Korea

Timmer VR and Stone EL (1978) Comparative foliar analysis of young balsam is fertilized with nitrogen phosphorus potassium and lime. Soil Science Society American Journal 42:125-130

Tsadilas CD et al (1994) The availability of soil boron fractions to olive trees and barley and their relationships to soil properties. Plant and Soil 162:211–217

Ulrich A (1952) Physiological bases for assessing the nutritional requirements of plants. Annual Review Plant Physiology 3: 207–228

Ulrich A and Hills FJ (1967) Principles and practices of plant analysis In: Soil testing and plant analysis Part II Madison (WI): Soil Science Society of America (Special publication series; 2)

UNDP (1999) Human Development Report. Oxford University Press, Cary NC

Walworth JL et al (1986) Preliminary DRIS norms for alfafa. Journal of Agronomy 78:1046–1052

Walworth JL and Sumner ME (1987) The diagnosis and recommendation integrated system (DRIS). Adv Soil Science 6: 149–188

Walworth JL and Sumner ME (1987) The diagnosis and recommendation integrated system (DRIS) In: Stewart BA (ed) Advances in soil science. Springer-Verlag, New York, 6:149–88

Walworth JL (1986) Preliminary DRIS norms for alfalfa. Agronomy Journal 78:1046-52

Walworth JL and Sumner ME (1987) The diagnosis and recommendation integrated system. Advances in Soil Sciences 6:149-188

Warner RM and Fox RL (1972) Concentration and distribution of S Mg and five micronutrients in macadamia in relation to yields. Hawaii Macadami Producers Association Hilo, Hawaii, pp 26–37

Welch RM and Graham RD (2000) A new paradigm for world agriculture: productive sustainable nutritious healthful food systems. Food Nutrition Bull 21:361–366

Welch RM (2002) The impact of mineral nutrients in food crops on global human health. Plant and Soil 247:83-90

Wilson JR (1976) Variation of leaf characteristics with level of insertion on a grass tiller I Development rate chemical composition and dry matter digestibility. Australian Journal of Agriculture Research 27:343–354

Worley RE (1969) Pecan leaf analysis service summary 1967.University of Georgia Exp Sta. Res. Rep. 55 p, 26

Wojcik P (2000) Behavior of soil boron and boron uptake by M26 apple rootstock as affected by application of different forms of nitrogen rates. J. Plant Nutr. 23: 1227-1239.

Yadahalli YH and Patil SV (1974) Response of tall and dwarf wheat to date of sowing and fertilizer levels under rainfall conditions. Mysore.J. of Agri. Sci. 8(1):20-30 and Soil and Fertilizer vol.38-1975.

Zadoks JC, Chang TT and Konzak CF (1974) A Decimal Code for the Growth Stages of Cereals. Weed Research 14:415-421

7 APPENDICES

Appendix 1 Cate and Nelson (1979) method to partition the dataset into low-yielding and high-yielding populations

Total samples	181.00
Parameters	8.00
TSS	153.73

I	TX1	CSS1	TX2	CSS2	CSS1	CSS2	R2	Yield (tonnsha^{-1})
1	6.28	39.44						6.28
2	12.43	77.26	493.26	1489.27	0.01	130.05	15.40	6.15
3	18.43	113.26	487.26	1453.27	0.04	119.46	22.26	6.00
4	24.31	147.84	481.38	1418.70	0.09	109.53	28.69	5.88
5	29.25	172.24	476.44	1394.30	1.13	104.57	31.24	4.94
6	34.10	195.76	471.59	1370.77	1.96	99.95	33.70	4.85
7	38.87	218.51	466.82	1348.02	2.67	95.62	36.06	4.77
8	43.57	240.60	462.12	1325.93	3.31	91.53	38.30	4.7
9	48.16	261.67	457.53	1304.86	3.96	87.83	40.29	4.59
10	52.64	281.74	453.05	1284.79	4.65	84.50	42.01	4.48
11	56.98	300.58	448.71	1265.96	5.42	81.62	43.38	4.34
12	61.25	318.81	444.44	1247.72	6.18	78.95	44.62	4.27
13	65.24	334.73	440.45	1231.80	7.33	77.08	45.09	3.99
14	69.22	350.57	436.47	1215.96	8.33	75.23	45.65	3.98
15	73.20	366.41	432.49	1200.12	9.20	73.35	46.30	3.98
16	77.07	381.39	428.62	1185.15	10.15	71.74	46.73	3.87
17	80.84	395.60	424.85	1170.93	11.18	70.36	46.96	3.77
18	84.60	409.74	421.09	1156.80	12.12	68.98	47.24	3.76
19	88.32	423.58	417.37	1142.96	13.03	67.68	47.50	3.72
20	91.99	437.05	413.70	1129.49	13.94	66.48	47.69	3.67
21	95.62	450.22	410.07	1116.31	14.83	65.35	47.84	3.63
22	99.21	463.11	406.48	1103.42	15.72	64.29	47.96	3.59
23	102.76	475.71	402.93	1090.82	16.60	63.29	48.03	3.55
24	106.31	488.32	399.38	1078.22	17.41	62.29	48.16	3.55
25	109.84	500.78	395.85	1065.76	18.18	61.31	48.29	3.53
26	113.34	513.03	392.35	1053.51	18.95	60.37	48.40	3.50
27	116.83	525.21	388.86	1041.33	19.68	59.45	48.53	3.49
28	120.32	537.39	385.37	1029.15	20.36	58.51	48.70	3.49
29	123.81	549.57	381.88	1016.97	20.98	57.56	48.90	3.49
30	127.28	561.61	378.41	1004.93	21.60	56.64	49.10	3.47
31	130.71	573.37	374.98	993.16	22.24	55.78	49.25	3.43
32	134.14	585.14	371.55	981.40	22.84	54.91	49.42	3.43
33	137.56	596.84	368.13	969.70	23.42	54.05	49.61	3.42

Appendix 1 continued

Total samples	181.00
Parameters	8.00
TSS	153.73

I	TX1	CSS1	TX2	CSS2	CSS1	CSS2	R2	Yield (tonnsha^{-1})
34	140.97	608.46	364.72	958.07	23.98	53.19	49.80	3.41
35	144.36	619.92	361.33	946.61	24.54	52.37	49.97	3.39
36	147.74	631.35	357.95	935.19	25.08	51.54	50.16	3.38
37	151.09	642.57	354.60	923.97	25.63	50.76	50.31	3.35
38	154.42	653.66	351.27	912.88	26.18	50.00	50.44	3.33
39	157.73	664.61	347.96	901.92	26.74	49.27	50.56	3.31
40	161.03	675.50	344.66	891.03	27.28	48.54	50.68	3.30
41	164.32	686.33	341.37	880.21	27.81	47.82	50.81	3.29
42	167.60	697.09	338.09	869.45	28.32	47.11	50.93	3.28
43	170.85	707.65	334.84	858.89	28.86	46.43	51.02	3.25
44	174.10	718.21	331.59	848.32	29.37	45.75	51.13	3.25
45	177.33	728.64	328.36	837.89	29.88	45.09	51.23	3.23
46	180.55	739.01	325.14	827.52	30.39	44.44	51.32	3.22
47	183.77	749.38	321.92	817.15	30.88	43.77	51.44	3.22
48	186.95	759.49	318.74	807.04	31.40	43.16	51.50	3.18
49	190.13	769.61	315.56	796.93	31.90	42.54	51.57	3.18
50	193.30	779.65	312.39	786.88	32.40	41.93	51.65	3.17
51	196.46	789.64	309.23	776.90	32.88	41.33	51.73	3.16
52	199.61	799.56	306.08	766.97	33.37	40.73	51.80	3.15
53	202.76	809.48	302.93	757.05	33.83	40.12	51.89	3.15
54	205.91	819.41	299.78	747.13	34.28	39.50	52.01	3.15
55	209.04	829.20	296.65	737.33	34.74	38.90	52.10	3.13
56	212.16	838.94	293.53	727.60	35.19	38.31	52.18	3.12
57	215.28	848.67	290.41	717.86	35.63	37.71	52.29	3.12
58	218.38	858.28	287.31	708.25	36.08	37.13	52.37	3.1
59	221.48	867.89	284.21	698.64	36.52	36.54	52.47	3.10
60	224.57	877.44	281.12	689.09	36.95	35.96	52.57	3.09
61	227.65	886.97	278.03	679.56	37.37	35.37	52.68	3.09
62	230.73	896.46	274.95	670.08	37.79	34.78	52.79	3.08
63	233.80	905.89	271.88	660.65	38.21	34.20	52.90	3.07
64	236.87	915.31	268.81	651.23	38.61	33.61	53.02	3.07
65	239.94	924.73	265.74	641.80	39.01	33.01	53.15	3.07
66	243.00	934.10	262.68	632.44	39.40	32.41	53.29	3.06
67	246.05	943.37	259.64	623.16	39.80	31.83	53.41	3.05
68	249.09	952.61	256.60	613.92	40.19	31.24	53.53	3.04
69	252.12	961.82	253.56	604.71	40.58	30.65	53.66	3.04
70	255.12	970.82	250.56	595.71	41.00	30.11	53.74	3.00

Appendix 1 Continued

Total samples	181.00
Parameters	8.00
TSS	153.73

I	TX1	CSS1	TX2	CSS2	CSS1	CSS2	R2	Yield (tonnsha^{-1})
71	258.12	979.82	247.56	586.71	41.41	29.55	53.84	3.00
72	261.09	988.64	244.59	577.89	41.85	29.03	53.89	2.97
73	264.06	997.47	241.62	569.07	42.27	28.50	53.96	2.97
74	267.03	1006.29	238.65	560.25	42.69	27.95	54.05	2.97
75	269.99	1015.05	235.69	551.49	43.10	27.42	54.13	2.96
76	272.94	1023.75	232.74	542.79	43.52	26.88	54.20	2.95
77	275.89	1032.45	229.79	534.08	43.92	26.34	54.29	2.95
78	278.82	1041.04	226.86	525.50	44.35	25.82	54.36	2.93
79	281.74	1049.53	223.95	517.00	44.78	25.30	54.41	2.92
80	284.63	1057.89	221.06	508.65	45.23	24.82	54.44	2.89
81	287.51	1066.18	218.18	500.35	45.68	24.33	54.45	2.88
82	290.39	1074.48	215.30	492.06	46.12	23.84	54.49	2.88
83	293.27	1082.77	212.42	483.77	46.56	23.34	54.53	2.88
84	296.14	1091.01	209.55	475.53	46.99	22.84	54.57	2.87
85	299.01	1099.24	206.68	467.29	47.41	22.33	54.63	2.87
86	301.87	1107.42	203.82	459.11	47.84	21.83	54.68	2.86
87	304.69	1115.38	201.00	451.16	48.31	21.37	54.67	2.82
88	307.49	1123.22	198.20	443.32	48.80	20.92	54.64	2.8
89	310.28	1131.00	195.41	435.54	49.29	20.49	54.61	2.79
90	313.06	1138.76	192.62	427.78	49.78	20.04	54.58	2.79
91	315.85	1146.51	189.84	420.03	50.25	19.59	54.56	2.78
92	318.63	1154.23	187.06	412.30	50.73	19.14	54.55	2.78
93	321.40	1161.91	184.29	404.63	51.20	18.69	54.54	2.77
94	324.16	1169.52	181.53	397.01	51.68	18.24	54.52	2.76
95	326.91	1177.09	178.78	389.45	52.16	17.79	54.49	2.75
96	329.64	1184.54	176.05	382.00	52.66	17.37	54.45	2.73
97	332.35	1191.88	173.34	374.65	53.18	16.95	54.38	2.71
98	335.04	1199.12	170.65	367.42	53.72	16.55	54.29	2.69
99	337.73	1206.36	167.96	360.18	54.24	16.15	54.21	2.69
100	340.36	1213.27	165.33	353.26	54.85	15.81	54.04	2.63
101	342.98	1220.14	162.71	346.40	55.46	15.47	53.86	2.62
102	345.59	1226.95	160.10	339.59	56.07	15.13	53.68	2.61
103	348.19	1233.71	157.50	332.83	56.68	14.80	53.50	2.60
104	350.76	1240.31	154.93	326.22	57.33	14.49	53.28	2.57
105	353.32	1246.87	152.37	319.67	57.99	14.19	53.05	2.56
106	355.88	1253.42	149.81	313.11	58.63	13.87	52.84	2.56
107	358.42	1259.87	147.27	306.66	59.29	13.58	52.60	2.54

Appendix 1 Continued

Total samples	181.00
Parameters	8.00
TSS	153.73

I	TX1	CSS1	TX2	CSS2	CSS1	CSS2	R2	Yield (tonnsha^{-1})
108	360.93	1266.17	144.76	300.36	59.99	13.30	52.32	2.51
109	363.44	1272.47	142.25	294.06	60.68	13.02	52.06	2.51
110	365.93	1278.67	139.76	287.86	61.38	12.75	51.78	2.49
111	368.41	1284.82	137.28	281.71	62.09	12.49	51.49	2.48
112	370.89	1290.97	134.80	275.56	62.79	12.21	51.21	2.48
113	373.37	1297.12	132.32	269.41	63.48	11.93	50.95	2.48
114	375.84	1303.23	129.85	263.31	64.17	11.65	50.68	2.47
115	378.30	1309.28	127.39	257.26	64.86	11.38	50.41	2.46
116	380.75	1315.28	124.94	251.26	65.56	11.10	50.13	2.45
117	383.20	1321.28	122.49	245.25	66.24	10.82	49.87	2.45
118	385.62	1327.14	120.07	239.40	66.97	10.56	49.57	2.42
119	388.04	1333.00	117.65	233.54	67.68	10.29	49.28	2.42
120	390.45	1338.80	115.24	227.73	68.40	10.02	48.98	2.41
121	392.86	1344.61	112.83	221.92	69.11	9.75	48.70	2.41
122	395.25	1350.32	110.44	216.21	69.83	9.48	48.40	2.39
123	397.64	1356.04	108.05	210.50	70.55	9.21	48.11	2.39
124	400.02	1361.70	105.67	204.84	71.27	8.94	47.82	2.38
125	402.40	1367.36	103.29	199.17	71.98	8.66	47.54	2.38
126	404.78	1373.03	100.91	193.51	72.68	8.36	47.28	2.38
127	407.15	1378.65	98.54	187.89	73.39	8.07	47.01	2.37
128	409.51	1384.22	96.18	182.32	74.10	7.78	46.74	2.36
129	411.86	1389.74	93.83	176.80	74.81	7.49	46.46	2.35
130	414.17	1395.07	91.52	171.46	75.58	7.23	46.13	2.31
131	416.44	1400.23	89.25	166.31	76.42	7.00	45.74	2.27
132	418.70	1405.33	86.99	161.20	77.25	6.77	45.34	2.26
133	420.94	1410.37	84.75	156.16	78.11	6.54	44.93	2.25
134	423.18	1415.39	82.51	151.14	78.96	6.31	44.53	2.24
135	425.41	1420.36	80.28	146.17	79.81	6.08	44.13	2.23
136	427.63	1425.29	78.05	141.24	80.67	5.85	43.72	2.22
137	429.85	1430.22	75.83	136.31	81.52	5.61	43.32	2.22
138	432.05	1435.06	73.63	131.47	82.39	5.38	42.90	2.20
139	434.24	1439.86	71.44	126.68	83.27	5.14	42.48	2.19
140	436.42	1444.61	69.26	121.93	84.16	4.91	42.06	2.18
141	438.59	1449.32	67.09	117.22	85.05	4.67	41.64	2.17
142	440.73	1453.90	64.95	112.64	85.98	4.45	41.17	2.14
143	442.86	1458.44	62.82	108.10	86.92	4.23	40.70	2.13
144	444.97	1462.89	60.71	103.65	87.89	4.02	40.21	2.11

Appendix 1 Continued

Total samples	181.00
Parameters	8.00
TSS	153.73

I	TX1	CSS1	TX2	CSS2	CSS1	CSS2	R2	Yield (tonnsha^{-1})
145	447.04	1467.17	58.64	99.36	88.93	3.83	39.66	2.07
146	449.10	1471.42	56.58	95.12	89.96	3.64	39.11	2.06
147	451.10	1475.42	54.58	91.12	91.11	3.49	38.46	2
148	453.10	1479.42	52.58	87.12	92.25	3.33	37.83	2
149	455.07	1483.30	50.61	83.24	93.43	3.18	37.15	1.97
150	457.04	1487.18	48.64	79.36	94.60	3.02	36.49	1.97
151	459.00	1491.02	46.68	75.52	95.77	2.87	35.83	1.96
152	460.93	1494.74	44.75	71.79	97.00	2.72	35.13	1.93
153	462.84	1498.39	42.84	68.14	98.25	2.58	34.41	1.91
154	464.74	1502.00	40.94	64.53	99.51	2.44	33.68	1.90
155	466.63	1505.57	39.05	60.96	100.77	2.30	32.95	1.89
156	468.49	1509.03	37.19	57.50	102.09	2.16	32.19	1.86
157	470.33	1512.42	35.35	54.12	103.43	2.03	31.40	1.84
158	472.15	1515.73	33.53	50.80	104.80	1.91	30.58	1.82
159	473.96	1519.01	31.72	47.53	106.18	1.78	29.77	1.81
160	475.76	1522.25	29.92	44.29	107.57	1.64	28.96	1.80
161	477.55	1525.45	28.13	41.08	108.96	1.50	28.14	1.79
162	479.33	1528.62	26.35	37.91	110.36	1.36	27.33	1.78
163	481.08	1531.68	24.60	34.85	111.81	1.22	26.47	1.75
164	482.83	1534.73	22.86	31.81	113.26	1.07	25.63	1.75
165	484.54	1537.65	21.15	28.88	114.77	0.93	24.74	1.71
166	486.23	1540.51	19.46	26.03	116.32	0.78	23.83	1.69
167	487.92	1543.36	17.77	23.17	117.84	0.62	22.94	1.69
168	489.51	1545.89	16.18	20.64	119.60	0.50	21.87	1.59
169	491.03	1548.20	14.66	18.33	121.54	0.42	20.66	1.52
170	492.43	1550.16	13.26	16.37	123.79	0.39	19.22	1.4
171	493.83	1552.12	11.86	14.41	126.02	0.35	17.80	1.40
172	495.21	1554.03	10.48	12.51	128.28	0.30	16.36	1.38
173	496.56	1555.85	9.13	10.69	130.60	0.27	14.87	1.35
174	497.89	1557.62	7.80	8.92	132.96	0.23	13.36	1.33
175	499.14	1559.18	6.55	7.35	135.54	0.20	11.70	1.25
176	500.37	1560.69	5.32	5.84	138.16	0.18	10.01	1.23
177	501.57	1562.13	4.12	4.40	140.84	0.16	8.28	1.20
178	502.76	1563.55	2.93	2.99	143.53	0.12	6.55	1.19
179	503.89	1564.83	1.80	1.71	146.38	0.09	4.72	1.13
180	505.00	1566.06	0.69	0.48	149.27	0.00	2.90	1.11
181	505.69	1566.54	0.00	0.00	153.73	-	-	0.69

Appendix 2 Ratio of the nutrients in shoot material (GS-29) for the high-yielding population in irrigated wheat

No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
127	3.54	0.25	156.96	24.04	0.04	0.10	0.60	13.98	556.02	85.15	87.19	33.99	5.93	39.77	6.09	0.16	0.41	2.36	6.53	6.38	16.36	93.82	0.98	2.51	14.37	2.57	14.71	5.73
128	9.22	0.77	94.30	16.29	0.15	0.38	0.21	11.95	869.43	150.19	62.90	24.05	44.45	72.77	12.57	0.19	0.50	0.27	5.79	13.82	36.15	19.56	2.39	6.25	3.38	2.62	1.42	0.54
151	3.52	0.22	165.62	32.43	0.04	0.11	0.20	16.20	582.31	114.03	88.09	32.94	17.19	35.94	7.04	0.18	0.49	0.94	5.11	6.61	17.68	33.88	1.29	3.46	6.63	2.67	5.12	1.92
102	6.05	0.43	74.65	25.77	0.22	0.19	0.21	14.18	451.66	155.90	27.90	31.47	28.52	31.86	11.00	0.51	0.45	0.50	2.90	16.19	14.35	15.84	5.59	4.95	5.47	0.89	0.98	1.10
118	7.96	0.76	98.64	10.27	0.13	0.34	0.52	10.50	785.67	81.76	63.48	23.65	15.18	74.80	7.78	0.17	0.44	0.69	9.61	12.38	33.22	51.76	1.29	3.46	5.39	2.68	4.18	1.56
13	6.33	0.44	128.13	17.66	0.10	0.26	0.74	14.33	810.43	111.73	64.11	23.88	8.50	56.56	7.80	0.22	0.60	1.68	7.25	12.64	33.93	95.30	1.74	4.68	13.14	2.68	7.54	2.81
12	4.63	0.42	101.74	15.22	0.11	0.34	0.18	11.15	471.07	70.45	40.47	13.46	25.46	42.23	6.32	0.28	0.83	0.44	6.69	11.64	34.99	18.51	1.74	5.23	2.77	3.01	1.59	0.53
114	9.83	0.82	137.70	14.07	0.14	0.38	0.40	11.98	1353.53	138.30	68.51	26.20	24.84	113.01	11.55	0.17	0.46	0.48	9.79	19.76	51.66	54.50	2.02	5.28	5.57	2.61	2.76	1.05
103	11.01	0.51	126.64	18.65	0.13	0.23	0.37	21.44	1393.92	205.29	81.95	48.63	29.58	65.03	9.58	0.26	0.44	0.72	6.79	17.01	28.66	47.13	2.51	4.22	6.94	1.68	2.77	1.64
100	8.12	0.51	138.86	18.37	0.18	0.23	0.43	15.86	1127.80	149.21	45.52	34.56	18.82	71.12	9.41	0.35	0.46	0.84	7.56	24.77	32.63	59.93	3.28	4.32	7.93	1.32	2.42	1.84
142	11.18	0.54	78.66	16.45	0.13	0.22	0.21	20.76	879.09	183.84	87.44	50.13	52.50	42.35	8.86	0.24	0.41	0.40	4.78	10.05	17.54	16.74	2.10	3.67	3.50	1.74	1.67	0.95
150	11.30	0.55	110.09	19.29	0.11	0.21	0.29	20.50	1244.05	217.98	104.37	52.82	38.95	60.67	10.63	0.20	0.39	0.53	5.71	11.92	23.55	31.94	2.09	4.13	5.60	1.98	2.68	1.36
111	4.52	0.50	82.28	15.76	0.12	0.22	0.41	9.12	372.12	71.30	37.97	20.79	10.99	40.79	7.82	0.24	0.44	0.83	5.22	9.80	17.90	33.87	1.88	3.43	6.49	1.83	3.46	1.89
146	7.56	0.55	128.29	15.50	0.15	0.24	0.36	13.68	969.92	117.21	48.85	30.88	21.14	70.90	8.57	0.28	0.44	0.65	8.28	19.86	31.41	45.89	2.40	3.80	5.55	1.58	2.31	1.46
30	6.62	0.56	107.14	15.61	0.09	0.26	0.17	11.91	709.55	103.38	70.43	25.18	38.12	59.57	8.68	0.17	0.47	0.31	6.86	10.07	28.18	18.61	1.47	4.11	2.71	2.80	1.85	0.66
154	22.09	0.56	55.01	19.03	0.13	0.25	0.30	39.61	1215.08	420.42	171.44	88.97	73.23	30.68	10.61	0.23	0.45	0.54	2.89	7.09	13.66	16.59	2.45	4.73	5.74	1.93	2.34	1.21
40	7.10	0.58	109.40	8.56	0.13	0.23	0.48	12.16	776.92	60.79	55.25	30.42	14.82	63.91	5.00	0.22	0.40	0.82	12.78	14.06	25.54	52.41	1.10	2.00	4.10	1.82	3.73	2.05
31	10.38	0.51	86.24	14.90	0.09	0.27	0.25	20.35	895.51	154.67	110.37	37.89	41.48	44.01	7.60	0.18	0.54	0.49	5.79	8.11	23.63	21.59	1.40	4.08	3.73	2.91	2.66	0.91
62	11.24	0.59	87.76	17.31	0.14	0.30	0.41	19.10	986.43	194.59	82.86	37.92	27.24	51.64	10.19	0.23	0.50	0.70	5.07	11.90	26.01	36.21	2.35	5.13	7.14	2.19	3.04	1.39
48	6.66	0.50	122.10	16.56	0.11	0.23	0.36	13.44	812.79	110.20	62.48	28.59	18.35	60.46	8.20	0.22	0.47	0.73	7.38	13.01	28.43	44.29	1.76	3.86	6.00	2.19	3.40	1.56
6	11.20	0.61	89.01	15.16	0.15	0.39	0.21	18.40	996.96	169.82	74.02	28.46	53.59	54.19	9.23	0.25	0.65	0.34	5.87	13.47	35.03	18.61	2.29	5.97	3.17	2.60	1.38	0.53
26	10.92	0.56	77.87	13.12	0.10	0.30	0.33	19.35	850.56	143.30	106.71	36.59	33.30	43.96	7.41	0.18	0.53	0.58	5.94	7.97	23.25	25.54	1.34	3.92	4.30	2.92	3.20	1.10
25	10.54	0.62	83.15	12.61	0.11	0.38	0.51	17.06	876.30	132.90	93.39	27.70	20.62	51.37	7.79	0.18	0.62	0.83	6.59	9.38	31.64	42.49	1.42	4.80	6.44	3.37	4.53	1.34
170	7.01	0.57	93.97	5.68	0.17	0.33	0.31	12.36	659.18	39.85	42.03	21.25	22.60	53.33	3.22	0.29	0.58	0.55	16.54	15.68	31.03	29.17	0.95	1.88	1.76	1.98	1.86	0.94
145	9.30	0.54	113.72	15.36	0.16	0.24	0.31	17.19	1058.01	142.89	56.87	38.17	29.66	61.55	8.31	0.30	0.45	0.58	7.40	18.61	27.72	35.67	2.51	3.74	4.82	1.49	1.92	1.29

Appendix 2 continued

No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
22	13.17	0.89	86.81	10.80	0.13	0.38	0.70	14.85	1143.21	142.18	97.90	34.70	18.72	77.01	9.58	0.15	0.43	0.79	8.04	11.68	32.94	61.06	1.45	4.10	7.59	2.82	5.23	1.85
105	8.74	0.55	66.67	15.13	0.17	0.27	0.48	15.80	582.46	132.20	52.61	31.82	18.07	36.87	8.37	0.30	0.50	0.87	4.41	11.07	18.31	32.24	2.51	4.15	7.32	1.65	2.91	1.76
97	13.37	0.94	63.30	5.58	0.20	0.41	0.16	14.17	846.44	74.68	67.66	32.81	84.34	59.76	5.27	0.21	0.43	0.17	11.33	12.51	25.80	10.04	1.10	2.28	0.89	2.06	0.80	0.39
78	12.44	0.90	92.44	10.76	0.16	0.42	0.60	13.88	1150.45	133.85	79.99	29.61	20.73	82.89	9.64	0.17	0.47	0.67	8.60	14.38	38.86	55.48	1.67	4.52	6.46	2.70	3.86	1.43
76	11.34	0.63	98.07	11.47	0.08	0.21	0.29	17.88	1112.27	130.10	143.75	53.69	39.15	62.20	7.28	0.12	0.33	0.46	8.55	7.74	20.72	28.41	0.91	2.42	3.32	2.68	3.67	1.37
68	11.47	0.67	94.87	16.55	0.16	0.28	0.73	17.12	1088.34	189.85	69.64	40.33	15.73	63.58	11.09	0.25	0.42	1.09	5.73	15.63	26.99	69.20	2.73	4.71	12.07	1.73	4.43	2.56
74	9.01	0.69	93.26	13.20	0.11	0.32	0.43	13.10	840.11	118.92	85.30	27.87	21.01	64.13	9.08	0.15	0.47	0.62	7.06	9.85	30.15	39.98	1.39	4.27	5.66	3.06	4.06	1.33
73	13.81	0.80	71.91	14.79	0.18	0.35	0.47	17.37	993.10	204.25	77.90	39.91	29.30	57.17	11.76	0.22	0.44	0.59	4.86	12.75	24.89	33.89	2.62	5.12	6.97	1.95	2.66	1.36
117	7.61	0.52	90.59	15.21	0.22	0.25	0.33	14.53	689.37	115.71	35.13	30.38	23.30	47.45	7.96	0.41	0.48	0.62	5.96	19.63	22.69	29.58	3.29	3.81	4.97	1.16	1.51	1.30
166	5.86	0.49	118.85	10.94	0.12	0.22	0.21	12.00	696.87	64.14	48.32	26.44	28.04	58.09	5.35	0.25	0.45	0.43	10.87	14.42	26.35	24.86	1.33	2.43	2.29	1.83	1.72	0.94
23	10.22	0.49	70.73	11.86	0.14	0.22	0.36	20.89	722.63	121.20	72.56	46.71	28.02	34.60	5.80	0.29	0.45	0.75	5.96	9.96	15.47	25.79	1.67	2.59	4.33	1.55	2.59	1.67
90	34.52	0.65	94.63	7.69	0.15	0.38	0.50	53.04	3266.36	265.34	227.51	90.27	69.19	61.58	5.00	0.23	0.59	0.77	12.31	14.36	36.19	47.21	1.17	2.94	3.83	2.52	3.29	1.30
79	11.46	0.70	83.55	14.51	0.18	0.34	0.24	16.38	957.76	166.33	64.50	34.09	48.67	58.47	10.15	0.25	0.48	0.34	5.76	14.85	28.09	19.68	2.58	4.88	3.42	1.89	1.33	0.70
39	4.16	0.17	246.25	63.03	0.05	0.06	0.07	24.03	1024.93	262.34	90.51	67.20	60.25	42.65	10.92	0.27	0.36	0.40	3.91	11.32	15.25	17.01	2.90	3.90	4.35	1.35	1.50	1.12
86	6.89	0.69	35.06	17.95	0.15	0.36	0.56	10.03	241.47	123.66	44.81	19.08	12.22	24.06	12.32	0.22	0.53	0.82	1.95	5.39	12.66	19.76	2.76	6.48	10.12	2.35	3.67	1.56
107	18.48	0.77	41.23	11.03	0.10	0.38	0.12	24.15	762.03	203.82	194.03	48.60	160.61	31.55	8.44	0.12	0.50	0.15	3.74	3.93	15.68	4.74	1.05	4.19	1.27	3.99	1.21	0.30
171	10.45	0.81	74.71	6.33	0.21	0.35	0.46	12.97	780.59	66.13	50.54	29.73	22.58	60.18	5.10	0.26	0.44	0.57	11.80	15.44	26.26	34.56	1.31	2.22	2.93	1.70	2.24	1.32
58	8.89	0.79	86.31	12.57	0.14	0.38	0.30	11.19	767.42	111.78	64.03	23.13	29.70	68.56	9.99	0.17	0.48	0.38	6.87	11.99	33.18	25.84	1.75	4.83	3.76	2.77	2.16	0.78
63	17.73	0.76	69.93	10.25	0.16	0.44	1.16	23.35	1240.00	181.76	113.05	39.96	15.34	53.10	7.78	0.21	0.58	1.52	6.82	10.97	31.03	80.83	1.61	4.55	11.85	2.83	7.37	2.60
52	17.06	0.85	58.87	13.03	0.17	0.47	0.45	20.15	1004.40	222.27	101.70	36.09	37.88	49.85	11.03	0.20	0.56	0.53	4.52	9.88	27.83	26.51	2.19	6.16	5.87	2.82	2.68	0.95
168	12.99	0.89	78.96	5.08	0.22	0.44	0.22	14.57	1025.65	66.02	59.09	29.41	59.96	70.41	4.53	0.25	0.50	0.24	15.54	17.36	34.88	17.11	1.12	2.24	1.10	2.01	0.99	0.49
65	28.95	0.75	68.99	11.96	0.15	0.49	0.56	38.52	1997.09	346.11	196.81	59.36	52.04	51.85	8.99	0.20	0.65	0.74	5.77	10.15	33.64	38.37	1.76	5.83	6.65	3.32	3.78	1.14
165	9.93	0.63	97.09	8.54	0.15	0.35	0.59	15.71	964.32	84.82	67.40	28.64	16.78	61.39	5.40	0.23	0.55	0.94	11.37	14.31	33.67	57.45	1.26	2.96	5.05	2.35	4.02	1.71
174	10.32	0.83	71.25	8.25	0.19	0.36	0.24	12.50	735.35	85.16	54.98	28.96	42.67	58.85	6.82	0.23	0.43	0.29	8.63	13.37	25.39	17.23	1.55	2.94	2.00	1.90	1.29	0.68
104	10.40	0.60	41.12	12.46	0.15	0.36	0.77	17.41	427.61	129.58	69.51	28.88	13.43	24.57	7.44	0.25	0.60	1.30	3.30	6.15	14.81	31.85	1.86	4.49	9.65	2.41	5.18	2.15
72	14.67	0.89	75.54	12.54	0.17	0.51	0.31	16.56	1107.96	183.89	85.32	29.03	47.52	66.90	11.10	0.19	0.57	0.35	6.03	12.99	38.17	23.32	2.16	6.33	3.87	2.94	1.80	0.61
143	10.56	0.83	50.77	8.91	0.15	0.37	0.31	12.68	536.04	94.07	69.28	28.30	34.49	42.28	7.42	0.18	0.45	0.37	5.70	7.74	18.94	15.54	1.36	3.32	2.73	2.45	2.01	0.82
64	7.96	0.86	57.70	10.97	0.23	0.43	0.57	9.26	459.27	87.31	34.63	18.46	13.86	49.61	9.43	0.27	0.50	0.67	5.26	13.26	24.87	33.13	2.52	4.73	6.30	1.88	2.50	1.33

Appendix 2 continued

No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
56	11.14	0.80	67.62	12.03	0.19	0.38	0.35	13.94	753.24	133.96	58.33	29.70	31.97	54.03	9.61	0.24	0.47	0.44	5.62	12.91	25.36	23.56	2.30	4.51	4.19	1.96	1.82	0.93
133	22.29	0.64	70.56	13.71	0.16	0.35	0.19	34.74	1573.07	305.71	137.31	63.48	118.74	45.28	8.80	0.25	0.55	0.29	5.15	11.46	24.78	13.25	2.23	4.82	2.57	2.16	1.16	0.53
163	8.38	0.59	93.98	16.41	0.14	0.37	1.52	14.29	787.96	137.57	59.47	22.54	5.52	55.13	9.62	0.24	0.63	2.59	5.73	13.25	34.96	142.73	2.31	6.10	24.92	2.64	10.77	4.08
164	9.22	0.83	35.18	6.26	0.19	0.44	0.38	11.16	324.55	57.79	49.26	21.03	24.13	29.09	5.18	0.23	0.53	0.46	5.62	6.59	15.43	13.45	1.17	2.75	2.40	2.34	2.04	0.87
177	8.81	0.80	76.50	13.32	0.17	0.37	0.31	10.95	673.71	117.29	52.17	24.12	28.34	61.52	10.71	0.21	0.45	0.39	5.74	12.91	27.93	23.77	2.25	4.86	4.14	2.16	1.84	0.85
139	13.62	0.79	83.91	5.66	0.18	0.36	0.26	17.20	1142.90	77.03	77.20	37.42	51.76	66.43	4.48	0.22	0.46	0.33	14.84	14.80	30.54	22.08	1.00	2.06	1.49	2.06	1.49	0.72
140	17.93	0.82	47.88	9.00	0.18	0.38	0.33	21.91	858.63	161.34	99.82	47.36	54.24	39.18	7.36	0.22	0.46	0.40	5.32	8.60	18.13	15.83	1.62	3.41	2.97	2.11	1.84	0.87
161	24.76	0.83	90.62	10.89	0.16	0.38	0.70	29.87	2243.33	269.48	153.25	64.35	35.27	75.10	9.02	0.19	0.46	0.85	8.32	14.64	34.86	63.60	1.76	4.19	7.64	2.38	4.34	1.82
180	7.22	0.62	71.13	13.46	0.17	0.36	0.65	11.65	513.79	97.23	43.47	20.17	11.09	44.10	8.35	0.27	0.58	1.05	5.28	11.82	25.48	46.32	2.24	4.82	8.77	2.16	3.92	1.82
162	8.13	0.81	86.53	10.83	0.17	0.38	0.51	10.01	703.36	88.05	47.54	21.34	15.88	70.26	8.80	0.21	0.47	0.63	7.99	14.80	32.96	44.29	1.85	4.13	5.54	2.23	2.99	1.34
179	11.63	0.91	81.38	8.43	0.18	0.38	0.39	12.83	946.63	98.09	63.97	30.35	29.71	73.81	7.65	0.20	0.42	0.43	9.65	14.80	31.19	31.87	1.53	3.23	3.30	2.11	2.15	1.02
175	9.93	0.90	63.76	8.37	0.20	0.36	0.23	11.06	633.23	83.12	48.64	27.32	43.78	57.25	7.51	0.23	0.40	0.25	7.62	13.02	23.18	14.46	1.71	3.04	1.90	1.78	1.11	0.62
160	13.04	0.64	91.39	11.06	0.13	0.33	0.33	20.25	1191.73	144.17	97.67	39.08	39.23	58.84	7.12	0.21	0.52	0.52	8.27	12.20	30.50	30.37	1.48	3.69	3.67	2.50	2.49	1.00
130	11.27	0.78	69.43	12.08	0.26	0.39	0.32	14.49	782.66	136.16	44.09	29.18	35.46	54.01	9.40	0.33	0.50	0.41	5.75	17.75	26.82	22.07	3.09	4.67	3.84	1.51	1.24	0.82
138	9.51	0.56	88.15	15.91	0.10	0.25	0.18	16.97	838.03	151.27	95.65	38.41	53.95	49.38	8.91	0.18	0.44	0.31	5.54	8.76	21.82	15.53	1.58	3.94	2.80	2.49	1.77	0.71
84	6.78	0.90	68.60	13.53	0.24	0.40	0.19	7.51	465.20	91.78	28.29	17.04	35.42	61.95	12.22	0.27	0.44	0.21	5.07	16.44	27.30	13.14	3.24	5.39	2.59	1.66	0.80	0.48
149	15.03	0.75	69.45	9.75	0.20	0.35	0.43	19.91	1044.01	146.50	75.47	42.51	34.96	52.42	7.36	0.26	0.47	0.57	7.13	13.83	24.56	29.86	1.94	3.45	4.19	1.78	2.16	1.22
134	10.54	0.71	73.68	15.22	0.15	0.29	0.20	14.93	776.25	160.37	70.93	35.90	53.86	51.99	10.74	0.21	0.42	0.28	4.84	10.94	21.62	14.41	2.26	4.47	2.98	1.98	1.32	0.67
131	10.50	0.85	67.61	10.39	0.27	0.39	0.32	12.34	709.88	109.10	38.27	27.17	32.31	57.54	8.84	0.32	0.45	0.38	6.51	18.55	26.13	21.97	2.85	4.02	3.38	1.41	1.18	0.84
101	9.50	0.75	62.02	11.52	0.27	0.39	0.62	12.66	589.42	109.44	34.77	24.68	15.27	46.54	8.64	0.36	0.51	0.83	5.39	16.95	23.88	38.59	3.15	4.43	7.17	1.41	2.28	1.62
91	17.18	1.03	45.46	13.18	0.18	0.39	0.14	16.76	781.04	226.41	94.57	43.75	125.75	46.61	13.51	0.18	0.38	0.13	3.45	8.26	17.85	6.21	2.39	5.18	1.80	2.16	0.75	0.35
147	10.99	0.88	94.28	9.43	0.21	0.40	0.46	12.53	1036.17	103.59	53.36	27.42	23.88	82.67	8.27	0.23	0.46	0.52	10.00	19.42	37.79	43.39	1.94	3.78	4.34	1.95	2.23	1.15
81	12.24	0.88	35.26	14.33	0.17	0.34	0.78	13.95	431.52	175.32	71.88	35.92	15.75	30.93	12.57	0.19	0.39	0.89	2.46	6.00	12.01	27.40	2.44	4.88	11.13	2.00	4.56	2.28
135	15.23	0.65	52.69	10.09	0.17	0.31	0.21	23.46	802.49	153.75	88.85	49.18	72.21	34.21	6.55	0.26	0.48	0.32	5.22	9.03	16.32	11.11	1.73	3.13	2.13	1.81	1.23	0.68
132	24.75	0.83	73.74	10.03	0.15	0.32	0.21	29.91	1824.83	248.12	160.05	76.80	116.89	61.01	8.30	0.19	0.39	0.26	7.35	11.40	23.76	15.61	1.55	3.23	2.12	2.08	1.37	0.66
136	9.56	0.88	93.35	9.95	0.19	0.42	0.21	10.85	892.07	95.10	51.61	22.56	44.70	82.20	8.76	0.21	0.48	0.24	9.38	17.29	39.54	19.96	1.84	4.21	2.13	2.29	1.15	0.50
148	10.62	0.71	78.94	9.29	0.16	0.38	0.45	15.03	838.04	98.59	64.59	28.25	23.38	55.76	6.56	0.23	0.53	0.64	8.50	12.97	29.67	35.84	1.53	3.49	4.22	2.29	2.76	1.21

Appendix 2 continued

No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
137	8.08	0.90	46.45	10.72	0.18	0.37	0.34	8.97	375.24	86.60	45.54	21.67	23.74	41.82	9.65	0.20	0.41	0.38	4.33	8.24	17.31	15.81	1.90	4.00	3.65	2.10	1.92	0.91
176	9.24	1.09	58.40	6.86	0.33	0.53	0.32	8.46	539.64	63.43	28.01	17.45	29.30	63.82	7.50	0.30	0.48	0.29	8.51	19.26	30.92	18.42	2.26	3.63	2.17	1.61	0.96	0.60
144	13.24	0.70	66.02	9.56	0.15	0.37	0.26	18.99	874.17	126.62	89.19	36.24	51.03	46.04	6.67	0.21	0.52	0.37	6.90	9.80	24.12	17.13	1.42	3.49	2.48	2.46	1.75	0.71
96	17.84	1.35	61.84	8.75	0.19	0.39	0.20	13.23	1103.11	156.14	95.79	45.31	88.78	83.37	11.80	0.14	0.29	0.15	7.07	11.52	24.35	12.42	1.63	3.45	1.76	2.11	1.08	0.51
89	17.20	0.95	43.23	14.15	0.25	0.38	0.55	18.15	743.62	243.45	67.56	45.60	31.52	40.96	13.41	0.27	0.40	0.58	3.05	11.01	16.31	23.59	3.60	5.34	7.72	1.48	2.14	1.45
99	10.80	0.84	54.02	6.68	0.28	0.43	0.76	12.84	583.21	72.12	38.43	24.94	14.15	45.42	5.62	0.33	0.51	0.91	8.09	15.17	23.38	41.21	1.88	2.89	5.10	1.54	2.72	1.76

Appendix 3 Ratio of the nutrients in shoot material (GS-29) for the low-yielding population in irrigated wheat

No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
141	11.84	0.72	89.25	10.74	0.19	0.38	0.26	16.38	1056.68	127.14	60.83	30.81	45.32	64.53	7.76	0.27	0.53	0.36	8.31	17.37	34.30	23.32	2.09	4.13	2.81	1.97	1.34	0.68
27	7.04	0.55	93.90	13.20	0.10	0.27	0.33	12.75	660.96	92.94	67.99	26.33	21.46	51.85	7.29	0.19	0.48	0.59	7.11	9.72	25.11	30.80	1.37	3.53	4.33	2.58	3.17	1.23
67	7.65	0.51	98.12	24.83	0.14	0.24	0.45	14.99	750.26	189.88	56.60	31.87	16.82	50.04	12.67	0.26	0.47	0.89	3.95	13.26	23.54	44.60	3.35	5.96	11.29	1.78	3.36	1.89
94	16.36	1.16	81.04	7.58	0.13	0.34	0.24	14.06	1326.02	124.00	128.91	47.79	68.73	94.33	8.82	0.11	0.29	0.20	10.69	10.29	27.75	19.29	0.96	2.59	1.80	2.70	1.88	0.70
178	12.19	0.79	74.02	10.30	0.20	0.39	0.41	15.43	902.09	125.51	61.92	31.59	29.63	58.47	8.14	0.25	0.49	0.52	7.19	14.57	28.55	30.45	2.03	3.97	4.24	1.96	2.09	1.07
106	8.27	0.29	134.81	27.97	0.09	0.15	0.16	28.79	1114.90	231.28	95.60	53.88	51.68	38.72	8.03	0.30	0.53	0.56	4.82	11.66	20.69	21.57	2.42	4.29	4.47	1.77	1.85	1.04
55	14.76	0.90	95.50	15.02	0.15	0.36	0.34	16.37	1409.57	221.70	101.72	41.54	43.76	86.09	13.54	0.16	0.39	0.37	6.36	13.86	33.93	32.21	2.18	5.34	5.07	2.45	2.32	0.95
16	14.91	0.64	94.60	17.56	0.22	0.36	1.84	23.21	1410.75	261.84	69.26	41.50	8.08	60.78	11.28	0.34	0.56	2.87	5.39	20.37	34.00	174.54	3.78	6.31	32.40	1.67	8.57	5.13
110	11.95	0.42	104.36	24.87	0.11	0.19	0.21	28.56	1247.48	297.33	105.54	62.19	57.16	43.67	10.41	0.27	0.46	0.50	4.20	11.82	20.06	21.83	2.82	4.78	5.20	1.70	1.85	1.09
169	26.67	0.82	95.87	6.25	0.29	0.36	0.31	32.49	2557.16	166.58	92.08	73.88	86.60	78.71	5.13	0.35	0.44	0.38	15.35	27.77	34.61	29.53	1.81	2.25	1.92	1.25	1.06	0.85
113	13.49	0.50	61.30	27.37	0.08	0.20	0.21	27.01	827.29	369.38	159.33	67.49	63.77	30.63	13.68	0.17	0.40	0.42	2.24	5.19	12.26	12.97	2.32	5.47	5.79	2.36	2.50	1.06
172	12.86	0.74	108.15	11.73	0.16	0.21	0.25	17.49	1391.38	150.93	81.04	61.78	52.44	79.55	8.63	0.22	0.28	0.33	9.22	17.17	22.52	26.53	1.86	2.44	2.88	1.31	1.55	1.18
82	22.99	1.10	36.62	5.95	0.26	0.44	0.33	20.81	841.82	136.80	87.91	51.93	70.40	40.44	6.57	0.24	0.40	0.30	6.15	9.58	16.21	11.96	1.56	2.63	1.94	1.69	1.25	0.74
41	27.95	0.63	95.92	12.07	0.14	0.31	0.18	44.65	2680.81	337.29	201.94	90.76	151.98	60.05	7.55	0.22	0.49	0.29	7.95	13.28	29.54	17.64	1.67	3.72	2.22	2.22	1.33	0.60
98	10.55	0.47	94.65	15.26	0.10	0.22	0.12	22.69	998.98	161.02	101.33	47.51	85.21	44.03	7.10	0.22	0.48	0.27	6.20	9.86	21.03	11.72	1.59	3.39	1.89	2.13	1.19	0.56
19	16.02	0.64	118.64	15.98	0.10	0.30	0.26	24.84	1900.15	255.90	165.75	53.33	60.62	76.50	10.30	0.15	0.47	0.41	7.43	11.46	35.63	31.34	1.54	4.80	4.22	3.11	2.73	0.88
50	9.18	0.90	62.26	10.96	0.13	0.53	0.25	10.15	571.75	100.67	73.04	17.23	37.26	56.31	9.92	0.14	0.59	0.27	5.68	7.83	33.18	15.34	1.38	5.84	2.70	4.24	1.96	0.46
173	9.26	0.68	90.06	8.41	0.16	0.25	0.22	13.67	834.29	77.92	58.87	36.96	42.64	61.04	5.70	0.23	0.37	0.32	10.71	14.17	22.57	19.57	1.32	2.11	1.83	1.59	1.38	0.87
66	6.25	0.43	107.55	19.37	0.10	0.22	0.42	14.45	672.63	121.17	62.23	28.29	14.93	46.54	8.38	0.23	0.51	0.97	5.55	10.81	23.77	45.05	1.95	4.28	8.12	2.20	4.17	1.89
38	8.67	0.63	100.80	17.67	0.15	0.31	0.34	13.80	874.35	153.31	57.12	28.26	25.76	63.37	11.11	0.24	0.49	0.54	5.70	15.31	30.94	33.95	2.68	5.42	5.95	2.02	2.22	1.10
7	9.61	0.67	90.78	16.05	0.14	0.42	0.33	14.30	872.10	154.23	70.71	22.92	29.06	60.99	10.79	0.20	0.62	0.49	5.65	12.33	38.05	30.01	2.18	6.73	5.31	3.09	2.43	0.79
29	7.61	0.64	86.02	18.04	0.12	0.33	0.19	11.95	655.03	137.35	63.41	23.06	40.49	54.80	11.49	0.19	0.52	0.30	4.77	10.33	28.41	16.18	2.17	5.96	3.39	2.75	1.57	0.57
9	8.77	0.56	95.07	21.32	0.16	0.37	0.39	15.77	833.85	186.96	54.11	24.02	22.23	52.86	11.85	0.29	0.66	0.71	4.46	15.41	34.71	37.51	3.46	7.78	8.41	2.25	2.43	1.08
36	9.59	0.64	189.19	11.27	0.09	0.29	0.46	15.10	1814.88	108.15	110.32	33.57	20.68	120.19	7.16	0.14	0.45	0.73	16.78	16.45	54.06	87.74	0.98	3.22	5.23	3.29	5.33	1.62
115	19.84	0.47	76.34	22.61	0.16	0.21	0.27	42.55	1514.81	448.72	121.56	95.77	72.44	35.60	10.55	0.35	0.44	0.59	3.38	12.46	15.82	20.91	3.69	4.69	6.19	1.27	1.68	1.32
112	14.13	0.55	68.04	23.04	0.10	0.30	0.26	25.92	961.36	325.54	147.35	46.78	55.15	37.09	12.56	0.18	0.55	0.47	2.95	6.52	20.55	17.43	2.21	6.96	5.90	3.15	2.67	0.85

Appendix 3 continued

No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
88	20.49	0.92	51.47	8.99	0.22	0.40	0.29	22.25	1054.45	184.17	94.92	50.77	70.93	47.39	8.28	0.23	0.44	0.31	5.73	11.11	20.77	14.87	1.94	3.63	2.60	1.87	1.34	0.72
35	41.61	1.23	39.89	13.57	0.20	0.73	0.46	33.84	1660.03	564.87	209.73	56.94	90.56	49.05	16.69	0.16	0.59	0.37	2.94	7.92	29.16	18.33	2.69	9.92	6.24	3.68	2.32	0.63
153	7.35	0.24	150.51	36.30	0.09	0.14	0.16	30.37	1106.55	266.91	83.21	54.28	45.66	36.44	8.79	0.36	0.56	0.67	4.15	13.30	20.39	24.23	3.21	4.92	5.85	1.53	1.82	1.19
83	29.35	1.07	52.19	5.93	0.24	0.47	0.43	27.38	1531.77	174.17	121.30	62.23	68.18	55.94	6.36	0.23	0.44	0.40	8.79	12.63	24.61	22.47	1.44	2.80	2.55	1.95	1.78	0.91
8	12.40	0.64	87.61	18.25	0.14	0.38	0.27	19.28	1086.14	226.22	91.62	32.65	46.39	56.34	11.73	0.21	0.59	0.42	4.80	11.85	33.26	23.41	2.47	6.93	4.88	2.81	1.98	0.70
20	12.88	0.77	64.90	17.77	0.17	0.41	1.36	16.63	835.62	228.83	75.58	31.18	9.48	50.25	13.76	0.22	0.53	1.75	3.65	11.06	26.80	88.13	3.03	7.34	24.13	2.42	7.97	3.29
4	16.12	0.59	142.91	14.62	0.09	0.28	0.23	27.17	2303.81	235.72	173.04	57.60	70.18	84.80	8.68	0.16	0.47	0.39	9.77	13.31	40.00	32.83	1.36	4.09	3.36	3.00	2.47	0.82
167	25.43	0.91	71.13	11.87	0.14	0.49	1.85	27.91	1808.65	301.86	186.25	51.53	13.71	64.81	10.82	0.15	0.54	2.04	5.99	9.71	35.10	131.92	1.62	5.86	22.02	3.61	13.58	3.76
71	13.27	0.68	107.79	8.52	0.18	0.36	0.24	19.49	1429.86	112.97	74.77	37.24	54.52	73.36	5.80	0.26	0.52	0.36	12.66	19.12	38.39	26.23	1.51	3.03	2.07	2.01	1.37	0.68
59	21.29	1.09	37.12	9.87	0.15	0.52	1.35	19.55	790.39	210.15	139.86	40.59	15.83	40.43	10.75	0.14	0.48	1.24	3.76	5.65	19.47	49.95	1.50	5.18	13.28	3.45	8.84	2.56
3	12.54	0.67	126.05	20.66	0.11	0.36	0.29	18.76	1580.77	259.16	112.37	34.76	42.77	84.27	13.81	0.17	0.54	0.44	6.10	14.07	45.47	36.96	2.31	7.46	6.06	3.23	2.63	0.81
57	22.01	1.09	71.86	9.28	0.18	0.50	0.46	20.13	1581.48	204.35	123.15	44.23	48.20	78.57	10.15	0.16	0.46	0.42	7.74	12.84	35.76	32.81	1.66	4.62	4.24	2.78	2.56	0.92
24	13.02	0.73	89.86	14.07	0.18	0.36	0.72	17.76	1169.79	183.18	72.04	36.49	17.97	65.86	10.31	0.25	0.49	0.99	6.39	16.24	32.06	65.09	2.54	5.02	10.19	1.97	4.01	2.03
11	18.66	0.66	84.43	22.04	0.21	0.35	0.22	28.37	1575.38	411.33	88.64	52.57	84.97	55.54	14.50	0.32	0.54	0.33	3.83	17.77	29.97	18.54	4.64	7.82	4.84	1.69	1.04	0.62
15	14.29	0.67	80.49	14.95	0.18	0.42	1.83	21.42	1150.47	213.65	79.89	34.27	7.82	53.72	9.98	0.27	0.62	2.74	5.38	14.40	33.57	147.04	2.67	6.23	27.31	2.33	10.21	4.38
87	20.49	1.05	87.63	12.71	0.27	0.38	0.19	19.59	1795.59	260.34	76.89	54.30	109.19	91.65	13.29	0.25	0.36	0.18	6.90	23.35	33.07	16.44	3.39	4.79	2.38	1.42	0.70	0.50
21	15.02	0.76	65.96	15.08	0.16	0.42	1.56	19.83	990.93	226.49	93.63	35.84	9.64	49.97	11.42	0.21	0.55	2.06	4.38	10.58	27.65	102.84	2.42	6.32	23.51	2.61	9.72	3.72
92	17.57	0.65	78.79	21.07	0.11	0.26	0.32	27.02	1384.15	370.16	165.01	66.51	54.79	51.23	13.70	0.16	0.41	0.49	3.74	8.39	20.81	25.26	2.24	5.57	6.76	2.48	3.01	1.21
33	16.05	0.74	54.43	16.31	0.13	0.49	0.21	21.62	873.54	261.73	121.57	32.46	78.24	40.41	12.11	0.18	0.67	0.28	3.34	7.19	26.91	11.16	2.15	8.06	3.35	3.75	1.55	0.41
156	15.94	0.70	73.86	10.80	0.11	0.28	0.29	22.72	1177.02	172.10	150.71	57.40	54.17	51.80	7.57	0.15	0.40	0.42	6.84	7.81	20.50	21.73	1.14	3.00	3.18	2.63	2.78	1.06
53	20.48	0.83	61.32	13.16	0.16	0.45	0.26	24.59	1256.06	269.59	129.00	45.28	79.12	51.07	10.96	0.19	0.54	0.31	4.66	9.74	27.74	15.87	2.09	5.95	3.41	2.85	1.63	0.57
158	8.61	0.47	111.74	16.57	0.10	0.23	0.24	18.46	962.16	142.69	82.09	37.04	35.52	52.13	7.73	0.22	0.50	0.52	6.74	11.72	25.98	27.09	1.74	3.85	4.02	2.22	2.31	1.04
77	16.31	1.02	61.21	11.81	0.21	0.52	0.63	16.03	998.11	192.63	76.74	31.23	25.93	62.28	12.02	0.21	0.51	0.62	5.18	13.01	31.96	38.50	2.51	6.17	7.43	2.46	2.96	1.20
93	13.37	0.79	82.36	12.21	0.21	0.54	2.30	16.98	1101.07	163.22	62.79	24.66	5.82	64.84	9.61	0.27	0.69	2.92	6.75	17.54	44.64	189.22	2.60	6.62	28.05	2.55	10.79	4.24
14	14.57	0.85	97.30	9.71	0.10	0.24	0.27	17.09	1417.64	141.42	148.86	60.78	54.45	82.97	8.28	0.11	0.28	0.31	10.02	9.52	23.32	26.03	0.95	2.33	2.60	2.45	2.73	1.12
116	10.01	0.61	86.56	19.40	0.12	0.25	0.25	16.33	866.71	194.29	84.04	39.82	39.59	53.09	11.90	0.19	0.41	0.41	4.46	10.31	21.76	21.89	2.31	4.88	4.91	2.11	2.12	1.01
46	25.81	1.15	111.13	11.80	0.17	0.54	0.17	22.35	2867.81	304.51	155.77	47.48	156.28	128.33	13.63	0.14	0.47	0.14	9.42	18.41	60.40	18.35	1.95	6.41	1.95	3.28	1.00	0.30

Appendix 3 continued

No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
61	12.28	0.85	74.82	22.18	0.16	0.42	0.16	14.39	918.82	272.40	75.21	29.29	78.35	63.86	18.93	0.19	0.49	0.18	3.37	12.22	31.36	11.73	3.62	9.30	3.48	2.57	0.96	0.37
54	16.37	0.68	68.86	14.87	0.13	0.34	0.40	24.08	1126.87	243.38	126.94	47.49	40.82	46.79	10.11	0.19	0.51	0.59	4.63	8.88	23.73	27.60	1.92	5.12	5.96	2.67	3.11	1.16
120	13.57	0.68	107.53	13.54	0.16	0.32	0.28	20.04	1458.62	183.67	86.28	42.94	48.41	72.78	9.16	0.23	0.47	0.41	7.94	16.91	33.97	30.13	2.13	4.28	3.79	2.01	1.78	0.89
42	12.11	0.83	57.94	13.78	0.11	0.40	0.28	14.51	701.86	166.97	111.11	30.27	42.61	48.36	11.51	0.13	0.48	0.34	4.20	6.32	23.19	16.47	1.50	5.52	3.92	3.67	2.61	0.71
121	19.54	0.62	107.50	15.99	0.16	0.26	0.17	31.36	2100.72	312.45	121.46	74.22	114.89	66.98	9.96	0.26	0.42	0.27	6.72	17.30	28.30	18.28	2.57	4.21	2.72	1.64	1.06	0.65
122	12.72	0.57	107.46	18.74	0.17	0.22	0.15	22.24	1366.96	238.41	76.99	57.36	82.31	61.47	10.72	0.29	0.39	0.27	5.73	17.76	23.83	16.61	3.10	4.16	2.90	1.34	0.94	0.70
37	18.97	0.72	69.83	14.75	0.16	0.24	0.59	26.40	1324.88	279.91	115.83	78.16	32.28	50.19	10.60	0.23	0.34	0.82	4.73	11.44	16.95	41.04	2.42	3.58	8.67	1.48	3.59	2.42
32	13.03	0.64	74.90	16.83	0.14	0.37	0.29	20.48	976.10	219.35	91.14	35.19	45.33	47.65	10.71	0.22	0.58	0.45	4.45	10.71	27.74	21.53	2.41	6.23	4.84	2.59	2.01	0.78
10	14.97	0.78	97.53	17.51	0.18	0.43	0.21	19.10	1459.88	262.14	83.94	34.84	72.58	76.43	13.72	0.23	0.55	0.26	5.57	17.39	41.90	20.12	3.12	7.52	3.61	2.41	1.16	0.48
129	8.63	0.22	317.22	48.70	0.07	0.09	0.07	39.14	2736.33	420.05	122.49	93.86	116.52	69.91	10.73	0.32	0.42	0.34	6.51	22.34	29.15	23.48	3.43	4.48	3.61	1.31	1.05	0.81
28	22.36	0.70	139.85	18.97	0.10	0.26	0.44	32.17	3127.23	424.20	217.95	86.55	50.93	97.22	13.19	0.15	0.37	0.63	7.37	14.35	36.13	61.41	1.95	4.90	8.33	2.52	4.28	1.70
95	13.98	0.55	148.15	12.97	0.07	0.20	0.32	25.64	2070.67	181.35	202.92	70.03	43.72	80.76	7.07	0.13	0.37	0.59	11.42	10.20	29.57	47.36	0.89	2.59	4.15	2.90	4.64	1.60
75	14.96	0.85	78.63	29.28	0.16	0.35	1.17	17.60	1176.37	438.07	94.89	43.01	12.82	66.85	24.89	0.19	0.41	1.37	2.69	12.40	27.35	91.73	4.62	10.19	34.16	2.21	7.40	3.35
45	12.07	0.90	65.07	11.54	0.19	0.43	0.18	13.39	785.47	139.34	62.91	28.17	68.65	58.68	10.41	0.21	0.48	0.20	5.64	12.49	27.88	11.44	2.21	4.95	2.03	2.23	0.92	0.41
51	12.55	0.87	48.86	10.36	0.13	0.45	0.40	14.40	612.99	129.95	94.92	27.68	31.32	42.57	9.02	0.15	0.52	0.46	4.72	6.46	22.14	19.57	1.37	4.69	4.15	3.43	3.03	0.88
152	9.37	0.23	179.51	41.06	0.06	0.11	0.08	41.01	1682.07	384.78	167.99	87.01	113.32	41.02	9.38	0.24	0.47	0.36	4.37	10.01	19.33	14.84	2.29	4.42	3.40	1.93	1.48	0.77
2	10.96	0.79	120.38	11.44	0.10	0.38	0.24	13.90	1318.96	125.33	104.74	29.15	46.02	94.91	9.02	0.13	0.48	0.30	10.52	12.59	45.24	28.66	1.20	4.30	2.72	3.59	2.28	0.63
17	16.37	0.94	67.30	18.95	0.22	0.49	0.25	17.49	1101.36	310.19	74.26	33.73	65.34	62.98	17.74	0.24	0.52	0.27	3.55	14.83	32.65	16.85	4.18	9.20	4.75	2.20	1.14	0.52
18	12.11	0.98	68.18	19.59	0.25	0.46	0.48	12.34	825.43	237.15	49.12	26.20	25.26	66.89	19.22	0.25	0.47	0.49	3.48	16.80	31.50	32.68	4.83	9.05	9.39	1.87	1.94	1.04
5	18.00	0.99	52.66	13.50	0.13	0.52	0.19	18.19	948.00	243.04	139.28	34.54	94.82	52.12	13.36	0.13	0.53	0.19	3.90	6.81	27.44	10.00	1.75	7.04	2.56	4.03	1.47	0.36
85	13.34	0.59	110.13	19.78	0.17	0.22	0.09	22.73	1468.63	263.79	78.45	60.21	145.23	64.60	11.60	0.29	0.38	0.16	5.57	18.72	24.39	10.11	3.36	4.38	1.82	1.30	0.54	0.41
126	13.67	0.32	200.78	21.47	0.06	0.14	0.70	42.73	2744.31	293.45	235.57	98.65	19.49	64.22	6.87	0.18	0.43	2.19	9.35	11.65	27.82	140.80	1.25	2.97	15.06	2.39	12.09	5.06
159	8.55	0.52	96.85	16.98	0.13	0.23	0.28	16.48	827.98	145.15	63.92	36.48	30.54	50.25	8.81	0.26	0.45	0.54	5.70	12.95	22.70	27.12	2.27	3.98	4.75	1.75	2.09	1.19
47	8.92	0.23	273.32	34.93	0.04	0.10	0.12	39.62	2438.15	311.59	201.26	88.66	77.16	61.53	7.86	0.20	0.45	0.51	7.82	12.11	27.50	31.60	1.55	3.51	4.04	2.27	2.61	1.15
44	21.08	0.90	91.04	7.80	0.10	0.43	0.16	23.31	1919.41	164.43	210.95	49.43	134.80	82.34	7.05	0.11	0.47	0.17	11.67	9.10	38.83	14.24	0.78	3.33	1.22	4.27	1.56	0.37
49	15.38	0.39	128.73	27.09	0.07	0.11	0.11	39.40	1980.07	416.64	230.98	139.67	134.89	50.25	10.57	0.17	0.28	0.29	4.75	8.57	14.18	14.68	1.80	2.98	3.09	1.65	1.71	1.04
155	21.27	1.27	64.27	12.49	0.15	0.54	0.58	16.74	1366.61	265.50	141.25	39.25	36.68	81.63	15.86	0.12	0.43	0.46	5.15	9.68	34.82	37.26	1.88	6.76	7.24	3.60	3.85	1.07

Appendix 3 continued

No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
70	10.88	0.76	124.53	17.29	0.17	0.21	0.26	14.23	1354.41	188.03	64.12	51.32	42.09	95.15	13.21	0.22	0.28	0.34	7.20	21.12	26.39	32.18	2.93	3.66	4.47	1.25	1.52	1.22
109	4.03	0.21	166.01	42.50	0.04	0.10	0.11	19.05	668.90	171.26	112.24	41.19	35.69	35.11	8.99	0.17	0.46	0.53	3.91	5.96	16.24	18.74	1.53	4.16	4.80	2.72	3.15	1.15
43	15.30	0.96	44.28	11.01	0.10	0.48	0.25	16.01	677.68	168.43	146.93	31.61	61.85	42.34	10.52	0.11	0.51	0.26	4.02	4.61	21.44	10.96	1.15	5.33	2.72	4.65	2.38	0.51
119	23.38	0.92	70.10	19.90	0.13	0.69	0.36	25.33	1639.16	465.24	173.56	34.05	64.55	64.71	18.37	0.15	0.74	0.39	3.52	9.44	48.14	25.39	2.68	13.66	7.21	5.10	2.69	0.53
1	11.53	0.80	97.24	11.26	0.12	0.30	0.16	14.34	1121.43	129.82	98.94	38.48	72.56	78.18	9.05	0.14	0.37	0.20	8.64	11.33	29.15	15.46	1.31	3.37	1.79	2.57	1.36	0.53
69	14.31	1.22	67.50	13.16	0.13	0.43	0.29	11.73	965.80	188.30	114.11	32.97	49.57	82.36	16.06	0.10	0.36	0.24	5.13	8.46	29.29	19.48	1.65	5.71	3.80	3.46	2.30	0.67
108	5.36	0.27	105.86	29.84	0.04	0.13	0.05	20.09	567.08	159.85	121.13	41.20	103.94	28.22	7.96	0.17	0.49	0.19	3.55	4.68	13.76	5.46	1.32	3.88	1.54	2.94	1.17	0.40
125	8.72	0.39	198.23	18.95	0.08	0.17	0.11	22.48	1728.65	165.21	108.06	51.98	80.73	76.91	7.35	0.21	0.43	0.28	10.46	16.00	33.25	21.41	1.53	3.18	2.05	2.08	1.34	0.64
80	12.87	1.02	71.83	17.92	0.13	0.45	0.34	12.67	924.61	230.66	97.52	28.39	38.14	72.99	18.21	0.13	0.45	0.33	4.01	9.48	32.57	24.24	2.37	8.12	6.05	3.44	2.56	0.74
60	14.61	1.71	49.71	13.24	0.24	0.67	0.86	8.53	726.21	193.43	62.07	21.78	17.05	85.15	22.68	0.14	0.39	0.50	3.75	11.70	33.34	42.59	3.12	8.88	11.34	2.85	3.64	1.28
124	6.35	0.35	231.17	22.82	0.07	0.15	0.13	18.10	1468.80	145.01	86.00	41.36	50.22	81.16	8.01	0.21	0.44	0.36	10.13	17.08	35.51	29.25	1.69	3.51	2.89	2.08	1.71	0.82
34	4.69	0.30	303.95	28.22	0.07	0.15	0.05	15.77	1425.20	132.31	71.42	30.28	88.60	90.40	8.39	0.22	0.52	0.18	10.77	19.95	47.06	16.09	1.85	4.37	1.49	2.36	0.81	0.34
157	6.50	0.34	209.13	26.87	0.05	0.12	0.13	19.32	1359.89	174.71	130.27	54.00	51.90	70.39	9.04	0.15	0.36	0.37	7.78	10.44	25.18	26.20	1.34	3.24	3.37	2.41	2.51	1.04
123	5.82	0.41	302.84	29.72	0.05	0.17	0.07	14.33	1761.46	172.84	118.97	34.87	85.80	122.88	12.06	0.12	0.41	0.17	10.19	14.81	50.51	20.53	1.45	4.96	2.01	3.41	1.39	0.41
32	2.27	0.10	731.47	131.34	0.02	0.06	0.03	21.77	1663.77	298.75	95.67	39.71	82.71	76.43	13.72	0.23	0.55	0.26	5.57	17.39	41.90	20.12	3.12	7.52	3.61	2.41	1.16	0.48

Appendix 4 Ratio of the nutrients in leaf tissue (GS-39) for the high-yielding population in irrigated wheat

No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
45	15.34	1.00	108.84	12.77	0.20	0.37	0.38	15.36	1669.29	195.91	76.45	41.96	40.19	108.64	12.75	0.20	0.37	0.38	8.52	21.83	39.78	41.54	2.56	4.67	4.87	1.82	1.90	1.04
74	16.66	0.80	135.71	11.57	0.18	0.62	0.35	20.76	2261.18	192.81	94.38	26.98	**47.36**	108.95	9.29	0.22	0.77	0.44	11.73	23.96	83.80	47.75	2.04	7.15	4.07	3.50	1.99	0.57
17	11.69	0.82	145.32	14.71	0.13	0.32	0.34	14.32	1698.84	172.00	87.38	36.41	34.48	118.61	12.01	0.16	0.39	0.42	9.88	19.44	46.66	49.27	1.97	4.72	4.99	2.40	2.53	1.06
44	12.65	0.77	152.93	26.77	0.13	1.53	0.32	16.51	1934.66	338.63	99.80	8.25	39.66	117.15	20.50	0.17	2.00	0.42	5.71	19.38	234.41	48.78	3.39	41.03	8.54	12.09	2.52	0.21
23	14.34	0.98	118.92	8.22	0.18	0.37	0.39	14.70	1705.58	117.94	78.42	38.78	37.05	116.00	8.02	0.19	0.38	0.40	14.46	21.75	43.99	46.04	1.50	3.04	3.18	2.02	2.12	1.05
16	12.75	0.93	118.22	11.83	0.15	0.38	0.36	13.66	1506.67	150.73	87.69	33.23	35.37	110.31	11.04	0.16	0.41	0.39	10.00	17.18	45.34	42.60	1.72	4.54	4.26	2.64	2.48	0.94
46	21.52	0.90	109.07	19.94	0.26	0.33	0.30	24.00	2346.70	429.08	82.02	64.49	71.28	97.79	17.88	0.29	0.37	0.34	5.47	28.61	36.39	32.92	5.23	6.65	6.02	1.27	1.15	0.90
13	10.34	1.17	123.92	10.33	0.21	0.37	0.60	8.82	1281.59	106.80	49.67	27.97	17.35	145.23	12.10	0.18	0.32	0.51	12.00	25.80	45.82	73.89	2.15	3.82	6.16	1.78	2.86	1.61
8	23.13	1.02	112.71	12.40	0.16	0.33	0.21	22.77	2607.13	286.90	140.63	69.41	108.77	114.50	12.60	0.16	0.33	0.21	9.09	18.54	37.56	23.97	2.04	4.13	2.64	2.03	1.29	0.64
69	12.18	0.97	143.94	14.52	0.23	0.38	0.35	12.52	1753.91	176.96	53.10	32.37	35.01	140.10	14.14	0.24	0.39	0.36	9.91	33.03	54.18	50.10	3.33	5.47	5.05	1.64	1.52	0.92
2	11.40	0.75	141.99	15.91	0.14	0.27	0.25	15.18	1619.23	181.39	82.85	42.82	44.76	106.67	11.95	0.18	0.35	0.34	8.93	19.54	37.82	36.17	2.19	4.24	4.05	1.93	1.85	0.96
26	35.56	1.18	113.07	15.54	0.19	0.34	0.30	30.02	4020.93	552.74	183.48	105.93	118.69	133.94	18.41	0.16	0.28	0.25	7.27	21.91	37.96	33.88	3.01	5.22	4.66	1.73	1.55	0.89
65	12.23	0.77	180.53	18.63	0.12	0.31	0.19	15.83	2207.33	227.84	99.91	39.46	63.67	139.42	14.39	0.16	0.40	0.25	9.69	22.09	55.94	34.67	2.28	5.77	3.58	2.53	1.57	0.62
70	18.83	0.89	143.09	22.68	0.27	0.47	0.37	21.22	2694.23	426.99	69.97	40.30	50.77	126.94	20.12	0.30	0.53	0.42	6.31	38.51	66.86	53.07	6.10	10.60	8.41	1.74	1.38	0.79
76	10.99	1.46	119.98	7.84	0.20	0.45	0.40	7.54	1318.91	86.13	55.19	24.48	27.73	174.81	11.42	0.14	0.31	0.27	15.31	23.90	53.89	47.57	1.56	3.52	3.11	2.25	1.99	0.88
61	8.21	1.02	94.85	10.59	0.22	0.49	0.49	8.03	779.19	87.00	37.08	16.67	16.67	97.00	10.83	0.22	0.48	0.48	8.96	21.01	46.74	46.74	2.35	5.22	5.22	2.22	2.22	1.00
37	13.00	0.95	120.79	15.88	0.22	0.37	0.76	13.69	1569.84	206.38	59.42	34.71	17.14	114.67	15.07	0.23	0.39	0.80	7.61	26.42	45.23	91.57	3.47	5.95	12.04	1.71	3.47	2.02
20	11.92	1.00	107.80	8.80	0.19	0.35	0.28	11.91	1284.95	104.84	61.86	34.33	42.52	107.85	8.80	0.19	0.35	0.28	12.26	20.77	37.43	30.22	1.69	3.05	2.47	1.80	1.45	0.81
58	7.10	0.44	207.93	21.31	0.09	0.22	0.25	16.12	1476.28	151.28	75.04	32.83	28.76	91.57	9.38	0.21	0.49	0.56	9.76	19.67	44.97	51.33	2.02	4.61	5.26	2.29	2.61	1.14
66	6.08	0.67	201.05	19.93	0.11	0.22	0.21	9.12	1223.34	121.28	55.46	27.53	29.54	134.07	13.29	0.16	0.33	0.31	10.09	22.06	44.44	41.41	2.19	4.41	4.11	2.01	1.88	0.93
55	6.69	0.53	182.11	18.11	0.12	0.24	0.22	12.53	1218.07	121.16	56.77	27.31	30.67	97.23	9.67	0.22	0.46	0.41	10.05	21.46	44.60	39.71	2.13	4.44	3.95	2.08	1.85	0.89
15	8.26	0.69	141.70	12.24	0.13	0.25	0.32	11.99	1170.00	101.11	63.79	33.60	25.67	97.55	8.43	0.19	0.36	0.47	11.57	18.34	34.82	45.57	1.59	3.01	3.94	1.90	2.48	1.31
72	11.08	1.26	104.09	11.24	0.36	0.62	0.55	8.82	1153.64	124.62	30.38	17.82	20.10	130.86	14.14	0.29	0.49	0.44	9.26	37.97	64.75	57.40	4.10	6.99	6.20	1.71	1.51	0.89
77	11.02	0.53	125.22	16.02	0.21	0.33	0.22	20.85	1380.14	176.55	51.57	33.22	50.73	66.21	8.47	0.40	0.63	0.41	7.82	26.76	41.55	27.21	3.42	5.32	3.48	1.55	1.02	0.65
60	22.74	0.61	95.42	19.06	0.17	0.26	0.31	37.13	2169.90	433.37	133.95	88.36	**73.30**	58.44	11.67	0.28	0.42	0.51	5.01	16.20	24.56	29.60	3.24	4.90	5.91	1.52	1.83	1.21
56	12.33	0.65	153.62	16.58	0.14	0.26	0.24	18.92	1894.40	204.49	88.02	46.81	51.27	100.14	10.81	0.21	0.40	0.37	9.26	21.52	40.47	36.95	2.32	4.37	3.99	1.88	1.72	0.91

Appendix 4 continued

No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
9	14.23	0.95	103.69	8.83	0.19	0.37	0.42	14.99	1475.37	125.58	75.39	38.66	34.11	98.45	8.38	0.20	0.39	0.44	11.75	19.57	38.17	43.25	1.67	3.25	3.68	1.95	2.21	1.13
12	14.14	1.20	115.08	10.18	0.24	0.45	0.31	11.77	1627.75	143.98	60.04	31.74	46.24	138.24	12.23	0.20	0.37	0.25	11.31	27.11	51.28	35.20	2.40	4.54	3.11	1.89	1.30	0.69
34	10.16	0.91	115.71	12.92	0.19	0.39	0.28	11.12	1175.19	131.17	53.61	26.21	36.39	105.64	11.79	0.21	0.42	0.31	8.96	21.92	44.83	32.29	2.45	5.00	3.60	2.05	1.47	0.72
10	5.06	0.96	118.13	8.53	0.25	0.45	2.56	5.24	597.16	43.12	20.50	11.29	1.98	113.98	8.23	0.26	0.46	2.65	13.85	29.13	52.90	301.87	2.10	3.82	21.80	1.82	10.36	5.71
7	15.89	1.05	128.09	11.03	0.16	0.37	1.06	15.17	2035.67	175.32	96.77	43.31	15.01	134.23	11.56	0.16	0.35	1.01	11.61	21.04	47.01	135.63	1.81	4.05	11.68	2.23	6.45	2.89
50	9.05	0.73	164.09	19.30	0.14	0.39	0.33	12.39	1484.79	174.65	64.42	23.17	27.12	119.81	14.09	0.19	0.53	0.46	8.50	23.05	64.09	54.76	2.71	7.54	6.44	2.78	2.38	0.85
52	6.13	0.79	100.38	26.28	0.35	0.43	0.28	7.77	615.68	161.21	17.31	14.31	21.84	79.27	20.76	0.45	0.54	0.36	3.82	35.56	43.04	28.20	9.31	11.27	7.38	1.21	0.79	0.66
73	9.67	0.92	97.69	10.73	0.11	0.58	0.18	10.53	944.60	103.79	85.85	16.69	53.81	89.67	9.85	0.12	0.63	0.20	9.10	11.00	56.60	17.55	1.21	6.22	1.93	5.14	1.60	0.31
27	11.99	0.50	108.66	15.95	0.14	0.17	0.28	24.21	1303.24	191.32	83.10	69.94	**43.32**	53.84	7.90	0.29	0.35	0.56	6.81	15.68	18.63	30.08	2.30	2.74	4.42	1.19	1.92	1.61
36	10.85	0.94	97.21	8.86	0.13	0.35	0.70	11.49	1054.71	96.08	81.31	30.85	15.60	91.76	8.36	0.14	0.37	0.74	10.98	12.97	34.19	67.62	1.18	3.11	6.16	2.64	5.21	1.98
1	17.00	0.88	98.74	17.04	0.13	0.39	0.21	19.24	1678.98	289.73	127.68	43.96	81.05	87.29	15.06	0.15	0.44	0.24	5.79	13.15	38.19	20.72	2.27	6.59	3.57	2.90	1.58	0.54
30	14.57	0.94	98.42	7.85	0.20	0.32	0.17	15.57	1433.74	114.42	71.90	45.21	87.19	92.08	7.35	0.22	0.34	0.18	12.53	19.94	31.71	16.44	1.59	2.53	1.31	1.59	0.82	0.52
24	11.97	1.00	96.24	15.02	0.31	0.48	0.37	11.96	1152.04	179.75	38.32	24.83	32.44	96.33	15.03	0.31	0.48	0.37	6.41	30.07	46.40	35.52	4.69	7.24	5.54	1.54	1.18	0.77
63	9.71	0.57	148.43	23.21	0.12	0.36	0.30	17.01	1441.67	225.41	83.49	26.78	32.69	84.77	13.25	0.20	0.63	0.52	6.40	17.27	53.83	44.10	2.70	8.42	6.90	3.12	2.55	0.82
21	30.63	0.86	95.81	9.22	0.16	0.32	0.27	35.50	2934.58	282.30	192.40	94.34	111.82	82.67	7.95	0.18	0.38	0.32	10.40	15.25	31.11	26.24	1.47	2.99	2.52	2.04	1.72	0.84
49	7.33	0.53	127.86	21.71	0.10	0.20	0.17	13.92	937.11	159.14	73.93	36.41	42.11	67.34	11.44	0.19	0.38	0.33	5.89	12.68	25.74	22.26	2.15	4.37	3.78	2.03	1.76	0.86
22	10.10	0.67	126.09	13.44	0.16	0.27	0.34	15.15	1273.66	135.76	63.83	37.55	30.02	84.06	8.96	0.24	0.40	0.50	9.38	19.95	33.92	42.42	2.13	3.62	4.52	1.70	2.13	1.25
25	9.28	0.51	121.21	19.81	0.14	0.19	0.20	18.11	1124.97	183.88	68.37	49.74	46.88	62.13	10.16	0.26	0.36	0.39	6.12	16.45	22.62	24.00	2.69	3.70	3.92	1.37	1.46	1.06
29	8.72	0.69	139.41	19.74	0.19	0.23	0.12	12.60	1215.10	172.07	46.84	38.36	74.70	96.46	13.66	0.27	0.33	0.17	7.06	25.94	31.68	16.27	3.67	4.49	2.30	1.22	0.63	0.51
51	30.97	0.88	85.21	21.79	0.34	0.49	0.30	35.02	2639.12	674.76	91.03	63.43	101.96	75.36	19.27	0.38	0.55	0.34	3.91	28.99	41.60	25.88	7.41	10.64	6.62	1.44	0.89	0.62
179	14.37	1.18	96.38	10.89	0.26	0.37	0.23	12.14	1385.15	156.52	54.53	38.77	62.89	114.14	12.90	0.22	0.31	0.19	8.85	25.40	35.73	22.02	2.87	4.04	2.49	1.41	0.87	0.62
38	8.11	0.67	135.59	16.95	0.23	0.25	0.57	12.10	1100.01	137.50	35.75	33.00	14.13	90.91	11.36	0.34	0.37	0.86	8.00	30.77	33.33	77.85	3.85	4.17	9.73	1.08	2.53	2.34
62	21.01	0.81	117.06	17.22	0.15	0.38	0.56	25.88	2459.21	361.73	137.87	55.10	37.28	95.01	13.98	0.19	0.47	0.69	6.80	17.84	44.63	65.97	2.62	6.57	9.70	2.50	3.70	1.48
82	11.62	0.86	115.89	20.44	0.17	0.39	0.21	13.47	1346.79	237.58	68.36	29.61	55.38	99.98	17.64	0.20	0.45	0.24	5.67	19.70	45.49	24.32	3.48	8.02	4.29	2.31	1.23	0.53
107	16.18	1.07	100.01	10.20	0.11	0.40	0.20	15.14	1617.91	165.09	148.85	40.35	81.38	106.90	10.91	0.10	0.38	0.19	9.80	10.87	40.10	19.88	1.11	4.09	2.03	3.69	1.83	0.50
39	15.22	0.77	99.88	16.51	0.41	0.35	0.81	19.84	1519.99	251.32	37.35	43.74	18.76	76.60	12.67	0.53	0.45	1.06	6.05	40.69	34.75	81.04	6.73	5.75	13.40	0.85	1.99	2.33
102	12.67	0.74	103.14	12.52	0.25	0.28	0.37	17.12	1307.09	158.67	50.60	45.88	34.70	76.33	9.27	0.34	0.37	0.49	8.24	25.83	28.49	37.67	3.14	3.46	4.57	1.10	1.46	1.32

Appendix 4 continued

No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
134	12.49	1.05	81.39	14.91	0.21	0.36	0.25	11.89	1016.22	186.16	58.72	35.07	49.72	85.43	15.65	0.20	0.34	0.24	5.46	17.30	28.98	20.44	3.17	5.31	3.74	1.67	1.18	0.71
118	12.66	0.84	135.17	11.51	0.19	0.27	0.17	15.09	1710.71	145.69	66.52	46.42	73.08	113.40	9.66	0.23	0.32	0.21	11.74	25.72	36.85	23.41	2.19	3.14	1.99	1.43	0.91	0.64
28	15.96	0.73	106.23	16.56	0.22	0.33	1.51	21.83	1695.39	264.24	73.28	48.16	10.56	77.65	12.10	0.30	0.45	2.07	6.42	23.14	35.21	160.59	3.61	5.49	25.03	1.52	6.94	4.56
140	11.05	1.13	79.18	10.24	0.17	0.41	0.57	9.74	874.68	113.09	65.94	27.02	19.48	89.77	11.61	0.15	0.36	0.50	7.73	13.26	32.37	44.90	1.72	4.18	5.81	2.44	3.39	1.39
31	17.47	0.97	82.66	15.26	0.15	0.45	0.89	18.08	1444.13	266.53	114.29	38.44	19.72	79.88	14.74	0.16	0.47	0.92	5.42	12.64	37.57	73.24	2.33	6.93	13.52	2.97	5.80	1.95
155	16.09	0.81	88.83	9.39	0.24	0.36	0.45	19.80	1428.91	151.02	68.17	44.50	35.53	72.18	7.63	0.29	0.44	0.56	9.46	20.96	32.11	40.22	2.22	3.39	4.25	1.53	1.92	1.25
110	11.12	0.90	114.85	12.75	0.18	0.38	0.35	12.32	1277.33	141.78	62.67	29.28	31.48	103.71	11.51	0.20	0.42	0.39	9.01	20.38	43.63	40.58	2.26	4.84	4.50	2.14	1.99	0.93
57	11.97	0.72	90.82	21.09	0.09	0.29	0.23	16.54	1087.36	252.54	126.42	40.78	52.99	65.75	15.27	0.13	0.41	0.31	4.31	8.60	26.66	20.52	2.00	6.19	4.77	3.10	2.39	0.77
112	14.90	0.81	103.21	18.75	0.11	0.39	0.33	18.46	1537.47	279.32	130.06	38.02	44.99	83.29	15.13	0.14	0.49	0.41	5.50	11.82	40.44	34.18	2.15	7.35	6.21	3.42	2.89	0.85
11	17.06	1.14	80.76	15.79	0.22	0.35	2.27	14.90	1377.79	269.42	76.92	48.47	7.50	92.45	18.08	0.19	0.31	1.99	5.11	17.91	28.42	183.63	3.50	5.56	35.91	1.59	10.25	6.46
128	14.71	0.95	100.88	6.81	0.25	0.42	0.43	15.43	1483.93	100.23	57.94	35.32	33.86	96.20	6.50	0.27	0.44	0.46	14.81	25.61	42.01	43.82	1.73	2.84	2.96	1.64	1.71	1.04
149	18.24	0.86	81.99	13.98	0.22	0.37	0.35	21.31	1495.42	255.05	81.50	49.28	51.57	70.16	11.97	0.26	0.43	0.41	5.86	18.35	30.34	29.00	3.13	5.18	4.95	1.65	1.58	0.96
153	15.97	1.10	83.35	11.33	0.20	0.37	0.49	14.55	1330.74	180.83	80.15	42.64	32.42	91.44	12.43	0.18	0.34	0.45	7.36	16.60	31.21	41.05	2.26	4.24	5.58	1.88	2.47	1.32
139	15.10	1.13	84.48	12.19	0.17	0.37	0.47	13.41	1275.83	184.05	88.46	41.17	32.03	95.13	13.72	0.15	0.33	0.42	6.93	14.42	30.99	39.83	2.08	4.47	5.75	2.15	2.76	1.29
91	10.88	1.32	82.82	12.58	0.18	0.35	0.27	8.23	901.29	136.86	59.53	31.52	40.37	109.55	16.64	0.14	0.26	0.20	6.59	15.14	28.59	22.32	2.30	4.34	3.39	1.89	1.47	0.78
116	29.49	1.07	101.26	9.65	0.24	0.42	0.33	27.65	2985.98	284.59	121.95	69.58	90.44	108.00	10.29	0.23	0.40	0.31	10.49	24.49	42.92	33.02	2.33	4.09	3.15	1.75	1.35	0.77
146	18.01	1.09	90.97	14.43	0.20	0.35	0.53	16.52	1638.08	259.86	89.63	50.79	34.03	99.15	15.73	0.18	0.33	0.49	6.30	18.28	32.25	48.13	2.90	5.12	7.64	1.76	2.63	1.49
178	24.26	1.09	97.14	11.87	0.25	0.32	0.39	22.34	2356.75	287.91	97.07	75.85	62.57	105.48	12.89	0.23	0.29	0.36	8.19	24.28	31.07	37.66	2.97	3.80	4.60	1.28	1.55	1.21
75	10.07	1.10	88.45	6.89	0.20	0.40	0.80	9.16	891.05	69.40	50.96	25.07	12.56	97.28	7.58	0.18	0.37	0.73	12.84	17.49	35.54	70.96	1.36	2.77	5.53	2.03	4.06	2.00
129	16.51	0.76	87.85	20.01	0.38	0.51	0.50	21.63	1450.58	330.38	43.19	32.59	33.23	67.06	15.27	0.50	0.66	0.65	4.39	33.58	44.51	43.65	7.65	10.14	9.94	1.33	1.30	0.98
165	12.90	0.97	75.70	11.43	0.26	0.39	0.52	13.27	976.54	147.41	50.50	33.07	24.58	73.59	11.11	0.26	0.40	0.54	6.62	19.34	29.53	39.72	2.92	4.46	6.00	1.53	2.05	1.35
180	17.06	1.10	83.96	6.40	0.22	0.35	0.18	15.51	1432.77	109.16	78.77	48.59	93.68	92.40	7.04	0.20	0.32	0.17	13.12	18.19	29.49	15.29	1.39	2.25	1.17	1.62	0.84	0.52
64	11.95	0.91	84.25	21.73	0.29	0.41	0.58	13.07	1007.10	259.79	40.77	29.23	20.77	77.03	19.87	0.32	0.45	0.63	3.88	24.70	34.45	48.49	6.37	8.89	12.51	1.39	1.96	1.41
89	10.27	0.65	109.92	25.29	0.11	0.35	0.43	15.87	1129.42	259.82	93.22	29.73	23.98	71.16	16.37	0.17	0.53	0.66	4.35	12.12	37.98	47.11	2.79	8.74	10.84	3.14	3.89	1.24
80	28.68	0.92	87.86	12.50	0.35	0.55	0.43	31.11	2519.74	358.36	80.85	52.09	66.98	81.00	11.52	0.38	0.60	0.46	7.03	31.16	48.37	37.62	4.43	6.88	5.35	1.55	1.21	0.78
47	8.65	0.63	118.45	19.79	0.17	0.31	0.14	13.69	1024.78	171.21	50.39	27.82	59.99	74.84	12.50	0.27	0.49	0.23	5.99	20.34	36.84	17.08	3.40	6.15	2.85	1.81	0.84	0.46
94	11.73	1.25	83.52	6.46	0.23	0.50	1.43	9.39	979.84	75.78	51.44	23.28	8.23	104.39	8.07	0.18	0.40	1.14	12.93	19.05	42.09	119.10	1.47	3.26	9.21	2.21	6.25	2.83

Appendix 4 continued

No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
95	18.67	1.12	94.62	8.74	0.17	0.34	0.30	16.62	1766.34	163.11	112.03	55.08	62.77	106.29	9.82	0.15	0.30	0.26	10.83	15.77	32.07	28.14	1.46	2.96	2.60	2.03	1.78	0.88
114	14.12	1.16	94.07	10.76	0.18	0.32	0.26	12.13	1328.51	151.99	77.26	43.74	54.23	109.50	12.53	0.16	0.28	0.22	8.74	17.19	30.37	24.50	1.97	3.47	2.80	1.77	1.42	0.81
172	42.22	1.27	81.77	8.10	0.22	0.34	0.29	33.12	3452.09	341.88	188.52	122.78	143.60	104.23	10.32	0.18	0.27	0.23	10.10	18.31	28.12	24.04	1.81	2.78	2.38	1.54	1.31	0.86
141	15.98	0.95	91.03	13.95	0.17	0.39	0.91	16.84	1454.35	222.87	91.45	40.64	17.58	86.37	13.24	0.18	0.41	0.96	6.53	15.90	35.78	82.71	2.44	5.48	12.67	2.25	5.20	2.31
167	20.83	1.17	90.95	7.29	0.23	0.44	0.33	17.87	1894.05	151.74	88.67	47.43	62.53	106.02	8.49	0.20	0.38	0.29	12.48	21.36	39.93	30.29	1.71	3.20	2.43	1.87	1.42	0.76
117	17.36	1.25	92.69	10.46	0.19	0.35	0.24	13.87	1608.65	181.50	93.07	49.86	71.42	115.96	13.08	0.15	0.28	0.19	8.86	17.29	32.26	22.52	1.95	3.64	2.54	1.87	1.30	0.70

Appendix 5 Ratio of the nutrients in leaf tissue (GS-39) for the low-yielding population in irrigated wheat

No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
123	12.21	2.24	74.95	8.74	0.26	0.52	0.67	5.46	915.21	106.67	46.59	23.39	18.13	167.61	19.53	0.12	0.23	0.30	8.58	19.64	39.13	50.49	2.29	4.56	5.89	1.99	2.57	1.29
151	16.58	0.75	103.56	14.18	0.20	0.42	1.12	22.06	1716.55	235.02	83.16	39.47	14.79	77.83	10.66	0.27	0.56	1.49	7.30	20.64	43.49	116.10	2.83	5.95	15.90	2.11	5.62	2.67
150	16.31	1.08	78.33	11.37	0.20	0.39	0.88	15.09	1277.90	185.51	83.46	41.95	18.51	84.66	12.29	0.18	0.36	0.82	6.89	15.31	30.46	69.06	2.22	4.42	10.02	1.99	4.51	2.27
93	43.92	1.23	75.94	7.39	0.19	0.39	0.71	35.77	3335.17	324.68	229.33	112.74	61.97	93.23	9.08	0.16	0.32	0.58	10.27	14.54	29.58	53.82	1.42	2.88	5.24	2.03	3.70	1.82
19	15.44	0.71	92.10	14.26	0.33	0.41	0.35	21.82	1422.38	220.28	46.17	37.58	43.85	65.18	10.09	0.47	0.58	0.50	6.46	30.81	37.85	32.44	4.77	5.86	5.02	1.23	1.05	0.86
152	19.90	1.01	87.11	11.74	0.18	0.35	0.57	19.66	1733.76	233.57	110.86	57.42	35.00	88.19	11.88	0.18	0.34	0.56	7.42	15.64	30.19	49.53	2.11	4.07	6.67	1.93	3.17	1.64
138	20.96	1.05	72.94	10.19	0.17	0.41	1.00	20.01	1529.18	213.63	126.47	51.40	20.92	76.40	10.67	0.16	0.39	0.96	7.16	12.09	29.75	73.08	1.69	4.16	10.21	2.46	6.04	2.46
119	14.42	1.66	89.67	6.63	0.16	0.38	0.22	8.69	1292.69	95.53	89.58	37.46	66.13	148.84	11.00	0.10	0.23	0.13	13.53	14.43	34.51	19.55	1.07	2.55	1.44	2.39	1.35	0.57
33	15.16	0.75	96.45	9.70	0.18	0.37	0.37	20.19	1462.18	147.08	84.70	41.41	41.32	72.41	7.28	0.24	0.49	0.49	9.94	17.26	35.31	35.39	1.74	3.55	3.56	2.05	2.05	1.00
32	7.90	0.79	104.07	13.31	0.26	0.39	1.47	10.01	821.71	105.10	30.51	20.28	5.37	82.07	10.50	0.33	0.49	1.86	7.82	26.93	40.52	152.91	3.44	5.18	19.56	1.50	5.68	3.77
181	15.81	1.30	68.27	9.80	0.30	0.36	0.43	12.12	1079.18	154.87	53.26	43.80	36.37	89.04	12.78	0.23	0.28	0.33	6.97	20.26	24.64	29.67	2.91	3.54	4.26	1.22	1.46	1.20
14	26.44	1.06	70.29	8.70	0.20	0.40	1.50	24.84	1858.71	230.11	132.42	66.41	17.60	74.83	9.26	0.19	0.37	1.41	8.08	14.04	27.99	105.61	1.74	3.46	13.07	1.99	7.52	3.77
148	13.48	0.69	112.83	16.16	0.23	0.30	0.48	19.43	1520.59	217.83	59.02	45.20	27.96	78.26	11.21	0.33	0.43	0.69	6.98	25.76	33.64	54.38	3.69	4.82	7.79	1.31	2.11	1.62
175	13.18	0.97	82.35	7.58	0.18	0.37	0.39	13.64	1085.30	99.90	72.40	35.85	34.18	79.58	7.33	0.19	0.38	0.40	10.86	14.99	30.27	31.76	1.38	2.79	2.92	2.02	2.12	1.05
92	10.06	1.36	73.68	12.07	0.20	0.35	1.17	7.41	741.10	121.40	50.19	28.69	8.58	100.06	16.39	0.15	0.26	0.86	6.10	14.77	25.83	86.40	2.42	4.23	14.15	1.75	5.85	3.34
121	23.49	1.49	75.16	7.88	0.27	0.41	0.34	15.74	1765.48	185.21	87.56	57.40	69.76	112.14	11.76	0.18	0.27	0.23	9.53	20.16	30.76	25.31	2.12	3.23	2.65	1.53	1.26	0.82
106	16.17	0.72	99.30	14.17	0.27	0.41	0.21	22.31	1605.57	229.08	59.72	39.28	76.28	71.96	10.27	0.37	0.57	0.29	7.01	26.88	40.88	21.05	3.84	5.83	3.00	1.52	0.78	0.51
48	18.64	1.02	85.74	15.06	0.20	0.52	0.27	18.20	1598.51	280.74	91.43	35.97	68.47	87.85	15.43	0.20	0.51	0.27	5.69	17.48	44.44	23.35	3.07	7.81	4.10	2.54	1.34	0.53
6	29.71	1.18	74.79	4.62	0.26	0.47	0.51	25.15	2222.19	137.24	115.77	63.65	58.02	88.34	5.46	0.22	0.40	0.43	16.19	19.20	34.91	38.30	1.19	2.16	2.37	1.82	2.00	1.10
171	23.81	1.46	66.98	11.65	0.37	0.49	0.35	16.26	1594.53	277.42	64.77	48.64	67.92	98.08	17.06	0.25	0.33	0.24	5.75	24.62	32.78	23.48	4.28	5.70	4.08	1.33	0.95	0.72
113	12.99	0.83	91.12	23.08	0.16	0.38	0.47	15.58	1183.22	299.70	79.72	33.89	27.88	75.95	19.24	0.20	0.46	0.56	3.95	14.84	34.91	42.44	3.76	8.84	10.75	2.35	2.86	1.22
147	28.12	1.13	72.31	10.10	0.21	0.35	1.56	24.85	2033.63	283.96	136.84	79.81	18.01	81.85	11.43	0.18	0.31	1.38	7.16	14.86	25.48	112.89	2.08	3.56	15.76	1.71	7.60	4.43
160	15.69	1.28	76.69	5.82	0.28	0.46	0.72	12.23	1203.00	91.28	57.04	34.46	21.81	98.40	7.47	0.21	0.35	0.56	13.18	21.09	34.91	55.15	1.60	2.65	4.18	1.66	2.61	1.58
120	17.78	1.19	80.78	13.28	0.26	0.35	0.24	14.91	1436.56	236.10	69.65	51.31	72.99	96.35	15.84	0.21	0.29	0.20	6.08	20.62	28.00	19.68	3.39	4.60	3.23	1.36	0.95	0.70
108	24.92	1.09	72.01	12.24	0.18	0.44	1.12	22.84	1794.50	305.13	136.48	56.56	22.28	78.58	13.36	0.17	0.40	1.03	5.88	13.15	31.73	80.56	2.24	5.40	13.70	2.41	6.13	2.54
143	27.40	1.18	68.15	5.93	0.28	0.43	1.11	23.23	1867.27	162.39	99.40	63.93	24.72	80.40	6.99	0.23	0.36	0.94	11.50	18.78	29.21	75.55	1.63	2.54	6.57	1.55	4.02	2.59

Appendix 5 continued

No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
168	10.25	0.98	91.66	12.87	0.14	0.41	0.27	10.44	939.33	131.93	75.72	25.08	38.01	90.01	12.64	0.14	0.42	0.27	7.12	12.40	37.45	24.72	1.74	5.26	3.47	3.02	1.99	0.66
83	18.12	1.14	85.36	10.16	0.22	0.44	0.23	15.88	1547.05	184.14	82.70	41.18	78.02	97.41	11.59	0.19	0.39	0.20	8.40	18.71	37.57	19.83	2.23	4.47	2.36	2.01	1.06	0.53
122	19.14	1.34	75.45	10.78	0.27	0.43	0.34	14.32	1444.20	206.28	71.05	44.90	55.59	100.86	14.41	0.20	0.32	0.26	7.00	20.33	32.16	25.98	2.90	4.59	3.71	1.58	1.28	0.81
43	15.69	1.01	80.04	9.80	0.19	0.43	0.62	15.53	1255.86	153.72	83.30	36.63	25.20	80.84	9.89	0.19	0.42	0.62	8.17	15.08	34.29	49.83	1.85	4.20	6.10	2.27	3.31	1.45
98	14.50	0.72	70.66	16.40	0.13	1.04	0.32	20.26	1024.49	237.73	109.99	13.99	45.67	50.58	11.74	0.18	1.45	0.44	4.31	9.31	73.25	22.43	2.16	17.00	5.20	7.86	2.41	0.31
35	18.31	0.69	105.34	16.54	0.15	0.41	0.45	26.43	1928.84	302.77	122.41	44.16	40.37	72.98	11.46	0.22	0.60	0.65	6.37	15.76	43.68	47.78	2.47	6.86	7.50	2.77	3.03	1.09
90	31.41	1.10	71.17	10.20	0.16	0.36	0.36	28.45	2235.24	320.33	190.47	88.24	86.24	78.55	11.26	0.15	0.32	0.33	6.98	11.74	25.33	25.92	1.68	3.63	3.71	2.16	2.21	1.02
88	13.26	1.10	77.66	6.20	0.21	0.36	1.05	12.03	1030.06	82.30	64.64	37.01	12.69	85.65	6.84	0.19	0.32	0.95	12.52	15.93	27.83	81.20	1.27	2.22	6.49	1.75	5.10	2.92
164	22.94	0.93	82.68	15.41	0.18	0.37	0.90	24.56	1896.71	353.62	124.93	62.00	25.53	77.22	14.40	0.20	0.40	0.96	5.36	15.18	30.59	74.28	2.83	5.70	13.85	2.01	4.89	2.43
84	27.46	0.79	88.86	18.34	0.11	0.38	0.30	34.86	2440.39	503.60	258.52	71.76	92.91	70.01	14.45	0.13	0.49	0.38	4.85	9.44	34.01	26.27	1.95	7.02	5.42	3.60	2.78	0.77
135	23.56	1.09	66.14	13.19	0.22	0.39	0.25	21.66	1558.06	310.77	106.28	60.56	95.18	71.93	14.35	0.20	0.36	0.23	5.01	14.66	25.73	16.37	2.92	5.13	3.26	1.76	1.12	0.64
103	12.82	0.63	116.35	23.28	0.34	0.39	0.41	20.24	1491.04	298.38	37.97	32.82	31.59	73.66	14.74	0.53	0.62	0.64	5.00	39.27	45.43	47.20	7.86	9.09	9.45	1.16	1.20	1.04
126	16.43	1.01	80.92	5.43	0.27	0.42	0.54	16.20	1329.43	89.21	61.55	39.58	30.30	82.09	5.51	0.26	0.41	0.53	14.90	21.60	33.59	43.87	1.45	2.25	2.94	1.56	2.03	1.31
169	14.50	1.27	77.69	7.57	0.21	0.44	0.21	11.38	1126.41	109.77	70.33	32.63	69.49	99.01	9.65	0.16	0.35	0.16	10.26	16.02	34.52	16.21	1.56	3.36	1.58	2.16	1.01	0.47
109	15.74	0.89	94.61	10.19	0.09	0.42	0.24	17.65	1489.33	160.41	174.26	37.69	65.05	84.36	9.09	0.10	0.47	0.27	9.28	8.55	39.52	22.89	0.92	4.26	2.47	4.62	2.68	0.58
157	22.30	1.00	82.39	6.13	0.23	0.36	0.72	22.34	1837.45	136.80	95.09	61.57	30.96	82.24	6.12	0.23	0.36	0.72	13.43	19.32	29.84	59.36	1.44	2.22	4.42	1.54	3.07	1.99
68	17.83	1.07	72.85	11.57	0.23	0.72	1.35	16.62	1298.68	206.19	76.24	24.66	13.20	78.16	12.41	0.22	0.67	1.26	6.30	17.03	52.67	98.38	2.70	8.36	15.62	3.09	5.78	1.87
85	10.56	0.67	103.14	25.79	0.11	0.34	0.24	15.65	1089.53	272.42	93.32	30.74	43.23	69.62	17.41	0.17	0.51	0.36	4.00	11.68	35.44	25.20	2.92	8.86	6.30	3.04	2.16	0.71
144	21.04	0.94	76.49	16.20	0.18	0.38	0.29	22.38	1609.80	340.89	120.08	55.02	73.55	71.94	15.23	0.19	0.41	0.30	4.72	13.41	29.26	21.89	2.84	6.20	4.63	2.18	1.63	0.75
174	18.41	0.94	77.73	7.51	0.18	0.35	0.46	19.58	1430.74	138.27	99.73	52.67	40.10	73.05	7.06	0.20	0.37	0.49	10.35	14.35	27.16	35.68	1.39	2.63	3.45	1.89	2.49	1.31
156	22.72	1.08	79.05	8.37	0.25	0.43	1.03	21.08	1795.66	190.02	92.38	52.96	22.11	85.20	9.02	0.23	0.40	0.95	9.45	19.44	33.90	81.22	2.06	3.59	8.59	1.74	4.18	2.40
78	18.91	0.92	89.17	13.08	0.15	0.55	0.26	20.64	1686.29	247.29	122.11	34.08	73.58	81.70	11.98	0.17	0.61	0.28	6.82	13.81	49.48	22.92	2.03	7.26	3.36	3.58	1.66	0.46
132	10.05	0.97	73.21	9.46	0.16	0.38	0.46	10.35	735.37	95.04	62.16	26.78	21.65	71.02	9.18	0.17	0.39	0.48	7.74	11.83	27.46	33.96	1.53	3.55	4.39	2.32	2.87	1.24
86	7.34	0.70	92.33	26.23	0.17	0.36	0.48	10.56	678.00	192.61	44.01	20.30	15.23	64.21	18.24	0.24	0.52	0.69	3.52	15.41	33.40	44.52	4.38	9.49	12.65	2.17	2.89	1.33
97	8.70	0.96	84.25	10.98	0.17	0.35	0.39	9.02	733.34	95.58	51.40	24.71	22.55	81.26	10.59	0.18	0.37	0.40	7.67	14.27	29.67	32.52	1.86	3.87	4.24	2.08	2.28	1.10
105	10.82	0.72	78.88	13.56	0.22	0.43	0.25	15.01	853.58	146.73	49.90	25.10	42.64	56.86	9.77	0.30	0.60	0.35	5.82	17.11	34.01	20.02	2.94	5.85	3.44	1.99	1.17	0.59
142	8.85	1.11	60.79	12.35	0.19	0.42	1.45	7.99	537.71	109.27	45.50	20.99	6.10	67.31	13.68	0.18	0.38	1.31	4.92	11.82	25.62	88.21	2.40	5.21	17.92	2.17	7.46	3.44

Appendix 5 continued

No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
137	15.57	1.06	66.99	13.49	0.22	0.40	1.40	14.66	1043.27	210.04	72.40	38.59	11.16	71.19	14.33	0.20	0.38	1.31	4.97	14.41	27.04	93.49	2.90	5.44	18.82	1.88	6.49	3.46
115	10.46	1.20	81.24	10.49	0.21	0.45	1.06	8.73	850.06	109.76	50.34	23.48	9.90	97.35	12.57	0.17	0.37	0.88	7.74	16.89	36.20	85.84	2.18	4.67	11.08	2.14	5.08	2.37
124	10.28	1.56	94.18	9.00	0.22	0.45	0.18	6.59	967.81	92.49	47.37	22.91	57.25	146.95	14.04	0.14	0.29	0.12	10.46	20.43	42.25	16.91	1.95	4.04	1.62	2.07	0.83	0.40
125	8.33	0.81	91.18	10.36	0.16	0.32	0.19	10.30	759.82	86.33	51.68	25.86	44.00	73.77	8.38	0.20	0.40	0.23	8.80	14.70	29.38	17.27	1.67	3.34	1.96	2.00	1.17	0.59
5	15.84	1.23	55.28	7.99	0.20	0.63	0.24	12.85	875.92	126.57	79.85	25.12	65.22	68.17	9.85	0.16	0.51	0.20	6.92	10.97	34.87	13.43	1.59	5.04	1.94	3.18	1.22	0.39
161	12.28	0.85	90.14	8.00	0.18	0.29	0.77	14.39	1107.29	98.25	67.38	42.60	15.96	76.92	6.83	0.21	0.34	0.90	11.27	16.43	26.00	69.37	1.46	2.31	6.16	1.58	4.22	2.67
40	7.99	0.86	76.65	13.09	0.17	0.42	2.32	9.24	612.52	104.59	48.13	18.93	3.44	66.29	11.32	0.19	0.49	2.69	5.86	12.73	32.35	178.02	2.17	5.52	30.40	2.54	13.99	5.50
130	20.48	1.23	62.40	9.90	0.35	0.49	0.64	16.70	1277.89	202.74	59.01	41.79	31.87	76.51	12.14	0.28	0.40	0.52	6.30	21.66	30.58	40.09	3.44	4.85	6.36	1.41	1.85	1.31
176	9.01	0.88	76.18	10.19	0.23	0.31	0.50	10.28	686.25	91.79	39.81	29.31	17.86	66.73	8.92	0.26	0.35	0.58	7.48	17.24	23.41	38.42	2.31	3.13	5.14	1.36	2.23	1.64
42	18.93	1.14	68.48	4.73	0.30	0.45	0.69	16.54	1296.71	89.54	63.30	42.19	27.55	78.39	5.41	0.26	0.39	0.60	14.48	20.48	30.73	47.07	1.41	2.12	3.25	1.50	2.30	1.53
162	8.41	0.73	83.92	16.04	0.18	1.38	0.39	11.59	705.63	134.84	47.56	6.07	21.43	60.91	11.64	0.24	1.91	0.54	5.23	14.84	116.22	32.93	2.84	22.21	6.29	7.83	2.22	0.28
159	12.82	0.89	82.07	11.63	0.22	0.40	2.28	14.34	1052.29	149.13	59.22	32.11	5.61	73.39	10.40	0.24	0.45	2.55	7.06	17.77	32.77	187.44	2.52	4.64	26.56	1.84	10.55	5.72
87	9.45	0.74	87.24	15.42	0.22	0.39	0.62	12.84	824.68	145.79	42.80	23.99	15.36	64.21	11.35	0.30	0.54	0.84	5.66	19.27	34.37	53.68	3.41	6.08	9.49	1.78	2.79	1.56
67	20.11	0.80	73.84	15.06	0.18	0.51	1.10	25.10	1484.86	302.79	111.72	39.40	18.26	59.16	12.06	0.22	0.64	1.37	4.90	13.29	37.68	81.32	2.71	7.68	16.58	2.84	6.12	2.16
145	13.79	0.93	60.56	11.58	0.16	0.37	1.72	14.84	834.90	159.70	84.60	37.67	8.00	56.25	10.76	0.18	0.39	1.86	5.23	9.87	22.17	104.39	1.89	4.24	19.97	2.25	10.58	4.71
154	10.78	0.99	58.40	16.38	0.25	0.52	3.62	10.92	629.63	176.56	42.67	20.85	2.98	57.68	16.17	0.26	0.52	3.67	3.57	14.76	30.20	211.44	4.14	8.47	59.29	2.05	14.33	7.00
170	10.67	0.92	75.24	6.63	0.26	0.41	0.55	11.63	802.94	70.74	41.50	26.05	19.24	69.05	6.08	0.28	0.45	0.60	11.35	19.35	30.82	41.73	1.70	2.72	3.68	1.59	2.16	1.35
131	11.72	1.32	55.53	9.20	0.42	0.55	0.86	8.90	650.80	107.87	27.79	21.20	13.58	73.09	12.11	0.32	0.42	0.66	6.03	23.42	30.70	47.92	3.88	5.09	7.94	1.31	2.05	1.56
163	14.32	1.05	65.27	5.93	0.24	0.48	0.58	13.61	934.47	84.91	60.01	30.11	24.54	68.68	6.24	0.23	0.45	0.55	11.01	15.57	31.03	38.07	1.41	2.82	3.46	1.99	2.45	1.23
177	14.54	0.90	67.16	9.76	0.17	0.34	0.44	16.14	976.53	141.84	83.41	42.24	32.84	60.51	8.79	0.19	0.38	0.49	6.88	11.71	23.12	29.73	1.70	3.36	4.32	1.97	2.54	1.29
127	6.22	0.84	68.22	8.61	0.15	0.33	0.22	7.38	424.16	53.50	42.67	18.93	28.79	57.44	7.25	0.17	0.39	0.26	7.93	9.94	22.41	14.73	1.25	2.83	1.86	2.25	1.48	0.66
3	9.16	0.63	70.66	11.42	0.12	0.36	0.34	14.50	647.19	104.61	74.28	25.66	26.87	44.63	7.21	0.20	0.57	0.54	6.19	8.71	25.22	24.09	1.41	4.08	3.89	2.89	2.76	0.96
136	14.71	1.10	52.20	12.91	0.22	0.41	0.34	13.37	767.67	189.83	68.16	35.93	43.20	57.41	14.20	0.20	0.37	0.31	4.04	11.26	21.36	17.77	2.79	5.28	4.39	1.90	1.58	0.83
133	13.43	0.88	71.24	10.56	0.16	0.33	0.51	15.23	956.57	141.86	85.28	41.03	26.48	62.81	9.31	0.18	0.37	0.58	6.74	11.22	23.31	36.12	1.66	3.46	5.36	2.08	3.22	1.55
158	16.54	1.41	53.60	14.94	0.26	0.50	0.70	11.74	886.28	246.98	64.22	33.20	23.55	75.52	21.05	0.18	0.35	0.50	3.59	13.80	26.69	37.64	3.85	7.44	10.49	1.93	2.73	1.41
173	19.85	1.09	65.49	7.00	0.24	0.36	0.29	18.28	1300.18	139.01	82.10	54.63	69.57	71.11	7.60	0.22	0.33	0.26	9.35	15.84	23.80	18.69	1.69	2.54	2.00	1.50	1.18	0.79
104	25.27	1.04	59.00	8.29	0.23	0.43	0.52	24.37	1491.05	209.44	109.68	58.30	49.03	61.18	8.59	0.22	0.42	0.50	7.12	13.59	25.58	30.41	1.91	3.59	4.27	1.88	2.24	1.19

Appendix 5 continued

No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
111	25.90	0.90	69.57	12.34	0.33	0.41	0.33	28.62	1801.79	319.54	78.81	63.31	77.72	62.96	11.17	0.36	0.45	0.37	5.64	22.86	28.46	23.18	4.05	5.05	4.11	1.24	1.01	0.81
41	21.76	0.76	83.16	12.19	0.27	0.39	0.65	28.63	1809.64	265.36	79.18	56.39	33.42	63.20	9.27	0.36	0.51	0.86	6.82	22.86	32.09	54.14	3.35	4.71	7.94	1.40	2.37	1.69
81	8.62	0.83	73.23	12.30	0.18	0.38	0.36	10.41	631.31	106.07	48.55	22.84	23.99	60.65	10.19	0.21	0.46	0.43	5.95	13.00	27.64	26.32	2.19	4.64	4.42	2.13	2.02	0.95
18	13.30	0.92	52.68	16.30	0.25	0.53	0.39	14.47	700.52	216.79	53.60	24.92	34.45	48.42	14.98	0.27	0.58	0.42	3.23	13.07	28.11	20.33	4.04	8.70	6.29	2.15	1.56	0.72
79	10.15	0.88	40.85	12.93	0.16	0.42	0.23	11.47	414.52	131.17	61.83	24.25	44.30	36.13	11.43	0.19	0.47	0.26	3.16	6.70	17.09	9.36	2.12	5.41	2.96	2.55	1.40	0.55
99	5.74	0.69	73.49	11.27	0.27	0.41	1.59	8.37	421.98	64.69	21.61	13.93	3.62	50.41	7.73	0.39	0.60	2.31	6.52	19.53	30.30	116.56	2.99	4.65	17.87	1.55	5.97	3.85
53	13.19	0.87	41.79	9.37	0.21	0.62	0.87	15.14	551.12	123.60	64.25	21.20	15.17	36.41	8.16	0.24	0.71	1.00	4.46	8.58	26.00	36.33	1.92	5.83	8.15	3.03	4.24	1.40
54	18.03	1.15	56.80	18.13	0.28	0.66	0.20	15.67	1024.00	326.79	65.18	27.31	89.76	65.34	20.85	0.24	0.57	0.17	3.13	15.71	37.50	11.41	5.01	11.97	3.64	2.39	0.73	0.30
59	6.12	0.49	80.29	18.35	0.10	0.31	0.55	12.56	491.45	112.32	63.53	19.44	11.09	39.13	8.94	0.20	0.65	1.13	4.38	7.74	25.28	44.30	1.77	5.78	10.12	3.27	5.73	1.75
4	9.23	1.23	44.34	12.81	0.25	0.62	0.22	7.48	409.47	118.25	37.01	14.88	41.05	54.76	15.81	0.20	0.50	0.18	3.46	11.06	27.52	9.98	3.20	7.95	2.88	2.49	0.90	0.36
96	18.09	1.15	46.90	8.44	0.25	0.52	0.42	15.76	848.58	152.75	71.51	34.95	42.95	53.86	9.69	0.22	0.45	0.37	5.56	11.87	24.28	19.76	2.14	4.37	3.56	2.05	1.66	0.81
166	8.57	1.09	42.66	8.00	0.23	0.51	0.34	7.87	365.75	68.61	37.72	16.95	25.52	46.50	8.72	0.21	0.46	0.31	5.33	9.70	21.57	14.33	1.82	4.05	2.69	2.22	1.48	0.66
71	20.49	1.12	40.26	7.33	0.33	0.89	0.25	18.34	824.89	150.24	61.44	22.98	81.25	44.99	8.19	0.30	0.80	0.23	5.49	13.43	35.90	10.15	2.45	6.54	1.85	2.67	0.76	0.28
101	12.39	0.85	45.55	11.31	0.28	0.41	0.92	14.56	564.56	140.15	43.66	29.97	13.42	38.77	9.62	0.33	0.49	1.09	4.03	12.93	18.83	42.06	3.21	4.68	10.44	1.46	3.25	2.23
100	6.50	0.86	57.43	10.95	0.31	0.41	1.81	7.57	373.38	71.20	21.13	15.95	3.58	49.29	9.40	0.36	0.47	2.11	5.24	17.67	23.41	104.19	3.37	4.46	19.87	1.32	5.90	4.45

Appendix 6 Function values for the low-yielding population in leaf tissue (GS-39) of irrigated wheat

Sample No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
123	-4.42	60.73	-19.63	-18.14	9.13	9.35	5.71	-49.95	-18.23	-17.37	-16.18	-16.44	-24.39	31.87	21.69	-23.70	-18.30	-7.73	0.11	-2.69	-1.29	0.71	-3.97	-2.53	-0.33	-0.89	1.36	0.71
151	2.94	-8.79	-3.15	-0.20	-0.10	2.63	17.14	8.68	2.47	3.03	1.22	-0.88	-33.60	-12.09	-5.79	5.56	6.51	25.24	-5.33	-0.95	0.65	17.11	0.31	1.12	19.15	0.05	18.60	14.67
150	2.54	7.82	-17.05	-7.31	-0.68	0.59	11.02	-2.11	-5.78	-1.82	1.31	0.46	-23.55	-7.45	-0.09	-5.85	-4.24	8.20	-7.54	-12.88	-6.74	5.35	-4.64	-3.00	7.73	-0.91	12.31	10.59
93	44.45	14.55	-18.85	-26.62	-1.30	0.63	6.61	29.63	28.97	11.52	44.25	37.92	6.14	-2.59	-13.24	-11.09	-7.72	2.20	6.29	-15.33	-7.47	1.54	-17.84	-11.38	-1.82	-0.53	7.74	6.06
19	1.22	-11.91	-8.52	-0.03	19.78	2.04	-3.19	8.33	-2.59	1.63	-16.53	-2.02	-0.46	-23.26	-8.17	31.04	7.62	0.19	-10.13	15.03	-1.94	-5.58	13.26	0.91	-2.40	-11.63	-15.96	-5.23
152	7.99	4.69	-11.30	-6.20	-3.35	-2.41	3.03	5.02	2.75	2.89	9.38	8.65	-4.72	-5.33	-1.37	-6.50	-5.56	1.81	-4.74	-11.92	-6.96	0.47	-5.92	-4.36	1.21	-1.44	4.73	4.25
138	9.60	6.29	-21.26	-11.47	-6.07	1.83	14.10	5.57	-0.61	1.00	13.97	5.46	-18.93	-13.16	-5.71	-10.54	-2.27	11.75	-6.08	-25.19	-7.33	6.36	-11.96	-4.00	8.09	2.81	20.97	12.51
119	-0.35	34.34	-9.84	-33.00	-7.14	0.32	-12.23	-22.12	-5.42	-21.64	3.11	-2.10	7.65	23.21	-4.44	-34.30	-18.58	-33.71	18.21	-15.70	-3.86	-17.11	-29.75	-14.49	-37.50	2.27	-9.47	-14.24
33	0.79	-8.84	-6.33	-13.48	-3.45	-0.95	-2.60	5.84	-1.82	-7.32	1.68	0.18	-1.50	-16.40	-25.61	2.26	2.91	-0.03	5.09	-7.66	-3.36	-4.12	-11.13	-6.84	-8.23	-0.44	-1.80	-2.68
32	-18.98	-6.41	-2.94	-2.08	8.65	0.61	26.04	-15.87	-23.22	-17.92	-36.96	-22.30	-121.16	-9.12	-6.43	13.29	3.22	34.60	-2.92	8.95	-0.64	26.31	4.43	-0.70	26.26	-6.49	18.90	25.84
181	1.77	18.05	-25.46	-13.07	14.24	-1.32	-0.41	-8.77	-11.56	-5.98	-11.24	1.44	-3.93	-4.84	1.38	0.93	-12.04	-5.81	-7.09	-1.59	-12.55	-7.21	0.85	-6.92	-4.95	-11.92	-7.78	-0.16
14	17.92	7.08	-23.58	-18.32	-0.04	1.20	26.89	12.93	4.80	2.56	15.72	13.41	-25.61	-14.39	-12.22	-4.67	-3.25	23.21	-1.83	-17.08	-8.91	14.49	-11.11	-7.33	13.66	-0.87	29.33	25.84
148	-1.92	-13.00	0.40	3.77	4.17	-6.86	0.82	4.67	-0.76	1.40	-7.87	2.18	-10.04	-11.77	-3.66	13.41	-0.01	5.16	-7.03	7.12	-4.41	1.69	6.07	-1.71	3.38	-9.97	-1.37	4.01
175	-2.46	2.58	-14.26	-25.25	-2.90	-0.84	-1.92	-5.01	-11.35	-19.85	-2.12	-3.17	-5.24	-10.82	-25.25	-4.54	-2.83	-2.81	8.46	-13.87	-6.89	-5.95	-18.79	-12.19	-12.58	-0.65	-1.31	-2.01
92	-10.12	20.51	-20.65	-5.23	0.06	-2.10	18.46	-30.25	-28.53	-12.93	-13.35	-9.39	-69.78	0.71	12.24	-13.26	-14.47	9.41	-12.52	-14.59	-11.15	9.69	-2.76	-3.71	15.76	-3.29	19.89	21.50
121	13.43	26.65	-19.46	-23.17	10.04	1.92	-3.87	-1.00	3.27	-1.85	2.52	8.64	8.97	6.28	-1.75	-6.04	-12.35	-14.46	3.59	-1.76	-6.51	-10.51	-5.82	-8.80	-15.05	-6.18	-11.27	-5.96
106	2.32	-10.66	-5.00	-0.23	10.40	2.08	-12.91	9.07	0.65	2.47	-7.51	-1.00	11.34	-16.78	-7.41	18.87	6.98	-8.34	-6.87	8.88	-0.47	-15.04	7.03	0.84	-11.94	-6.25	-26.00	-16.90
48	6.08	5.25	-12.12	1.56	0.57	9.10	-7.50	2.79	0.54	7.36	3.66	-3.09	8.50	-5.53	9.34	-2.85	3.84	-10.42	-15.67	-7.14	1.06	-12.39	1.93	5.40	-5.59	3.45	-9.80	-16.33
6	22.88	12.41	-19.75	-59.76	8.33	5.71	1.58	13.42	10.75	-9.22	10.82	11.95	4.70	-5.24	-46.60	-0.34	-1.92	-1.61	27.93	-3.53	-3.61	-2.90	-24.91	-19.46	-18.33	-2.54	-2.21	-1.38
171	13.91	25.38	-26.72	-6.44	24.64	7.20	-3.26	-0.17	0.47	7.05	-5.11	4.00	8.30	-0.21	14.26	3.81	-6.23	-12.93	-15.24	5.32	-5.00	-12.25	10.01	0.54	-5.66	-9.46	-18.99	-8.69
113	-2.83	-3.82	-9.04	17.61	-6.70	0.21	0.40	-1.27	-8.29	9.16	0.21	-4.61	-10.12	-13.51	20.79	-3.40	1.50	1.73	-36.43	-14.34	-3.61	-1.46	6.53	7.80	9.14	1.97	2.99	-0.04
147	20.47	10.16	-21.80	-11.84	0.81	-1.96	28.38	12.95	7.66	7.67	17.03	20.50	-24.64	-9.27	-2.89	-5.72	-8.29	22.40	-6.06	-14.28	-11.55	16.30	-6.29	-6.80	18.89	-3.69	29.74	32.49
160	1.59	17.08	-18.27	-41.54	11.03	4.95	6.87	-8.47	-7.73	-23.55	-8.95	-4.18	-17.49	-0.06	-24.08	-0.71	-4.61	1.78	16.92	-0.22	-3.61	1.88	-13.65	-13.48	-5.24	-4.41	1.61	3.64
120	4.77	12.95	-15.32	-2.16	8.13	-2.41	-9.73	-2.45	-2.31	3.13	-3.12	5.41	10.14	-1.03	10.57	-0.75	-10.43	-17.27	-12.66	-0.98	-8.90	-16.91	4.06	-2.39	-10.24	-8.97	-18.97	-9.08

Appendix 6 continued

Sample No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
108	15.60	8.30	-22.06	-4.75	-2.81	3.99	17.08	9.88	3.74	9.67	16.92	8.19	-16.79	-11.54	3.13	-8.51	-1.41	13.48	-14.18	-20.49	-5.76	8.23	-4.51	-0.18	14.87	2.44	21.44	13.35
143	19.37	12.35	-25.57	-40.27	11.12	3.20	16.82	10.47	4.94	-4.81	6.01	12.09	-13.51	-10.25	-28.22	1.68	-3.99	11.33	10.78	-4.34	-7.80	6.97	-13.00	-14.60	1.01	-5.75	9.55	13.83
168	-9.52	3.29	-8.75	-3.12	-14.05	1.88	-7.69	-14.21	-17.10	-10.36	-1.01	-13.87	-3.06	-4.31	0.96	-16.11	-0.73	-9.68	-6.28	-23.71	-2.15	-11.04	-11.03	-0.51	-8.74	7.17	-2.23	-10.48
83	5.29	10.58	-12.35	-11.59	2.82	3.96	-10.77	-0.77	-0.31	-1.97	1.09	0.05	11.97	-0.52	-2.32	-3.93	-2.50	-17.37	-0.55	-4.49	-2.09	-16.70	-4.60	-2.82	-18.39	-0.75	-15.77	-16.19
122	6.83	19.54	-19.23	-9.29	10.21	3.04	-3.53	-3.58	-2.16	0.31	-2.60	2.02	3.82	1.08	6.27	-2.48	-7.58	-11.14	-6.91	-1.48	-5.44	-9.92	0.82	-2.41	-7.41	-5.37	-10.83	-6.30
43	1.59	4.58	-15.83	-13.07	-1.82	3.18	4.41	-1.34	-6.33	-6.17	1.27	-2.64	-12.94	-9.95	-9.08	-4.86	-0.30	3.19	-1.45	-13.60	-3.99	0.55	-9.38	-3.84	0.10	1.36	5.51	2.36
98	-0.22	-11.31	-23.24	4.24	-15.21	43.20	-4.80	5.94	-13.55	3.29	9.12	-42.11	0.21	-43.10	-1.84	-5.26	51.48	-1.29	-30.75	-42.64	13.32	-13.38	-5.30	26.68	-1.91	45.00	0.44	-36.84
35	5.57	-13.06	-2.42	4.51	-9.91	2.28	0.09	15.36	5.94	9.45	12.78	1.63	-1.92	-15.91	-2.79	-0.51	8.52	4.15	-10.69	-11.58	0.73	0.03	-2.30	3.21	2.82	5.25	3.96	-1.43
90	25.45	8.87	-22.79	-11.43	-6.26	-1.69	-2.71	18.46	10.96	11.11	32.81	24.96	14.96	-11.56	-3.50	-12.77	-7.25	-5.99	-7.04	-26.97	-11.72	-9.98	-12.09	-6.41	-7.40	0.46	-0.72	-2.38
88	-2.31	8.83	-17.54	-37.18	0.76	-1.51	15.21	-9.03	-13.34	-28.21	-5.17	-2.39	-41.87	-6.84	-29.65	-4.93	-7.03	11.54	14.50	-11.08	-9.06	8.39	-21.92	-18.48	0.85	-3.32	15.62	17.18
164	12.60	1.10	-14.05	2.27	-2.62	-0.67	11.46	12.51	5.42	14.26	13.52	11.07	-12.56	-12.55	6.24	-3.21	-1.86	11.89	-18.56	-13.28	-6.64	6.66	0.34	0.54	15.17	-0.69	14.47	12.23
84	19.46	-6.46	-10.29	8.12	-25.96	0.18	-6.01	28.24	14.32	28.47	52.85	16.24	17.39	-18.52	6.39	-17.07	2.82	-3.78	-23.89	-41.63	-4.18	-9.69	-7.91	3.58	-1.37	11.73	2.55	-7.16
135	13.54	8.13	-27.57	-2.36	3.18	0.59	-9.41	8.08	-0.13	10.21	8.03	10.31	18.21	-16.81	6.09	-2.15	-4.39	-14.24	-22.04	14.94	-11.26	-22.74	0.96	-0.83	-10.04	-3.22	-14.30	-11.33
103	-3.16	-18.22	1.66	18.01	20.22	0.69	-1.26	5.91	-1.29	9.03	-25.13	-5.47	-7.01	-15.35	7.28	38.47	9.44	3.80	-22.22	28.33	1.48	-0.11	33.83	8.38	6.60	-13.37	-12.35	-2.15
126	2.71	4.78	-15.22	-46.56	9.84	2.31	2.35	-0.27	-4.56	-24.53	-6.59	-0.83	-8.00	-9.10	-45.80	5.29	-1.10	1.12	23.22	0.58	-4.45	-1.02	-17.00	-18.06	-12.41	-5.74	-1.94	0.87
169	-0.22	16.68	-17.52	-25.32	0.91	4.23	-13.30	-10.97	-10.00	-16.34	-2.87	-5.63	8.87	0.22	-10.26	-9.73	-5.07	-24.60	6.26	-10.85	-3.85	-23.08	-14.46	-7.92	-33.29	0.43	-17.13	-19.73
109	1.67	-0.86	-7.23	-11.47	-35.71	2.48	-9.88	1.96	-1.32	-5.11	28.04	-1.96	7.26	-7.63	-13.18	-31.66	1.94	-9.95	2.69	-49.47	-1.10	-12.87	-37.41	-3.61	-17.10	19.70	1.97	-13.65
157	11.63	4.04	-14.24	-37.95	5.08	-1.23	6.91	9.12	4.45	-9.31	4.74	10.84	-7.48	-9.00	-37.49	1.84	-4.02	5.84	17.84	-3.29	-7.25	2.93	-17.27	-18.51	-4.34	-5.90	4.19	7.78
68	4.84	7.46	-21.34	-6.70	4.97	22.56	23.00	0.37	-5.27	0.30	-0.84	-14.48	-39.60	-11.85	0.27	-0.26	12.33	19.37	-11.17	-8.21	4.56	12.68	-0.52	6.69	18.61	7.74	19.46	6.56
85	-8.57	-14.51	-3.33	23.03	-22.55	-2.65	-9.67	-1.15	-11.21	6.57	4.22	-7.31	-0.70	-18.88	15.29	-8.43	4.00	-4.36	-35.56	-27.28	-3.29	-10.60	0.93	7.85	0.49	7.30	-1.04	-8.83
144	9.72	1.39	-18.42	3.84	-4.15	0.17	-6.58	9.17	0.72	13.06	12.09	7.37	10.35	-16.80	8.76	-4.88	-1.24	-7.54	-25.33	-19.45	-7.75	-14.01	0.39	1.68	-3.59	0.64	-5.62	-7.79
174	5.72	1.37	-17.49	-25.74	-2.46	-2.18	0.23	4.91	-2.42	-9.01	6.10	6.13	-2.04	-15.85	-27.59	-3.25	-3.40	-0.04	6.57	-16.00	-9.73	-3.99	-18.61	-13.72	-8.88	-1.79	0.89	0.94
156	12.26	7.68	-16.53	-20.20	6.75	3.22	14.75	7.19	3.76	-1.32	3.94	6.29	-17.04	-7.11	-13.58	1.00	-1.75	11.67	3.29	-3.07	-4.24	8.39	-6.51	-6.64	4.95	-3.34	10.44	11.90
78	6.48	0.28	-10.12	-2.63	-8.57	11.51	-8.63	6.52	1.97	4.19	12.69	-4.47	10.36	-9.37	-1.05	-8.15	8.88	-9.22	-7.93	-17.91	3.20	-12.84	-6.90	4.13	-9.41	11.58	-5.32	-20.17
132	-10.16	2.76	-21.04	-14.55	-6.99	-0.33	0.35	-14.53	-28.96	-21.85	-6.30	-11.61	-17.74	-17.60	-12.67	-8.67	-2.44	-0.31	-3.28	-26.48	-9.43	-4.80	-15.15	-6.85	-4.45	1.72	3.05	0.17

Appendix 6 continued

Sample No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
86	-22.08	-12.86	-8.40	23.91	-5.84	-1.26	0.82	-13.76	-33.58	-1.04	-18.49	-22.25	-32.15	-24.30	17.80	2.45	4.56	5.12	-44.65	-12.60	-4.58	-0.83	10.64	9.30	12.83	0.53	3.16	1.14
97	-15.15	2.50	-13.04	-8.59	-5.32	-1.97	-1.90	-20.35	-29.11	-21.62	-12.49	-14.40	-16.39	-9.66	-6.04	-6.84	-3.86	-2.77	-3.57	-16.27	-7.39	-5.53	-9.17	-5.24	-5.03	-0.16	-0.29	-1.40
105	-7.84	-10.94	-16.65	-1.52	2.48	3.36	-8.88	-2.26	-21.40	-7.38	-13.56	-13.84	-0.94	-33.32	-9.65	9.93	8.50	-4.83	-14.68	-8.04	-4.18	-16.42	1.07	0.87	-8.92	-0.92	-13.04	-13.24
142	-14.56	9.03	-33.51	-4.46	-0.85	2.73	25.57	-26.23	-49.03	-16.50	-17.12	-20.81	-104.86	-21.08	4.08	-6.84	-2.82	20.67	-23.05	-26.55	-11.39	10.14	-2.92	-0.64	23.09	0.53	28.99	22.50
137	1.42	6.99	-26.71	-1.68	2.22	1.55	24.15	-2.93	-12.84	0.66	-2.12	-1.41	-49.85	-17.46	6.05	-2.35	-2.87	20.74	-22.54	-15.78	-9.86	11.46	0.81	-0.06	24.84	-1.95	23.48	22.65
115	-8.87	13.21	-15.01	-10.33	1.16	4.31	15.50	-21.87	-21.59	-16.34	-13.24	-16.29	-58.25	-0.55	0.75	-7.25	-3.40	9.87	-3.25	-8.58	-2.84	9.55	-5.09	-2.16	9.79	0.34	15.55	11.65
124	-9.44	29.78	-7.45	-16.76	2.49	4.51	-17.32	-37.14	-15.84	-22.98	-15.53	-17.25	4.42	22.34	5.18	-15.74	-10.77	-40.24	7.00	-1.30	0.12	-21.64	-7.85	-4.49	-32.29	-0.26	-23.90	-25.30
125	-16.82	-5.20	-9.01	-10.81	-7.07	-4.48	-15.82	-14.73	-27.20	-25.99	-12.29	-12.80	-0.41	-15.26	-17.40	-2.81	-1.73	-13.49	0.92	-14.80	-7.64	-20.94	-12.30	-8.08	-24.51	-0.83	-12.94	-13.28
5	1.83	14.79	-40.83	-22.50	-0.24	16.50	-9.80	-6.85	-20.20	-11.62	0.25	-13.81	7.32	-20.25	-9.29	-9.92	4.12	-18.36	-7.36	-31.18	-3.63	-30.32	-13.96	-1.08	-24.91	8.42	-11.88	-26.76
161	-4.26	-2.77	-9.58	-22.44	-2.86	-7.94	8.16	-3.43	-10.62	-20.51	-4.01	0.80	-29.91	-12.77	-29.81	-0.81	-5.92	10.37	9.94	-9.73	-10.97	5.43	-16.79	-17.36	0.20	-5.37	10.68	14.66
40	-18.49	-2.18	-18.30	-2.60	-6.02	2.77	47.83	-19.29	-39.91	-18.10	-14.92	-25.43	-198.44	-22.10	-3.27	-3.94	2.94	55.31	-14.37	-22.27	-5.30	32.58	-5.17	0.13	47.34	3.45	65.83	43.33
130	8.86	14.47	-31.61	-12.64	21.62	7.24	4.92	0.51	-5.78	-0.03	-7.88	0.38	-6.80	-13.08	-0.55	7.75	-1.65	0.86	-11.14	0.67	-6.65	-2.24	4.37	-1.61	0.60	-7.99	-3.40	0.92
176	-13.89	-1.62	-18.66	-11.47	3.87	-5.91	1.39	-14.79	-32.86	-23.31	-22.90	-8.73	-24.99	-21.66	-14.09	4.71	-4.90	2.16	-4.49	-7.72	-14.14	-2.86	-3.81	-9.45	-2.09	-8.95	-0.60	4.26
42	6.52	10.74	-25.25	-57.71	14.57	4.53	6.06	0.26	-5.32	-24.37	-5.77	0.59	-10.44	-11.68	-47.27	5.08	-2.10	2.79	21.68	-1.21	-6.52	-0.14	-17.88	-19.97	-10.13	-6.55	-0.18	3.15
162	-16.47	-10.58	-13.25	3.52	-3.86	66.11	-1.69	-10.32	-31.26	-9.72	-15.38	-125.35	-18.10	-28.08	-2.17	2.90	74.73	1.28	-19.81	-14.36	31.61	-5.32	0.37	38.74	0.47	44.75	-0.66	-40.82
159	-3.15	-0.74	-14.45	-6.51	2.42	1.27	46.84	-3.54	-12.51	-6.95	-7.77	-6.07	-115.27	-15.57	-6.83	2.71	0.84	52.00	-6.62	-6.49	-5.01	34.93	-1.93	-2.25	39.89	-2.27	46.41	45.53
87	-12.19	-9.85	-11.23	2.29	3.07	0.92	4.22	-6.87	-23.04	-7.55	-19.67	-15.48	-31.72	-24.29	-3.16	9.84	5.32	8.72	-15.98	-3.39	-3.94	1.51	4.17	1.40	6.69	-2.91	2.57	3.46
67	8.30	-5.66	-20.52	1.55	-3.27	8.58	16.64	13.33	-1.40	9.45	9.63	-0.92	-24.09	-30.26	-0.79	0.57	10.47	22.29	-23.23	-19.91	-2.03	8.42	-0.48	5.12	20.48	5.74	21.39	9.49
145	-1.37	0.87	-33.80	-6.65	-6.68	-0.95	32.54	-2.57	-22.45	-5.22	1.65	-1.97	-76.03	-34.16	-5.37	-6.87	-1.98	34.41	-19.86	-38.38	-15.95	14.18	-8.75	-3.67	27.07	1.14	46.58	35.31
154	-7.95	3.56	-36.52	4.19	7.75	9.02	80.99	-12.49	-38.13	-2.88	-19.80	-21.09	-231.83	-32.19	11.59	4.40	4.73	80.01	-43.67	-14.62	-6.96	40.93	9.04	6.94	103.53	-0.43	67.76	58.51
170	-8.26	0.35	-19.39	-32.98	8.40	1.95	2.67	-10.19	-24.36	-35.96	-21.01	-12.54	-22.03	-19.40	-37.97	7.40	0.83	2.88	10.24	-3.24	-6.45	-1.69	-11.68	-12.84	-7.59	-5.22	-1.06	1.36
131	-5.54	18.59	-40.47	-15.75	32.61	11.36	10.55	-20.96	-36.05	-16.97	-42.86	-20.38	-38.04	-15.82	-0.63	12.34	-0.52	4.17	-13.04	3.44	-6.55	0.07	7.34	-0.95	3.68	-9.88	-1.83	3.45
163	-0.50	6.51	-28.47	-40.22	5.67	6.28	3.41	-5.08	-17.32	-26.75	-7.36	-7.92	-13.72	-19.76	-36.08	0.83	1.10	1.62	8.97	-12.11	-6.29	-2.99	-17.87	-11.90	-8.81	-0.88	0.65	0.07
177	-0.15	-0.42	-26.54	-13.25	-4.33	-2.60	-0.19	-0.36	-15.47	-8.30	1.30	0.61	-6.11	-28.56	-14.88	-3.70	-2.73	0.03	-7.56	-27.11	-14.55	-7.17	-11.75	-7.96	-4.72	-1.04	1.18	0.67
127	-30.11	-3.37	-25.50	-18.84	-10.96	-3.92	-12.46	-30.42	-69.01	-53.75	-19.80	-25.44	-9.28	-32.51	-25.94	-7.33	-2.22	-11.24	-2.45	-37.86	-15.58	-26.59	-22.54	-11.84	-26.54	1.20	-7.53	-10.56

Appendix 6 continued

Sample No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
3	-13.30	-18.37	-23.24	-7.15	-18.29	-1.62	-3.68	-3.22	-36.40	-18.09	-1.48	-13.06	-11.12	-54.90	-26.22	-3.43	6.83	1.25	-11.94	-47.89	-11.85	-11.64	-18.04	-4.33	-6.52	6.20	2.45	-3.42
136	0.10	8.70	-45.61	-3.04	2.32	1.93	-3.70	-5.61	-26.66	-1.34	-3.70	-3.11	-0.72	-32.55	5.64	-3.28	-3.38	-7.20	-34.82	-29.50	-17.21	-20.01	0.03	-0.45	-4.43	-1.75	-6.27	-5.76
133	-2.01	-1.34	-22.73	-10.05	-7.95	-4.03	1.46	-1.87	-16.33	-8.29	1.85	-0.03	-11.52	-25.85	-11.95	-6.27	-3.45	2.14	-8.37	-29.76	-14.28	-3.80	-12.43	-7.37	-1.52	-0.17	5.03	3.33
158	2.88	22.85	-43.37	1.31	8.45	7.77	6.44	-9.87	-19.66	4.16	-5.35	-5.16	-15.00	-13.85	26.23	-5.51	-4.71	0.21	-43.21	-17.94	-10.21	-3.16	7.10	4.56	8.63	-1.40	2.24	1.92
173	7.91	8.05	-28.24	-29.70	6.15	-1.14	-6.63	2.92	-5.24	-8.86	0.91	7.17	8.90	-17.52	-22.98	0.33	-6.19	-10.67	2.94	-11.35	-13.63	-18.44	-11.89	-14.55	-23.86	-6.52	-12.82	-6.83
104	16.14	5.82	-35.75	-20.66	4.47	3.52	1.67	12.22	-1.29	0.61	9.03	9.11	1.43	-27.75	-16.06	0.27	-0.62	0.18	-6.28	-18.72	-11.44	-6.75	-8.44	-6.61	-4.90	-1.90	-0.55	-0.32
111	17.09	-0.23	-24.23	-4.50	18.92	1.91	-4.03	18.71	3.86	11.04	-0.06	11.77	11.86	-25.68	-3.83	17.59	1.11	-4.08	-16.13	2.56	-8.47	-12.56	8.49	-1.06	-5.55	-11.26	-17.07	-6.14
41	10.81	-8.22	-13.74	-4.89	11.00	0.39	5.13	18.73	3.99	5.90	0.05	8.10	-5.72	-25.41	-12.20	17.40	3.93	9.24	-7.93	2.55	-5.49	1.62	3.81	-2.05	3.67	-8.12	0.22	4.73
81	-15.52	-4.12	-21.02	-4.59	-3.71	-0.17	-2.90	-14.31	-37.96	-17.58	-14.59	-17.36	-14.42	-28.39	-7.74	-0.70	1.30	-1.59	-13.64	-21.08	-9.25	-9.65	-5.04	-2.25	-4.33	0.20	-1.99	-3.48
18	-2.24	0.41	-44.83	4.05	7.07	10.10	-1.91	-3.29	-31.67	1.30	-11.02	-14.09	-5.06	-47.05	8.01	6.14	7.61	-2.06	-51.44	-20.81	-8.80	-15.99	8.42	7.47	0.47	0.40	-6.55	-8.47
79	-9.84	-1.20	-69.40	-2.99	-6.43	2.53	-11.08	-10.67	-71.22	-10.54	-6.46	-15.08	-0.29	-78.51	-2.88	-5.01	2.18	-11.01	-53.30	-72.22	-25.98	-48.70	-5.75	-0.14	-12.27	3.51	-8.81	-15.17
99	-34.43	-13.61	-20.81	-7.64	9.67	2.13	29.02	-23.88	-69.50	-41.12	-61.77	-42.39	-187.79	-43.40	-22.01	20.57	8.65	45.92	-9.71	-2.90	-6.87	17.22	1.42	-2.25	22.98	-5.79	20.55	26.58
53	-2.45	-1.86	-66.93	-14.96	0.77	15.92	10.71	-2.03	-47.21	-12.36	-5.34	-20.38	-32.34	-77.56	-18.85	1.92	14.36	12.80	-28.67	-49.17	-10.97	-3.70	-8.24	0.83	4.08	7.27	10.76	1.80
54	5.14	11.01	-38.68	7.69	11.27	18.43	-14.26	-1.11	-13.57	11.72	-4.93	-10.96	16.24	-23.09	25.64	2.51	7.27	-22.30	-54.02	-11.71	-2.13	-37.81	14.88	15.03	-7.79	2.24	-29.06	-37.16
59	-30.93	-36.13	-15.66	8.14	-31.64	-5.17	2.60	-7.59	-56.06	-15.53	-5.66	-24.20	-50.23	-69.00	-13.98	-3.05	10.93	16.18	-29.82	-58.14	-11.78	-0.90	-10.60	0.71	7.92	9.12	19.18	5.38
4	-13.01	14.88	-60.78	-3.29	7.28	15.82	-11.50	-29.73	-72.41	-13.79	-26.39	-38.27	-1.61	-36.33	10.50	-2.40	3.66	-20.86	-45.91	-30.63	-9.37	-44.95	2.77	5.73	-12.94	3.02	-20.85	-29.20
96	5.24	10.91	-55.28	-19.75	7.79	9.06	-0.79	-0.97	-21.67	-6.33	-2.44	-3.81	-0.82	-37.70	-10.03	0.04	1.05	-4.15	-16.84	-26.30	-13.00	-16.80	-5.58	-3.18	-8.25	-0.43	-5.26	-6.17
166	-15.72	8.24	-64.75	-22.41	4.02	8.27	-3.90	-27.03	-84.13	-37.68	-25.46	-30.94	-12.57	-50.86	-15.27	-1.48	1.72	-7.28	-18.87	-39.64	-16.87	-27.66	-9.78	-4.45	-14.71	0.97	-7.58	-10.32
71	8.88	9.50	-71.00	-27.07	19.63	33.66	-9.02	3.00	-23.03	-6.76	-6.65	-17.12	13.15	-54.09	-18.65	9.64	18.60	-14.46	-17.41	-19.37	-3.02	-43.95	-2.53	2.47	-26.72	4.48	-27.38	-40.91
101	-4.03	-2.88	-58.11	-7.51	12.34	2.20	12.09	-3.10	-45.48	-8.63	-18.83	-8.05	-38.68	-70.07	-10.38	13.95	2.82	14.99	-35.08	-21.39	-21.92	-1.58	2.87	-2.15	8.54	-7.24	5.21	10.25
100	-27.82	-2.51	-37.82	-8.68	15.84	1.82	34.85	-29.03	-81.89	-35.60	-63.70	-34.25	-189.88	-45.41	-11.51	17.02	2.27	40.91	-19.70	-6.71	-14.15	14.13	3.93	-2.85	26.87	-9.59	20.14	32.69

Appendix 7 Function values for the low-yielding population in whole shoot material (GS-29) of irrigated wheat

Sample No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
141	0.68	1.22	1.78	-4.53	6.76	5.01	-9.49	-0.40	3.75	-2.38	-5.15	-3.33	2.99	6.18	-3.79	6.55	6.71	-10.27	5.03	12.39	10.93	-5.99	1.65	0.54	-11.96	-4.16	-14.08	-13.55
27	-13.39	-9.92	3.24	-0.17	-17.04	-10.45	-3.92	-7.14	-7.64	-11.08	-2.50	-7.95	-9.85	-2.18	-6.54	-8.71	0.55	-0.40	0.69	-9.38	-1.64	-0.91	-11.92	-5.88	-2.64	7.38	1.97	-0.43
67	-10.64	-13.80	4.57	16.31	-5.76	-16.05	2.43	-2.59	-4.20	7.30	-7.03	-2.43	-16.29	-3.54	18.65	5.83	-1.27	6.88	-18.79	1.81	-4.13	5.45	19.00	17.84	17.46	-9.10	2.92	7.99
94	9.07	24.55	-0.83	-14.29	-8.14	0.27	-12.15	-4.31	10.13	-2.98	13.71	8.59	11.52	25.53	1.31	-42.66	-39.48	-29.59	13.63	-7.10	2.02	-10.35	-28.32	-21.86	-26.63	9.50	-6.29	-12.89
178	1.33	4.76	-3.41	-5.54	7.19	5.18	0.51	-1.86	0.09	-2.69	-4.71	-2.66	-3.41	2.25	-1.87	3.20	1.09	-2.56	0.97	5.19	3.12	-1.09	0.78	-0.94	-3.02	-4.49	-4.28	-2.88
106	-8.23	-53.23	16.12	20.75	-26.55	-46.74	-26.78	16.94	5.13	13.53	5.00	12.72	5.31	-15.02	-2.38	11.90	7.08	-1.42	-10.89	-2.46	-9.61	-7.68	6.16	2.10	-2.09	-9.15	-6.56	-3.31
55	6.10	10.66	3.74	2.41	-3.21	1.73	-3.32	-0.41	12.11	12.09	6.60	4.35	2.42	20.18	22.60	-16.50	-13.62	-9.41	-2.21	3.36	10.43	-0.21	2.87	11.97	-0.15	4.93	-2.50	-5.19
16	6.39	-3.31	3.46	6.00	10.80	2.19	64.51	9.14	12.14	18.13	-2.09	4.32	-48.51	3.75	12.41	17.58	10.33	55.34	-7.11	20.10	10.52	64.81	24.84	21.17	77.21	-12.24	28.06	48.80
110	0.90	-24.91	6.53	16.36	-12.89	-29.57	-16.29	16.62	8.27	23.48	7.60	18.35	7.31	-9.27	8.47	6.80	-2.81	-3.29	-16.23	-1.99	-11.04	-7.42	11.62	6.72	0.23	-11.38	-6.60	-2.51
169	28.20	6.40	3.86	-21.37	25.33	2.38	-5.33	22.10	39.30	3.80	4.08	26.28	18.03	15.39	-25.52	20.54	-5.72	-9.34	30.46	39.12	11.36	-1.59	-2.40	-30.96	-24.08	-29.96	-21.28	-7.57
113	3.76	-14.84	-9.58	19.90	-27.78	-26.94	-15.90	14.44	-1.82	34.32	21.66	21.95	9.72	-28.42	23.21	-13.73	-12.48	-6.57	-52.24	-45.71	-40.80	-22.66	4.78	13.26	1.90	3.32	-1.40	-3.02
172	2.59	1.88	7.72	-2.55	-0.25	-24.34	-11.26	1.16	11.68	1.44	1.19	18.08	5.59	15.93	0.45	-2.53	-43.47	-12.37	8.30	11.87	-5.93	-3.45	-1.56	-25.62	-11.29	-26.48	-10.48	-1.10
82	21.37	21.40	-33.77	-23.37	19.83	11.62	-4.02	5.80	-1.42	-0.71	2.99	11.40	12.13	-12.86	-11.46	1.13	-12.35	-15.87	-3.11	-10.02	-22.14	-25.85	-7.19	-20.97	-23.69	-11.51	-16.14	-11.24
41	30.57	-4.38	3.87	-1.96	-4.87	-4.00	-20.98	39.07	42.23	29.49	32.80	37.72	41.85	3.27	-4.96	-1.55	1.55	-16.07	3.71	1.86	4.46	-12.72	-4.85	-3.66	-18.94	0.82	-14.36	-17.62
98	-1.85	-18.69	3.48	2.74	-16.76	-20.40	-39.81	8.41	2.39	2.96	6.50	8.40	17.52	-8.90	-7.76	-1.05	-0.32	-19.27	-2.89	-8.81	-8.89	-26.66	-6.48	-7.72	-24.77	-0.88	-17.61	-20.00
19	8.43	-3.17	11.03	3.77	-20.50	-5.08	-9.18	11.41	23.73	17.24	23.34	12.35	8.57	13.96	8.00	-20.57	-1.92	-7.30	1.83	-3.06	12.74	-0.63	-7.46	6.88	-3.09	17.03	-0.13	-6.86
50	-5.30	10.82	-9.03	-4.06	-8.51	21.83	-11.12	-14.90	-12.15	-8.60	-0.95	-24.71	0.06	0.84	6.25	-25.17	14.22	-18.49	-5.46	-19.46	9.41	-16.85	-11.60	16.75	-12.97	37.77	-5.44	-27.37
173	-5.07	-1.21	2.03	-11.01	-0.53	-13.71	-15.02	-5.09	-1.63	-17.32	-5.98	1.25	2.02	3.92	-19.08	0.36	-18.63	-13.48	13.68	4.17	-5.84	-10.00	-13.20	-35.79	-26.11	-14.74	-13.32	-7.20
66	-17.74	-22.87	7.54	8.58	-18.50	-20.70	0.84	-3.55	-7.13	-3.54	-4.58	-5.75	-20.06	-6.50	-0.67	0.37	4.01	8.76	-6.17	-5.20	-3.73	5.66	-0.32	2.01	8.48	0.36	6.80	8.00
38	-6.86	-4.20	5.41	6.17	-1.67	-4.15	-3.35	-4.82	-0.58	1.80	-6.78	-5.78	-5.95	5.43	11.64	1.93	1.07	-2.07	-5.33	7.09	6.36	0.58	9.80	12.80	2.36	-3.15	-3.26	-2.35
7	-4.13	-1.55	2.26	3.87	-5.55	8.96	-3.75	-3.84	-0.64	1.94	-1.63	-12.68	-3.74	3.88	10.18	-5.29	18.74	-3.58	-5.60	-0.57	16.04	-1.32	2.90	25.13	0.53	16.61	-1.79	-9.49
29	-10.77	-3.66	0.76	6.68	-10.39	-1.14	-20.12	-9.16	-7.90	-0.62	-4.12	-12.45	1.23	-0.14	13.35	-8.47	5.00	-15.91	-11.28	-6.93	2.92	-15.22	2.69	17.83	-7.38	10.46	-10.16	-19.25
9	-6.55	-9.59	3.61	11.33	0.41	2.84	-0.25	-1.30	-1.64	6.86	-8.27	-11.00	-9.04	-1.45	14.98	10.29	23.00	2.44	-13.79	7.35	11.49	2.21	20.38	35.08	9.31	1.32	-1.79	-2.64
36	-4.16	-3.77	33.23	-3.42	-26.25	-7.31	2.85	-2.40	21.71	-6.53	8.85	-1.10	-10.72	42.32	-7.35	-26.17	-4.20	2.94	35.63	10.03	37.81	25.16	-27.29	-10.13	0.31	20.30	12.43	4.57
115	15.53	-18.55	-2.51	13.16	0.63	-24.65	-8.22	36.13	14.61	46.26	11.78	41.11	12.87	-19.47	9.09	20.07	-5.03	-0.58	-26.25	-0.23	-23.58	-8.39	23.62	5.82	3.04	-28.70	-8.60	0.78

Appendix 7 continued

Sample No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
112	4.93	-10.53	-6.02	13.77	-20.89	-4.83	-10.02	12.93	1.50	27.72	18.53	7.90	6.57	-17.26	18.17	-11.82	9.65	-4.44	-33.58	-29.79	-9.92	-13.05	3.28	27.30	2.22	17.80	-0.44	-7.71
88	16.73	11.69	-16.44	-9.09	10.91	7.19	-6.87	7.80	3.70	6.44	4.82	10.61	12.32	-5.74	-1.17	0.74	-5.96	-14.10	-5.22	-4.18	-9.45	-17.87	-0.41	-4.70	-14.09	-6.65	14.17	-12.07
35	55.91	28.02	-28.84	0.36	7.50	44.22	2.66	23.98	18.05	63.74	34.84	14.79	19.47	-4.34	36.80	-16.36	14.89	-9.44	-33.87	-18.89	3.94	-11.68	9.92	55.29	3.16	27.59	-2.56	-15.94
153	-11.92	-70.05	21.06	32.56	-25.34	-58.08	-26.50	19.13	4.94	18.90	1.76	12.99	3.12	-18.20	1.17	22.57	10.35	1.35	-16.73	1.92	-10.29	-5.20	16.98	8.01	2.05	-16.88	-6.86	-0.95
83	33.16	19.67	-15.84	-23.48	16.01	14.89	1.36	14.97	15.01	4.94	11.72	18.38	11.32	0.60	-13.12	-0.72	-5.68	-7.74	6.77	0.20	-2.39	-6.78	-10.05	-17.47	-14.55	-4.74	-7.35	-6.04
8	1.72	-3.28	1.26	6.98	-5.70	4.49	-8.87	3.65	4.45	12.77	3.96	-1.80	3.38	0.86	14.45	-3.58	14.37	-6.98	-11.03	-1.89	9.52	-5.90	6.85	27.01	-0.72	11.48	-5.30	-12.54
20	2.61	3.93	-7.59	6.31	2.02	8.26	42.77	-0.04	-1.59	13.17	-0.24	-3.01	-39.36	-3.38	23.58	-1.74	6.96	27.99	-22.38	-4.36	0.74	25.34	14.51	30.90	53.82	4.48	25.17	25.55
4	8.63	-6.65	18.66	1.84	-22.42	-8.26	-13.24	14.67	33.30	14.20	25.25	15.24	12.05	19.34	0.66	-17.89	-1.10	-8.59	10.31	1.96	18.69	0.07	-12.06	0.21	-7.60	15.13	-1.59	-8.50
167	25.89	11.17	-4.62	-2.30	-5.37	17.36	64.93	15.70	21.57	24.16	28.70	11.12	-23.05	6.36	10.31	-20.58	8.02	34.87	-3.87	-9.43	12.02	45.34	-5.83	16.90	47.83	26.32	52.29	31.47
71	3.33	-1.06	7.61	-10.64	3.40	1.83	-11.50	3.95	12.59	-5.35	-0.46	1.44	6.34	11.91	-18.15	5.13	5.64	-10.54	20.73	16.90	16.50	-3.67	-8.21	-13.15	-21.32	-3.44	-13.50	-13.40
59	18.22	20.60	-32.96	-6.60	-1.59	20.89	42.21	4.03	-2.90	10.35	16.57	3.71	-18.17	-12.88	10.01	-24.83	0.21	15.30	-21.00	-39.38	-12.45	7.89	-8.41	10.47	23.10	23.23	29.36	16.44
3	1.99	-1.74	13.36	10.40	-13.55	2.35	-6.50	2.93	16.17	17.73	9.38	-0.24	2.06	18.99	23.83	-14.52	7.77	-5.83	-3.36	3.90	26.13	1.96	4.61	31.99	2.66	19.31	-0.67	-8.73
57	19.55	20.81	-4.31	-8.20	3.66	17.83	2.53	4.84	16.19	9.48	12.20	6.18	4.04	15.29	7.31	-15.66	-3.42	-6.87	2.96	0.75	12.91	0.06	-5.06	5.20	-3.01	11.09	-1.07	-5.92
24	2.87	1.74	1.97	1.06	4.05	1.90	14.48	1.54	6.43	6.29	-1.24	0.93	-14.38	7.04	8.04	2.77	0.89	9.26	-2.09	9.48	7.89	14.81	7.86	8.98	14.36	-4.17	6.03	9.70
11	13.34	-2.38	0.26	12.36	9.86	1.69	-14.67	16.34	16.04	40.63	3.18	11.83	17.44	0.34	26.92	15.05	7.75	-12.35	-20.17	13.43	5.04	-11.37	36.64	35.47	-0.84	-11.72	-21.94	-16.45
15	5.24	-1.81	-1.02	2.31	3.69	8.71	63.69	6.64	5.98	10.88	0.89	-0.59	-50.56	-0.86	6.52	6.36	18.86	52.04	-7.13	4.76	9.94	52.25	9.66	20.45	62.80	2.77	35.99	39.31
87	16.73	18.30	1.27	-0.91	20.79	4.22	-20.21	4.09	21.26	17.91	0.11	13.01	26.26	23.79	21.45	4.15	-20.65	-35.82	-0.08	27.76	9.26	-14.73	19.42	6.84	-16.63	-21.58	-38.92	-24.34
21	6.59	3.05	-7.04	2.49	0.09	8.96	51.75	4.43	2.20	12.81	4.48	0.49	-38.52	-3.60	13.04	-3.31	9.55	35.43	-14.54	-6.00	1.89	32.06	6.16	21.26	52.04	7.94	33.61	30.98
92	11.31	-2.84	-1.61	10.98	-15.72	-11.05	-4.42	14.46	11.51	34.44	23.15	21.28	6.44	-2.63	23.31	-15.57	-11.35	-3.54	-21.26	-16.01	-9.35	-4.38	3.75	14.14	4.63	5.53	1.22	-0.60
33	8.49	2.24	-14.10	4.24	-6.63	17.47	-16.97	6.92	-0.60	18.12	11.79	-1.95	14.99	-12.90	16.13	-11.29	24.22	-18.03	-26.84	-24.08	0.89	-28.75	2.51	37.74	-7.69	28.73	-10.35	-32.34
156	8.28	0.07	-3.47	-4.40	-16.04	-8.64	-6.42	8.46	6.60	4.63	19.41	15.11	6.22	-2.22	-4.86	-20.21	-13.28	-6.78	-0.30	-19.58	-10.02	-7.51	-19.60	-13.75	-8.86	8.18	0.11	-3.00
53	16.72	7.03	-9.56	-0.23	-0.24	12.71	-9.73	11.07	8.48	19.30	13.73	6.89	15.31	-2.75	10.97	-7.94	8.22	-14.37	-12.13	-9.32	2.01	-15.79	1.64	17.80	-7.29	12.28	-9.24	-19.08
158	-7.06	-18.53	8.85	4.60	-16.42	-17.79	-11.61	2.51	1.52	0.20	1.46	1.30	-0.60	-1.97	-3.97	-0.89	2.38	-2.60	-0.66	-2.28	-0.39	-3.08	-3.60	-2.17	-3.98	0.66	-2.59	-3.31
77	8.97	16.80	-9.63	-2.41	10.25	20.61	10.22	-0.92	2.37	7.72	0.07	-2.97	-5.82	4.72	15.73	-3.90	4.33	0.20	-8.39	1.17	7.76	2.66	7.41	19.83	6.54	5.09	0.97	-0.73
93	3.52	4.62	-0.40	-1.72	10.34	22.86	84.71	0.45	4.81	3.29	-4.37	-10.09	-72.64	6.38	4.88	6.77	27.15	56.48	-0.65	12.82	25.00	71.52	8.64	24.07	64.90	6.71	38.79	37.52

Appendix 7 continued

Sample No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
14	5.75	8.08	4.31	-7.03	-19.83	-16.09	-8.84	0.59	12.30	0.01	18.92	17.40	6.32	18.15	-1.18	-38.61	-44.23	-14.09	11.22	-10.25	-4.50	-3.80	-29.02	-28.82	-14.08	4.94	-0.13	-2.04
116	-3.10	-5.24	0.93	8.62	-10.72	-13.55	-10.39	-0.47	-0.77	7.97	1.97	3.19	0.91	-1.29	15.20	-7.07	-10.67	-7.15	-13.78	-7.00	-7.38	-7.35	4.69	7.64	-0.63	-1.32	-4.00	-4.01
46	26.59	24.06	8.66	-2.43	1.11	23.02	-25.40	7.94	46.66	24.56	20.73	8.38	43.41	47.60	22.98	-23.20	-1.24	-48.74	9.02	15.06	46.43	-11.65	-0.21	22.14	-23.59	20.20	-23.59	-49.95
61	1.50	8.12	-3.09	12.55	0.64	8.96	-27.72	-3.67	0.49	19.72	-0.34	-4.73	15.02	5.75	46.91	-7.79	1.45	-34.65	-26.29	-0.88	6.94	-26.65	22.66	49.41	-6.85	7.11	-25.00	-37.61
54	9.08	-1.11	-5.64	2.20	-7.53	0.52	0.04	10.36	5.42	15.36	13.19	8.39	1.36	-6.27	7.11	-8.17	3.52	-0.51	-12.36	-13.35	-3.81	-2.74	-0.74	9.97	2.38	9.04	1.69	-1.32
120	3.89	-1.27	7.53	0.31	-0.55	-2.93	-7.63	4.72	13.28	6.37	2.56	5.30	4.12	11.54	2.86	0.39	-1.77	-7.06	3.69	11.20	10.48	-1.26	2.18	1.96	-5.06	-3.40	-7.31	-6.67
42	1.19	7.13	-11.66	0.66	-14.61	6.82	-7.26	-3.44	-5.95	3.85	9.05	-3.82	2.01	-4.91	13.42	-29.27	-0.07	-11.80	-16.16	-31.83	-4.73	-14.67	-8.40	13.67	-4.44	27.36	-0.78	-12.28
121	14.97	-4.57	7.52	3.78	0.18	-11.21	-24.14	20.52	28.49	25.75	11.76	26.51	28.33	7.77	6.46	4.72	-8.50	-18.43	-0.73	12.20	2.78	-11.74	8.27	1.32	-12.79	-13.29	-21.48	-15.08
122	2.32	-8.28	7.51	7.68	1.02	-20.51	-28.36	7.78	11.10	14.61	0.13	15.08	16.47	4.20	9.88	9.84	-14.89	-18.77	-5.17	13.38	-3.64	-14.43	15.46	0.81	-11.12	-24.98	-26.01	-12.82
37	13.92	0.99	-5.19	2.03	0.74	-15.41	8.38	13.60	10.11	20.85	10.29	29.18	-2.02	-3.43	9.35	-0.35	-26.32	5.08	-11.55	-3.14	-19.61	3.82	6.13	-5.25	10.05	-18.84	4.00	14.62
32	2.90	-3.71	-3.06	4.97	-3.71	3.44	-6.99	5.34	1.85	11.74	3.83	0.05	3.00	-5.52	9.82	-0.90	13.30	-5.22	-13.88	-5.54	2.01	-7.72	5.99	20.45	-0.84	7.52	-4.97	-9.89
10	6.49	4.43	4.38	5.94	3.58	10.14	-16.78	3.41	13.31	18.18	1.95	-0.19	12.92	13.91	23.42	-0.41	8.88	-19.67	-6.06	12.44	21.27	-9.32	15.82	32.64	-6.05	4.21	-18.48	-25.79
129	-7.02	-80.59	73.53	50.11	-39.75	-103.83	-78.63	31.38	43.54	41.95	12.03	39.82	28.93	9.68	9.93	14.97	-9.45	-12.18	-1.56	25.16	3.94	-5.84	20.02	3.83	-6.09	-26.82	-21.67	-8.96
28	20.20	-0.26	17.70	8.00	-17.48	-12.15	1.75	21.65	52.80	42.57	36.99	34.86	5.04	27.40	21.00	-21.48	-18.22	0.53	1.63	4.62	13.43	13.13	-0.33	7.86	9.09	6.21	7.34	5.54
95	4.65	-10.52	20.31	-0.50	-41.34	-27.06	-4.49	12.54	27.77	6.02	33.06	23.67	2.41	16.72	-7.93	-31.55	-19.44	-0.60	16.25	-7.42	4.50	6.71	-32.55	-21.99	-3.40	13.17	9.09	4.31
75	6.48	7.95	-1.67	22.61	-0.46	0.89	34.22	1.31	6.59	44.66	4.81	5.35	-25.58	7.69	73.79	-9.24	-10.83	18.65	-39.42	-0.40	1.48	26.98	36.31	57.79	82.20	0.48	22.41	26.38
45	1.11	10.67	-7.50	-2.90	6.23	10.01	-22.77	-5.69	-3.05	-0.31	-4.32	-5.87	11.49	2.38	8.47	-3.11	-0.63	-31.76	-5.69	-0.17	2.21	-27.69	3.36	8.28	-22.06	0.97	-26.82	-32.86
51	2.00	9.06	-18.72	-5.40	-6.58	12.80	0.03	-3.65	-9.90	-1.87	4.82	-6.39	-2.49	-10.43	2.23	-19.85	5.22	-4.88	-11.67	-30.43	-6.64	-9.99	-11.86	5.90	-3.39	22.91	1.31	-6.75
152	-4.77	-76.43	30.18	39.30	-58.39	-82.97	-68.53	33.99	18.57	36.64	23.92	35.18	27.76	-12.19	3.84	2.36	-1.15	-10.23	-14.57	-8.17	-12.80	-17.93	4.40	3.33	-7.36	-5.17	-11.49	-10.17
2	-1.00	4.68	11.57	-3.10	-16.55	4.06	-12.14	-4.62	9.97	-2.72	7.39	-4.87	3.25	25.91	2.21	-28.22	-0.43	-15.23	13.02	0.11	25.82	-2.09	-17.47	2.17	-12.75	25.93	-2.84	-15.70
17	9.08	12.48	-6.38	7.98	11.79	16.42	-10.66	1.16	4.81	25.41	-0.60	-0.98	10.29	5.17	41.52	0.92	5.01	-19.09	-23.72	5.86	8.69	-14.00	30.28	48.44	-1.14	0.39	-19.05	-22.87
18	1.18	14.87	-5.96	8.88	16.89	13.81	3.54	-8.14	-1.88	14.42	-11.15	-8.10	-6.34	7.71	48.19	3.55	-1.20	-3.71	-24.70	10.94	7.13	0.00	39.21	47.07	12.08	-6.52	-5.59	-3.41
5	12.12	15.33	-15.47	0.26	-7.44	20.49	-19.77	2.13	1.18	15.30	16.42	-0.40	21.03	-1.98	21.79	-29.28	6.06	-32.54	-19.35	-27.22	1.61	-33.85	-3.48	28.03	-14.46	33.98	-11.72	-39.03
85	3.46	-7.16	8.35	9.15	1.95	-20.58	-59.94	8.48	13.51	18.43	0.51	17.01	39.39	6.23	13.86	10.00	-16.95	-43.24	-6.07	15.86	-2.73	-33.30	19.11	2.94	-26.36	-26.92	-54.80	-32.37
126	4.08	-44.02	36.88	11.54	-54.92	-55.92	13.45	36.40	43.73	22.89	41.59	43.07	-12.21	5.98	-9.31	-10.30	-6.75	38.72	8.79	-2.49	2.12	49.40	-15.71	-14.16	28.13	3.82	45.05	47.89

Appendix 7 continued

Sample No	N/P	N/K	Fe/N	Mn/N	N/Zn	N/Cu	N/B	K/P	Fe/P	Mn/P	Zn/P	Cu/P	B/P	Fe/K	Mn/K	K/Zn	K/Cu	K/B	Fe/Mn	Fe/Zn	Fe/Cu	Fe/B	Mn/Zn	Mn/Cu	Mn/B	Zn/Cu	Zn/B	Cu/B
159	-7.27	-12.93	4.17	5.18	-6.14	-17.34	-7.66	-0.26	-1.80	0.57	-3.93	0.92	-2.90	-3.38	1.26	4.64	-3.92	-1.95	-5.33	1.04	-5.60	-3.06	4.13	-0.88	-1.12	-9.76	-4.25	-0.87
47	-6.08	-78.12	59.71	30.61	-81.56	-91.51	-43.93	32.05	36.48	25.62	32.62	36.30	14.59	4.24	-3.26	-6.47	-4.63	-2.80	3.27	-1.16	1.69	-0.51	-7.36	-6.08	-3.88	1.65	-0.78	-1.53
44	17.83	10.82	2.34	-13.36	-18.78	9.79	-27.81	9.28	24.19	3.47	35.16	9.70	35.59	17.75	-8.05	-41.60	-1.12	-37.73	17.17	-12.24	17.09	-19.32	-41.28	-8.60	-46.34	38.30	-10.18	-38.67
49	7.26	-29.38	14.20	19.50	-43.83	-80.28	-44.78	31.75	25.63	41.43	40.40	70.88	35.62	-3.38	9.21	-13.39	-43.84	-16.24	-11.40	-14.97	-30.44	-18.29	-2.49	-14.01	-9.53	-12.73	-8.16	-3.44
155	18.17	30.17	-7.92	-1.26	-1.96	22.83	8.02	0.12	11.10	18.68	16.93	2.80	-0.15	17.28	33.04	-36.17	-7.83	-5.02	-8.61	-9.59	11.64	2.10	-1.30	25.46	6.00	26.03	5.27	-2.82
70	-1.16	3.39	12.88	5.62	1.88	-23.24	-9.79	-3.96	10.81	7.02	-3.86	10.98	1.82	26.06	21.10	-1.38	-45.65	-12.00	1.02	22.04	0.18	-0.23	13.21	-4.26	-2.12	-29.79	-10.82	-0.53
109	-39.29	-85.53	25.93	41.34	-108.02	-95.23	-45.40	3.34	-7.29	4.50	9.35	4.12	-0.54	-20.24	2.08	-13.66	-2.37	-2.13	-19.29	-35.67	-22.04	-11.09	-7.87	0.83	-0.97	9.99	1.86	-1.45
43	7.11	13.55	-23.37	-3.97	-16.75	16.31	-11.01	-0.95	-6.92	4.07	18.42	-2.64	9.02	-10.69	8.99	-42.74	3.43	-20.26	-18.00	-55.52	-8.03	-29.58	-19.42	11.89	-12.76	45.29	-2.16	-23.26
119	22.10	11.80	-5.07	9.32	-5.86	39.22	-1.86	12.10	17.55	48.75	25.38	-0.75	10.00	6.30	44.35	-22.15	34.37	-8.28	-24.10	-10.61	29.76	-4.28	9.75	90.66	5.91	53.53	-0.35	-22.04
1	0.12	5.50	4.29	-3.46	-11.65	-5.17	-27.08	-3.75	5.29	-1.89	5.87	2.28	12.92	15.04	2.35	-22.55	-17.97	-31.13	6.21	-3.46	3.93	-16.62	-13.55	-7.93	-26.98	7.18	-13.65	-21.84
69	5.27	27.52	-6.28	-0.23	-8.63	10.63	-6.89	-9.78	1.60	7.07	9.84	-1.55	4.54	17.76	33.94	-47.62	-21.85	-23.56	-8.73	-15.58	4.13	-10.10	-5.24	15.51	-5.04	23.51	-2.65	-14.20
108	-24.28	-60.21	7.00	23.40	-81.81	-62.12	-120.74	4.79	-12.42	2.78	11.67	4.12	24.35	-33.90	-2.78	-14.86	1.00	-32.17	-23.77	-54.22	-32.43	-74.45	-13.32	-1.89	-33.76	13.94	-18.25	-34.58
125	-6.71	-29.79	36.08	7.97	-30.71	-39.49	-48.27	8.12	19.67	3.59	8.26	11.43	15.89	14.22	-6.17	-4.07	-6.88	-17.77	12.80	8.86	9.51	-7.85	-7.80	-10.79	-21.77	-1.95	-14.16	-15.19
80	2.60	16.73	-4.31	6.52	-6.63	12.83	-3.31	-7.33	0.63	13.44	5.50	-5.65	0.38	11.67	43.64	-29.64	-4.73	-12.49	-18.16	-10.44	8.58	-5.19	5.42	38.32	2.63	23.03	-1.06	-11.00
60	5.82	53.60	-17.95	-0.11	14.72	37.40	20.39	-22.17	-5.04	7.84	-4.65	-14.57	-15.89	19.57	63.81	-25.92	-14.13	-3.28	-21.08	-2.34	9.62	4.53	15.73	45.45	17.62	12.28	4.25	0.22
124	-17.13	-36.81	46.44	13.46	-36.43	-46.67	-38.60	2.01	13.52	0.55	2.49	4.23	4.78	16.98	-2.49	-3.58	-6.06	-10.34	11.59	11.64	12.58	-1.75	-4.55	-6.19	-11.21	-1.94	-8.16	-8.41
34	-30.77	-50.14	69.35	21.10	-44.91	-45.99	-117.11	-1.32	12.48	-1.46	-1.42	-3.80	18.76	22.97	-0.63	-1.61	5.29	-36.24	13.91	19.03	28.29	-15.39	-1.71	2.83	-35.20	3.28	-32.32	-42.64
157	-16.25	-39.99	39.51	19.19	-68.92	-70.13	-39.15	3.71	10.94	5.02	14.06	12.80	5.39	9.98	2.31	-21.18	-21.35	-9.53	3.12	-6.52	-1.53	-3.68	-12.67	-9.92	-7.55	4.27	-1.33	-3.35
123	-20.68	-26.86	69.00	23.23	-71.02	-39.94	-87.50	-3.77	20.45	4.74	11.11	-0.17	17.74	44.06	15.91	-34.95	-10.48	-39.57	11.82	5.80	32.98	-8.82	-9.62	8.38	-22.34	22.59	-13.21	-33.33
32	-86.02	-211.09	203.91	167.18	-179.05	-189.83	-241.89	7.13	18.14	23.69	5.01	3.11	16.61	13.91	23.42	-0.41	8.88	-19.67	-6.06	12.44	21.27	-9.32	15.82	32.64	-6.05	4.21	-18.48	-25.79

Appendix 8 Index values in leaf tissue (GS-39) for irrigated wheat

Sample No	IN	IP	IK	IFe	IMn	IZn	ICu	IB
123	118.27	146.97	-213.98	-9.15	-20.75	5.52	-2.06	-24.82
151	17.18	16.14	72.65	-1.30	22.94	15.07	2.83	-145.51
150	45.66	28.94	-4.28	-52.08	-1.59	36.77	25.35	-78.76
93	110.40	-202.89	14.30	-7.42	-65.68	97.03	70.46	-16.20
19	16.50	10.43	90.51	-36.98	15.32	-123.23	-4.25	31.71
152	27.44	-31.96	-3.23	-37.03	-9.00	40.36	33.64	-20.23
138	58.47	-16.06	17.09	-67.28	-17.97	91.53	26.92	-92.71
119	57.77	40.86	-161.81	-10.51	-159.03	82.80	18.00	131.92
33	4.76	2.15	61.84	-34.61	-77.69	19.41	6.18	17.97
32	14.93	256.41	57.20	-3.58	6.48	-59.87	7.54	-279.11
181	70.86	38.27	-40.27	-70.31	-21.61	-45.36	46.03	22.37
14	94.94	-41.74	47.75	-46.51	-30.92	77.08	58.42	-159.02
148	-20.96	12.34	51.67	-14.77	16.27	-49.96	29.15	-23.74
175	33.97	49.21	18.30	-54.71	-122.38	36.02	18.23	21.36
92	52.68	174.36	-82.04	-77.06	15.89	33.81	46.83	-164.48
121	90.81	-33.98	-65.03	-25.09	-60.03	-11.34	34.59	70.08
106	-3.53	-17.35	61.44	-34.64	-2.36	-84.94	-21.08	102.46
48	24.07	-25.83	-15.70	-51.27	35.68	4.80	-42.27	70.53
6	130.42	-65.29	48.98	3.64	-206.19	26.53	32.37	29.55
171	101.02	-28.44	-54.96	-53.62	35.00	-77.33	8.25	70.08
113	-21.31	17.76	-4.89	-86.68	107.45	23.08	-12.53	-22.89
147	91.51	-61.62	23.33	-38.99	4.79	68.55	85.27	-172.84
160	101.33	68.79	-4.95	-11.09	-138.47	-8.20	20.62	-28.03
120	31.19	-15.58	-53.39	-58.11	15.64	-41.52	29.43	92.34
108	68.97	-47.22	13.55	-62.06	32.42	77.12	22.45	-105.25
143	128.70	-34.55	45.61	-25.27	-110.67	14.35	54.87	-73.03
168	-14.22	69.13	-40.69	-73.34	-26.52	68.85	-30.01	46.81
83	35.81	-15.35	-32.31	-37.01	-41.15	-5.21	-11.95	107.17
122	64.60	-4.63	-51.66	-44.06	-4.80	-25.87	13.48	52.95
43	40.86	26.56	11.13	-50.61	-39.99	37.79	3.30	-29.05
98	30.67	37.32	107.11	-153.35	55.89	122.98	-258.63	58.00
35	-17.12	-48.82	59.28	-33.89	25.59	46.30	-19.79	-11.55
90	57.89	-138.71	-1.37	-79.10	-22.69	90.65	49.20	44.13
88	75.71	102.31	18.21	-34.98	-149.08	44.30	54.18	-110.66
164	33.64	-56.83	24.54	-53.00	57.38	46.08	32.62	-84.43
84	-16.61	-176.96	28.79	-93.87	61.17	159.71	-5.05	42.83
135	45.96	-68.24	-10.10	-115.49	26.08	3.45	18.10	100.26
103	-21.40	27.11	83.91	-7.50	105.36	-171.70	-14.23	-1.54
126	83.78	42.06	55.16	-10.57	-187.58	-12.97	27.09	3.03
169	51.15	37.16	-57.02	-58.83	-113.84	14.57	-13.19	140.01
109	-23.60	-30.55	-16.03	-76.93	-90.56	203.96	-35.03	68.74
157	78.62	-23.98	55.23	-8.56	-142.71	16.67	55.53	-30.78

Appendix 8 continued

Sample No	IN	IP	IK	IFe	IMn	IZn	ICu	IB
68	90.86	54.69	35.93	-40.60	29.82	30.37	-61.80	-139.27
85	-77.65	18.16	8.15	-110.13	89.71	67.80	-29.35	33.32
144	15.13	-62.49	2.16	-101.04	49.46	35.21	6.08	55.49
174	45.91	-9.40	40.29	-58.91	-110.13	45.52	37.90	8.82
156	81.39	-15.08	31.12	-15.52	-46.59	12.87	30.95	-79.14
78	13.82	-37.75	8.17	-52.99	-3.74	60.48	-63.94	75.95
132	21.22	111.15	1.58	-111.60	-72.25	55.77	5.90	-11.77
86	-56.73	143.34	17.74	-128.94	118.08	-9.46	-29.64	-54.39
97	-0.22	129.50	-20.62	-84.58	-52.11	24.66	2.83	0.53
105	-3.65	67.22	65.24	-114.68	-10.84	-32.96	-34.71	64.39
142	59.89	249.11	-7.25	-154.47	25.71	49.54	13.29	-235.82
137	64.72	67.06	17.02	-93.72	53.16	34.50	34.43	-177.17
115	50.64	156.45	-36.06	-42.27	-20.13	22.42	-0.89	-130.14
124	34.24	113.76	-161.18	-16.78	-86.19	-17.29	-31.66	165.10
125	-29.56	110.24	5.10	-93.94	-100.01	10.92	-3.32	100.57
5	86.41	43.08	-16.26	-153.77	-76.00	52.09	-64.90	129.35
161	22.35	71.94	45.57	-38.29	-116.65	31.48	63.02	-79.42
40	44.80	334.58	62.57	-89.67	32.70	91.78	13.92	-490.67
130	101.35	10.73	6.63	-69.83	1.28	-53.68	11.97	-8.45
176	13.96	141.47	24.55	-102.40	-59.73	-29.50	38.89	-27.26
42	125.39	38.53	54.23	-28.46	-199.01	-13.06	34.36	-11.99
162	43.26	226.61	109.41	-80.47	51.01	43.66	-422.11	28.64
159	67.60	155.27	75.15	-25.72	22.04	39.66	46.88	-380.88
87	-4.89	116.52	54.31	-80.37	19.82	-33.70	-12.81	-58.88
67	43.55	-14.31	83.37	-88.93	58.57	59.85	-19.31	-122.80
145	64.85	107.97	61.64	-150.40	17.26	110.05	54.76	-266.12
154	125.69	334.17	93.69	-131.16	176.08	40.96	24.13	-663.56
170	57.49	134.36	57.93	-64.30	-149.27	-28.16	10.56	-18.60
131	123.80	180.80	-7.10	-108.42	-10.24	-110.30	-10.39	-58.14
163	90.06	78.65	47.79	-77.97	-150.60	15.89	3.85	-7.67
177	32.10	28.49	37.10	-126.96	-53.29	48.34	30.15	4.07
127	-16.47	237.81	10.60	-209.51	-157.01	52.57	-3.65	85.65
3	-24.87	96.66	100.94	-197.86	-68.41	94.82	-11.72	10.44
136	58.00	41.03	-1.26	-206.37	31.24	18.71	12.00	46.66
133	18.90	38.20	29.70	-121.12	-43.24	63.11	32.60	-18.15
158	90.45	48.00	-55.10	-151.41	95.21	3.38	0.76	-31.29
173	72.28	-13.72	18.83	-91.48	-114.76	-1.68	42.37	88.17
104	88.03	-47.26	50.04	-107.97	-49.79	29.00	25.85	12.09
111	62.39	-74.27	63.07	-80.65	20.72	-75.95	23.39	61.29
41	37.73	-41.86	95.12	-44.39	2.18	-42.61	24.17	-30.34
81	-0.80	131.74	24.95	-141.00	-27.89	14.16	-10.68	9.52
18	54.22	66.08	47.03	-220.58	81.16	-17.99	-39.35	29.43
79	46.37	124.09	58.08	-419.33	18.73	77.66	-12.34	106.75

Appendix 8 continued

Sample No	IN	IP	IK	IFe	IMn	IZn	ICu	IB
99	21.23	460.89	130.28	-135.98	-38.91	-75.78	-11.67	-350.07
53	104.99	122.11	125.31	-284.22	-20.83	67.42	-46.00	-68.79
54	62.58	-2.54	-27.18	-181.01	121.20	-48.70	-88.97	164.61
59	-93.76	190.20	135.58	-241.35	6.49	126.06	-22.64	-100.59
4	77.54	195.22	-38.38	-300.38	34.89	-21.24	-86.34	138.69
96	107.24	30.80	32.79	-187.60	-36.28	15.93	-3.47	40.59
166	88.07	233.53	23.81	-302.79	-85.43	14.82	-30.90	58.89
71	160.72	28.54	80.02	-231.88	-61.85	-36.92	-114.22	175.59
101	85.34	126.79	112.00	-253.63	17.82	-28.63	28.49	-88.19
100	68.68	462.17	90.60	-191.54	-8.14	-83.24	20.94	-359.47

Appendix 9 Index values in shoot material (GS-29) for irrigated wheat

Sample No	IN	IP	IK	IFe	IMn	IZn	ICu	IB
141	6.94	3.83	-1.01	34.07	-25.51	-50.73	-35.91	68.32
27	-57.79	59.55	2.94	-17.82	-38.92	53.91	1.66	-3.52
67	-64.69	35.86	7.54	-18.82	115.34	-34.09	18.27	-59.42
94	28.73	-45.74	-167.42	33.04	-106.41	103.13	45.25	109.41
178	27.92	13.89	-5.27	7.11	-14.24	-29.84	-9.49	9.92
106	-198.39	-50.40	105.14	-24.41	48.96	0.22	65.74	53.15
55	5.81	-43.28	-93.37	47.41	54.00	22.51	-16.29	23.20
16	71.11	0.48	79.55	107.68	166.87	-59.59	21.15	-387.24
110	-105.66	-82.52	43.01	-31.15	83.12	-13.91	63.92	43.18
169	74.49	-141.77	31.31	137.90	-131.01	-129.75	71.61	87.22
113	-92.04	-104.02	1.71	-201.23	149.62	106.03	82.56	57.37
172	-36.55	-41.72	-75.48	46.14	-47.43	-43.31	142.81	55.54
82	127.33	-51.55	-18.36	-109.19	-84.27	-28.42	55.51	108.94
41	-5.58	-253.72	29.07	46.69	-8.60	28.67	20.95	142.54
98	-103.73	-44.33	23.14	-50.28	-38.15	21.09	26.61	165.64
19	-44.29	-105.08	-37.16	59.60	23.52	91.83	-24.17	35.75
50	20.80	66.55	-62.25	-52.69	-8.78	96.12	-152.05	92.31
173	-26.56	31.83	-20.47	6.33	-136.19	-24.84	82.76	87.15
66	-95.09	62.37	39.63	-15.54	20.70	26.22	20.31	-58.59
38	-31.81	28.97	-16.75	18.95	49.89	-30.33	-21.07	2.15
7	-12.16	24.71	-6.48	14.06	50.14	21.71	-107.65	15.67
29	-53.53	43.79	-38.08	-37.78	43.82	19.28	-66.77	89.28
9	-28.07	30.94	30.49	7.78	111.73	-47.18	-87.36	-18.32
36	-68.46	-5.64	-61.03	205.88	-90.04	111.26	-32.99	-58.98
115	-45.90	-178.31	79.52	-65.81	127.24	-69.60	118.02	34.83
112	-49.08	-80.08	15.93	-108.12	126.04	95.11	-39.81	40.01
88	65.17	-62.43	-16.29	-55.19	-17.80	-23.05	18.11	91.48
35	166.79	-230.79	-47.42	-75.62	203.16	77.70	-147.08	53.27
153	-245.50	-48.91	140.49	-22.50	96.39	-38.11	78.91	39.23
83	124.41	-109.50	-6.32	-2.43	-80.51	-5.80	27.73	52.42
8	-19.87	-28.14	-4.57	-2.73	78.37	14.47	-81.21	43.69
20	60.86	28.48	9.03	-13.22	164.67	18.97	-28.81	-239.99
4	-62.45	-123.33	-26.26	102.33	-13.04	89.19	-17.92	51.49
167	120.90	-104.08	10.16	67.37	94.94	148.53	-38.02	-299.79
71	-0.96	-21.85	11.48	82.57	-97.54	-34.61	-19.35	80.26
59	139.89	-31.82	-23.01	-113.68	59.92	143.36	-22.21	-152.47
3	-41.22	-50.02	-50.74	77.15	94.59	47.57	-96.52	19.18
57	76.88	-72.48	-64.53	43.86	2.76	38.53	-43.35	18.32
24	22.00	-2.45	-2.37	45.53	48.69	-23.53	-4.85	-83.03
11	-4.78	-118.80	1.92	3.56	171.36	-105.47	-42.85	95.05
15	78.24	21.53	80.05	63.92	119.75	15.18	-22.00	-356.66
87	39.48	-99.36	-111.77	68.52	48.17	-132.53	10.58	176.90

Appendix 9 continued

Sample No	IN	IP	IK	IFe	IMn	IZn	ICu	IB
21	74.98	7.52	33.62	4.96	122.34	49.09	-18.11	-274.39
92	-32.08	-122.58	-33.83	-43.72	112.51	73.43	32.75	13.53
33	14.47	-57.75	-3.64	-106.39	97.88	69.66	-143.34	129.11
156	-14.88	-68.71	-24.80	-36.50	-46.54	103.12	49.63	38.68
53	36.28	-91.50	-18.26	-39.07	54.34	32.63	-65.21	90.80
158	-84.86	0.68	25.87	1.99	-8.27	22.73	15.31	26.56
77	78.89	-9.41	-37.54	0.66	63.22	-8.82	-61.32	-25.67
93	128.16	75.03	74.96	119.48	104.71	2.57	-78.35	-426.57
14	-28.21	-61.30	-121.39	27.43	-91.33	121.45	104.06	49.31
116	-52.53	-9.69	-34.04	-36.64	57.27	16.75	24.45	34.44
46	43.16	-178.27	-159.89	161.79	34.43	24.58	-152.12	226.32
61	-17.96	-27.99	-105.45	-43.73	170.70	-32.86	-116.21	173.51
54	4.43	-63.15	5.48	-38.76	48.63	53.72	-12.17	1.81
120	-16.33	-40.23	-16.86	56.45	4.93	-21.37	-5.71	39.12
42	4.27	-2.90	-60.22	-89.91	34.91	119.75	-59.15	53.25
121	-36.06	-156.34	-11.35	46.28	33.51	-48.37	40.32	131.99
122	-69.00	-67.49	-21.84	12.94	42.49	-90.56	65.47	127.99
37	11.78	-95.92	-14.89	-28.99	54.71	-7.94	129.22	-47.97
32	-9.99	-28.70	11.92	-31.86	66.01	10.54	-56.56	38.63
10	-2.46	-56.06	-49.54	49.93	96.00	-43.75	-103.12	109.00
129	-433.46	-190.63	85.71	148.45	121.31	-56.86	163.19	162.29
28	-33.65	-214.11	-65.67	130.72	86.56	85.21	43.28	-32.33
95	-98.58	-110.12	-37.31	84.85	-76.60	168.17	78.80	-9.22
75	28.14	-43.62	-89.53	1.25	356.77	1.50	-18.09	-236.42
45	15.66	6.63	-62.71	-39.51	0.52	-36.48	-59.58	175.46
51	41.42	17.49	-24.02	-97.79	-2.72	97.77	-53.34	21.18
152	-360.58	-171.30	109.74	-16.91	94.72	67.07	123.78	153.48
2	-29.43	-7.39	-81.29	84.31	-44.69	92.60	-78.11	64.00
17	37.51	-49.17	-71.18	-19.57	176.21	-68.11	-102.80	97.11
18	47.37	20.00	-80.29	-6.75	194.56	-93.84	-71.80	-9.26
5	35.95	-67.78	-88.78	-95.07	66.79	106.10	-129.60	172.39
85	-99.76	-100.78	-54.64	1.85	43.20	-128.13	48.88	289.39
126	-185.76	-179.55	105.42	144.40	14.59	173.90	161.84	-234.85
159	-60.67	14.68	13.56	-13.97	14.47	-21.61	37.55	15.99
47	-391.51	-171.58	95.30	103.72	32.39	130.05	133.63	68.02
44	2.88	-135.23	-91.68	46.98	-131.33	177.17	-84.42	215.63
49	-224.71	-252.96	-18.18	-38.66	55.51	94.20	248.73	136.07
155	86.41	-67.64	-129.39	16.00	89.23	97.25	-78.15	-13.70
70	-47.42	-21.65	-113.54	72.76	39.55	-80.22	113.22	37.30
109	-440.75	25.82	88.86	-89.69	59.20	186.42	111.48	58.65
43	36.55	-28.10	-72.37	-152.11	6.80	195.98	-94.79	108.04
119	61.15	-135.13	-46.41	9.55	232.83	107.43	-270.32	40.90
1	-39.11	-20.82	-98.29	14.67	-57.67	50.61	0.39	150.23

Appendix 9 continued

Sample No	IN	IP	IK	IFe	IMn	IZn	ICu	IB
69	34.41	-16.97	-182.04	-17.21	54.74	107.76	-47.68	66.99
108	-379.56	-11.02	55.66	-224.18	-1.79	171.57	51.02	338.29
125	-199.01	-60.25	1.14	93.29	-47.77	25.86	45.84	140.89
80	20.02	-9.57	-126.24	-17.22	128.12	68.76	-94.67	30.79
60	149.99	48.66	-202.48	-12.69	171.40	9.68	-104.97	-59.61
124	-235.55	-10.44	4.34	111.00	-22.02	25.32	44.10	83.24
34	-379.38	7.52	-6.09	150.66	-28.98	-1.25	-40.14	297.66
157	-293.14	-35.67	-20.65	51.81	-6.74	126.30	108.11	69.97
123	-338.23	-29.41	-121.88	175.29	8.47	130.28	-47.03	222.51
32	-1278.97	12.32	169.70	254.29	262.75	141.94	100.15	337.80

Appendix 10 Interpretation of the nutrients in leaf tissue (GS-39) for irrigated wheat. H = high, A = adequate, D =deficient.

Sample No	N	P	K	Fe	Mn	Zn	Cu	B
123	H	H	D	A	A	A	A	A
151	A	A	H	A	A	A	A	D
150	H	A	A	D	A	H	A	D
93	H	D	A	A	A	H	A	A
19	A	A	H	A	A	D	A	A
152	H	D	A	D	A	H	H	A
138	H	A	A	D	A	H	A	D
119	A	A	D	A	D	A	A	H
33	A	A	H	D	D	A	A	A
32	A	H	A	A	A	A	A	D
181	H	A	A	D	A	D	H	A
14	H	A	A	A	A	H	A	D
148	A	A	H	A	A	D	H	A
175	A	H	A	D	D	A	A	A
92	A	H	D	A	A	A	A	D
121	H	A	D	A	D	A	A	H
106	A	A	H	A	A	D	A	H
48	A	A	A	D	H	A	D	H
6	H	A	A	A	D	A	A	A
171	H	A	D	D	A	D	A	H
113	A	A	A	D	H	A	A	A
147	H	A	A	A	A	H	H	D
160	H	H	A	A	D	A	A	A
120	A	A	D	D	A	A	A	H
108	H	A	A	D	A	H	A	D
143	H	A	A	A	D	A	A	D
168	A	H	A	D	A	H	A	H
83	H	A	A	D	D	A	A	H
122	H	A	D	D	A	A	A	H
43	H	A	A	D	D	H	A	A
98	A	A	H	D	A	H	D	A
35	A	D	H	D	A	H	A	A
90	A	D	A	D	A	H	A	A
88	H	H	A	A	D	A	A	D
164	A	D	A	D	H	A	A	D
84	A	D	A	D	A	H	A	A
135	A	D	A	D	A	A	A	H
103	A	A	H	A	H	D	A	A
126	H	A	H	A	D	A	A	A
169	A	A	A	A	D	A	A	H
109	A	A	A	D	D	H	A	H

Appendix 10 continued

Sample No	N	P	K	Fe	Mn	Zn	Cu	B
157	H	A	H	A	D	A	H	A
68	H	A	A	A	A	A	D	D
85	D	A	A	D	H	H	A	A
144	A	D	A	D	H	A	A	H
174	H	A	A	D	D	H	A	A
156	H	A	A	A	D	A	A	D
78	A	A	A	D	A	H	D	H
132	A	H	A	D	D	H	A	A
86	A	H	A	D	H	A	A	A
97	A	H	A	D	D	A	A	A
105	A	H	H	D	A	A	A	H
142	A	H	A	D	A	A	A	D
137	A	A	A	D	A	A	A	D
115	A	H	A	A	A	A	A	D
124	A	H	D	A	D	A	A	H
125	A	H	A	D	D	A	A	H
5	H	A	A	D	A	A	A	H
161	A	H	A	A	D	A	H	D
40	A	H	A	A	A	A	A	D
130	H	A	A	D	A	D	A	A
176	A	H	A	D	D	A	A	A
42	H	A	A	A	D	A	A	A
162	A	H	A	A	A	A	D	A
159	A	H	A	A	A	A	A	D
87	A	H	H	D	A	A	A	D
67	A	A	H	D	A	A	A	D
145	A	H	A	D	A	H	A	D
154	A	H	A	A	A	A	A	D
170	A	H	A	A	D	A	A	A
131	H	H	A	D	A	D	A	A
163	H	H	A	D	D	A	A	A
177	A	A	A	D	D	H	A	A
127	A	H	A	D	D	A	A	A
3	A	H	H	D	A	H	A	A
136	H	A	A	D	A	A	A	A
133	A	A	A	D	A	H	A	A
158	H	A	A	D	H	A	A	A
173	H	A	A	D	D	A	A	H
104	H	A	A	D	A	A	A	A
111	H	D	H	D	A	D	A	H
41	A	D	H	D	A	D	A	A
81	A	H	A	D	A	A	A	A
18	A	A	A	D	H	A	A	A

Appendix 10 continued

Sample No	N	P	K	Fe	Mn	Zn	Cu	B
79	A	H	A	D	A	A	A	A
99	A	H	A	A	A	A	A	D
53	H	H	H	D	A	A	A	A
54	A	A	A	D	H	A	D	H
59	A	H	H	D	A	H	A	A
4	A	H	A	D	A	A	A	H
96	H	A	A	D	A	A	A	A
166	A	H	A	D	A	A	A	A
71	H	A	A	D	A	A	D	H
101	A	H	H	D	A	A	A	A
100	A	H	A	D	A	A	A	D

Appendix 11 Interpretation of the nutrients in shoot material (GS-29) for irrigated wheat. H = high, A = adequate, D =deficient.

Sample No	N	P	K	Fe	Mn	Zn	Cu	B
141	A	A	A	H	A	D	D	H
27	D	H	A	A	D	H	A	A
67	D	A	A	A	H	A	A	D
94	A	A	D	A	D	H	A	H
178	H	A	A	A	A	D	A	A
106	D	A	H	A	A	A	A	A
55	A	D	D	H	H	A	A	A
16	A	A	A	A	H	A	A	D
110	D	D	A	A	H	A	H	A
169	A	D	A	H	D	D	A	A
113	A	D	A	D	H	H	A	A
172	A	A	D	A	A	A	H	A
82	H	A	A	D	D	A	A	H
41	A	D	A	A	A	A	A	H
98	D	A	A	A	A	A	A	H
19	A	D	A	H	A	H	A	A
50	A	A	A	A	A	H	D	H
173	A	A	A	A	D	A	H	H
66	D	H	A	A	A	A	A	D
38	D	H	A	A	H	D	A	A
7	A	A	A	A	H	A	D	A
29	D	A	A	A	A	A	D	H
9	A	A	A	A	H	D	D	A
36	A	A	A	H	D	H	A	A
115	A	D	A	A	H	A	H	A
112	A	D	A	D	H	H	A	A
88	H	D	A	D	A	A	A	H
35	H	D	A	A	H	A	D	A
153	D	A	H	A	H	A	A	A
83	H	D	A	A	D	A	A	H
8	A	A	A	A	H	A	D	H
20	A	A	A	A	H	A	A	D
4	D	D	A	H	A	H	A	A
167	H	A	A	A	A	H	A	D
71	A	A	A	H	D	A	A	H
59	H	A	A	D	A	H	A	D
3	A	A	A	H	H	A	D	A
57	H	D	D	A	A	A	A	A
24	A	A	A	H	H	A	A	D
11	A	D	A	A	H	D	A	H
15	A	A	A	A	H	A	A	D

Appendix 11 continued

Sample No	N	P	K	Fe	Mn	Zn	Cu	B
87	A	D	D	A	A	D	A	H
21	H	A	A	A	H	A	A	D
92	A	D	A	A	H	H	A	A
33	A	A	A	D	H	A	D	H
156	A	D	A	A	A	H	H	A
53	A	D	A	A	H	A	D	H
158	D	A	H	A	A	A	A	H
77	H	A	D	A	H	A	D	A
93	H	A	A	A	A	A	A	D
14	A	A	D	A	D	H	H	A
116	D	A	D	D	H	A	A	H
46	A	D	D	H	A	A	D	H
61	A	A	D	A	H	A	D	H
54	A	D	A	D	H	H	A	A
120	A	D	A	H	A	A	A	H
42	A	A	D	D	A	H	D	H
121	A	D	A	A	A	A	A	H
122	D	D	A	A	A	D	H	H
37	A	D	A	A	H	A	H	A
32	A	A	A	D	H	A	D	H
10	A	A	A	A	H	A	D	H
129	D	D	A	A	A	A	A	A
28	A	D	A	H	H	A	A	A
95	D	D	A	H	A	H	A	A
75	A	A	A	A	H	A	A	D
45	A	A	D	A	A	A	D	H
51	A	A	A	D	A	H	D	A
152	D	D	A	A	A	A	A	H
2	A	A	D	H	A	H	D	H
17	A	A	A	A	H	A	D	H
18	A	A	D	A	H	D	D	A
5	A	A	A	A	A	H	D	H
85	D	D	A	A	A	D	A	H
126	D	D	A	A	A	H	H	D
159	D	A	A	A	A	A	H	A
47	D	D	A	A	A	A	A	A
44	A	D	A	A	D	H	A	H
49	D	D	A	A	A	A	H	H
155	H	A	D	A	H	H	D	A
70	A	A	D	H	A	D	H	A
109	D	A	A	A	A	H	A	A
43	A	A	A	D	A	H	D	H
119	A	D	A	A	H	A	D	A

Appendix 11 continued

Sample No	**N**	**P**	**K**	**Fe**	**Mn**	**Zn**	**Cu**	**B**
1	A	A	D	A	D	A	A	H
69	A	A	D	A	A	H	A	H
108	D	A	A	D	A	H	A	H
125	D	A	A	H	A	A	A	H
80	A	A	D	A	H	H	D	A
60	H	A	D	A	H	A	D	A
124	D	A	A	H	A	A	A	H
34	D	A	A	H	A	A	A	H
157	D	A	A	A	A	H	H	A
123	D	A	A	H	A	A	A	H
32	D	A	A	A	A	A	A	H

Acknowledgements

This work would not have been possible without the support from numerous people and organizations from Bonn (Germany) and Hyderabad (Pakistan). I would like to thank the Asian Development Bank for providing me with financial support to pursue my PhD studies in Germany. I especially wish to thank Prof. Dr. Paul Vlek for selecting me as a student and supporting my research ambitions. On Professor Vlek's recommendation, I met with Prof. Dr. Heiner Goldbach who then became my first supervisor. From proposal writing to thesis writing, his guidance was remarkable. During my field work, whenever I called him on the telephone or sent him emails, he immediately replied me and guided me accordingly. Prof. Goldbach not only rigorously reviewed the content but also the context of all my writings and provided detailed comments on my drafts. Through his critical reading and suggestions, the academic quality of this thesis is ensured.

I am also thankful to ZEF for providing me logistical and academic support. I would like to express my gratitude to all staff members of ZEF, especially to Dr. Günter Manske and Mrs. Rosemarie Zabel. I especially want to thank Mrs. Zabel for her wonderful support during my stay in Germany. It is hard to imagine how ZEF students would be able to survive without her kindness and constant readiness to help. Furthermore, I am very grateful to my friends at ZEF, including Fazal Akther, Abdul Salam Lodhi and Sarah. Special thanks also go to Dr. Usman Khalid Awan for his consistent help throughout the degree process.

My most sincere gratitude goes to Dr. Muhammad Saleem Saif. He joined me in the field and worked with me on sampling. Many thanks to him for his help. I am also thankful to Prof. Dr. Kazi Suleman Memon for his kind guidance.

I would like to express my gratitude to the scientific staff of the laboratory at the plant nutrition department, University of Bonn, during my all research work. Special thanks to Dr. Monika Wimmer for her fruitful guidance during the Boron analysis. I am also thankful to Angelika Viets, Brigeta, Angelika Glugau and Mr.Seven.

I am particularly grateful to my brothers (Mir Javed, Mir Pervez, Mir Sohail, Mir Asif and Mir Kashif Ali), sisters (Neelofer and Dr. Nargis) for their unconditional support, encouragement and love, irrespective of my physical absence. My special gratitude also goes to my field assistants Zulfiqar, Ahmed Khan and Ghulam Murtaza.