BORON REQUIREMENT OF TOMATO (*Lycopersicon esculentum* mill) IN SOME SELECTED SOILS OF THE NIGERIAN SAVANNA

«

BY

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DECLARATION

I hereby declare that this thesis titled: **"BORON REQUIREMENTS OF TOMATO (Lycopersicon esculetum mill) IN SOME SELECTED SOILS OF THE NIGERIAN SAVANNA"** is the record of my own research work and has been written by me. The work embodied in this thesis has not been presented before in any previous application for a higher degree, and is not being concurrently submitted in any candidature for any other degree.

Any portion of the thesis to which the author is indebted to other sources are clearly mentioned and explicit references are given.

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CERTIFICATION

This thesis entitled "Boron Requirement of tomato (Lycopersicon esculentum Mill) in Some selected Soils of the Nigerian Savanna" by Eunice Yetunde Oyinlola, meets the regulations governing the award of the degree of DOCTOR OF PHILOSOPHY of the Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

TO

My late mother, Comfort Adesodun

and

My son, Oluwamuyiwa Oyinlola

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ABSTRACT

Boron deficiency is the **most** wide-spread micronutrient fertility problems in the Northern Nigerian savanna. Recent report has indicated response of cotton and some legumes to boron. Application of boron fertilizer with NPK increases the vegetative growth and yield and also modifies the fruit of tomatoes. However, there is dearth of information on the B needs of tomato and soils supporting the growth of the crop in Northern Nigeria savanna where about 70% of tomato consumed in Nigeria is produced.

This study established the B requirement of tomato through systematic laboratory, greenhouse and field experiments. In the laboratory and greenhouse experiments, the B supplying power of thirty soils and ability of five extractants (Hotwater, 0.01M $CaCl_2$, 0. 1N HC1, double acid and morgan solution) to predict the availability of B to tomato plants were evaluated, and critical levels in soils and plant established. The field trials which were conducted at Samaru and Kadawa during the 1992/93 and 1993/94 dry seasons and 1993 and 1994 rainy (wet) seasons tested the response of tomato to six levels of B (0, 1, 2, 3, 4 and 5 kg B ha^{-1} for dry seasons and 0, 0.5, 1.0, 1.5, 2.0 and 2.5 kg B ha^{-1} for rainy seasons) applied in the form of Borax.

Results obtained from the laboratory indicated that, total B varied from 6-130 mg kg^{-1}, while available B varied from 0.04 - 0.58 mg kg^{-1}. There were correlation among the soil properties, while the soil B test correlated with some soil properties. Results also indicated that various combination of soil properties such as pH

and O.C influenced the availability of B in the soils.

Results of the B adsorption and desorption studies revealed that the values of adsorption maximum (b) (0.030-0.0725 ug g^{-1}) were low which can render the soil B susceptible to leaching losses. Also twenty nine out of the thirty soils best fit in Langmuir equation. The B adsorption of the soils was found to be irreversible.

Results obtained from the greenhouse indicated response of some soils to B fertilizer. Although the uptake of B by tomato in the thirty soils was not correlated with the amount of B extracted chemically, relative yield correlated with the amounts of B extracted by hot water.

The critical B level in the soil and plant were established, the values being 0.13 an 1.06 mg kg^{-1} B. respectiely.

Results from the field studies indicated that there was response to B application in the field. Most of the parameters determined were positively affected by B application. The highest fruit yield recorded during the dry season was 46 ton ha^{-1} in 1993/94 which gave an increase of 148% over the control. While the highest fruit yield recorded for the rainy season was 28 tons ha^{-1} gave an increase of 165% above the control. Also fruit components total soluble solids, ascorbic acid, titratable acids, pH and reducing sugars were modified by recording significant increase over the controls. However, the highest B rates in both seasons were toxic to the tomato plants. Boron rates of 2.0 to 3.0 kg ha^{-1} and 0.5 to 1.5 kg ha^{-1} appeared to be optimum for tomato plants under irrigation and rainfed conditions respectively in the savanna agro-ecology.

TABLE OF CONTENTS

		PAGE
	Title Page	i
	Declaration	ii
	Certification	iii
	Dedication	iv
	Acknowledgement	v
	Abstract	vii
	Table of Contents	ix
	List of Tables	xiv
	List of Figures	xviii
CHAPTER		
1.	INTRODUCTION	1
2.	LITERATURE REVIEW	4
2.1	Occurrence of Boron	4
2.1.1	Occurrence in Rocks and Minerals	4
2.2	Boron Status of Soils	5
2.2.1	Total Boron	6
2.2.2	Available B	8
2.3	Factors Affecting the Availability of B in Soils	10
2.3.1	Soil pH	10
2.3.2	Texture	11
2.3.3	Liming	12
2.3.4	Leaching	12
2.3.5	Moisture Content	13
2.3.6	Organic Matter	13
2.4	Reaction of B in Soils	14
2.4.1	Retention by Soil Clays	14
2.4.2	Reactions with Organic Matter	16
2.4.3	Reactions with Other Soil Components	17
2.5	Interaction Between B and other Elements	17
2.6	Methods of Estimating Available Soil B	20
2.7	Methods of Boron Determination	22
2.8	Role of Boron in Plant Nutrition	23
2.8.1	Primary Functions	23
2.8.2	Secondary Functions	23
2.8.2.1	Transport of Sugar	23
2.8.2.2	Pollination	24
2.8.2.3	Meristem	24
2.8.2.4	Disease Resistance	25

TABLE OF CONTENTS

		PAGE
2.9	Boron Requirements of Crops	25
2.10	Boron Requirements of Tomato	27
2.11	Deficiency Symptoms of Boron on Crops	28
2.12	Deficiency Symptoms of Boron on Tomato	30
2.13	Toxicity Symptoms of Boron on Crops	30
2.14	Correction of Boron Deficiency	31
2.14.1	Types of Boron Fertilizer	31
2.14.2	Method of Boron Fertilizer Application	32
2.15	Importance of Tomato	33
3	MATERIALS AND METHODS	35
3.1	Greenhouse Studies	35
3.1.1	Location	35
3.1.2	Soil Sampling Method	35
3.1.3	Greenhouse Technique	39
3.2	Laboratory Studies	39
3.2.1	Soil Analysis	40
3.2.2	Plant Tissue Analysis	43
3.2.3	Fruit Analysis	43
3.4	Field Studies	45
3.4.1	Site Description and History	45
3.4.2	Soil Characterisation	45
3.4.3	Field Trials	46
3.4.4	Treatments, Design and Cultural Practices	46
3.4.5	Dry Season Trial	47
3.4.6	Wet Season Trial	48
3.4.7	Observation and Measurements	48
3.4.8	Plant Sampling	49
3.5	Weather Data	50
3.6	Statistical Analysis	50
4	RESULTS AND DISCUSSION	51
4.1	Laboratory Analysis	51
4.1.1	Fertility Assessment of Surface Soils	51
4.1.1.1	Particle Size Distribution: Soil Texture	51
4.1.1.2	Soil Reaction	51
4.1.1.3	Organic Carbon Content	53
4.1.1.4	Exchangeable Cations	56
4.1.1.5	Effective Cation Exchangeable Capacity	57
4.1.1.6	Exchangeable Acidity	58
4.1.1.7	Available Phosphorus	58
4.1.1.8	Total Nitrogen	58
4.1.1.9	Micronutrients	59

TABLE OF CONTENTS

		PAGE
4.1.2	Total and Available Boron	60
4.1.2.1	Total Boron Content	60
4.1.2.2	Available Boron Content	62
4.1.2.3	Relationship Amongst Soil Properties	65
4.1.2.4	Relationship Among soil Boron Tests	68
4.1.2.5	Relationship Between Soil Boron Test and Soil Properties	69
4.1.3	Boron Adsorption and Desorption Characteristics	75
4.1.3.1	Boron Adsorption Characteristics	75
4.1.3.2	Soil Properties Affecting Boron Sorption	86
4.1.3.3	Boron Desorption Characteristics	87
4.2	Crop Response to Boron in the Greenhouse	91
4.2.1	Observations on the Assay Crops	91
4.2.2	Crop Parameters	91
4.2.3	Relationship Among Crop Parameters	94
4.2.4	Relationship Between Crop Parameters and Soil Properties	95
4.2.5	Relationship Between Crop Parameters and Extractable Boron	98
4.2.6	Predicting Boron Uptake	100
4.2.7	Critical Level of Boron in the Soils	102
4.2.8	Critical Boron Concentration in Plant Tissue	104
4.2.9	Delineation of Soils into Boron Fertility Classes	104
4.3	Field Studies	108
4.3.1	Soil Characterization	108
4.3.1.1	Selected Properties of the Soil Profiles	110
4.3.2	Physicochemical Properties of the Surface Soils of the Experimental Sites	110
4.3.3	Dry Season Trials 1992/93 and 1993/94	115
4.3.3.1	Effect of Boron Application on Morphological Appearance of Plants	115
4.3.3.2	Effect of Boron Application on Number of Leaves	116
4.3.3.3	Effect of Boron Application on Number of Days to 50% flowering	119
4.3.3.4	Effect of Boron Application on Number of Flowers Per Plant	122
4.3.3.5	Effect of Boron Application on Number of Fruits Per Plant	125
4.3.3.6	Effect of Boron Rates on Fruit Size	127
4.3.3.7	Effect of Boron Rates on Marketable Fruit Yield	129

TABLE OF CONTENTS

		PAGE
4.3.3.8	Effect of Boron Rates on Dry Matter Yield of Tomato Plants	133
4.3.3.9	Effect of Boron Rates on Boron Concentration in Tomato Plants	135
4.3.3.10	Effect of Boron Rates on the Macronutrient Concentration	137
4.3.3.11	Effect of Boron Rates on the Micronutrients	143
4.3.3.12	The Effect of Boron Rates on Boron Uptake in Tomato Plant	147
4.3.3.13	Simple Correlation Matrix (r) Among Yield Parameters and Nutrient Concentration in 1992/93 Trials	151
4.3.3.14	Simple Correlation Matrix (r) Among Yield Parameters and Nutrient Concentration in 1993/94 Trials	155
4.3.3.15	Effect of Boron Rates on the Ascorbic Acid (AA) Contents of Tomato Fruits	161
4.3.3.16	Effect of Boron Rates on Total Soluble Solids	164
4.3.3.17	Effect of Boron Rates on Titratable Acidity	164
4.3.3.18	Effect of Boron Rates on pH of Tomato Fruits	167
4.3.3.19	Effect of Boron Rates on Reducing Sugars	167
4.3.3.20	Simple Correlation Among Fruit Components	171
4.3.4	Rainfed Trials 1993 and 1994	174
4.3.4.1	Effect of Boron Application on Morphological Appearance of Tomato Plants During the Wet Season	174
4.3.4.2	Effect of Boron Fertilizer Rates on Number of Leaves Under Rainfed Conditions	174
4.3.4.3	Effect of Boron Rates on Days to 50% Flowering	177
4.3.4.4	Effect of Boron on Number of Flowers	179
4.3.4.5	Effect of Boron Rates on Number of Fruits Per Plant	182
4.3.4.6	Effect of Boron Rates on Fruit Size	184
4.3.4.7	Effect of Boron Rates on Marketable Fruit Yield	186
4.3.4.8	Effect of Boron Rates on Dry Matter Yield of Tomato Plants	190
4.3.4.9	Effect of Boron Rates on the Concentration of Boron in the Plant Tissue	192

TABLE OF CONTENTS

		PAGE
4.3.4.10	Effect of Boron Rates on the Concentration of Macronutrients.....	194
4.3.4.11	Effect of Boron Rates on the Concentration of Micronutrients.....	200
4.3.4.12	The Effect of Boron Rates on Boron Uptake in Tomato Plant.....	204
4.3.4.13	Simple Correlation Among Yield Parameters and Nutrient Concentration in 1993 Rainfed Trials.....	208
4.3.4.14	Simple Correlation Among Yield Parameters and Nutrient Concentration in 1994 Rainfed Trials.....	213
4.3.4.15	Effect of Boron Application on Ascorbic Acid Content of Tomato Fruits.....	217
4.3.4.16	Effect of Boron Application on Total Soluble Solids of Tomato Fruits.....	220
4.3.4.17	Effect of Boron Application on Titratable Acidity.....	221
4.3.4.18	Effect of Boron Application on pH of Tomato Fruits.....	224
4.3.4.19	Effect of Boron Application on Reducing Sugar Contents of Tomato Fruit.....	225
4.3.4.20	Relationship Among Fruit Components.....	229
4.3.4.21	Effect of Boron Rates on the Distribution of Boron in Different Tomato Plant Parts	231
4.4	General Discussion.....	232
5	SUMMARY AND CONCLUSION.....	238
	REFERENCES.....	241
	APPENDIX A: Profile Descriptions.....	262
	APPENDIX B: Particle Size Distribution.....	266
	APPENDIX B: Soil Chemical Properties.....	267
	APPENDIX C: Combine Analysis of Variance for Assessing the Effect of Boron Rates on Marketable Fruit Yield Over Locations	268
	APPENDIX D: Weather Data During the Period of the Trials at Sanaru.....	270
	APPENDIX D: Weather Data During the Period of the Trials at Kadawa.....	271

LIST OF TABLES

Table	Title	Page
1	Location, History, Parent Material, State and Ecological Zone of the Soils used in the Study	37
2	Particle Size Distribution of the Soils	52
3	Chemical Properties of the Soils	54
4	Total and Extractable Boron contents of the Soils	61
5	Simple Correlation Matrix Among Soil Properties	66
6	Simple Correlation Among Soil Boron Tests	69
7	Simple Correlation (r) Between Soil B and Soil Properties	71
8	Backward Stepwise Regression Analysis Between Boron Extractants (Y) and Soil Properties	74
9A	Selected Soil Properties Related to B Adsorption and Desorption	81
9B	Langmuir Best Fit Equation for the Adsorption of Maximum (b) and Constant (k)	82
9C	Langmuir adsorption maximum (b) and Constant (K)	84
9D	Relationship Between Selected Soil Properties with Boron Adsorption and Langmuir Constant (k)	85
9E	Boron Desorption Data	89
10	Crop Parameters From Greenhouse Study	94
11A	Simple Correlation Among Crop Parameters	96
11B	Simple Correlation Between Crop Parameters and Soil Properties	97
12	Relationship Between Crop Parameters and Extractable B	99
13	Prediction Equation for Other Crop Parameters	101
14	Some Selected Feature of the Sites and Classification of the Soil Profiles at the Experimental Sites	109

LIST OF TABLES

Table	Title	Page
15	Selected Physical and Chemical Properties of the Soil Profiles	111
16	Physicochemical Properties of the Soils at the Experimental sites at Samaru and Kadawa	112
17	Effect of Variety and Boron Rates on Number of Leaves at Samaru and Kadawa under Irrigation Condition During 1992/93 and 1993/94 Cropping Season	117
18	Effect of Variety x Boron Rates Interaction on Number of Leaves at Samaru and Kadawa in 1992/93 and 1993/94	118
19	Effect of Variety and Boron Rates on Number of Flowers per Plant at Samaru and Kadawa under Irrigation Conditions	123
20	Effect of Variety x Boron Rates Interaction on Number of Flowers per Plant at Samaru and Kadawa Under Irrigation Conditions in 1992/93 and 1993/94	124
21	Effect of Variety and Boron Rates on Marketable Fruit Yield (tons ha^{-1}) of Fresh Fruits at Samaru and Kadawa in 1992/93 and 1993/94	131
22	Effect of Variety x Boron Rates Interaction on Yield of Fresh Tomato Fruits at Samaru and Kadawa in 1992/93 and 1993/94	132
23	Effect of Variety and Boron Rates on Boron Uptake (g ha^{-1}) in Tomato Plants at Samaru and Kadawa Under Irrigation Condition in 1992/93 and 1993/94	149
24	Effect of Variety x Boron Rates Interaction on Boron Uptake in Tomato Plants at Samaru and Kadawa Under Irrigation Conditions in 1992/93 and 1993/94	150
25	Simple Correlation matrix (r) among Yield Parameters and Nutrient Uptake in 1992/93 dry season at Samaru and Kadawa	153

LIST OF TABLES

Table	Title	Page
26	Simple Correlation Matrix (r) Among Yield Parameters and Nutrient Uptake in 1993/94 Dry Season at Samaru and Kadawa	157
27	Effect of Variety and Boron Rates on Ascorbic Acid Contents (%) of Ripe Tomato Fruits at Samaru and Kadawa in 1992/93 and 1993/94	162
28	Effect of Variety x Boron Rates Interaction on Ascorbic Acid Contents (%) of Ripe Tomato Fruits at Samaru and Kadawa Under Irrigation conditions in 1992/93 and 1993/94	163
29	Effect of Variety and Boron Rates on pH of Ripe Tomato Fruits at Samaru and Kadawa in 1992/93 and 1993/94	168
30	Effect of Variety x Boron Rates Interaction on pH of Ripe Tomato Fruits at Samaru and Kadawa in 1992/93 and 1993/94	169
31	Simple Correlation Among Fruit Components Under Irrigation Conditions	173
32	Effect of Variety and Boron Rates on Number of Leaves at Samaru and Kadawa Under Rainfed Conditions in 1993 and 1994	175
33	Effect of VAriety x Boron Rates interaction on Number of Leaves at Samaru and Kadawa in 1993 and 1994	176
34	Effect of Variety and Boron Rates on Number of Flowers Per Plant at Samaru and Kadawa under Rainfed Conditions in 1993 and 1994	180
35	Effect of Variety x Boron Rates Interaction on Number of Flowers per Plant at Samaru and Kadawa Under Rainfed Condition in 1993 and 1994	181
36	Effect of Variety and Boron Rates on Marketable Fruit Yield (tons ha^{-1}) of Tomato at Samaru and Kadawa Under Rainfed Condition in 1993 and 1994	188
37	Effect of Variety x Boron Rates Interaction on Marketable Fruit Yield of Tomato at Samaru and Kadawa Under Rainfed Condition in 1993 and 1994	189

LIST OF TABLES

Table	Title	Page
38	Effect of Variety and Boron Rates on Boron uptake (g ha^{-1}) in Tomato Plants at Samaru and Kadawa under Rainfed Condition in 1993 and 1994	206
39	Effect of variety and Boron Rates on Boron uptake in Tomato Plants at Samaru and Kadawa Under Rainfed Condition in 1993 and 1994	207
40	Simple Correlation Matrix (r) Among Yield parameters and Nutrient Uptake in 1993 trials at Samaru and Kadawa	209
41	Simple Correlation Matrix (r) Among Yield Parameters and Nutrient Uptake in 1994 trials at Samaru and Kadawa	214
42	Effect of Variety and Boron Rates on Ascorbic Acid Contents (%) of Fruits at Samaru and Kadawa in 1993 and 1994	218
43	Effect of Variety x Boron Rates Interaction on Ascorbic Acid Contents of Fruits at Samaru and Kadawa in 1993 and 1994	219
44	Effect of Variety and Boron Rates on pH of tomato fruits at Samaru and Kadawa in 1993 and 1994	226
45	Effect of Variety x Boron Rates Interaction on pH of Tomato Fruits at Samaru and Kadawa in 1993 and 1994	227
46	Simple Correlation Among Fruit Components at Samaru and Kadawa Under Rainfed Condition	230

LIST OF FIGURE

Figure	Title	Page
1A	Ecological Map of Nigeria Showing Locations of Sample Sites	36
1B	Soil Boron-test Levels	64
2A-D	Boron Adsorption Isotherms	76
3A	Scatter Diagram of Relative Dry Matter Yield of Tomato Plants vs Hot Water Soluble B	103
3B	Scatter Diagram of Relative Dry Matter Yield of Tomato Plants vs Tissue B Concentration	105
3C	Boron Fertility Map of Fallow Soils in Northern Guinea and Sudan Savanna of Nigeria	106
3D	Boron Fertility Map of cultivated Soils in Northern Guinea and Sudan Savanna of Nigeria	107
4	Number of Days to 50% Flowering as Influenced by Variety and Rtes of Boron at Samaru and Kadawa under Irrigation Conditions 1992/93 and 1993/94	121
5	Number of Fruits per Plant as Influenced by Variety and Rates of Boron at Samaru and Kadawa Under Irrigation Condition in 1992/93 and 1993/94	126
6	Size of Fresh Tomato fruits as Influenced by Variety and Rates of Boron at Samaru and Kadawa Under Irrigation Condition in 1992/93 and 1993/94	128
7	Dry Matter Yield as Influenced by Variety and Rates of Boron at Samaru and Kadawa under Irrigation Conditions in 1992/93 and 1993/94	134
8	Boron Concentration in Plant Tissue as Influenced by Variety and Rates of Boron at Samaru and Kadawa Under Irrigation Conditions in 1992/93 and 1993/94	136
9	Plant Macronutrient Concentration as Influenced by Variety and Boron Rates at Samaru and Kadawa in 1992/93	138
10	Plant Macronutrient Concentration as Influenced by Variety and Boron Rates at Samaru and Kadawa in 1993/94	139

LIST OF FIGURE

Figure	Title	Page
11	Effect of Boron rates on Macronutrient Concentration at Samaru and Kadawa in 1992/93 and 1993/94	140
12	Micronutrient concentration as Influenced by Variety and Boron Rates at Samaru and Kadawa in 1992/93 and 1993/94	144
13	Effect of Boron Rates on Micronutrient Concentration in Plant Tissue at Samaru and Kadawa in 1992/93 and 1993/94	146
14	Total Soluble Solids Contents of Tomato Fruits as Influenced by Variety and Rates of Boron at Samaru and Kadawa Under Irrigation Condition in 1992/93 and 1993/94	165
15	Titratable Acidity Contents of Tomato Fruits as Influenced by Variety and Rates of B at Samaru and Kadawa Under Irrigation Conditions in 1992/93 and 1993/94	166
16	Reducing Sugars of Tomato Fruits as Influenced by Variety and Rates of Boron at Samaru and Kadawa in 1992/93 and 1993/94	170
17	Number of Days to 50% Flowering as Influenced by Variety and Rates of Boron Under Rainfed Conditions at Samaru and Kadawa in 1993 and 1994	178
18	Number of Fresh Tomato fruits as Influenced by Variety and rates of Boron Under Rainfed Conditions at Samaru and Kadawa in 1993 and 1994	183
19	Size of fresh tomato Fruits as Influenced by Variety and Rates of Boron at Samaru and Kadawa under Rainfed Conditions in 1993 and 1994	185
20	Dry Matter Yield as Influenced by Variety and Rates of Boron at Samaru and Kadawa Under Rainfed Conditions in 1993 and 1994	191
21	Boron Concentration in Plant Tissue as Influenced by Variety and Rates of Boron at Samaru and Kadawa Under Rainfed Conditions in 1993 and 1994	193
22	Plant Nutrient Concentration as Influenced by Variety and Boron Rates at Samaru and Kadawa Under Rainfed Conditions in 1993	195

LIST OF FIGURE

Figure	Title	Page
23	Plant Nutrient Concentration as Influenced by Variety and Boron Rates at Samaru and Kadawa under Rainfed Conditions in 1994	196
24	Effect of Boron rates on Micronutrient Concentration in Plant Tissue at Samaru and Kadawa in 1993 and 1994	197
25	Micronutrient Concentration as Influenced by Variety and Boron Rates at Samaru and Kadawa in 1993 and 1994	201
26	Effect of Boron Rates on Micronutrient Concentration in Plant Tissue at Samaru and Kadawa in 1993 and 1994	202
27	Total Soluble Solids Contents of Tomato Fruits as Influenced by Variety and Rates of Boron Under Rainfed Conditions at Samaru and Kadawa in 1993 and 1994	222
28	Tritratable Acidity of Tomato fruits as Influenced by Variety and Rates of Boron at Samaru and Kadawa in 1993 and 1994	223
29	Reducing Sugars of Tomato Fruits as Influenced by Variety and Rates of Boron at Samaru and Kadawa in 1993 and 1994	228
30	Boron Distribution in two Tomato Varieties	233

CHAPTER 1

1.0 INTRODUCTION

The Nigerian savanna soils are generally characterised by low organic matter content, low CEC and low inherent fertility (Lombin 1981), which has often been responsible for low crop yields. Therefore the use of fertilizers is mandatory, for a successful arable agriculture in the Nigerian savanna.

The pressure of population on land makes it imperative further to increase the output per hectare and this has been done by making use of improved and high yielding crop varieties and the application of inorganic fertilizers. The practice of continuous cultivation and the application of fertilizers containing only the essential macronutrients (NPK) have led to the depletion of some micronutrients not supplied in the fertilizers. Findings from literature have confirmed the deficiency of some of these micronutrients; Molybdenum (Heathcote and Stockinger, 1970, Heathcote, 1973b), Boron, (Heathcote 1973a; Heathcote and Smithson, 1974, Anande-kur, 1976 and Lombin 1985a).

According to Heathcote (1973b), Heathcote and Smithson (1974), B deficiency appears to be the most widely observed deficiency especially in farmers field in the North-western Nigeria. Lombin (1983a and 1983b) reported that Cu, Zn and Mn do not appear to pose immediate threat to agriculture in the savanna, but low levels of Mo and B are bound to limit crop yields. Anande-kur (1976), and Lombin (1985a) reported the levels of available B in the savanna

soils to be in the range of 0.14-0.25 mg/kg which is suboptimum for the growth of B sensitive crops.

Most of the research work on B in Northern Nigeria have been concentrated on cotton; Faulkner et al, 1970; Smithson 1972; Heathcote, 1973a; Heathcote and Smithson 1974 and Lombin 1985a). In most of these studies, good response of cotton to B was established. Balasubramanian et al (1980) found that groundnut and cotton responded to a mixture of trace elements (B, Cu, Mo and Zn) applied as foliar spray at Mokwa and attributed this to the B components of the mixture.

Virtually, no work has been done with regards to optimum level of B for tomato in the savanna soils of Nigeria.

Boron is essential for the growth of tomato. It increases the number of flowers and fruits. Boron improves the flavour of tomato fruit, increases the vitamin C content and also gives a better keeping quality. So far, there is limited information on the B supplying power of savanna soils and tomato response to soil applied B in the area.

Considering the importance of tomato in the daily diet, and the role of B in the mineral nutrition of tomato, this study was undertaken with the following objectives:-

1. To assess the status of different forms of boron in soils of Northern Nigeria and develop suitable extractant for the predictions of plant available boron to tomato under greenhouse conditions;
2. To investigate the boron adsorption and desorption

characteristics of the soils;

3. To determine optimum boron rate for tomato in field trials and assess the effect of B on some biochemical property of the tomato fruit.

CHAPTER 2

2.0 LITERATURE REVIEW

Boron is one of the most important essential micronutrients required for the normal growth of most plants. the essentiality of boron for the growth of higher plants was conclusively demonstrated by Sommer and Lipman (1926) and Sommer (1927).

Oertli et al (1975) asserted that B is unique among the essential mineral nutrients because it is the only element that is normally present in soil solution as a non-ionized molecule over the pH range suitable for plant growth. According to this report, plant roots absorb B most efficiently in the form of Boric acid.

2.1 OCCURRENCE OF BORON

2.1.1 Occurrence in Rocks and Minerals

The amount of B in rocks depends on the type of rock, Fleet (1965) found that the highest average amount of B in soil forming rocks is found in sedimentary rocks especially those of marine origin. Among the sedimentary rocks, shales have the highest B concentration of up to 100 $mgkg^{-1}$ with B present mainly in clay minerals.

Maurice (1966) reported that acid igneous rocks contain considerably lower B concentration which ranges from 5-15 $mgkg^{-1}$. This is also in agreement with the findings of Konrad (1972) who reported that B may be greater in granitic igneous rocks than in basalts and that, micas, show the highest concentration of B among

the minerals of igneous rocks. The parent rocks in Nigeria consist mainly of older granite and sandstone which contain low to very low amounts of B.

B is found in rocks in many different minerals. Over 80 bearing minerals are known to be present in the earthcrust (Neumodruk and Karalova, 1970). Among these, Tourmaline is the most important.

Tourmaline which contains about 3-4% B is present in soils formed from acid rocks and metamorphosed sediments. B can substitute for tetrahedrally co-ordinated Si in some minerals. Norrish (1975) found that much of the B in rocks and soils is dispersed in the silicate minerals, in this way the element is made available only after long periods of weatherings.

Tourmaline is a very resistant mineral which cannot be dissolved even in hydrofluoric acid. It also remains unchanged during rock forming process. It is therefore useless as a B source for plants. Fertilizer experiments by Berger and Truog (1940) with well ground Tourmaline showed that this mineral is of little relevance in plant nutrition.

A better source of B is associated with impurities in many common minerals. Bowen (1977) found that most of the B in soil that is available to plants is derived from sediments or plant material.

2.2 BORON STATUS OF SOILS

Boron in soils can be classified into two namely:-

Total and

available forms.

From the nutritional point of view, B could be divided into four fractions: (1) Totally unavailable B (chiefly tourmaline) (2) unavailable B impurities (in feldspars and quartz) (3) Temporarily available B (in micas, illite, sesquioxides and undecomposed organic matter) (4) Available B, usually regarded as equivalent to hot water soluble B (Berger and Truog 1939).

Temporarily unavailable B could be released, if there is an increase in microbiological activity and a steady production of acid extractants from roots, but available B may sometimes become unavailable because of drought (Bowen, 1977 and Gupta, 1979).

2.2.1 Total Boron

The distribution pattern of total B in soils is inconsistent due to factors such as organic matter content, soil texture and soil mineral composition of the area. In humid regions, the largest fraction of B in soils is associated with tourmaline, but in regions of low rainfall, soluble and adsorbed borates may account for a large fraction of total soil B.

The B content of soils in arid and semi-arid climates is in general higher than in humid climatic zones (Kanwar and Shan Singh 1961). Soils in high rainfall areas are often deficient in B. This is because of the non-ionic nature of B once it has been released from soil minerals, it can be leached from the soil fairly rapidly.

Berger and Pratt (1963) had reported that the total concentration of B in most soils varies between 2-200 $mgkg^{-1}$, and frequently ranges from 7-80 $mgkg^{-1}$. He also reported that, the amount of total B in soils depends largely on the soil parent materials.

Gupta (1968) worked on a number of soils from Eastern Canada and found that total B ranged from 45-124 $mgkg^{-1}$, whereas hot water soluble B ranged from 0.38-4.67 $mgkg^{-1}$. This indicated that only a small fraction of total B occured in an available form. Generally, less than 5% of total soil B is available to plants.

Aubert and Pinta (1971) got a range of 250-270 $mgkg^{-1}$ for Israel soils. In Poland, a range of 5-73 $mgkg^{-1}$ B was reported for various soil types in USSR (Aubert and Pinta 1977).

The B content in soils is known to be dependent on the content of the element in the parent material and upon the type of weathering this material has undergone. This is confirmed by Wheatstone et al (1942) who on a very extensive study of soils in the United States of America got a range of 8 to 98 $mgkg^{-1}$. He also found that soils derived from alluvial limestone, shale, and glacial drift to be high in B content while those formed from igneous rocks, unconsolidated materials were found to be low in boron.

In South-Western Nigeria, Banjoko et al (1981) found that parent rock was the most important factor in determining both the total and available (hot water soluble) B in Nigerian soils. In their study, they got the range of total B content of surface soils

to be 25.2 to 31.2 $mgkg^{-1}$ for soils derived from sandstones compound while a range of 9.6 to 61.2 $mgkg^{-1}$ was obtained for soils derived from basement complex rocks.

In Northern Nigeria, Anande-kur (1976) reported values of 8.3 to 38.7 $mgkg^{-1}$ total B for few samples of some Nigerian savanna soils. Daudu (1989) got a range of 37.9-44.5 $mgkg^{-1}$ B in some savanna soils developed from loess. Similarly, Kparmwang (1993) worked with basaltic soils in Northern guinea savanna soils of Nigeria, and obtained a range of 19 to 160 $mgkg^{-1}$ B.

It would be observed that from the various studies considered, that the amount of total B in soils is erratic and it depends on the type of content of the soil parent material.

2.2.2 Available Boron

Available or extractable soil B is that fraction of the total boron content that is accessible to plant roots. A variety of extractants have been used to estimate the available B status of soils. The values obtained have varied widely depending on the extractant used.

Most attempt have been based on extractantion with boiling water although the values are frequently described as hot water soluble boron. Care should be taken in interpreting and comparing values without reference to the actual extraction procedure used; particularly the time of extraction as major variation in determined levels can be expected as a result of minor differences in procedure.

Available B as determined by Berger and Truog method accounts for a very small fraction of total soil B, and values normally lie between 0.1 and 3.0 $mgkg^{-1}$. Gupta (1968) got hot water soluble B (HWS-B) to range from 0.38 to 4.67 mgk^{-1}. In another study, Podlesak (1990) reported a range of 0.13 to 0.26 $mgkg^{-1}$ B. Aubert and Pinta (1971) studied Russia soils and got a range of 1 to 2 $mgkg^{-1}$ B.

In South Western Nigeria, Chude and Obigbesan (1984) worked on 30 soil samples and obtained values ranging from 0.40 to 1.60 $mgkg^{-1}$ HWS-B. Banjoko et al (1981) got a range of HWS-B to be between 0.03 and 0.21 $mgkg^{-1}$ for soils derived from sandstone, while a range of 0.23 to 0.81 $mgkg^{-1}$ was obtained for soils from basement complex.

Egbe and Omotosho (1972) also reported low available B content in surface soil samples from cocoa belt soils of Western Nigeria ranging from 0.01 to 0.44 ppm HWS-B. This is considered insufficient to satisfy the B needs of the early maturing and high yielding Amazon variety of cocoa. Similarly, Chude and Obigbesan (1982) analysed 21 surface soils samples in Western Nigerian, and got a range between 0.19 and 0.46 $mgkg^{-1}$ HWS-B.

Ojeniyi et al (1981) got a range of 0.4 to 0.57 $mgkg^{-1}$ HWS-B in a K-B fertilizer trial carried out in South Western Nigeria.

In Northern Nigeria, Anande-kur (1976) worked on 30 soil samples and got values ranging from 0.14 to 0.25 $mgkg^{-1}$ HWS-B. Also in the same part of the country, Lombin (1985b) worked on 30 representative cultivated soils and obtained the following values;

0.18 to 0.36 mgkg^{-1} HWSB; 0.19-0.44 mgkg^{-1} NaOAc extractable B, and 0.22 to 1.27 mgkg^{-1} double acid extractable B.

Daudu (1989) also got a range of 0.06 to 0.17 mgkg^{-1} HWS-B and 0.10 to 0.34 mgkg^{-1} NaOAc extractable B, for surface soils he worked with. Kparmwang who worked on the basaltic soils of Northern guinea savanna, obtained a range of 0.44 to 1.5 mgkg^{-1} HWS-B.

2.3 Factors Affecting the Availability of B in Soils

The availability of B for plant uptake depends upon its form and retention in the soil. Anande-kur (1976) reported that the factors which affect the availability of B in savanna soils are physicochemical processes such as solubility of B containing minerals, adsorption, desorption and precipitation reaction, biochemical reactions and leaching. Also Lombin (1985b) found that pH, organic matter, and exchangeable calcium and potassium, affect the availability of B in soils. Other factors such as, soil pH, soil moisture content, liming and soil texture may also affect availability of soil B.

2.3.1 Soil pH

Soil pH also determines the form of B in soil. At pH less than 7, (4.5-6) boric acid molecules predominate in solution owing to the low ionisation constant for boric acid, ($K = 5 \times 10^{-10}$), while $B(OH)_4$ ions predominate at pH 7.

Peterson and Newman (1976), Gupta (1972, 1977) reported a negative correlation between B uptake by plants and soil pH at pH

values greater than 6.5.

B availability to plant decreases very rapidly at high pH values, but the relationship between soil pH and the plant B values does not show any consistent trend at lower pH values.

Martens (1968) reported that of all the variables determined, only soil pH was related significantly by simple correlation to B uptake. Also Lombin (1985b) worked with 30 soils out of which 21 were acidic soils, and reported that soil pH was significantly correlated with biochemically extractable soil B and B removed by plants, whereas Gupta (1968) did not obtain any consistent relationship between hot water soluble B and pH in 108 soil samples from Eastern Canada having pH ranging from 4.5-6.5.

Soil pH also affects B availability indirectly through its effect on B adsorption and desorption. Hingston (1964) found that the amount of B adsorbed by 3 types of clays increased with an increase in soil pH up to a maximum adsorption at pH 9.2.

2.3.2 Texture

Soil texture plays an important role in determining B availability. B adsorption was greater in medium black clay than in dune sand and was intermediate in sandy loamy soil (Gupta 1980). Generally coarse textured soils usually contain less available B than fine textured soils. A level of 0.3 ppm hot water soluble B was suggested as a useful critical value in coarse-textured soils compared with 0.5 ppm B, in fine textured soils. Also Tisdale et al (1985) have reported that fine textured soils require more B

than do coarse-textured soils to produce similar concentrations of B in plants. This can be explained by the fact that the clay or organic matter associated with fine textured soils tends to hold large amount of B rather tightly such that it is not easily available.

2.3.3 Liming

As with other micronutrients liming reduces the availability of B in soils. This poorer availability may be ascribed to the increased adsorption of borate to soil particles. Liming strongly acid soils frequently induces B deficiency on plants because of (1) increase B fixation by the clay fraction of soils at reactions above neutrality (2) reduced absorption or translocation or both of B by the plant and (3) increased B requirements due to higher levels of Ca in plants grown on limed soils (Fox, 1968).

Tanaka (1967) reported that B uptake by radish (Raphanus sativus L.) was reduced when calcium content of the medium was increased.

2.3.4 Leaching

Excessive B movement within the soil profile will result in leaching losses. Leaching losses are influenced principally by the amount of percolating water and by the physical and chemical properties of the soil. Under high leaching conditions, Quellete (1963) found that B is easily removed from soils and podzolic soils in particular are low in B. B is fairly readily leached through

coarse textured soils, whereas on clayey soils movement is likely to be severely restricted. Gupta (1968) reported that the movement of B is less rapid in fine textured and alkaline soils.

2.3.5 Moisture Content

During low moisture conditions in the soil, available B may become unavailable. This is because low soil moisture impairs transport of B to adsorping root surfaces. Gupta (1971) reported that lack of soil moisture reduces the mobility of B which restricts its uptake by plant roots via massflow mechanism. Also Bowen (1977) and Gupta (1979) found that in a dry season, the soil dries from the top downwards, so that the roots tend to feed away from the zone that is very rich in B.

2.3.6 Organic Matter

The decomposing organic matter is definitely a very important natural source of B. Soils rich in organic matter are likely to have high B levels, while soils low in organic matter are likely to have low B levels (Anande-kur 1976). Organic matter is an important source of B in acid soils as relatively little B adsorption on the mineral fraction occurs at low pH levels (Okazaki and Chao 1968). Yermiyahu et al (1995) reported that boron status of surface soils and its availability is profundly influenced by organic matter.

Lombin (1985b) found organic matter to be highly significant in a regression analysis used to describe B uptake as a function of

extractable B and other soil properties. Miljkovic et al (1966) reported that an increase in hot water soluble B associated with an increase in pH is greater in soils with high O.M content.

The influence of O.M on available B is affected by the increase in the pH and the clay content of the soil.

2.4 Reaction of Boron in Soils

Extensive work has been done on various types of reactions that occur between B and soil constituents (Hingston 1964; Miljkovic et al 1966, Sims and Bingham 1967, 1968; Okazaki and Chao 1968 Tamai and Harada 1968). Reaction of B with the soil constituents can be classified into the following categories:

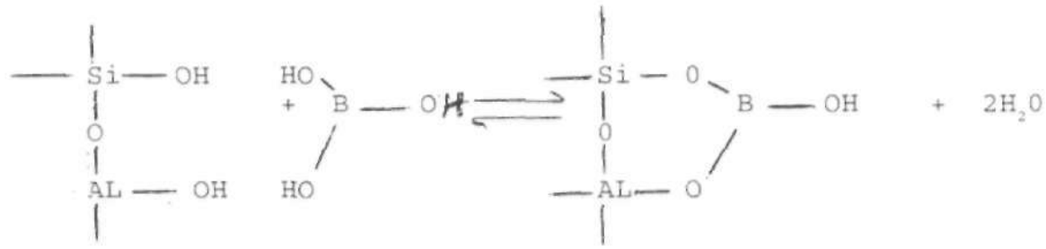
(1) retention by soil clays
(2) formation of B-organic complexes; and
(3) precipitation reactions with other soil constituents.

2.4.1 Retention by Soil Clays

Although B fixation by adsorption is most often considered the dominant phenomenon in controlling B availability, the reaction mechanism of B adsorption have never been clearly established (Toner and Sparks 1995).

Arnold (1990) reported that the principal adsorption sites are (1) broken S1-0 and Al-0 bonds at edges of aluminosilicate minerals (2) amorphous hydroxide structues (3) magnessium hydroxide clusters and (4) iron and aluminium oxy-and hydroxy-compounds.

Sims and Bingham (1967) reported that the retention of B involves the reaction of borate ions with the surface OH at least in part meeting the stoichiometric requirements for the formation of a diol borate complex.



Diol-Borate complex

Adsorption of B depends on some factors such as soil texture soil pH, and soil temperature. Kanwar and Chansingh (1961) and Singh (1971) found that heavy soil adsorbed more B than did light soil and that light soil released B more easily than did heavy soil on extraction with water.

Bingham et al (1971) reported that B adsorption is only slightly increased by an increase in soil temperature.

The adsorption of B is maximum in the alkaline range of the pH scale around pH 8-9. B adsorption decreases at pH below 5. This is confirmed by Toner and Sparks (1995) who reported that at pH above 10, deprotonation of the neutral surface site and formation of the Al0-site reduces the number of sites available for B adsorption.

Olsen and Berger (1947) reported that B fixation is a chemical process caused by alkalinity rather than the presence of basic cations and occurs in minerals of the clay fractions of the soil.

Scharrer et al (1956) and Sims and Bingham (1967), Goldberg and Glaubig (1985) had variously reported that Fe and Al possess marked affinity for B. Also Hatcher et al (1967) found that the surface areas over which the Al $(OH)_3$ is spread is an important factor in B adsorption.

In a comparison of Al oxides with Fe oxides, Sims and Bingham (1968) found that Al oxides removed nearly an order of magnitude more B from solution than Fe oxides on a weight basis. They also reported that the capacity for the hydroxyl compounds to retain B decreased with their age.

2.4.2 Reactions with Organic Matter

Humus was found to exhibit chemical affinity for B, and it appears to play an important role in the retention of B by soils (Parks and White, 1952; Gu and Lowe, 1990).

Soils below pH 7.3 and containing considerable O.M usually contain adequate supplies of B, whereas soils low in O.M and those containing significant amount of $CaCO_3$ are low in available B (Berger and Truog 1946).

The mechanism of B retention with O.M is thought to be through chelation and adsorption. The adsorption of borates by humus is similar to that of clay, i.e condensing with diol groups which in this case are probably associated with carboxylic acids. Russel (1973) suggested that as this bond is probably stronger than the borate sesquioxide bond, under acid or neutral conditions, humic colloids most likely form the principal reservoir of B in most

agricultural soils.

2.4.3 Reactions with Other Soil Components

Many studies have been carried out to show the reaction between B and other soil components. Parks and White (1952) had studied B retention by clay and humus systems saturated with various cations. They concluded that small amount of soil B may enter into complexes of Ca, with Si or complexes of Si with Al or Fe such as calcium alumino-silicates or calcium ferrosilicates.

Precipitation of B may occur in the soil by weathering of minerals or application of inorganic fertilizers. Rhoades (1970) reported similar results when Mg reacted with B.

2.5 Interaction Between B and Other elements

Uptake of B has been proved to be dependent on the concentration of other ions in the growth medium.

Potassium (K):- At low levels of B nutrition, increased rates of applied K may accentuate B deficiency symptoms. B uptake by tomato and corn was enhanced by high potassium in combination with high B. Heathcote (1973b) reported that the application of potassium fertilizers aggrevate the severity of B deficiency and suggested that the effectiveness of potash fertilizers may be reduced, if cotton is under B stress. Reeve and Shive (1944) worked with tomato plants and found that at any given B level in the substrate, there was progressive increase in the B content of plants as the K

concentration in the substrate increased.

Calcium (Ca):- Increase in concentration of Ca reduces the uptake of B. Tanaka (1967) reported that B uptake by radish (*Raphanus sativum L.*) was reduced when the Ca content of the medium was increased. Beauchamp and Hussein (1974) in their studies on rutabaga, found that increased Ca concentration in tissue generally increased the incidence of brown heart.

The response of tomato plant toward B appears to be determined by the direct and intimate reaction between Ca and B in metabolism, but K appears to influence the response of the plant to B indirectly through its determinate effect upon the processes involved in the absorption and accumulation of Ca (Reeve and Shive 1944).

Leaf tissue Ca/B ratio has also been considered as indicator of the B status of crops. Reeve and Shive (1944) found that Ca/B ratio in tomato tissue decreased markedly with increasing K concentration in a nutrient solution.

Magnesium (Mg):- If the concentration of Mg is increased in a medium then B uptake is reduced. Gupta and MaCleod (1977) found that Mg had a greater effect on B reduction in plants than did Ca, Na or K, but the difference between Ca and Mg effects were small.

Nitrogen (N):- Among the nutrients, N is of utmost importance in effecting B uptake by plants. Jackson and Chapman (1975) were

among the pioneers in establishing that liberal N applications are sometimes beneficial in controlling excess B in citrus. Jones et al (1963) stated that under conditions of high B, application of N depresses the level of B in citrus leaves, and under conditions of high B, high N depressed the level of B in orange.

Ogunlela et al (1976) and Lombin and Mustapha (1980) reported from the result of their field trials the need to correct B deficiency in order to obtain positive response to N.

Sulphur (S):- Different crops behave differently to concentration of sulphur in the plant nutrient solution. Tanaka (1967) speculated that there may be a slight effect of sulfate ion on the accumulation of B in plant tissues. Investigations showe that S application had no effect on the B concentration of pea, cauliflower, timothy, red clover, and wheat, but they significantly decreased the B content of alfalfa and rutabaga.

Phosphorus (P):- Stoyanov (1971) observed an increase in the severity of B deficiency in tobacco with high P. on the other hand, Tanaka (1967) got an increase in B uptake with an increase in P supply in radish.

Pollard et al (1977) reported that a deficiency of B in corn and broad beans reduced the capacity for absorption of phosphate. Also Nusbaum (1947) found that in the absence of added B, low P fertilizer with optimum rates of N and K resulted in severe B deficiency in sweet potatoes.

2.6 Methods of Estimating Available Soil B

Extensive work has been done on the estimation of available B level which usually comprises less than 5% of the total B in soils. Several extractants have been tested over the years, these include hot water, phosphoric acid, hydrochloric acid, sodium acetate, ammonium acetate, sodium bicabonate and calcium chloride.

The hot water method was proposed by Berger and Truog (1939). The method involves boiling water and soil mixture (ratio 2:1) for five minutes in a boron-free digestion flask, fitted with a reflux condenser. The mixture is filtered and B concentration is measured in an aliquot of the clear filterate. The hot water method is widely used because it gives good correlations between the amount of B extracted and plant absorption and because there is now a large body of data based on hot water extraction.

Many investigators have shown that a number of factors must be considered in interpreting the results obtained. Dregne and Powers (1942) reported that the availability of B in soils is influenced by soil reaction, soil moisture, active Ca and Organic Matter, while Dible and Berger (1952) also showed that B content decreased as moisture becomes limiting. Wear and Peterson (1962) reported that water soluble B content of soil is a good indicator of available plant B as long as soils of similar texture and close pH values are compared. Similarly, Baker (1971) concluded that the hot water method is unreliable for the measurement of available B to plants when a number of different soil types are compared. The hot water method has been modified by Baird and Dawson (1955) who

suggested a 6 hour soxhlet hot water extraction, but it was found that, this method is time consuming and not outstandingly better than the original procedure.

Catani et al (1970) used a method in which 5 g of soil were extracted with 20 ml of 0.05 N acetic acid and recommended this method because the amount of B extracted in the hot water method increases with increasing soil/water ratio.

Baker (1971) used aqeous solution of $CaCl_2$ to facilitate clarification of the extracts and this has been proved to remove the same amount of B as distilled water. Also phosphoric acid (H_3PO_4) was used as the extracting agent by Baker (1971) and found that the the acid extracted a high amount of B which did not correlate with biologically available B.

Other studies carried out by other workers (Berger and Truog, 1944; Rogers, 1947; Gestring and Soltanpour 1981) on dilute mineral acids as extratants have shown that acid-extractable B seems less efficient for the prediction of B availability.

Generally extraction with acids is complicated by the difficulty in controlling the level of acidity especially on calcareous or limed soils.

Morgan's solution which consists of sodium acetate buffered to a pH of 4.8 by acetic acid is another extractant used for extracting B from soil. It has the advantage that it is buffered. Some studies have in fact shown that Morgan's solution is more suitable for predicting the availability of B to plants than hot water or acid extraction, methods (Wolf, 1971; Lombin, 1985b).

B in adsorped, complexed or chelated forms can easily be removed by the use of organic extractants. Pickett et al (1971) used an organic extractant 2-ethyl-1, 3, hexanodiol to extract B from fertilizers. Other investigators have used different types of organic extractants.

2.7 Methods of Boron Determination

There are various methods for determining B in soil extracts. Plant materials, compost and manures, water and nutrient solutions. These include titration (Vasilekaya, 1972) emission spectroscopy (Pickett et al, 1971; Gestring et al, 1981) and colorimetry (Berger and Truog, 1939: Weir and Jones, 1970).

The most commonly used method is the colorimetric, using reagents such as curcumin, carminic acid, di-anthrimide, methylene blue, quinalizarine and azomethine-H.

Azomethine-H was first used by Basson et al (1969) for determining B in plant materials. It has been modified by Wolf (1971) and Gaines and Mitchell (1979). The method is sensitive subject to few interferences and works in aqeous medium. Interference is only felt from copper, iron, and aluminium but these could be complexed with disodium salt of EDTA. The disadvantage of the method is that azomethine-H is unstable unless it is carefully stored after the preparation.

2.8 Role of Boron in Plant Nutrition

According to Berger (1944), experiments had shown that the addition of small amount of B to a growth medium stimulated the growth of various crops. In another study, Blamey (1976) proved that B is important both in vegetative and reproductive stages of plants. The role of B in plants can be classified into two groups - primary and secondary.

2.8.1 Primary Functions

The primary role of B is yet to be established, but Pollard et al (1977) found that the activity of the outer membrane of the cytoplasm of the root cell of B-deficient plant is altered in such a way that the absorption of phosphorus, potassium, chlorine and rubidium is reduced.

Boron is also thought to control the level of phenol in the cells so as to prevent damaging effects of phenol accumulation (Lee and Aronoff, 1967).

2.8.2 Secondary Functions

2.8.2.1 Transport of Sugar

Reports from literature confirm that B helps in facilitating the transport of sugars through membrane (Gauch and Dugger 1954) and Eriksson 1979). B deficient tomato plants were found to translocate more sugar when 50 $mgkg^{-1}$ of B was added with sucrose through a cut petiole than when sucrose was applied alone.

Neales (1960) found that plants with adequate B are better

able to translocate carbohydrates than are the deficient ones.

2.8.2.2 **Pollination**

B helps in proper fertilization and fruit development in plants. Boron is required for growth of the pollen tube, the boron being absorbed as it grows through the stigma tissue. B increases the nectar level shortening of corolla tube and makes flowers more attractive to bees (Vassilieve 1941). Also Holmes (1960) and Kholi (1961) reported that B had effects on flower formation, pollen growth and nectar secretion which are vital factors in seed formation.

2.8.2.3 **Meristem**

Boron is very closely related to the activity of the meristem especially the apical meristem. Torsell (1956), Whittington (1957), and Spurr (1957), reported the need for and importance of B in the formation of cell walls. Perkins and Aronoff indicated the importance of B for lignin formation and for the lignification of cell walls. When B is in short supply, normal cell division does not proceed satisfactorily to complete separation of the dividing cells whose longitudinal walls remains short. This results in incomplete and irregular leaf expansion, the development of distorted leaves and the lack of elongation of internodes and eventual death of the apical meristem (Jackson and Chapman 1975).

Neales (1960), Albert and Wilson (1961) and Ko (1979) had reported that the root elongation of tomato ceased on B deficient

medium.

2.8.2.4 Disease Resistance

Application of B to tomato plants has been shown to increase their disease resistance. Edginton and Walker (1958) inoculated tomato plants with Fusarium Oxysponulai F. Lycopersici and showed progressive decline in severity of wilt symptoms with increase in Ca from 5 to 500 $mgkg^{-1}$ and B from 0.001 to 10 $mgkg^{-1}$. This is in accordance with the study of Koterowa and Wiezbicka (1975) who found that B and Mo increased the disease resistance of tomato fruit. Also Simojoki (1969) reported that tomato, capsicum and cabbage developed resistance to damping-off disease following seed treatment with boron and other trace elements.

2.9 Boron Requirement of Crops

Plants are known to differ in their micronutrient requirement (Andrew and Thorne, 1962). Also from the findings of Eaton (1944), crops vary widely in their requirement for B, their tolerance to high or excessive levels of the element and their ability to absorb the element from the soil.

Broad generalisation can be made in relation to plant families chenopodiaceae e.g sugar beet and cruciferae e.g cauliflover and leguminoseae e.g alfalfa have high B requirements, solananacease have moderate B requirements but all gramineae have low B requirements because their vegetative growth could be performed without B (Oram 1961, Shkol'nik, 1965; Tanaka, 1967).

Among the leguminous crops alfalfa has the greatest need for B (Rogers, 1947; Murphy and Walsh, 1972). The ratio of toxic to adequate levels of B is smaller than that for any other nutrient element (Reisenaeur et al, 1973). Both excessvie and deficient levels could be encountered in a crop during a single season. The sufficiency range of B varies from one part of the plant to another. In general B tends to accumulate in the leaves, leading to higher concentrations in old leaves. This is because B is not readily translocated from older to younger plant tissues. Gupta (1971) reported that very little B was found in the grain of cereals even at very high rates of applied B.

Silinas et al (1981) worked on the B tolerance of the pea (Pisum sativum) and got a response for concentrations of B up to 2 $mgkg^{-1}$ B/litre, whereas Agbenin (1987) got a negative response of cowpea to applied B over the range of 0.75-1.5 $mgkg^{-1}$. Chude and Obigbesan (1984) reported that the critical B content of soil and plant below which response of cocoa to B may be expected was 0.18 ug B/g and 32 ug B/g respectively. An increase in LAI and yield of tobacco was obtained by Jeong and Cho (1980) by the application of 10kg borax/ha and NPK fertilizers. Eschback (1980) worked on the micronutrients requirements of oil palm and got a positive response to B and Cu because oil palm has a heavy demand for B.

Heathcote and Smithson (1974) got a significant increase in cotton yield when 0.7 kg Bha^{-1} was applied in four sites in Northern Nigeria

2.10 Boron Requirements of Tomato

Tomato has been classified as a plant with medium requirements of B (Berger, 1949). Boron requirement of tomato depends on the condition of the soil and the variety of the tomato. Wall and Andrus (1962) had indicated that susceptibility to B deficiency is controlled by a single recessive gene. This has been shown in the tomato varieties T3238 (B-inefficient) and Rutgers (B-efficient). Also from the report of Wall and Andrus (1962) and Brown et al (1972). T3238 lacks the ability to transport B to the top of the plants and this explain the differential response of T3238 and Rutgers to a given supply of B.

Drews and Frank (1980a) found that tomatoes developed best when the B content of the soil is between 0.80 and 2.00 $mgkg^{-1}$ whereas Govindan (1950) reported that concentration of B up to 3 $mgkg^{-1}$ increased the ascorbic acid content with ripeness of fruits.

Phillips (1938) found that B in moderate amounts resulted in a steady low respiration rate apparently conducive to good keeping quality. In another study Yurkevich (1963) sprayed tomato plants with growth promoting substances 2, 4, 5-T and B and got increases in fruit yield.

Sobulo (1975) obtained the highest yield of tomato, when a mixture of NPK and 0.01% Borax was applied compared with mixtures of NPK and other micronutrients. Also the highest yield of tomato was obtained at 1.5 $mgkg^{-1}$ of B in a green house study conducted by Gulati et al (1980).

Aduayi (1978) got a normal and healthy growth of tomato plants

when 2 $mgkg^{-1}$ was used, but symptoms of B toxicity was observed when the rate of B was increased to 4 $mgkg^{-1}$. Also Adelana (1986) got a significant increase in the yield of tomatoes when he applied 0.5-1.5 kg Bha^{-1}. Carpena Ruiz and Carpena Artes (1987) worked on the nutrient balance of tomato using 5 levels of B. Plants were sampled at 5 different stages from vegetative to full fruiting stage. It was found that B nutrition had clear effects on the nutrient balance, but these effects depended on the growth stage of the plant.

The internal browning of tomato was found to be 22% with plants receiving 100 $mgkg^{-1}$ N and 0.02 $mgkg^{-1}$ B, but this was reduced to only 5% with plants receiving the same amount of N and 2 ppm B (Taylor 1957).

2.11 Deficiency Symptoms of Boron on Crops

Boron deficiency, as it is the case with other nutrients results in physiological disorder within the plant which is manifested on it. Visual deficiency symptoms of B observed on plants include the followings.

i. The youngest leaves usually the apical leaves are the first affected. They are mis-shaped, thick, brittle and small, but seldom exhibit any chlorosis, they are often dark green.

ii. Growing point of plants become moribound and die.

iii. Stems are short, severely affected plants are usually shrunken in appearance.

iv. Axillary meristem develops which also exhibit deficiency symptoms, hence plant becomes bush shaped.

v. Cracks and splits occurs in petiole, stem and sometimes fruits.

vi. Necrotic formation will be irregular as a result of incomplete fertilization. Fruits are also likely to be mis-shaped.

vii. Leaves will tend to have a mere simple shape and root growth will be impaired.

B deficiency symptoms in cereals are formation of small chlorotic spots between the veins of the youngest unfolded leaves, the spots enlarge and coalesce to form the characteristic white strips. Sterility of ears, increased tillering and short internodes are other B deficiency symptoms in cereals (Spragne 1964).

In cocoa, the deficiency symptoms are distorted puffy leaves, and formation of necrotic patches at the leaf tips. Also profuse flowering on the main stems and branches and swelling of flower cushions. Ultimately the terminal buds die and the trunk and branches may crack and tend to bleed.

Whittington (1957) found that B deficient field bean roots had enlarged apices and fewer cells than the normal B-sufficient roots. In another study, Hewitt (1958) reported that nodulation in legumes may be inhibited by inadequate B leading to N deficiency.

In vegetables B deficiency symptoms is indicated by dark brown spots on areas in the storage tissue (Gupta, 1979).

2.12 Deficiency Symptoms of Boron on Tomato

Shorrocks (1974) had listed the deficiency symptoms of B on tomato. these include:

i. Curled and chlorotic leaves (often near leaf apex).

ii. Leaves are thicker and more brittle than normal.

iii. the petioles and mid-ribs are often brittle and the older leaves become yellow or orange.

iv. The stems are short, thick and stiff.

v. Death of the growing points of the roots and stems, and the development of secondary roots and axillary buds.

vi. Failure to set fruit is common and the fruit may be ridged, show corky patches around the stem and of the fruit and ripen unevenly.

Sarin et al (1965) described the stages of B deficiency in seedlings growing in water culture as first reduced root growth followed by increased brittleness and thickness of the hypocotyls and cotyledons and finally by necrosis of the shoot apex.

Jena (1974) reported that tomato plant with slight to moderate symptoms of B deficiency exhibit deformed leaves, brittle and partly chlorotic, poorly developed leaves. Insevere B deficiency die-off of growing point is exhibited and for very severe cases, thickened stems and corky lesions are exhibited.

2.13 Toxicity Symptoms of Boron on Crops

When excess B is applied to crops, it leads to B toxicity. Symptoms of B toxicity are marginal and tip chlorosis followed by

necrosis (Shorrocks 1974).

In corn, leaves show tip burn and marginal burning and yellowing between the veins (Wilcox 1960). In wheat, B toxicity appears as light browning of older leaf tips converging into light greenish-blue spots (Gupta, 1971).

In beans, excess B causes mottled and necrotic areas on the leaves, especially along the leaf margins.

In cowpea, burning of leaf margins and vein of the older leaves are early symtoms of B toxicity. This progressively moved inwards and sideways till the leaves appeared scorched and later abscission of leaves occured (Agbenin, 1987).

In tomato, symptoms of B toxicity include chlorosis and necrosis of leaves, curled up of calyx and calyx leaflets (Shorrocks, 1974).

Burning and yellowing of older leaves which results in dying off of older leaves (Bergmann, 1986).

2.14 Correction of Boron Deficiency

Boron deficiency in plants can be corrected by the application of boron fertilizer to the soil or directly to the plant as foliar sprays.

2.14.1 Types of Boron Fertilizer

Sodium salts are the most common forms of B fertilizers. The most well known B fertilizers is borax ($Na_2B_4O_7.10H_2O$). It contains 11.3% B. Other B containing materials are fertilizer Borate 47

(14.8% B); fertilizer Borate 48, (45% B), Boric acid (17.5% B); solubor (20.5% B) and Boron silicate frits ($Na_2B_4.XH_20$) contained in moderately soluble glass. These are of sintered glass with a large surface area and provide a slow relase of B into the solution, it contains from 6 to 11% B.

Another recently available source of B is Ulexite ($NaCaB50_9.8H_20$) containing 10-23% B, and is considered to release B slowly, as compared with other sources of B. Other kinds of B-containing fertilizers include boronated gypsum, calcium carbonate, superphosphate and various mixed fertilizers (Berger and Pratt, 1963).

Additional sources include farmyard manure, seward sludge, compost and similar materials. The percentage of B in these sources depend on the origin of the materials present in the given source (Gupta, 1979).

2.14.2 Method of Boron Fertilizer Application

Two principal methods of applying B are by adding it directly to the soil in solid form, and by foliar spraying, in solution form. Uniform distribution of the fertilizer is important in view of the fact that only small maounts of borate are required. Unequal application may cause heavy local application which could result in limited toxicity in parts of the field, whilst the remaining parts are left in a deficient state. Borates could be applied alone or together with fertilizers or in combination with pesticides which they are known to be compatible.

Soil application of B could be broadcast or banded. It could be applied alone or mixed with other fertilizers. Most data reported on the B uptake have been obtained with B containing fertilizers added as broadcast or in bands (Gupta 1979). In field studies on rutabaga, Gupta and Cutcliffe (1978) reported that band application of B resulted in greater B concentrations in leaf tissue than did broadcast application at five locations.

Foliar applications besides resulting in higher B uptake could be used to advantage if a farmer omitted the addition of B in the NPK bulk fertilizer, or if B deficiency was suspected. Early foliar spray application result in greater absorption of B than do those applied at later stages of growth (Gupta and Cutcliffe 1978). Also Morvedt et al (1972) stated that early-morning applications of foliar applied nutrients may result in increased absorption as the relative humidity is high, the stomata are open and photosynthesis is taking place.

2.15 Importance of Tomato

Tomato is a very popular food which is often cooked fresh. McCollum (1956), reported that tomato is a cheap source of vitamin A, B and C with edible portions containing about 94.1% H_2O; 1% protein, 7 mg of Ca, and 22 mg of Niacin. Villareal (1980) compared nutrient yield of 16 different crops on dry matter per day basis and reported that tomato ranked 8th highest in vitamin C, and protein, 9th in Fe and 13th in vitamin A.

Tomato juice contributes significantly to man's nutrition in

the diet as a breakfast juice or an appetizer served at any meal of the day. According to Gould (1971), it contains from 15 to 25 mg/100gm of vitamin C and has 4 times the vitamin A content of orange juice. Like orange juice, it contains considerable basic ash and on digestion, leaves an alkaline residue. It is a good source of iron, manganese and copper (Tressler and Joslyn 1971).

Fresh tomato is used as ingredient for salad, stew, soup and in some dishes. According to Goose et al (1964), the fruit can be canned as puree with 8-24% solid, as paste with 25-37% solid, and as powder with more than 37% fatty solid.

CHAPTER THREE

MATERIALS AND METHODS

The study consists esentially of three components namely, greenhouse, laboratory and field studies.

3.1 Greenhous Studies

3.1.1 Locations

Thirty soil samples were collected from fields that had been under tomato cultivation for at least 3 years and under fallow for 5 years respectively (Fig. 1A). The fallow fields were not more than 2 km from each tomato cultivated field. Fields that had received boronated fertilizers in earlier years were avoided, so as not to influence treatment effect. Information about the locations are given in Table 1.

3.1.2 Soil Sampling Method

Soil samples were taken from thirty spots within an area of about $100m^2$ at 0-20cm depth. The samples were bulked thoroughly, mixed and air-dried on clean plastic sheets in a soil room, after which the air-dried samples were crushed and passed through a 2mm stainless sieve. Subsamples were taken and stored in plastic containers for laboratory analyses, while bulk of the samples were used for greenhouse studies.

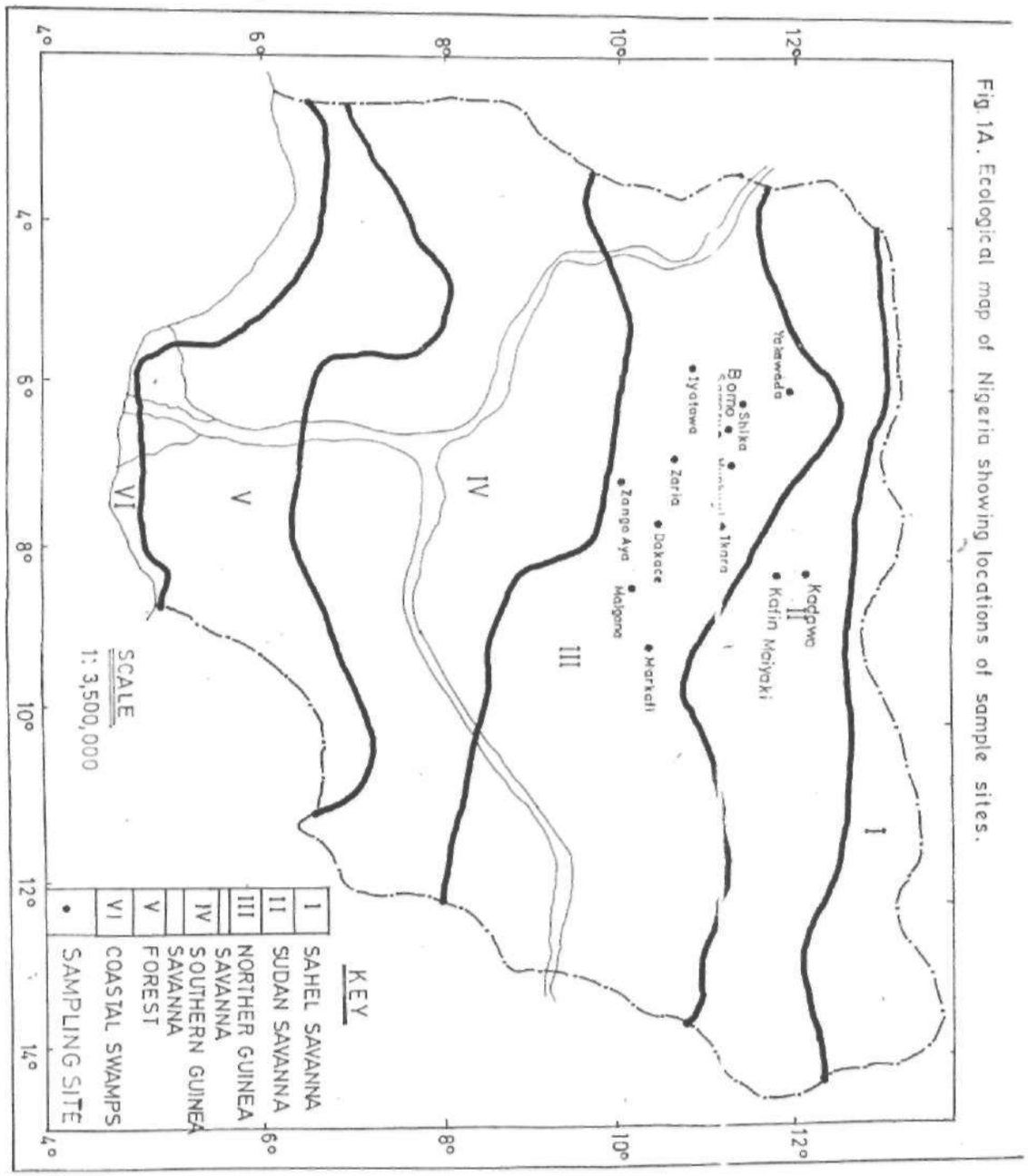


Fig 1A. Ecological map of Nigeria showing locations of sample sites.

Table 1: Location, history, parent mateial, state and ecological zone of the soils used in the study

Location	History	Parent Material	Taxonomy	State	Ecological Zone
Zaria Dam	Cultivated	Basement Complex	Alfisols	Kaduna	Northern Guinea savanna
Zaria Dam	Fallow	"	"	"	"
Kadawa	Cultivated	"	"	Kano	Sudan savanna
Kadawa	Fallow	"	"	"	"
Hunkuyi	Fallow	"	"	Kaduna	Northern Guinea savanna
Hunkuyi	Cultivated	"	"	"	"
Samaru I	Fallow	"	"	"	"
Samaru I	Cultivated	"	"	"	"
Shika	Fallow	"	"	"	"
Shika	Cultivated	"	"	"	"
Iyatawa	Fallow	"	"	"	"
Iyatawa	Cultivated	"	"	"	"
Karfin Maiyaki	Cultivated	"	"	Kano	Sudan savanna
Marfin Maiyaki	Fallow	"	"	"	"
Dakace	Cultivated	"	"	Kaduna	Northern Guinea savanna
Dakace	Fallow	"	"	"	"
Samaru 2	Cultivated	"	"	"	"
Samaru 2	Fallow	"	"	"	"
Yakawada	Fallow	"	"	Katsina	"
Yakawada	Cultivated	"	"	"	"
Zango-Aya	Fallow	"	"	Kaduna	"
Zango-Aya	Cultivated	"	"	"	"
Ikara	Cultivated	"	"	"	"
Ikara	Fallow	"	"	"	"
Makarfi	Cultivated	"	"	"	"

Table 1 Contd: Location, history, parent mateial, state and ecological zone of the soils used in the study

Location	History	Parent Material	Taxonomy	State	Ecological Zone
Makarfi	Fallow	Basement Complex	Alfisols	Kaduna	Northern Guinea savanna
Maigana	Fallow	"	"	"	"
Maigana	Cultivated	"	"	"	"
Bomo	Cultivated	"	"	"	"
Bomo	Fallow	"	"	"	"

3.1.3 Greenhouse Technique

The thirty soil samples were cropped to two tomato varieties in the greenhouse. Tomato seedlings were raised in a nursery and were transplanted at 4 weeks after planting (WAP), at the rate of three seedlings in each 3 litre plastic pot containing 2 kg of air-dried soil. The plastic pots were placed on plastic receivers. Two levels of boron -0 and 0.5 $mgkg^{-1}$ were applied and replicated 2 times in a randomised complete block design.

A basal nutrient solution containing 100 mgL^{-1} each of N,P,K and Ca, 24 mgL^{-1} Mg, 32 mgL^{-1} S, 8 mgL^{-1} Mn, 5 mgL^{-1} each of Fe, Cu, Zn and 0.5 mgL^{-1} Mo was applied at planting (Aremu 1976). At 2 weeks after transplanting (WAT), boron was applied in solution form. Also at 4 WAT additional 100 mgL^{-1} N was applied.

The potted plants were watered to 60% field capacity with distilled water, and the drained water in the receiver was returned into the pots. Observations were made of morphological appearance of the leaves. Measurement of plant height started at 2 WAT and continued at weekly intervals. The above ground portion was harvested at 8 WAT, washed first in tap water, rinsed in distilled water and dried in an oven set at 65°C. The dried samples were weighed and then ground with a stainless steel mill. The ground samples were stored in polythylene bags for laboratory analysis.

3.2 Laboratory Studies

Laboratory studies consist of soil analysis, plant tissue and fruit analysis and adsorption and desorption studies.

3.2.1 Soil Analysis

Particle size distribution analysis

This was determined by hydrometer method (Day 1965). The sand, silt and clay fractions were determined with the aid of the Bouyoucos hydrometer using sodium hexametaphosphate as dispersant. The USDA textural triangle was used to determine the textural class.

Soil pH

The soil pH was determined with a Pye Unicam model 190 MK pH meter in a 1:2.5 solution ratio of water and 0.01 $MCaCl_2$.

Total Nitrogen

The total nitrogen was determined by the microkjeldah procedure described by Bremner (1965).

Organic Carbon

The wet oxidation method of Walkley-Black as described by Allison (1965) was used for the determination of organic carbon.

Available Phosphorus

This was determined using the Bray 1 method described by Jackson (1962), and the concentration of phosphorus in the extract was determined colorimetrically in a spectrophotometer (spectronic 20) at 660mm wavelength.

Micronutrients

The micronutrients, Cu, Mn, Zn and Fe were extracted with 0.1M HCl and the various elements determined with Atomic Absorption Spectrophotometer.

Exchangeable Bases

The exchangeable bases was displaced with ammonium acetate buffered at pH 7.0. K and Na in the extract were determined by flame photometry Ca and Mg were determined by AAS.

Effective Cation Exchangeable Capacity (ECEC)

The ECEC was determined by summation of the exchangeable cations and the exchangeable acidity.

Exchangeable Acidity

This was determined by the KCl method (Juo, 1973).

Determination of Total and Available Boron in Soils

Total boron in the soil was brought into solution by Na_2CO_3 fusion. Available boron was extracted by five methods:- Hot water, 0.1% $CaCl_2$, 0.05 MHCl, Double acid, and Morgan solution.

Hot Water:- 20g of soil was weighed into 100ml beaker and 40ml of distilled water was added to the sample and the flask placed in boiling water bath for one hour (1 hr). The hot soil mixture was centrifuged for 5 min. and filtered with whatman No. 42 filter paper.

0.1% $CaCl_2$ Solution:- 20g of soil was weighed into 100ml extraction flask and 40ml of 0.1% $CaCl_2$ solution was added. The mixture was refluxed for 5 min. after boiling. The flask was cooled centrifuged and filtered (Baker and Mortensen 1966).

Morgan solution:- 20g of soil was weighed into the centrifuge tube and 40ml of Morgan solution (sodium acetate) was added. The mixture was shaken on a mechanical shaker for 5 min. and filtered Gaines and Mitchell (1979).

0.1N HCl Solution

20g of soil was weighed into centrifuge tube and 40ml of 0.1N HCl solution was added and shaken for 5 min. in a horizontal shaker at 180 cycles min^{-1}. The mixture was filtered (Ponnamperuma 1981).

Double Acid Solution (0.05M H_2SO_4 and 0.025M HCl

20g of soil was shaken with 40ml of the double acid solution for 5 min. in a centrifuge tube and filtered (Lombin 1985b).

Colorimetric Determination of Boron

Boron concentration in the soil was determined colorimetrically according to the azomethine-H method by Wolf (1971), and modified by Wolf (1974). 4ml of the soil extract or filtrate was pipetted into photometric tubes followed by the addition of 1ml buffer-masking reagent and azomethine-H and stirred thoroughly. The mixtures were allowed to stand for one hour (1 hr) and B in the filtrate was read at 420nm wavelength using spectronic

70 spectrophotometer.

3.2.2 Plant Tissue Analysis

The plant samples from the greenhouse and field studies were analysed for available B adopting the method described by Gaines and Mitchell (1979).

The ground plant material from the field trials were digested with a mixture of HNO_3, H_2SO_4 and $HClO_4$ acids on a hot plate (Juo 1979). The amount of P in the digest was determined colorimetrically, while flame photometry was adopted for Na and K. The Mg, Cu; Zn, Mn and Fe contents in the digests were determined by use of the atomic absorption spectrophotometer.

3.2.3 Fruit Analysis

Mature ripe fruits were used for the following analysis:

Ascorbic acid (Vitamic C)

The ascorbic acid contents of the fresh fruits were determined by the 2, 6-dichlorophenolindophenol (AOAC 1975).

Total Soluble Solids (TSS)

This was determined by the oven drying method as described by Goose and Binstead (1964).

Titratable Acidity

The titratable acidity was determined by titrating the tomato

juice with 0.1N NaOH as described by Goose and Binstead (1964).

Reducing Sugars

The fresh fruits were analysed for reducing sugars using 3, 5-Dinitrosaliysilic acid method as described by Clark and Switzer (1977).

Adsorption and Desorption Studies

Adsorption and desorption studies were carried out on the thirty soil samples using the method of Elrashidi and O'Connor (1982) to assess the boron retention and release properties of the soil.

Adsorption Procedure

20g of soil sample and 20ml of 0.01M $CaCl_2$ solution containing varying amounts of B (0, 10, 20, 30, 40 and 50 mgl^{-1}) were shaken for 14 hrs, after which it was centrifuged, and 10ml of the filterate was removed for B analysis. This procedure was repeated three more times resulting in a total of four desorptions for each adsorption sample.

Desorbed B was calculated as the difference between equilibrium B concentration at each desorption step and the equilibrium B concentration previous to each desorption step divided by 2 (dilution factor).

3.4 Field Studies

The field studies were conducted at two sites - Samaru and Kadawa.

3.4.1 Site Description and History

Samaru:- The site used for the field study was the Institute for Agricultural Research experimental farm, Samaru (Latitude 11° 11'N, Longitude 07° 38'E and Altitude 682m), which is situated in the Northern Guinea Savanna zone (Keay, 1958). The soils of the experimental farm have been classified as Typic Ustropept (Harpstead, 1973) while in a more detailed survey, the soil was reclassified as Typic Haplustulf in the USDA system or Orthic Acrisol in the FAO system (Valette and Ibanga, 1984).

Kadawa:- The experiment was laid out at the Irrigation Research Station Kadawa, (Latitude 11°, 39'N, Longitude 08° 02'E and Altitude 500m) which is situated in the Northern Guinea savanna zone. The station is located within the Hadejia Jamare River Project. The soils of the Research Station have been classified as Typic Ustropept (USDA) and Eutric Cambisol (FAO) by Ojanuga et al (1979), who also found the soil parent material to be aeolian sandy drift over iron pan.

Despite earlier classification of the soils, attempt was made in this study to reclassify the soils of the field trial.

3.4.2 Soil Characterization

One soil profile of 1m wide by 2m long by 2m deep was sunk at

Samaru and Kadawa sites, soil samples were collected from various horizons of the profile pit, air-dried, analysed and classified.

3.4.3 Field Trials

Boron rate trials were conducted to determine the optimum B level in tomato plants for optimum yield under irrigation and rainfed field conditions. The experiment was conducted at 2 sites - Samaru and Kadawa in two consecutive dry seasons (1992/93 and 1993/94) and wet seasons (1993 and 1994).

The effect of B application on the growth, yield and yield parameters of tomatoes (Roma VF and Dandino varieties) were evaluated.

3.4.4 Treatments, Design and Cultural Practices

The two tomato varieties were raised on nursery beds and transplanted onto field plots at 4 weeks after planting (4 WAP). During the nursery stage the seedlings received 25g of NPK fertilizer per square metre of seed bed.

Treatments consisted of factorial combination of 2 tomato varieties and six levels of boron arranged in a randomised block design with three replications.

A basal dose of 70 $kgha^{-1}$ NPK 15:15:15 was applied in each trial before sowing. The plot size was $9m^2$ which consisted of two raised beds of 1m width each, 15cm high and 0.75m apart. The seedlings were planted on the raised beds in double rows 0.60m apart, with a space of 0.4m between seedlings, to give a plant

density of 30 plants per plot (35,000 plants per ha). One week after transplanting, the missing stands were transplanted to ensure uniform plant population in all plots, 300 kg CAN ha^{-1} was applied in 2 split doses at 2 and 6 WAT. The boron was applied as borax at 2 WAT, when the seedlings were established by mixing thoroughly with the first dose of CAN fertilizer. Harvesting of ripe tomato fruits were done manually twice a week.

3.4.5 Dry Season Trial

1992/93

Seeds were sown on the 30th of October, 1992 and transplanted on the 1st of December, 1992 in Samaru. For the Kadawa trial, the seeds were sown on the 23rd of November and transplanted at 4 weeks after planting (Leskovar and Cantliffe 1991). The six levels of B used in the dry season trials were 0, 1.0, 2.0, 3.0, 4.0 and 5.0 kg B ha^{-1}. Hoeweeding was done three times at 2, 5 and 9 WAT in both sites.

1993/94

Seeds were sown on the 3rd of November, 1993 and transplanted on the 2nd of December 1993, in Samaru. For the Kadawa site, the seeds were sown on the 30th of November and transplanted on the 29th of December 1993. The same levels of B used for the 1992/93 trials were used for these trials. Hoe-weeding was carried out three times at 2, 5 and 9 weeks after transplanting (WAT) in both

sites.

3.4.6 Wet Season Trials

1993

The seeds were planted on the 15th of May, 1993. For the Samaru trial, and transplanted at 5 WAP, because the rains did not establish early. The Kadawa trial was planted on the 23rd of June 1993 and transplanted when they were 5 WAP. The six levels of B applied for wet season trials were 0, 0.5, 1.0, 1.5, 2.0 and 2.5 kg B/ha. Hoe-weeding was done four times in both sites at 2, 5, 8 and 10 WAT. Starting from 4 WAT, the trials were sprayed with a mixture of benlate (81g/ha) and Diethane M45 (290g/ha) forthnightly.

1994

Seeds were sown on the 16th May, 1994 and transplanted at 4 WAP. The seedlings transplanted in Kadawa were all lost due to excessive rainfall. Another set of seeds were sown onthe 29th of August, 1994. The treatment and cultural practices were the same as that of 1993 wet season trials.

3.4.7 Observation and Measurements

The following parameters were measured for all the trials (dry and wet seasons):-

(i) Morphological appearance of the plant;

(ii) No. of leaves per plant;

(iii) No. of days to 50% flowering;

(iv) No. of flowers per plant;

(v) No. of fruits per plot;

(vi) Size of fruit per plant

(vii) Fruit yield.

For both trials, plant samples were collected for analysis from Samaru site, at the first fruiting stage and the dry matter yield was determined at the end of harvesting.

In order to determine the distribution of B in tomato plants, plant samples were taken at flowering and B was determined in roots, shoots and leaves during the 1994 trial. Matured ripe fruits were also used to determine the vitamin C content, total soluble solids, pH reducing sugar and titratable acidity.

3.4.8 Plant Sampling

Sampling was done by randomly selecting 5 plants per plot and washed in clean water, rinsed twice in distilled water and dried in clean paper bags in an electric oven set at 70°C. After drying, the plant materials were ground by passing them through a mill fitted with stainless steel knives and 0.5mm sieves. The ground plant materials were stored in polythene bags.

For the determination of the distribution of B in tomato plants, six plant samples were uprooted at 50% flowering stage from each plot in 1994 trials and the root, shoot and leaves were bulked separately. The plant materials were washed with tap water, rinsed

with distilled water, dried, ground and stored in polythene bags as previously described.

3.5 Weather Data

The following weather data were collected in both sites during the cropping seasons:-

(i) Rainfall

(ii) Minimum and maximum Temperature

(iii) Relative humdity

(iv) Sunshine.

3.6 Statistical Analysis

The statistical analysis done include, analysis of variance, simple correlation and multiple stepwise regression analyses.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 LABORATORY ANALYSIS

4.1.1 Fertility Assessment of Surface Soils

4.1.1.1 Particle Size Distribution: Soil Texture

The sand, silt and clay fractions ranged from 27-71, 20-46 and 7-27% respectively, with corresponding means of 52, 34 and 14% as shown in Table 2. This is within the range earlier reported for similar soils (Malgwi, 1979).

The texture ranged from sandy loam to loam and the means of the particle size fraction indicate that the soils were generally of a sandy loam texture. This is a general charateristics of the soil of this area which are well developed Alfisols (Lombin, 1983a).

Soil texture has a direct relationsip with nutrient retention, drainage aeration, water holding capacity and water supply to crops in soils. The texture of these soils are considered very desirable for adequate root growth and development.

4.1.1.2 Soil Reaction

The pH in water is moderately acid and ranged from 4.60 to 6.80 with a mean of 5.48. The pH range in salt solution ($CaCl_2.2H_20$) was between 4.1 and 5.6 and a mean of 4.90 (Table 3). These values are close to those obtained by Lombin (1983a), Lombin and Singh (1986) for soils of Northern guinea savanna.

Only five out of the thirty soils samples were sufficiently

Table 2: Particle size distribution of the soils

Soil No	Site	Sand	Silt	Clay	Textural Classes
1	Zaria*	51	36	13	Sandy loam
2	Zaria**	53	32	15	Sandy loam
3	Kadawa*	53	36	11	Sandy loam
4	Kadawa**	51	40	9	Sandy loam
5	Hunkuyi**	57	28	15	Sandy loam
6	Hunkuyi*	51	36	13	Sandy loam
7	Samaru 1**	59	28	13	Sandy loam
8	Samaru 1*	53	36	11	Sandy loam
9	Shika**	33	42	25	Loam
10	Shika*	53	38	25	Sandy loam
11	Iyatawa**	57	32	9	Sandy loam
12	Iyatawa*	51	36	11	Sandy loam
13	Karfin Maiyaki*	71	22	13	Sandy loam
14	Karfin Maiyaki**	71	20	7	Sandy loam
15	Dakace*	45	44	9	Loam
16	Dakace**	49	36	15	Loam
17	Samaru 2*	27	46	27	Loam
18	Samaru 2**	53	30	17	Sandy loam
19	Yakawada**	57	30	13	Sandy loam
20	Yakawada*	35	42	23	Loam
21	Zango Aya**	63	24	13	Sandy loam
22	Zango Aya*	57	20	23	Sandy loam
23	Ikara*	51	38	11	Sandy loam
24	Ikara**	44	41	15	Loam
25	Makarfi*	55	34	9	Sandy loam
26	Makarfi**	59	34	7	Sandy loam
27	Maigana*	39	36	25	Loam

Table 2 contd: Particle size distribution of the soils

Soil No	Site	Sand	Silt	Clay	Textural Classes
28	Maigana**	52	38	10	Sandy loam
29	Bomo*	53	36	11	Sandy loam
30	Bomo**	53	38	9	Sandy loam
	Mean	52	34	14	

* Cropped soils
** Fallow soils

acidic for their pH values fall below 5.0 in water. In acid soils, exchangeable Al becomes toxic to plant growth only below 5.0 in water (Nye and Greenland 1960 and Kamprath, 1972;).

The pH of most Alfisols in the Nigerian savanna fall between 5.5-6.8. The acidity encountered with the five samples may have been induced through the ungaurded use of acid forming fertilizer or excessive leaching of basic cations.

The soils with pH values below 5.0 could be managed by application of lime or by growing tolerant plant species. Lime could be broadcasted at land preparation and incorporated into the soil as much as possible

4.1.1.3 Organic Carbon Content

The organic carbon contents in the soils fall within the low to medium fertility (Table 3). The values ranged from 2.6 in a cultivated sandy loam soil to 15.6 gkg^{-1} in a fallow loamy soil with a mean value of 5.48 gkg^{-1}.

Table 3: Chemical properties of the soils

Soil No	Soil 1:2.5 (H_2O)	pH 1:2.5 $CaCl_2$	Organic Carbon gKg^{-1}	ECEC	Exch. Acidity	Exchangeable bases				Avail. P	Total N	Available Micronutrients			
						Ca	Mg	K	Na	mgKg^{-1}	gKg^{-1}	Fe	Cu	Zn	Mn
				(----------		----------Cmol Kg^{-1}----------			----------)			(----------		----------mgKg^{-1}----------	)
1	5.0	4.4	4.9	1.32	0.2	0.78	0.27	0.09	0.11	1.54	0.56	2.3	3.0	3.2	1.33
2	4.8	4.6	5.6	1.11	0.2	0.63	0.24	0.11	0.13	2.05	0.84	4.2	2.8	2.8	3.20
3	4.9	4.8	5.9	2.64	0.3	4.52	0.52	0.15	0.15	4.11	0.61	14.5	2.4	3.4	7.90
4	5.6	4.6	6.8	1.95	0.2	3.41	0.74	0.21	0.14	2.45	0.68	6.8	3.2	3.5	7.14
5	5.5	5.0	5.8	2.44	0.2	1.82	0.62	0.17	0.18	2.64	0.89	6.2	3.0	5.2	5.20
6	5.2	5.0	2.8	2.69	0.2	1.64	0.84	0.16	0.15	5.65	0.40	6.5	2.2	3.3	5.70
7	5.3	5.1	4.0	2.89	0.2	4.49	1.32	0.35	0.35	3.94	0.42	5.2	1.6	2.6	3.66
8	5.3	4.4	3.6	4.74	0.3	3.05	0.82	0.25	0.23	3.56	0.42	4.8	2.7	3.1	4.72
9	4.9	4.7	18.4	1.68	0.2	1.52	0.48	0.17	0.17	2.33	1.12	4.5	2.3	5.6	16.0
10	5.3	5.2	3.4	1.98	0.2	1.18	0.38	0.13	0.13	7.22	1.09	3.1	1.6	3.1	8.1
11	6.2	5.3	5.1	11.02	0.5	6.38	2.52	0.65	0.31	1.73	1.82	6.1	1.8	1.2	6.6
12	6.3	5.3	5.1	11.02	0.5	6.38	2.52	0.65	0.31	9.85	1.88	1.3	2.1	2.2	6.72
13	5.9	5.3	2.6	5.17	0.2	3.48	1.34	0.23	0.18	7.75	0.48	12.2	3.0	3.4	4.82
14	5.8	5.6	2.8	5.88	0.2	4.02	1.34	0.23	0.18	7.75	0.48	8.5	1.8	4.6	6.82
15	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
16	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
17	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
18	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
19	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
20	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
21	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
22	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
23	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
24	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
25	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
26	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
27	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
28	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
29	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
30	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
31	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
32	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
33	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
34	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
35	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
36	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
37	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
38	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
39	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82
40	5.6	5.2	2.3	4.67	0.4	3.42	0.89	0.26	0.17	22.83	0.48	8.5	1.8	4.6	6.82

Table 3 contd: Chemical properties of the soils

Soil No	Soil 1:2.5 (H_2O)	pH 1:2.5 $CaCl_2$	Organic Cabon gKg^{-1}	ECEC	Exch. Acidity	Exchangeable bases				Aval. P $mgKg^{-1}$	Total N gKg^{-1}	Available Micronutrient			
						Ca	Mg	K	Na			Fe	Cu	Zn	Mn
				(Cmol Kg^{-1})								($mgkg^{-1}$)			
17	6.8	5.4	13.4	4.75	0.2	3.74	0.11	0.33	0.37	12.78	1.35	75.0	9.0	10.2	18.0
18	6.3	5.2	5.1	2.53	0.1	1.68	0.21	0.27	0.27	12.44	0.51	37.5	3.4	6.2	5.9
19	5.5	4.5	8.3	20.35	0.4	14.97	2.94	0.67	0.14	5.89	0.74	12.5	4.2	3.1	13.6
20	4.6	4.5	9.6	11.56	0.3	9.23	1.25	0.43	0.35	9.27	0.98	65.0	6.4	3.4	16.0
21	5.6	5.0	6.3	3.96	0.2	2.62	0.82	0.14	0.18	6.05	0.56	30.0	2.2	3.0	6.9
22	6.0	4.2	4.2	2.92	0.3	1.73	0.65	0.12	0.12	13.53	0.56	32.5	3.6	2.6	11.2
23	5.4	4.8	11.2	4.78	0.1	3.12	0.93	0.37	0.26	12.78	0.96	11.0	3.0	2.1	6.0
24	5.0	4.8	4.1	3.09	0.2	1.32	1.12	0.24	0.21	7.12	1.38	3.20	1.8	3.0	6.2
25	5.2	4.7	7.2	11.39	0.4	7.98	1.99	0.72	0.30	12.46	0.79	8.50	1.4	8.1	8.6
26	6.8	4.1	7.0	8.19	0.2	5.63	1.63	0.48	0.25	12.29	0.89	26.0	5.6	3.1	22.0
27	4.9	4.8	14.9	12.35	0.1	6.86	1.97	4.09	0.30	6.39	1.22	6.0	2.4	3.2	6.9
28	5.0	4.7	3.2	7.54	0.2	4.76	1.34	0.98	0.26	12.54	0.51	7.5	2.4	7.4	12.4
29	6.0	5.6	5.4	16.16	0.2	11.48	3.08	1.04	0.33	11.81	0.61	44.0	3.6	3.6	8.0
30	5.1	4.8	4.2	10.07	0.2	6.08	2.62	0.95	0.22	11.29	0.53	20.0	1.4	4.5	4.9
Mean	5.46	4.90	5.49	6.10	0.22	4.30	1.21	0.39	0.26	8.11	0.70	19.40	2.90	3.95	8.03

The low levels of organic carbon in the soils may be attributable to low vegetation and sandy nature of the soils (Jones 1973). It could also be due to low rate of litter addition owing to burning of grass vegetation.

Only four out of the thirty soil samples have their O.C above the critical value of 10 gkg^{-1}. There is therefore the need for increasing and maintaining optimum level of O.C if sustainable crop production is to be achieved. This could be achieved by adequate fertilization of crops to increase biomass production which may eventually be returned to the land after harvest, addition of animal manure; compost and green manure. Also effective conservation measures to minimize loss of O.C through water and wind erosion should be adopted.

4.1.1.4 Exchangeable Cations

Exchangeable cations Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} are low, reflecting the low CEC of the soils. The principal saturating cations in all the soils is Ca with a range of values of 0.63 to 14.97 cmol Kg^{-1}, mean being 4.30 cmol Kg^{-1} (Table 3). This is followed by Mg with values of 0.11 to 3.06 cmol Kg^{-1}, and mean of 1.21 cmol Kg^{-1}. This result is in agreement with the findings of Jones and Wild (1975) that Ca and Mg are dominant exchangeable cations in all the savanna soils.

Exchangeable K values varied from 0.11 to 1.087 cmol Kg^{-1} with a mean of 0.39 cmol kg^{-1}, while exchangeable Na values varied from 0.11 to 0.38 cmol Kg^{-1} with a mean of 0.26 cmol kg^{-1}.

The predominance of Ca over the other cations may imply that Ca is less leached out of soils than the rest of the exchangeable cations. It has also been stated that there are a number of exchange sites in the natural soil which show specific afinity for Ca than Mg (Beckett 1965).

The low values of K and Na (Table 3) suggest that these cations are easily leached from the soils or that the parent materials of the soils are low in minerals containing these elements. Mg content was low, but was significantly higher than Na and K contents. The soils will respond to K fertilizers and lower rates of Mg fertilizers.

4.1.1.5 Effective Cation Exchangeable Capacity (ECEC)

The effective cation exchangeable capacity was determined by summation of the exchangeable cations and the exchangeable acidity. The values of the ECEC varied from 1.1 to 20.3 cmol Kg^{-1}, with a mean of 6.1 cmol Kg^{-1} (Table 3).

Only 18 out of the 30 soils had ECEC higher than the critical value of 4.0 cmol Kg^{-1} needed to retain most cation against leaching in the highly weathered sandy soils as suggested by Sanchez (1976).

Soils with low ECEC have low ability to retain and release plant nutrient element for normal growth. Also the soils will be unable to meet high nutrient demand by crops and may lead to nutrient inbalance from the conventional fertilizer practices.

Low ECEC also signifies that nutrients applied as cations are weakly held and leaching may occur from surface soils (Jones and

Wild 1975).

4.1.1.6 Exchangeable Acidity (EA)

The exchangeable acidity values were generally low. They varied from 0.1 to 0.4 with a mean of 0.22 cmol Kg^{-1} (Table 3). Since exchangeable acidity is a measure of exchangeable Al and H^+, low exchangeable acidity signifies low amounts of Al and H^+. There are therefore no threats from aluminium toxicity in the soils.

4.1.1.7 Available Phosphorus

The available phosphorus (P) content of the soils fall within the low to medium fertility. The values varied from 1.73 to 13.50 mg kg^{-1} with a mean of 8.11 mg Kg^{-1}, as shown in Table 3. Jones and Wild (1975) reported low levels of available P in the soil of the Nigerian savanna, probably due to fixation by hydrous oxides of iron and aluminium (Brady 1984). However, plants will require available P through fertilizer to sustain growth and economic yields.

4.1.1.8 Total Nitrogen (N)

The total N contents of the soil are low and values fall short of the medium range. The values varied from 0.39 to 1.38 gKg^{-1} with a mean of 0.70 gKg^{-1}, (Table 3). There is a problem of N deficiency in these savanna soils. These low values are closely linked with the generally low levels of organic matter (OM) in these soils. Jones and Wild (1975) reported low values of total N in savanna soils, and attributed the variability in N contents to rainfall and

clay content of the savanna soil.

The use of appropriate inorganic N fertilizer source for the production of crops other than legumes in the area cannot be over-emphasized considering that this category of crops cannot meet their N requirements through fixation of atmospheric N.

Another important cultural measure that can improve on the present low levels of N in the soils is crop rotation, involving legumes as one of the rotational crops.

4.1.1.9 Micronutrients:

Available Iron (Fe)

Available Fe ranged from 2.5 to 85 $mgKg^{-1}$ with a mean of 19.40 $mgkg^{-1}$, as shown in Table 3. Although, available Fe is generally high in the tropical soils, localized deficiencies of Fe are known to occur (Enwezor et al 1989). Available Fe poses no fertility problems in the soils studied.

Available Copper (Cu)

The values of available Cu ranged from 1.2 to 9.0 $mgKg^{-1}$ with a mean of 2.9 $mgKg^{-1}$, as shown in Table 3. The levels of available copper in these soils are adequate, and therefore posses no fertility problem.

Available Zinc (Zn)

The 0.1N HCl extractable Zinc varied from 2.10 to 10.2 mg Kg^{-1} with a mean of 3.95 $mgKg^{-1}$ (Table 3). These values fall within medium to high fertility. These values are within the range obtained by other workers for similar soils (Lombin 1983b and Pam

1990). Available Zn poses no fertility problem in the soils studied.

Available Manganese (Mn)

The values of available Manganese (Mn) ranged from 3.2 to 22.0 $mgKg^{-1}$ with a mean of 8.03 (Table 3). The values are higher than those obtained by Lombin (1983a), who also concluded that the Northern Nigerian savanna soils which are predominantly mildly to medium acid, seem well supplied with Mn at present and the prospects of deficiency problems in the foreseable future seem remote.

4.1.2 Total and Available Boron (B)

4.1.2.1 Total Boron Content: Data on Table 4 shows that the total B ranged from 6.0 to 130 $mgKg^{-1}$ with a mean of 56.1 $mgKg^{-1}$. These values compared favourably with the 2.0 to 100 $mgKg^{-1}$ B, reported by Swaine (1955) for Western Europe and North America soils, and 8.0 to 98 $mgKg^{-1}$ B reported for different soils in USA.

Higher total soil B with a range of 7.0 to 630 $mgKg^{-1}$ were observed in Indian soils (Kanwar and Randhawa 1967).

The values obtained in this study are however high when compared to values of 0.78 to 3.48 $mgKg^{-1}$ B reported for soils derived from sandstone and 0.48 to 9.60 $mgKg^{-1}$ B for soils derived from Basement Complex rocks in Southern Guinea savanna and rainforest zones of Nigeria (Banjoko *et al* 1981). Anande-kur (1976) reported values of 8.3 to 38.7 $mgKg^{-1}$ for very few samples of some Northern Nigerian savanna soils.

Table 4: Total and Extractable B contents of the soils

Soil No	Hot Water	0.1% $CaCl_2$	0.1N HCl	Double acid	Morgan solution	Total Boron
	<---------- $mgKg^{-1}$ ---------->					
1	0.04	0.07	0.27	0.14	0.07	69.0
2	0.15	0.11	0.16	0.25	0.12	40.0
3	0.08	0.06	0.27	0.13	0.09	63.0
4	0.16	0.12	0.24	0.30	0.12	84.0
5	0.17	0.19	0.24	0.14	0.11	66.0
6	0.07	0.08	0.41	0.20	0.10	46.0
7	0.13	0.10	0.08	0.18	0.11	49.0
8	0.19	0.20	0.41	0.19	0.14	66.0
9	0.14	0.14	0.27	0.13	0.15	75.0
10	0.10	0.11	0.30	0.14	0.09	75.0
11	0.11	0.12	0.49	0.12	0.08	55.0
12	0.15	0.13	0.24	0.16	0.11	37.0
13	0.10	0.09	0.54	0.16	0.12	52.0
14	0.13	0.11	0.27	0.22	0.08	69.0
15	0.13	0.11	0.19	0.14	0.09	130.0
16	0.14	0.16	0.24	0.22	0.11	77.0
17	0.13	0.11	0.32	0.20	0.15	69.0
18	0.18	0.19	0.41	0.21	0.12	52.0
19	0.08	0.10	0.14	0.10	0.05	69.0
20	0.08	0.09	0.32	0.19	0.09	104.0
21	0.08	0.10	0.30	0.29	0.10	72.0
22	0.18	0.20	0.31	0.30	0.05	29.0
23	0.22	0.24	0.42	0.41	0.10	6.0
24	0.06	0.08	0.40	0.32	0.10	40.0
25	0.25	0.05	0.58	0.42	0.11	43.0
26	0.15	0.15	0.41	0.35	0.14	23.0
27	0.16	0.17	0.51	0.41	0.13	63.0
28	0.09	0.11	0.37	0.36	0.06	59.0
29	0.29	0.26	0.37	0.34	0.18	6.0
30	0.10	0.11	0.46	0.13	0.10	6.0
Mean	0.135	0.128	0.331	0.296	0.105	0.100

The values obtained in this study compare favourably with the 19 to 160 $mgKg^{-1}$ reported in Northern Nigeria (Kparmwang, 1993).

Total B content of the soil does not indicate the availability of B and need of B fertilization, because, generally less than 5% of the total B in soils is in an available form (Berger and Truog 1940).

4.1.2.2 Available Boron Content

The available B contents of the soils as indicated by five extractants ranged from low to medium and are presented in Table 4.

The values of the hot water soluble B varied from 0.04 to 0.29 $mgKg^{-1}$, and the mean was 0.135 $mgKg^{-1}$. These values are slightly lower than trace amounts to 0.69 $mgKg^{-1}$ B reported for some savanna soils (Anande-kur 1976) and slightly higher than 0.08 to 0.17 obtained by Daudu (1989).

In South Western Nigeria, Egbe and Omotosho (1972) got a range of hot water-B of 0.01 to 0.44 $mgKg^{-1}$. In another analysis, Abiodun and Corey (1972) reported a range of 0.01 to 0.30 $mgKg^{-1}$, while Chude and Obigbesan (1982) obtained a range of 0.19 to 0.46 $mgKg^{-1}$. Ojeniyi *et al* (1981) reported average soil B to be between 0.40 and 0.57 $mgkg^{-1}$.

The hot water on the average extracted only 0.24% of the total soil B (Fig. 1B), showing that the total B is not a good index of available amounts of soil B.

Data on Table 4 shows that $CaCl_2$ extractable B varied from 0.05 to 0.26 $mgKg^{-1}$ with the mean being 0.128 $mgKg^{-1}$, representing 0.23%

of the total soil B (Fig. 1B). The values are however lower than those obtained by Lombin (1985a) and Chude and Obigbesan (1984).

HCl extractable B varied from 0.08 to 0.58 $mgKg^{-1}$ with a mean of 0.331 $mgKg^{-1}$ as shown in Table 4. These values are not within the range got by Ponnamperuma *et al* (1981). The 0.1N HCl extracted 0.59% of the total B reserve of the soils. B levels extracted by this method are quite low according to Ponnamperuma (1981), and will result in deficiency for most crops.

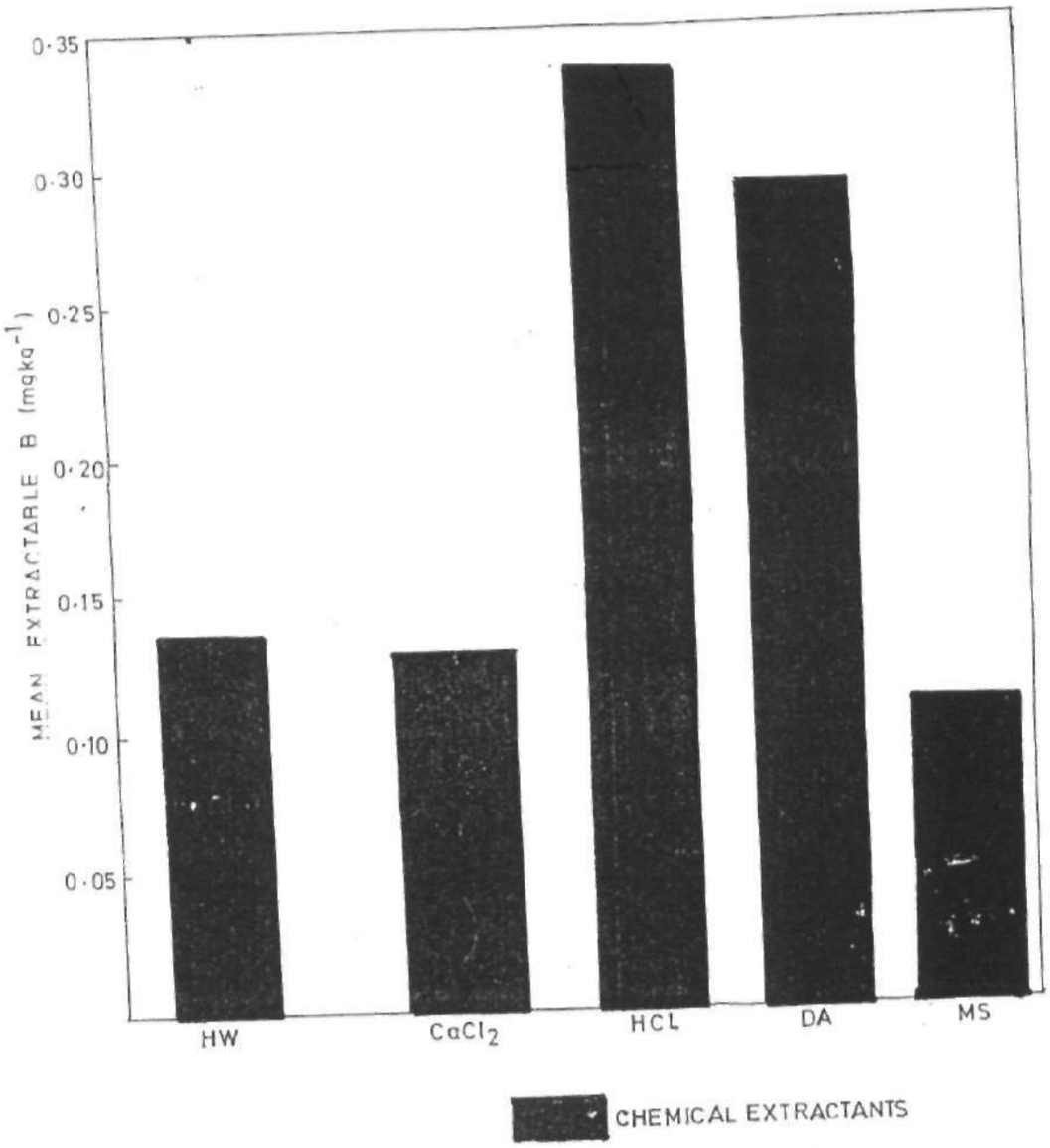
Double acid-B (DA-B) varied from 0.03 to 0.58 $mgKg^{1}$ with a mean of 0.29 $mgKg^{-1}$ (Table 4). Lombin (1985b) got a higher value range of 0.22 to 1.27 mgKg. These values indicate a poor B status of the soil, and on the average accounted for 0.41% of the soil total B (Fig. 1B).

Morgan solution (MS) extractable B varied from 0.05 to 0.18 with a mean of 0.105 $mgKg^{-1}$ as shown in Table 4. These values are however not similar to those of Lombin (1985b) of 0.19 to 0.44 $mgKg^{-1}$ and Daudu (1989) with values of 0.04 to 0.41 $mgKg^{-1}$. However, 0.188% of soil total B was extracted with MS, as shown in Figure 1B.

From the results obtained, the 0.1N HCl extracted more B than the other extractants. This is followed by the double acid extractable B. The higher values of available B obtained with the acid extractants may be due to the increased solubility of B containing compounds in the soil.

The amount of available B extracted by the different extractants were found to decrease in the following order 0.1N HCl

FIG. 18 SOIL B - TEST LEVELS



> DA > HW > $CaCl_2$ > MS.

Available B is low in most of the soils, and this will result in deficiency for most crops. Russel (1973) reported that B demanding crops are likely to respond to B fertilizers, if the hot water-B in soil falls between 0.3 and 1.0 $mgKg^{-1}$. It is expected that most of the soils will respond to B fertilization, as their hot water-B values fell below this range.

In other studies, critical hot water-B levels have been put between 0.15 $mgKg^{-1}$ (Rogers 1947) and 0.35 $mgKg^{-1}$ (Dawson and Gustafson, 1945) for sandy to medium-textured soils.

The major soil factors which may cause soil B to be low are, low B content in the parent material, low O.M content, type of soil and low B content of primary B containing minerals which decompose easily. Most of the soil samples collected for this study were soils that have been derived from the inherently low B-containing acid igneous rocks (Burridge and Ahn 1970). It is therefore expected that parent rock and soil type influence B status of soils (Gupta, 1968 and 1993).

4.1.2.3 Relationship Amongst Soil Properties

The relationship among soil properties is given in Table 5. Sand fraction correlated significantly, but negatively with silt (r = -0.828**), clay (r = -0.725**), available Fe (r = -0.296*), available Cu (r = -0.399**), available Zn (r = -0.445**) and available Mn (r = -0.453**).

Silt fraction increased with increasing O.C (r = 0.356**),

Table 5: Simple Correlation matrix amongst soil properties

	Sand	Silt	Clay	pH Water	pH $CaCl_2$	O.C	ECEC	Exch. Acidity	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	Av. P	Total N	Av. Fe	Av. Cu	Av. Zn	Av. Mn	Total B
Sand	-																		
Silt	-0.828**	-																	
Clay	-0.725**	0.216	-																
pH Water	0.225	-0.250	-0.079	-															
pH $CaCl_2$	0.114	-0.075	-0.099	0.275*	-														
O.C	-0.642**	0.356**	0.672**	-0.055	-0.119	-													
ECEC	0.022	0.036	-0.098	0.114	0.010	0.151	-												
Exc. Acid.	-0.073	0.080	0.004	-0.016	-0.191	-0.035	0.434**	-											
Exch. Ca	0.013	0.030	-0.072	0.079	0.002	0.178	0.968**	0.459**	-										
Exch. Mg	0.232	-0.097	-0.394**	0.087	0.128	-0.085	0.866**	0.349*	0.798**	-									
Exch. K	-0.064	0.142	0.076	0.932	-0.078	0.142	0.769**	0.084	0.707**	0.783**	-								
Exch. Na	0.313	-0.054	0.041	0.112	-0.089	0.195	0.737**	0.354**	0.774**	0.503**	0.380**	-							
Av. P	-0.097	0.102	0.030	0.275*	0.069	-0.020	0.224	-0.105	-0.262	0.157	0.345*	0.002	-						
Total N	-0.572**	0.464**	0.502**	0.005	-0.114	0.775**	0.153	-0.035	0.145	-0.134	0.162	0.180	0.319	-					
Av. Fe	-0.296*	0.186	0.469**	0.242	0.0037	0.346*	0.307*	0.141	0.332*	0.087	0.208	0.139	0.476**	0.417**	-				
Av. Cu	-0.399**	0.200	0.476**	0.436**	-0.134	0.510**	0.178	-0.069	0.229	-0.143	-0.009	0.279*	0.231	0.459**	0.540**	-			
Av. Zn	-0.445**	0.338*	0.404**	0.211	0.177	0.198	0.068	0.125	0.056	-0.122	0.239	0.049	0.383**	0.264*	0.575**	0.351*	-		
Av. Mn	-0.453**	0.354**	0.407**	0.376**	-0.377	0.522**	0.294*	0.351*	0.320*	0.015	0.187	0.332*	0.278*	0.545**	0.532**	0.589**	0.339**	-	
Total B	-0.278*	0.216	0.248	-0.176	0.073	0.0421	-0.156	0.265	-0.092	-0.384**	-0.367**	0.920	-0.258	-0.032	-0.107	0.060	0.112	0.116	-

total N (r = 0.464**) and available Mn (r = 0.354**) whereas, clay fraction increased with decrease in Mg content (r = -0.374**) and increase in O.C (r = 0.672**) total N (r = 0.602**), available Fe (r = 0.469**), Cu (r 0.476**), Zn (r = 0.404**) and Mn (r = 0.407**). The significant relationship between clay and O.C, total N and the micronutrients show the importance of clay in the availability of these nutrients. This result is in agreement with the findings of Lombin (1983b) that O.C and clay are generally considered the mainstay of extractable nutrients in the soil.

Soil pH (water) correlated significantly with available Cu (r = 0.436**) and negatively with availble Mn (r = -0.376**), as shown in Table 5. Lombin (1983a) also got a negative correlation between soil pH and available Mn. This result indicate the importance of pH in the availability of some micronutrients.

Highly significant correlations exist between O.C and total N (r = 0.796**), available Cu (r = 0.510**) Fe (r = 0.342*) and Mn (r = 0.522**). This emphasises the important contribution of O.C to total N, available Cu and Mn in savanna soils. Balasunbramanian *et al* (1984) also got significant correlation between soil O.C and total N. They also reported that the levels of many nutrients in savanna soils are intrinsically tied to the level of O.C in these soils.

Correlation matrix in Table 5 also show that effective CEC values increased with increasing exchangeable acidity (r = 0.434**), Ca (r = 0.969**), Mg (r = 0.866**), K (r = 0.769**), Na (r = 0.294*).

Exchangeable Ca correlated with exchangeable Mg (r = 0.798**), K (r = 0.707**), Na (r = 0.774**), available Fe (r = 0.332*) and Mn (r = 0.320*), while exchangeable acidity correlated with

exchangeable Ca (r = 0.459**), Mg (r = 0.349*), Na (r = 0.354*) and available Mn (r = 0.294*).

Exchangeable Mg correlated with exchangeable K (r = 0.783**) and Na (r = 0.503**), while exchangeable K correlated with exchangeable Na (r = 0.380**) and available P (r = 0.346*) as shown in Table 5.

Available P content increased steadily with increae in available Fe (r = 0.476**), Zn (r = 0.383**) and Mn (r = 0.278*). Also total N correlated with the micronutreints, Fe (r = 0.417**) Cu (r = 0.456**), Zn (r = 0.284*) and Mn (r = 0.545**) (Table 5). These emphasise the important contribution of available P and total N to the micronutrients in savanna soils.

Available Fe correlated strongly with the other micronutrients (Table 5); Cu (r = 0.540**), Zn (r = 0.578**) and Mn (r = 0.532**). Available Cu is strongly related to available Zn (r 0.351**) and Mn (r = 0.689**). Also, Zn correlated significantly with available Mn (r = 0.389**) as shown in Table 5.

With increasing total B content there was decrease in the content of sand fraction (r = -0.278*) exchangeable Mg (r = -0.384**) and K (r = -0.367**). The absence of significant correlation between pH and total B is similar to the earlier observation of Gupta (1968) and Chude and Obigbesan (1984).

4.1.2.4 Relationship Among Soil Boron Tests

Data in Table 6 show the relationship among extractable soil B. The Hot water-B correlated with $CaCl_2$-B (r = 0.708**), DA-B (r = 0.502**), and MS-B (r = 0.542**).

Table 6: Simple correlation amongst soil B tests

	Hot water	0.1% $CaCl_2$	0.5N HCl	DA	Morgan Solution
Hotwater	- *				
0.1% $CaCl_2$	0.708**	-			
0.5N HCl	0.215	0.085	-		
DA	0.502**	0.300*	0.420**	-	
Morgan Solution	0.542**	0.395**	0.198	0.207	-

* Significant at 5% level
** Significant at 1% level

Significant correlation exist between $CaCl_2$-B and DA-B (r = 0.300*) and MS-B (r = 0.395**). Also HCl-B correlated with DA-B (r = 0.420**) (Table 6).

A strong relationship between any two or more soil boron test indicates that similar fractions of the boron are being extracted. It is interesting to note that Hotwater test was significantly related to the other tests (Table 6) except MS test. It can be inferred from this, that at least a few fractions were extracted by both the hotwater and the other tests. Lombin (1985b), similarly observed a relationship between Hotwater-B and DA-B, whereas Chude and Obigbesan (1984) did not observe any relationship among the soil test methods.

4.1.2.5 Relationship Between Soil Boron Tests and Soil Properties

Simple correlation analysis between soil boron tests and soil properties was carried out to determine the soil property that has any relationship with the extractants. Coefficients of simple

correlation (Table 7) indicate that with increasing total-B content, the Hot water-B decreased slightly (r = -0.378**), whereas, there were increase in exchangeable K (r = 0.279*), available P (r = 0.273*) and available Fe (r = 0.290*) with increase in Hot water-B.

Anande-kur (1976) and Lombin (1985b) who had worked with the soils of this area also got a significant relationship between Hotwater-B and exchangeable K. This signifies that K is one of the dominant cation on the exchange site in the soils of the area. Similarly Reeve and Shive (1944) reported a relationship between Hotwater-B and exchangeable K.

Data on Table 7 shows that $CaCl_2$-B correlated negatively with sand (r = -0.311*), E.A (r = -0.413**) and total B (r = -0.366*). This indicates that as the $CaCl_2$-B increased, the sand, E.A and total B contents decreased. This is contrary to the report of Gupta (1978), Chude and Obigbesan (1984), who had variously reported positive correlation between $CaCl_2$-B and total B. Also $CaCl_2$-B correlated positively with silt (r = 0.287*), pH (H_20) (r = 0.310*), O.C (r = 0.276*) and available P (r = 0.274*). These soil components had been proved to influence soil B (Berger and Truog, 1946; Martens 1968 and Yermiyahu *et al* 1995).

HCl-B increased with incresing exchangeable K (r = 0.450**), available P (r = 0.339*) and available Fe (r = 0.332*), whereas HCl-B increase with decrease in total B content (r = -0.385*) as shown in Table 7.

DA-B correlated negatively with E.A (r = -0.284*) and total B (r = -0.411*), but positvely with Organic Carbon (r = 0.338*),

Table 7: Simple correlation (r) between Soil B and Soil properties

Soil Properties	Hot Water	0.1% $CaCl_2$	0.1N HCl	Double Acid	Morgan Solution
Sand	0.0314	-0.3110*	0.076	-0.071	-0.315*
Silt	-0.058	0.287*	-0.026	-0.037	0.317*
Clay	-0.010	0.191	-0.122	0.161	0.155
pH(H_2O)	0.269	0.310*	0.184	0.030	-0.219
pH ($CaCl_2$)	0.119	0.068	0.014	=0.206	0.251
O.C	0.262	0.276*	0.058	0.338*	0.289*
CEC	0.197	0.106	0.209	0.100	0.045
ECEC	0.215	0.0955	0.208	0.130	0.005
E.A	0.228	-0.413*	-0.056	-0.284*	0.421**
Exch. Ca	0.190	0.042	0.083	0.079	0.003
Exch. Mg	0.211	0.211	0.267	0.102	0.029
Exch. K	0.279*	0.171	0.450*	0.381**	0.132
Exch. Na	0.049	-0.048	-0.154	0.131	-0.183
Av. P	0.273*	0.274*	0.339*	0.416**	-0.027
Total N	0.117	0.140	0.141	0.340*	0.375**
Av. Fe	0.290*	-0.088	0.332*	0.345*	0.209
Av. Cu	0.020	0.102	-0.070	0.043	0.214
Av. Zn	0.137	-0.183	0.219	0.106	0.213
Av. Mn	-0.018	0.006	-0.028	0.107	0.115
Total B	-0.378**	-0.366**	-0.385**	-0.411**	-0.184

exchangeable K (r = 0.381**) available P (r = 0.416**), total N (r = 0.340*), and available Fe (r = 0.345*).

MS-B contents increased with decreasing sand content (r = - 0.315*) and increasing silt (r = 0.317*), O.C (r 0.289*), E.A (r = 0.421**) and total N (r = 0.375**).

The result of this study suggests the superiority of texture, O.C., E.A. exchangeable K, total N and B, available P and Fe in predicting levels of available B in the soils.

There was no relationship between Hotwater-B and pH of the soils. This result is in line with the report of Gupta (1968) who did not get any relationship between Hotwater-B and pH of 108 samples ranging in pH from 4.5-6.5. Clay did not correlate with any soil extractants. This can be explained by the fact that the clay associated with fine textured soils tends to hold large amount of B rather tightly such that it is not easily available (Tisdale et al 1985).

Statistical analysis (Table 7) also showed that, the relationship between extractable B and CEC was non significant contrary to the widely held view that extractable B is related to CEC

The significant correlation of available Fe and Hotwater-B, HCl-B and DA-B may be attributed to the fact that this soil component is active in B retention in these soils. Hydrated oxides of Fe have a marked though dependent afinity for B as has been shown by the works of Tamai and Harada (1968), Sims and Bingham (1968) and Bingham *et al* (1971). The soils used in this study are

tropical soils in which hydrated iron oxides may form an appreciable fraction of the clay, therefore B availability in these soils may depend on the amount and distribution of this soil components.

It is interesting to note that some soil variables are significant with some extractants, K, P, Fe and total B correlate with Hotwater-B, HCl-B and DA-B, whereas, sand, silt, EA and OC correlated with $CaCl_2$-B and MS-B as shown in Table 7.

Multiple stepwise regression analysis was used to determine which soil property or combination of soil property best predict the amount of soil B extracted by a particular test. The soil properties which were the independent variables entered the regression equations in order of decreasing contribution to the multiple correlation coefficient. The regression equations for the different methods are given in Table 8.

The regression equations indicated that various combinations of soil properties are required for different soil B tests, but combinations of soil variables including pH, O.C, appeared to be the most useful for predicting amount of B extracted by different extractants. For instance, the presence of sand, silt and clay in the regression equation, when Hotwater was the dependent variable (Table 8) produced an R^2 value of 15.69% (step 17), whereas when pH, O.C, Ca and Mn were added to the equation (step 13), R^2 value of 41.86% was obtained giving an increase of 26.17%.

Table 8: Backward stepwise regression analysis between boron extractants (y) and soil properties

Extractants	Stop	Relationship	R^2
Hotwater	5	Y = 4.983 - 0.05 sand - 0.05 Silt - 0.046 Clay + 0.065 pH - 0.044 pH $CaCl_2$ + 0.0098 O.C - 0.018 CEC + 0.007 ECEC - 0.16 BA + 0.026 Ca + 0.035 Mg - 0.16 Na - 0.04 Total N - 0.0005 Fe - 0.0076 Mn	0.612
	13	Y = 5.809 - 0.059 Sand - 0.059 Silt - 0.06 Clay + 0.045 pH H_2O + 0.0076 O.C + 0.0022 Ca - 0.0054 Mn	0.419
	17	Y = 6.274 - 0.061 Sand - 0.062 Silt - 0.061 Clay	0.157
$CaCl_2$	5	Y = -4.729 + 0.047 Sand + 0.047 Silt + 0.048 Clay + 0.050 pH H_2O - 0.032 pH H_2O + 0.0116 O.C - 0.009 CEC + 0.010 ECEC + 0.08 B.A + 0.06 K - 0.059 Na + 0.0039 Av. P - 0.007 Zn - 0.0079 Mn	0.588
	12	Y = -5.416 + 0.055 sand + 0.055 Silt + 0.054 Clay + 0.042 pH H_2O - 0.041 pH $CaCl_2$ + 0.0105 O.C + 0.0053 Av. P - 0.0074 Mn	0.494
	14	Y = -5.972 + 0.061 Sand + 0.059 Silt + 0.059 Clay + 0.0096 O.C + 0.0058 Av. P - 0.0033 Mn	0.375
HCl	3	Y = 16.29 - 0.162 Sand - 0.163 Silt - 0.171 Clay + 0.019 pH H_2O + 0.036 pH $CaCl_2$ + 0.007 CEC + 0.033 ECEC + 0.58 B.A - 0.085 Ca - 0.104 Mg + 0.51 K + 0.08 Na + 0.12 Total N + 0.003 Fe + 0.009 Cu - 0.036 Zn - 0.003 Mn	0.667
	7	Y = 13.34 - 0.13 Sand - 0.133 Silt - 0.139 Clay + 0.034 pH H_2O + 0.036 ECEC + 0.48 B.A - 0.07 Ca - 0.091 Mg + 0.45 K + 0.14 Total N - 0.028 Zn - 0.0051	0.661
	9	Y = 13.37 - 0.13 Sand - 0.13 Silt - 0.13 Clay - 0.037 ECEC + 0.39 B.A - 0.073 Ca - 0.072 Mg + 0.43 K + 0.119 Total N + 0.003 Fe - 0.025 Zn	0.639
	14	Y = 11.53 - 0.112 Sand - 0.113 Silt - 0.112 Clay + 0.03 ECEC - 0.054 B.A + 0.229 K	0.494
Double Acid	5	Y = 14.78 - 0.144 Sand - 0.149 Silt - 0.144 Clay + 0.014 pH - 0.0025 O.C - 0.045 CEC + 0.030 ECEC + 0.008 Ca - 0.057 Mg + 0.053 K - 0.08 Na - 0.002 Av. P - 0.184 Total N + 0.012 Cu - 0.041 Zn	0.776
	11	Y = 15.94 - 0.153 Sand - 0.16 Silt + 0.156 Clay - 0.041 + CEC + 0.024 ECEC + 0.493 K + 0.15 Total N + 0.021 Cu - 0.040 Zn	0.747
Morgan Solution	5	Y = 1.406 - 0.012 Sand - 0.010 Silt - 0.010 Clay + 0.025 pH H_2O - 0.010 pH $CaCl_2$ - 0.0019 O.C - 0.0023 ECEC - 0.27 B.A + 0.10 Ca + 0.03 Mg - 0.08 K - 0.088 Na - 0.002 Av. P - 0.0041 Cu + 0.0066 Zn	0.629
	7	Y = 0.174 - 0.0016 Sand - 0.005 Clay + 0.024 pH H_2O - 0.013 pH $CaCl_2$ + 0.0021 O.C - 0.28 A + 0.0092 Ca + 0.028 Mg - 0.092 K - 0.10 Na - 0.0028 Av. P - 0.0056 Cu + 0.0085 Zn	0.621

4.1.3 Boron Adsorption and Desorption Characteristics

Boron adsorption and desorption characteristics of thirty surface soils were studied.

When soil solutions containing B are added to soils, some of the B is removed from solution by adsorption. Boron applied to soils is sorbed to a variable extent and an equilibrium exists between B in solid and liquid phases (Hatcher and Bower 1958, Oka Zaki and Chao, 1968; Biggar and Fireman 1960; El-Rashidi and O'Connor 1982).

Boron adsorption and desorption studies were intended to give an insight into the B retention and release properties of the soils. It is also a way of better identifying those soils which are likely to respond to B and are likely to show long time residual effects from applied B (Arnold 1990).

Boron adsorption and desorption are useful for determining the amount of leaching required to reduce B concentrations in high-boron soils to a safe level.

4.1.3.1 Boron Adsorption Characteristics

Adsorption data obtained on the thirty soils were plotted according to the linear form of the Langmuir equation (Fig. 2A-2D). The sorption curves for all soils were similar indicating similarity in nature of adsorption reaction, but different in the intrinsic characteristics such as the slope of the isotherms and extent of adsorption. These characteristics tended to reflect the nature of the parent material and inherent B fertility of the

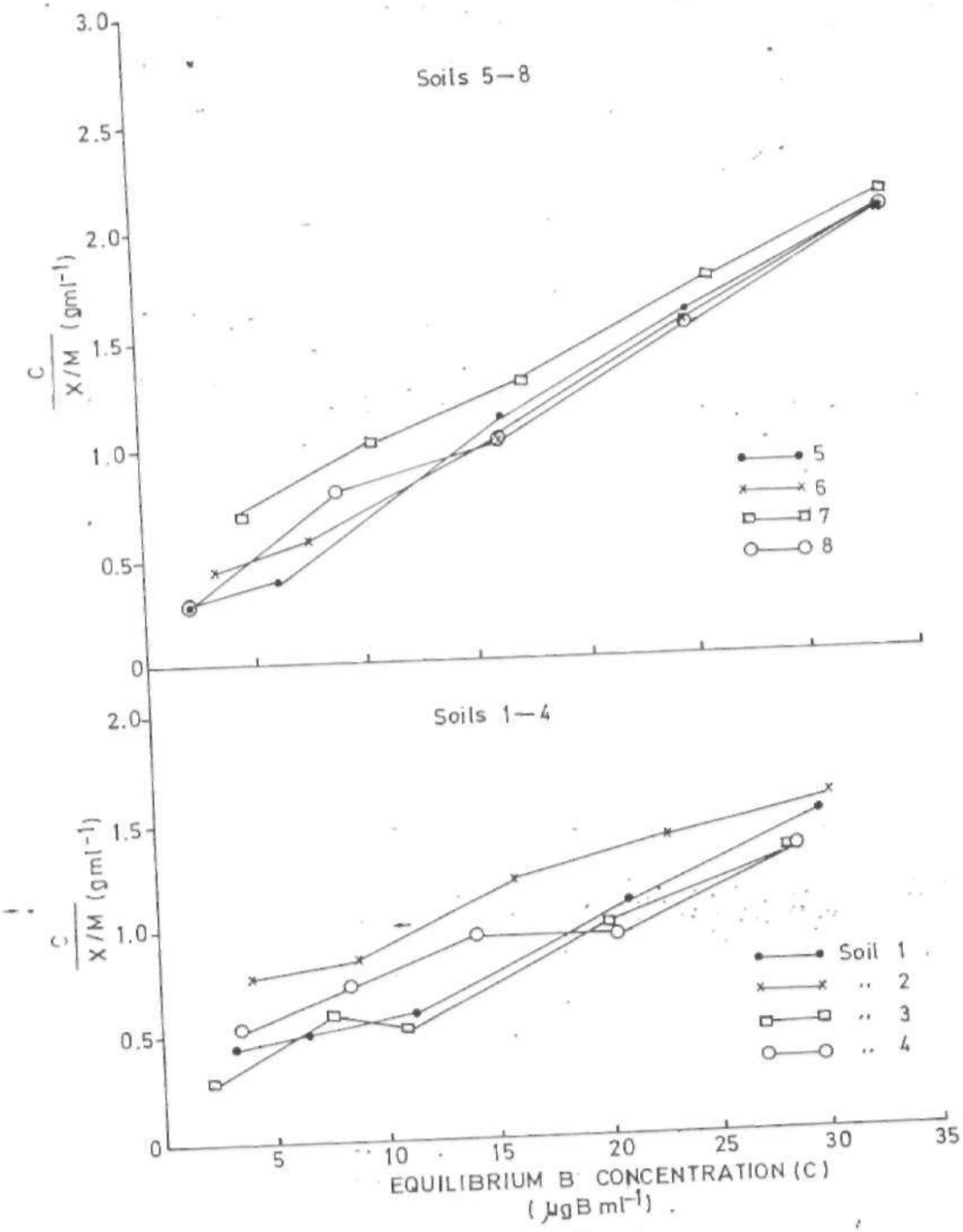


Fig.2A Boron adsorption Isotherms

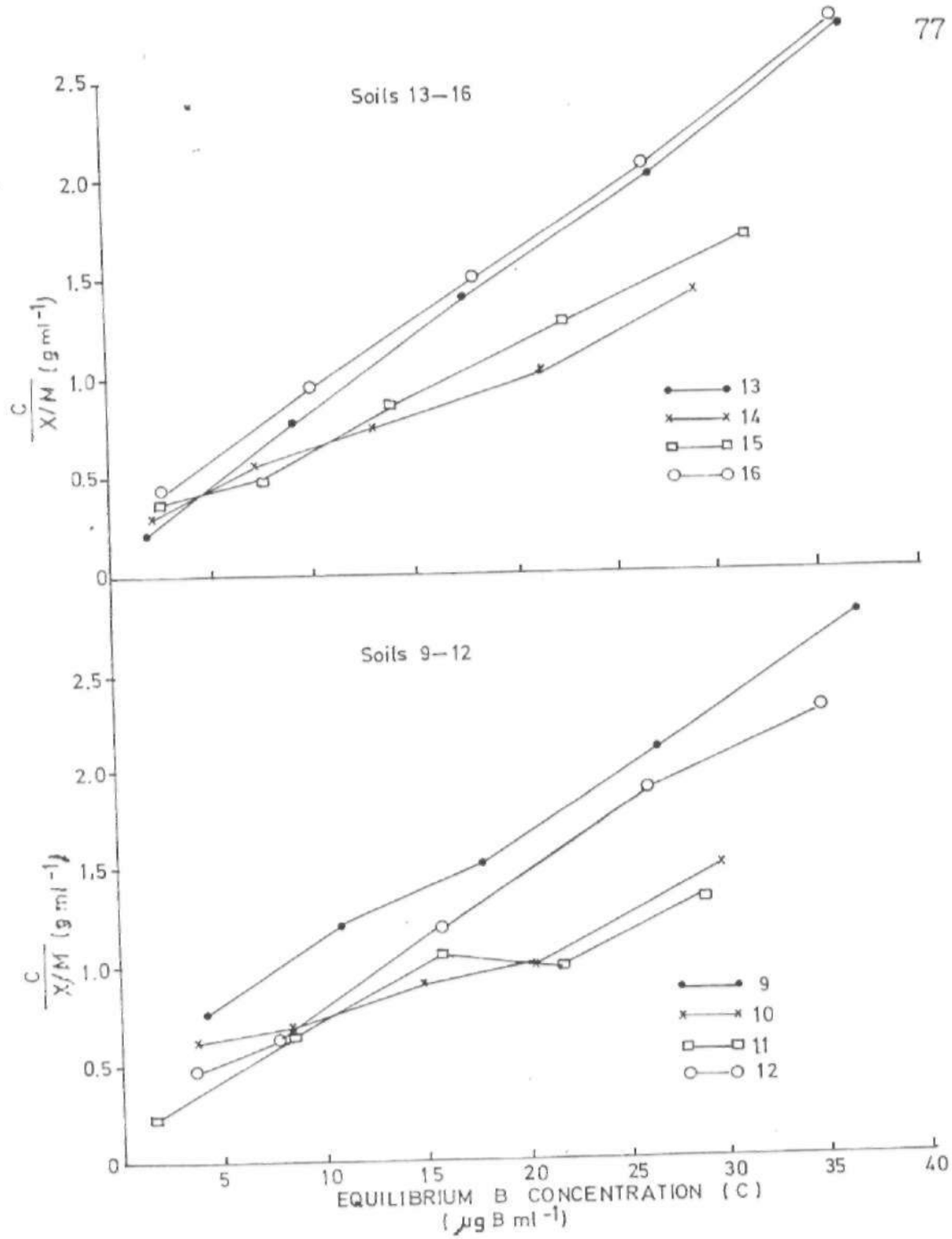


Fig. 2 B. Boron adsorption Isotherms

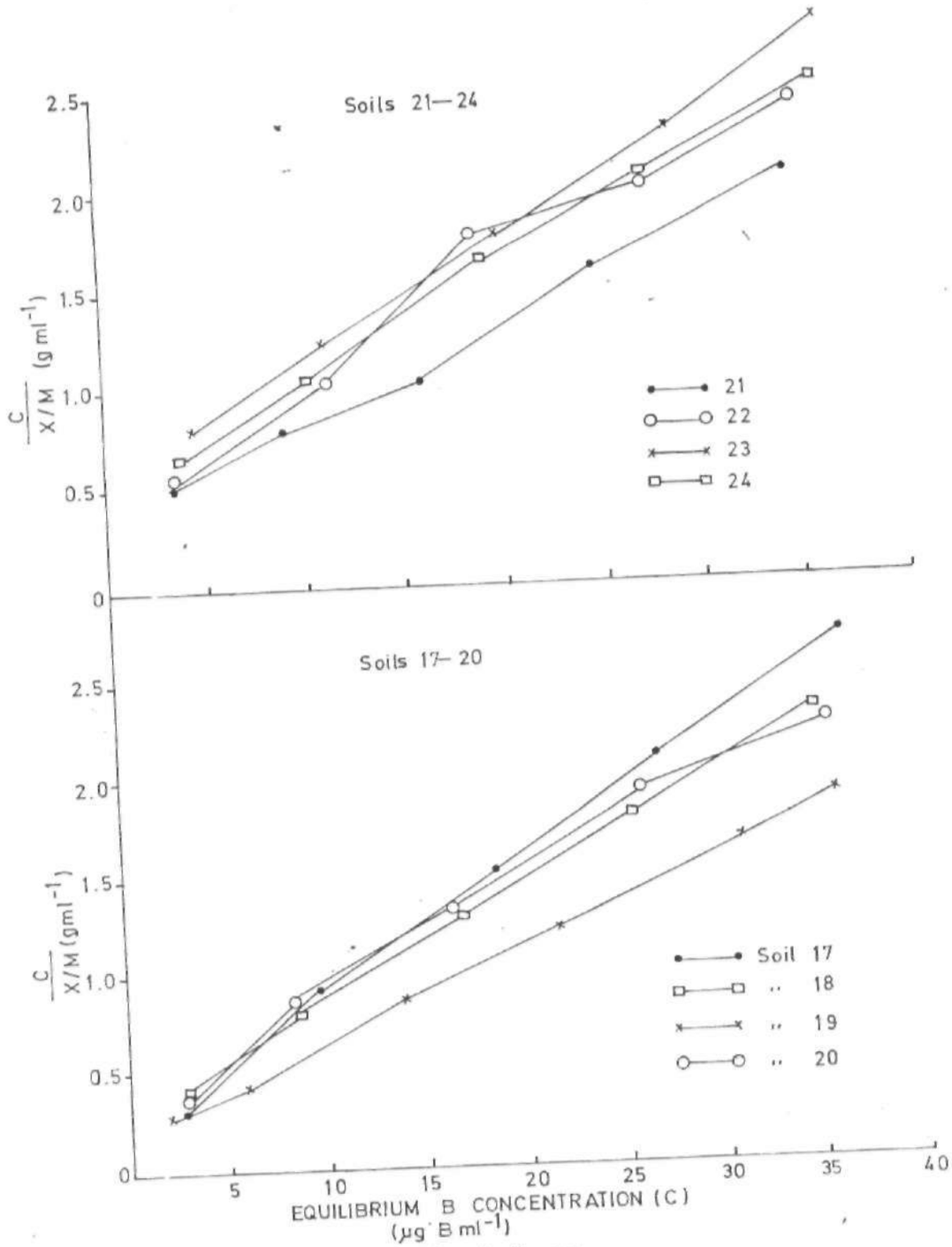


Fig. 2C. Boron adsorption isotherms

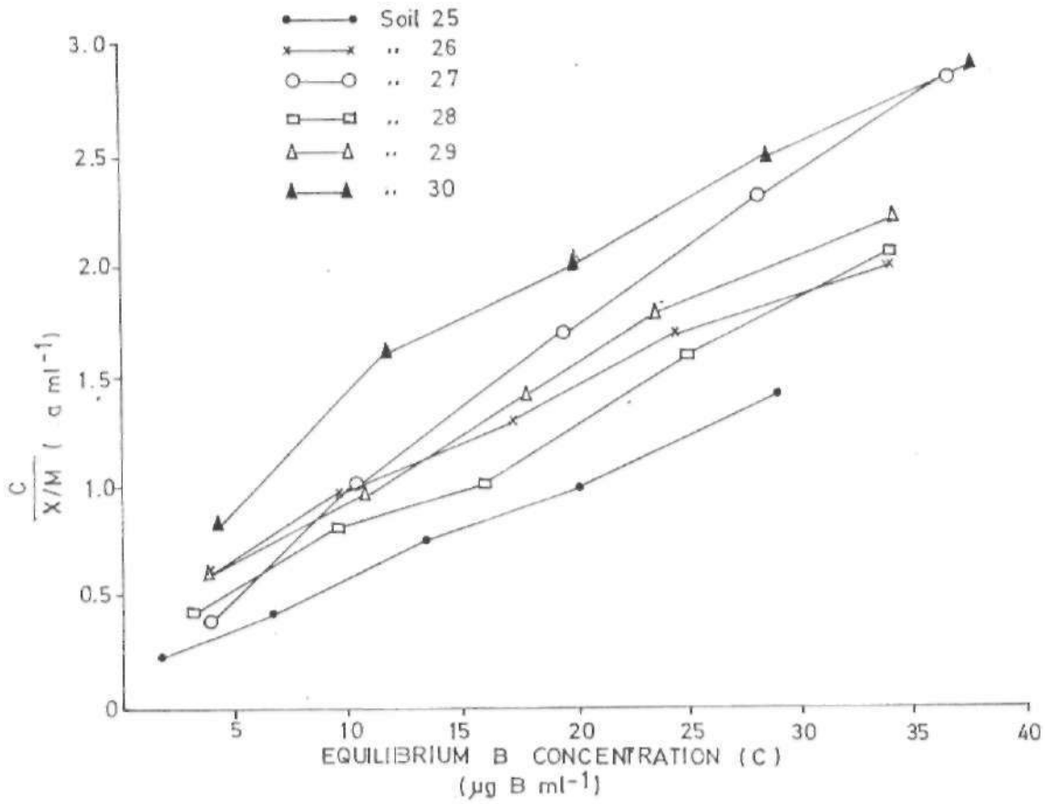


Fig.2D. Boron adsorption Isotherms

soils.

The amount of B adsorbed increased with increase in solution concentration of added B in all cases. Similar findings have also been reported by Okazaki and Chao (1968), Hatcher and Bower (1967). In most cases, the isotherm were straight lines, with gentle slopes, while others had steep slopes indicating that some of the soils had high buffering capacities, while others had low buffering capacities for boron.

The steeper sorption slopes were the more buffered, lower in solution B concentration, and more prone to be B deficient.

There were significant differences in the mean amount of adsorbed B between the soils, indicating that they had different capacities to adsorb B. The differences in the capacity of the soils to sorb B may be due to the fact that, the soil have different properties such as pH, OC and types of clay minerals which are known to affect B adsorption (Biggar and Fireman, 1960, ElRashidi and O'Connor, 1982, Yermiyahu et al 1995).

The soil properties which relate to B adsorption and desorption are shown in Table 9A.

An attempt was made to transform the B adsorption data into the adsorption equations. Goodness of fit was evaluated by the R^2 values. It was observed that adsorption isotherm did not fit the Freundlich equation, but closely fitted the Langmuir equation. Only soil 17 (Samaru 2) best fitted the Freundlich equation because the value of r for the Langmuir equation was low. However, there was an improvement in the value of r^2 when it was fitted into

Table 9A: Selected soil properties related to B adsorption and desorptio

Soil No	Texture	Clay (%)	Silt (%)	pH 1:1 H_2O	pH 1:1 $CaCl_2$	OC gkg^{-1}	Av. Fe <-mgkg^{-1}->	Av. Mn	Total Solu-ble B	Total Adsor-bed B	Total Desorbed B
1	Sandy loam	13	36	5.1	4.3	4.9	2.5	4.36	72.4	77.6	43.7
2	" "	15	32	4.9	4.1	5.6	4.2	3.20	83.6	66.4	60.0
3	" "	11	36	5.0	4.6	5.9	14.5	7.90	65.0	69.0	45.2
4	" "	9.0	40	6.0	5.1	6.8	6.5	7.15	75.6	74.4	45.2
5	" "	15	28	5.6	4.9	9.9	6.1	5.20	82.5	67.8	48.7
6	" "	13	36	4.9	4.5	2.6	6.5	3.70	84.1	65.9	54.0
7	" "	13	28	5.3	4.7	4.0	5.2	3.56	91.3	58.7	40.4
8	" "	11	36	5.5	5.1	3.5	4.5	4.70	86.2	63.8	27.8
9	Loam	25	42	4.7	4.5	15.6	4.5	16.0	97.5	52.5	30.2
10	Sandy loam	9.0	38	5.1	5.0	3.4	3.0	5.0	84.5	72.5	38.2
11	" "	11	32	5.6	4.9	4.0	6.1	6.6	77.6	72.4	38.2
12	" "	13	36	5.4	5.1	4.7	7.5	6.76	90.9	62.8	37.3
13	" "	7.0	22	6.0	5.7	2.6	7.0	3.20	91.8	58.2	34.1
14	" "	9.0	20	6.0	5.6	2.9	12.2	4.50	72.6	77.5	36.5
15	Loam	11	44	5.5	5.1	3.3	3.5	6.80	78.4	71.6	37.4
16	Loam	15	36	5.4	5.0	8.7	4.3	9.40	93.9	55.9	24.0
17	Loam	27	46	5.6	6.3	13.4	75.0	18.0	86.5	56.3	24.6
18	Sandy loam	17	30	6.2	6.0	5.1	37.5	5.9	90.5	59.5	27.9
19	" "	13	30	5.6	4.8	8.3	12.5	15.6	75.5	74.4	45.2
20	Loam	23	42	4.1	3.5	9.6	65.0	16.0	89.6	46.3	34.3
21	Sandy loam	13	24	5.2	4.4	6.3	30.0	6.9	86.9	63.1	32.9
22	" "	23	20	6.0	5.6	4.2	32.5	11.2	98.7	54.1	32.0
23	" "	11	38	5.1	4.6	11.2	11.0	6.0	100.2	49.8	31.6
24	Loam	15	41	4.9	3.9	4.1	3.2	6.2	95.7	54.7	34.4
25	Sandy loam	9.0	34	5.6	4.8	7.2	8.5	8.6	69.7	80.2	43.9
26	" "	7.0	34	6.8	6.1	7.0	26.0	22.0	89.0	51.0	39.4
27	Loam	25	36	4.7	4.1	14.9	6.0	6.9	97.8	52.3	35.2
28	Sandy loam	10	38	4.8	4.2	3.2	7.5	10.4	56.2	63.2	57.1
29	" "	11	36	6.1	5.4	6.4	44.0	6.0	90.4	59.6	62.9
30	" "	9.0	38	5.1	4.7	4.2	20.0	4.9	102.8	48.2	49.6

Table 9B: Langmuir best fit equations for the adsorption Isotherms

Soil No	Equation	R^2 Value
1	Y = -5.47 + 23.86x	0.9811
2	Y = -19.11 + 31.10x	0.9828
3	Y = -6.01 + 26.34x	0.9760
4	Y = -14.64 + 32.49x	0.9702
5	Y = -2.39 + 17.20x	0.9944
6	Y = -4.37 + 18.53x	0.9932
7	Y = -12.02 + 21.75x	0.9943
8	Y = -6.403 + 19.57x	0.9994
9	Y = -8.18 + 16.40x	0.9930
10	Y = -12.68 + 29.10x	0.9799
11	Y = -11.19 + 27.88x	0.9710
12	Y = -2.23 + 15.73x	0.9958
13	Y = -1.93 + 14.01x	0.9980
14	Y = -5.70 + 24.47x	0.9979
15	Y = -5.08 + 21.72x	0.9990
16	Y = -3.37 + 14.56x	0.9973
17	Y = -4.45 + 6.48x	0.4462
18	Y = -5.99 + 17.28x	0.9807
19	Y = -3.50 + 21.02x	0.9968
20	Y = -3.81 + 16.37x	0.9943
21	Y = -6.11 + 19.19x	0.9997
22	Y = -7.76 + 15.68x	0.9163
23	Y = -9.56 + 16.35x	0.9774
24	Y = -7.63 + 16.84x	0.9923
25	Y = -3.72 + 23.27x	0.9973
26	Y = -10.03 + 21.37x	0.9952
27	Y = -3.77 + 13.79x	0.9967
28	Y = -5.72 + 18.95x	0.9993
29	Y = -8.85 + 19.06x	0.9902
30	Y = -10.43 + 15.72x	0.9795
	Freundlich Equation	
17	Y = -18.27 + 2.89x	0.6402

Freundlich equation.

The standard form of the Langmuir equation is given below:

$$\frac{C}{(x/m)} = 1/Kb + C/b$$

where $\frac{x}{m}$ = amount of B adsorbed (μgg-1)

C = equilibrium concentration of B (μgml-1)

b = adsorption maximum (μgg-1)

k = a constant related to bonding energy mlμg-1.

A plot of C/(x/m) against C gave a straight line. Boron adsorption by twenty nine of the thirty soils conformed to the Langmuir sorption isotherm over limited concentration ranges. At high equilibrium B solution concentrations, sorption data deviated from the Langmuir model. Many workers reported that, B sorption by soil could be described by the Langmuir isotherm (Hatcher and Bower 1958, Biggar and Fireman 1960; Okazaki and Chao 1968).

Howevever, some workers (Hingston 1964 and Singh, 1971) have mentioned deviations at higher B concentrations. Hingston (1964) suggested that the deviations from the Langmuir model at higher B concentrations indicated that different reactions occur at higher B concentrations than at lower B concentrations.

The equations of the best fit lines and the corresponding r^2 values are shown in Table 9B.

The adsorption maximum B is taken as the reciprocal of the slope of the isotherm (1/slope) (Table 9C). They ranged from 30.8 to 72.5 x 10^{-3} μgg^{-1}. These values indicate low capacity of the soils to sorb B. The values are lower than those reported by ElRashidi and O'Connor (1982). However, they are within the range of values obtained by Hatcher and Bower (1958). The low capacities

Table 9C: Langmuir adnsorption maximum (b) and Constant (K)

Soil No	b x 10^{-3} (μugg^{-1})	K $ml\mu ug^{-1}$
1	42.0	5.47
2	32.0	19.11
3	37.9	6.01
4	30.8	14.64
5	58.1	2.39
6	54.1	2.39
7	46.1	12.02
8	51.1	6.40
9	61.1	8.18
10	34.4	12.68
11	35.9	11.19
12	63.6	2.23
13	71.4	1.93
14	40.9	5.70
15	46.0	5.08
16	68.7	3.37
17	15.4	4.45
18	5.79	5.99
19	47.6	3.50
20	61.1	3.81
21	52.1	6.11
22	63.8	7.76
23	61.2	9.59
24	59.4	7.63
25	43.0	3.72
26	46.8	10.03
27	72.5	3.77
28	52.8	5.72
29	52.5	8.85
30	63.6	10.43

Table 9D: Relationship between selected soil properties with boron adsorption and Langmuir constant (K)

Soil property	r value	
	Adsorption	Langmuir constant K
Silt	-0.187	0.348*
Clay	-0.452**	0.373*
pH water	0.0007	0.430*
OC	-0.384*	0.303*
Fe	0.415*	0.540**
Mn	0.361*	0.338*

* 5% level of significance
** 1% level of significance

of the soils to sorb B may be due to the coarse or sandy texture of the soils, since most of the soils are sandy loam.

The constant K, which relate to the bond energy of adsorption varied from 1.93 to 19.11 $ml\mu g^{-1}$ (Table 9C). These bond energies are higher than the values obtained by ElRashidi and O'Connor (1982), but lower than the values obtained by Hatcher and Bower (1958), Biggar and Fireman (1960). ElRashidi and O'Connor (1982) reported that K values tend to increase with the clay content of the soils. The soils used in this study have low clay content which explain why the K values are low.

4.1.3.2 Soil Properties Affecting Boron Sorption

Simple correlation coefficients relating soluble and adsorbed B, as well as Langmuir constant values to some physicochemical properties of the soils (Table 9D) indicated that clay, OC, Fe and Mn correlated with adsorbed B and Langmuir constants (K), but was poorly correlated with the other B paramters. The lack of relationship between soil pH and most B parameters in this study may be due to the narrow range of pH values in the soils investigated. However, pH in water was highly correlated with Langmuir constant K ($r = 0.430$).

The influence of clay and OC on B parameters in the soils investigated are in line with the findings of other workers (Gupta 1968, Prasad 1978, Gupta 1993 and Yermiyahu et al 1995).

The fact that most sesquioxides in soils are present as coatings or associated with clay may explain the correlation obtained between Fe and adsorbed B.

The best combination of factors useful for estimating the B adsorption was determined by Multiple regression analysis. The equation clearly shows that the amount of adsorb B can be determined by the amount of clay and Fe in the soil.

$$Y = 72.68 - 0.57 \text{ clay} - 0.14 \text{ Fe} \qquad R^2 = 0.20^*$$

Similarly, the amount of Langmuir constant K, can be determined by silt, clay, pH, water and Fe.

$$Y = -71.014 + 0.65 \text{ silt} + 0.48 \text{ clay} + 9.02 \text{ pH water} + 0.11 \text{ Fe}. \quad R^2 = 0.453^{**}$$

As it is evident from the equation, these variables could account for 45.3% prediction of variance in observed Langmuir K values for the soils.

4.1.3.3 Boron Desorption Characteristics

Boron desorption studies are intended to show whether the adsorbed borate can readily be desorbed and made available for plant uptake. In many soils, boron is adsorbed reversibly, which gives them very useful buffer powers. In some soils part of any adsorbed boron will not easily desorb, hence the response to boron may be low. It would be of considerable benefit to identify such soils and futhermore to categorise the major soil types in terms of their boron adsorption and desorption capabilities (Arnold 1990).

The data on desorption studies is shown in Table 9E. The first desorption process released large amount of B. The second desorption process relased small amount of B, which was not up to the first one. In the fourth desorption process, very small amount

of B was released.

A comparison of the total amount of B desorbed with the amounts initially adsorbed reveals that the greater proportion of initially adsorbed B was not recovered after the four extractions.

The fact that a high proportion of initially adsorbed B was not recoverable through desorption, signified more than one main mechanism of B adsorption in the soils.

The results of B desorption at all B solution concentrations investigated conform to the Langmuir model. However, when B desorption values were compared with the corresponding adsorption isotherms of the 30 soils, one type desorption reaction was observed. The desorption points deviated sharply from the corresponding adsorption isotherm (hysteretic desorption). Similar results had been reported by other workers (Hatcher and Bower 1958, Okazaki and Chao 1968, ElRashidi and O'Connor 1982).

Okazaki and Chao (1968) reported incomplete reversibility of B adsorption of Hawaiian soils and suggested that B formed various (unspecified) reaction products in the adsorption process, some of which were not readily released during desorption.

Chemical precipitation of B with a variety of cations has been suggested to occur at sorption surfaces (Biggar and Fireman 1960), such precipitation is expected to increase as levels of B in solution increased.

This study showed that soils not only vary in their capacity to fix B, but also in the energy with which they return it. These two factors affect the ability of a soil to maintain the B supply in solution. Also some of the soils have low B concentration in solution and are more prone to be B deficient.

Table 9E: Boron desorption data

Soil No	10 µgml⁻¹ Desorption				20 µgml⁻¹ Desorption				30 µgml⁻¹ Desorption				40 µgml⁻¹ Desorption				50 µgml⁻¹ Desorption			
	1	2	3	4	1	2	3	4	1	2	3	3	1	2	3	4	1	2	3	4
1	1.84	0.5	0.3	0.2	3.1	1.6	0.7	0.3	8.4	3.8	1.6	0.5	8.5	1.2	0.4	0.24	8.5	3.4	0.7	0.4
2	3.8	0.7	0.5	0.4	2.2	1.1	0.6	0.4	9.8	4.2	1.2	0.6	8.8	5.3	1.5	0.6	8.7	4.8	2.9	0.7
3	1.8	0.9	0.3	0.24	2.5	1.0	0.7	0.5	6.0	2.4	0.6	0.3	3.6	4.2	1.2	0.5	7.9	4.4	1.2	0.5
4	0.9	0.5	0.5	0.4	2.2	1.1	0.5	0.1	5.8	2.6	1.2	0.5	9.8	4.7	0.9	0.6	8.3	4.3	1.8	0.7
5	1.9	0.7	0.5	0.2	2.9	1.7	0.6	0.4	6.2	2.8	1.0	0.2	5.5	3.6	1.9	0.5	6.9	4.8	1.7	0.7
6	4.0	1.6	0.3	0.2	3.1	2.3	0.5	0.3	8.1	3.1	1.1	0.3	5.3	4.0	1.4	0.6	7.5	4.1	1.6	0.5
7	2.2	0.7	0.5	0.3	6.9	2.5	0.6	0.3	7.3	1.9	0.9	0.2	4.9	3.4	1.4	0.2	4.6	2.1	0.8	0.2
8	3.1	1.1	0.4	0.2	1.9	1.4	0.7	0.4	5.5	1.4	0.8	0.6	6.0	3.5	1.3	0.6	3.5	1.6	1.0	0.3
9	1.6	0.9	0.5	0.2	1.2	0.9	0.6	0.3	4.1	1.2	0.8	0.3	5.9	2.4	0.8	0.3	3.9	1.5	0.6	0.3
10	2.4	0.3	0.5	0.2	2.4	1.2	0.7	0.3	4.8	1.7	0.5	0.2	8.1	4.5	1.0	0.6	5.9	2.1	0.3	0.3
11	1.9	0.7	0.5	0.2	2.0	0.6	0.5	0.3	3.6	1.6	1.0	0.5	7.3	4.0	1.5	0.5	5.0	3.8	1.0	0.4
12	0.9	0.7	0.5	0.1	0.5	1.2	0.5	0.2	3.0	1.4	0.7	0.3	7.9	2.6	0.9	0.3	2.9	1.9	1.3	0.4
13	2.1	0.6	0.4	0.2	4.2	1.4	0.5	0.3	2.7	1.0	0.7	0.5	6.7	3.2	0.9	0.2	5.5	1.8	0.7	0.2
14	2.8	1.2	0.4	0.2	2.5	1.0	0.4	0.2	4.0	1.4	1.0	0.5	5.9	4.0	0.9	0.4	5.9	2.2	1.0	0.5
15	2.2	1.0	0.5	0.3	3.5	1.7	0.8	0.2	4.6	1.7	0.8	0.2	5.3	3.2	1.5	0.5	4.5	3.1	1.0	0.6
16	1.4	1.3	0.7	0.4	1.2	2.3	0.8	0.2	2.2	1.0	0.5	0.3	4.3	1.3	0.5	0.3	3.2	1.4	0.7	0.5
17	1.7	1.0	0.4	0.2	1.9	1.1	0.4	0.3	1.5	1.4	0.7	0.4	4.0	1.5	0.9	0.4	3.7	1.7	0.7	0.3
18	1.5	0.9	0.5	0.3	1.3	0.7	0.3	0.3	3.4	0.9	0.3	0.2	5.6	2.5	0.7	0.5	3.9	1.4	0.9	0.5

Table 9E contd: Boron desorption data

Soil No	<------ 10 $\mu g ml^{-1}$ ----------> Desorption				<---------- 20 $\mu g ml^{-1}$ -------> Desorption				<---------- 30 $\mu g ml^{-1}$ --------> Desorption				<---------- 40 $\mu g ml^{-1}$ ---------> Desorption				<---------- 50 $\mu g ml^{-1}$ ---------> Desorption			
	1	2	3	4	1	2	3	4	1	2	3	3	1	2	3	4	1	2	3	4
19	4.7	1.3	0.5	0.3	10.2	2.6	1.0	0.6	4.5	1.2	0.6	0.3	5.2	2.2	1.0	0.6	4.5	2.2	0.7	0.5
20	1.9	0.6	0.5	0.2	3.9	1.6	0.7	0.4	3.6	1.1	0.5	0.4	7.7	1.1	0.9	0.4	6.0	2.5	1.2	0.4
21	1.2	0.7	0.5	0.1	2.5	1.0	0.5	0.3	4.8	1.8	0.6	0.2	4.6	1.9	0.6	0.4	6.5	3.4	0.9	0.4
22	0.9	0.5	0.4	0.3	4.2	1.2	0.6	0.3	3.7	1.5	1.0	0.5	4.9	1.6	0.9	0.5	4.6	2.6	1.2	0.3
23	1.0	0.7	0.6	0.2	3.0	1.6	0.7	0.3	3.6	1.6	1.0	0.6	5.6	3.2	2.1	0.4	3.2	1.5	1.2	0.2
24	1.5	0.9	0.7	0.4	3.3	1.7	0.9	0.4	5.4	1.3	0.6	0.3	5.6	3.5	2.2	0.6	5.1	1.6	1.0	0.4
25	1.6	0.7	0.4	0.2	4.6	1.9	0.6	0.2	5.4	1.2	0.5	0.4	6.7	4.0	1.9	0.6	6.5	5.1	1.6	0.7
26	2.4	0.7	0.5	0.2	2.4	1.0	0.5	0.4	5.0	1.8	0.6	0.2	8.7	4.3	1.6	0.5	5.0	2.2	0.8	0.3
27	1.8	0.9	0.7	0.6	2.9	1.2	0.7	0.3	3.5	1.7	0.5	0.3	7.1	4.1	1.7	0.5	2.9	2.1	0.9	0.6
28	4.1	1.1	0.6	0.4	4.0	1.4	1.0	0.5	5.5	2.6	1.0	0.5	8.9	4.3	1.1	0.5	8.0	5.2	1.7	0.7
29	3.6	1.2	0.7	0.4	5.4	4.5	2.6	0.4	8.1	2.3	0.5	0.3	8.1	4.6	1.7	0.6	9.1	4.5	1.4	0.7
30	4.0	0.7	0.4	0.2	5.9	3.6	1.4	0.5	5.0	1.6	0.3	0.5	5.3	3.7	2.4	0.5	7.1	2.5	0.9	0.3

The low values of the adsorption maximum and K revealed that the soils used in this study (savanna soils) have low capacities to sorb B, which make B susceptible to leaching loses. This explained why the available B in these soils are low.

4.2 Crop Response to B in the Green House

4.2.1 Observations on the Assay Crop

Growth pattern observed varied across all the soils, reflecting the different nutrient status of the soil. At four weeks after transplanting, the plants exhibited symptoms which was suspected to be due to N and P deficiency. The leaves and stems changed from the normal green colour to light green, and pale yellow. Also there was a development of a purplish colour on the underside of the leaves. These are early symptoms of N and P deficiency in tomato as described by Sprague (1964). Additional N and P in nutrient solution were applied.

Boron deficiency was not observed in the +B plants, but some of the -B plants showed B deficiency symptoms which include, curled and chlorotic leaves, as well as brittle and yellowing of older leaves. Also +B plants flowered earlier than the -B plants.

4.2.2 Crop Parameters

The crop parameters measured from the greenhouse study are presented in Table 10. The plus and minus B treatments made possible the determination of crop response to B in the soils as well as calculation of the relative yield. Crop response (CR) was obtained by determining the difference between dry matter yield of plus B and minus B treatments. Relative yield is the ratio of dry matter produced in minus B treatment to plus B treatment expressed

Table 10: Crop parameters from green house study

Soil No	Number of leaves	Dry matter yield ($gPot^{-1}$)	B conc. ($MgKg^{-1}$)	B Uptake (mg Pot^{-1})	Relative yield (%)	Crop Response $gPot^{-1}$
1	12	8.5	0.87	7.40	88.0	1.0
2	11	8.7	0.89	7.74	85.0	1.3
3	14	9.5	0.76	7.22	90.5	0.9
4	14	9.8	1.62	15.88	75.5	2.4
5	13	10.6	1.59	16.85	96.2	0.4
6	14	11.8	1.28	15.10	80.5	2.3
7	12	8.2	1.11	9.10	82.9	1.4
8	11	9.5	1.04	9.88	94.7	0.5
9	18	8.0	0.90	7.20	77.5	1.8
10	13	10.4	1.00	10.40	56.7	4.5
11	16	10.2	1.28	13.06	63.7	3.7
12	13	11.4	0.93	10.60	92.1	0.9
13	10	9.4	1.69	15.89	95.7	0.4
14	12	9.0	0.96	8.64	92.2	0.7
15	11	9.5	1.04	9.88	97.9	0.2
16	11	9.7	1.06	10.28	94.8	0.5
17	14	11.6	1.25	14.50	74.1	3.0
18	12	10.6	0.99	10.49	90.6	1.0
19	13	11.4	1.08	12.31	90.4	1.1
20	14	10.6	0.99	10.49	58.5	4.4
21	10	8.0	0.94	7.52	72.5	2.2
22	13	10.2	0.67	6.83	94.1	0.6
23	12	10.6	1.15	12.19	78.3	2.3
24	12	7.3	0.74	5.40	70.0	2.2
25	21	9.3	1.30	12.09	86.0	1.3
26	10	9.2	0.94	8.65	89.1	1.0

Table 10 contd: Crop parameters from green house study

Soil No	Number of leaves	Dry matter yield ($gPot^{-1}$)	B conc. ($MgKg^{-1}$)	B Uptake (mg Pot^{-1})	Relative yield (%)	Crop Response $gPot^{-1}$
27	12	7.6	0.98	7.45	90.0	0.8
28	11	9.6	1.16	11.48	97.9	0.2
29	10	10.5	1.22	12.81	93.3	0.7
30	12	9.8	1.22	11.96	88.7	1.1

as percentage.

B uptake is the product of dry matter yield in +B treatment and B concentration.

The number of leaves ranged from 10.0 to 21.0 with a mean of 12.7 (Table 10). Data on Table 10 also shows that the dry matter yield varied from 8.0 to 11.8 g pot^{-1} with a mean of 9.68 in the +B treatment.

Boron concentration varied from 0.67 to 1.69 $mgKg^{-1}$ with a mean of 1.09 $mgKg^{-1}$. These values are lower than those obtained by Aremu (1976) and Aduayi (1978). The disparity might have been due to differences in soils, varieties, time of sampling and method of analysis.

Boron uptake by plants varied from 5.40 to 16.85 mg pot^{-1} with a mean of 10.64 mg pot^{-1}. Response to B application varied from 0.2 to 4.5 g pot^{-1}, mean being 1.49 g pot^{-1}. It is evident from the mean response that almost all the thrity soils used for this study responded to B application, indicating that B deficiency is imminent in all the soils used.

Relative yield in crops varied from 58.5 to 97.9%, mean being 84.58%. According to Lombin (1983b), a relative yield (RY) below 90% was not significant. Sixteen soils had their RY below 90%. This signifies that for significant yield increase to be expected, from the soils, B fertilizer should be applied.

4.2.3 Relationship Among Crop Parameters

The number of leaves correlated negatively with RY (r = -0..304*) and possitively with CR (r = 0.348*) as shown in Table 11A.

Dry matter yield (DMY) correlated with B concentration (r =

0.333*) and B uptake (r = 0.661**). B concentration also correlated with uptake (r = 0.925**). CR correlated with RY (r = 0.905**). This result signifies that number of leaves, DMY and CR could be used as index of yield.

4.2.4 Relationship Between Crop Parameters and Soil Properties

The relationship between crop parameters and soil properties is shown in Table 11B. Result from this study indicated that number of leaves correlated significantly but negatively with sand (r = 0.309*) and postively with E.A (r = 0.596**), available Fe (r = 0.370*) and Zn (r = 0.422**).

With increase in DMY, there were significant increase in pH water (r = 0.322*), ECEC (r = 0.275*), exchangeable Na (r = 0.290*) and available Cu (r = 0.3708*). In an earlier study, Daudu (1993) also got a significant relationship between pH water and DMY of maize.

Boron concentration correlated significantly with pH $CaCl_2$ (r = 0.313*) whereas, B uptake correlated with both pH water and $CaCl_2$ (r = 0.307* and 0.3298* respectively).

The relationship between pH and B uptake observed in this study is similar to the report of Lombin (1985b) who worked on soils of the same area. This indicates that soil pH has much influence on the B uptake. This may be due to the nature of the soils used in this study which varied from moderately to slightly acid, and the increase in uptake with increase in pH may be due to a shift towards a more favourable pH for plant growth.

There is a significant relationship between available P and relative yield (r = 0.354**) as shown in Table 11B. Crop response correlated negatively with sand (r = -0.349*), whereas as the CR

Table 11A: Simple Correlation among crop parameters

	Number of leaves	DMY	B Conc.	B uptake	RY	CR
Number of leaves	-					
DMY	0.106	-				
B Conc.	0.100	0.333*	-			
B uptake	0.120	0.661**	0.925**	-		
RY	-0.304	0.092	0.098	0.107	-	
C.R	0.348*	0.195	0.017	0.103	-0.905**	-

DMY - Dry matter yield
B Conc. - B concentration
RY - Relative yield
CR - Crop response

* Significant at 5% level
** Significant at 1% level

Table 11B: Simple correlation between crop parameters and soil properties

Soil Properties	Coefficient of Simple Correlation (r)					
	Number of leaves	DMY	B Conc.	B Uptake	CY	CR
Sand	-0.309*	-0.062	0.198	0.107	0.177	-0.349*
Silt	0.096	-0.149	-0.123	-0.155	-0.212	0.340*
Clay	0.028	-0.102	-0.260	-0.229	-0.048	0.192
pH(H_2O)	-0.133	0.322*	0.235	0.307*	0.179	0.020
pH ($CaCl_2$)	-0.089	0.199	0.313*	0.329*	0.055	0.060
O.C	0.111	0.094	0.094	0.121	-0.038	0.151
ECEC	-0.087	0.274*	0.182	0.246	0.057	-0.022
E.A	0.596**	0.119	-0.214	-0.136	-0.168	0.169
Exch. Ca	-0.103	0.262	0.148	0.208	0.052	-0.007
Exch. Mg	0.010	0.141	0.186	0.191	0.089	-0.149
Exch. K	0.003	0.038	0.214	0.183	0.18	-0.162
Exch. Na	0.042	0.290*	0.094	0.188	-0.024	0.164
Av. P	0.177	0.262	-0.102	0.012	0.354**	-0.212
Total N	0.230	-0.165	-0.096	-0.110	-0.110	0.195
Av. Fe	0.370**	0.185	0.007	0.068	-0.041	0.308*
Av. Cu	-0.023	0.371**	0.013	0.168	0.035	0.272
Av. Zn	0.422**	0.172	0.173	0.218	0.249	0.004
Av. Mn	0.209	0.144	-0.195	-0.094	-0.022	0.179
Total B	0.116	-0.080	0.013	-0.028	-0.142	0.174

increased there were increase in silt content (r = 0.340*) and extractable Fe (r = 0.308*).

4.2.5 Relationship Between Crop Parameters and Extractable Boron

The Hotwater-B correlated with RY (r = 0.293*) as shown in Table 12. Similar relationship has been reported by Chude and Obigbesan (1987) in their study of B nutrition of Cacao. This finding therefore points to the possibility of using RY to some degree as an index of B availability in the soils studied.

Furthermore, Kayode (1981) opined that correlation studies have been most successful when the RY is considered instead of growth parameters like absolute DMY or nutrient uptake.

$CaCl_2$-B showed negative correlation with number of leaves (r = -0.3215*). The other soil test methods did not correlate with the crop parameters. The lack of significant response of crop parameters to soil test methods has been reported in some greenhouse experiments (Anande-kur 1976 and Agbenin 1987). Also Chude and Obigbesan 1984 got a nonsignificant relationship between B soil tests and uptake, whereas combinations of soil properties and soil tests accounted for a higher percentage of the variation in plant uptake, than soil tests methods alone.

The magnitude of B test correlation with B uptake was in the following order:

Hotwater > HCl > MS > DA > $CaCl_2$.

For relative yield, it was in this order:

Hotwater > $CaCl_2$ > DA > HCl > MS

Table 12: Relationship between crop parameters and Extractable B

Extract-able B	Coefficient of simple correlation (r)					
	Number of leaves	DMY	B. Conc.	B uptake	RY	CR
Hotwater	0.124	0.144	0.200	-0.194	0.293*	-0.260
$CaCl_2$-B	-0.322*	0.207	0.038	0.107	0.254	-0.234
HCl-B	0.191	-0.023	0.250	0.190	-0.060	0.067
DA-B	-0.047	-0.261	-0.036	-0.130	0.048	-0.108
MS-B	-0.047	-0.084	0241	0160	0112	-0.035

Significant at 5% level
Significant at 1% level

Based on the relationship between Hotwater-B and RY, the Hotwater extractant would be recommended as a reliable extractant for separating B deficient soils from non-deficient ones. Therefore Hotwater test appears to be the 'best' extractant for the soils used.

4.2.6 Predicting Boron Uptake

The data on Table 12 indicates that the relationship between the B tests and B uptake was non significant, nevertheless, the relationship between Hotwater-B and RY was significant. Therefore Hotwater could be used as the sole predictor of yield in these soils.

When other soil properties and tests are taken into consideration in a multiple regression analysis the following prediction equation was obtained:

B uptake:

$Y = -36.63 + 15.4\ CaCl_2\ B + 3.05\ pH\ CaCl_2 + 0.193\ O.C - 4.18$ HWB + 4.91 HCl-B - 3.67 DAB + 1.34 Cu + 0.278 Sand + 0.283 Silt + 0.051 Fe + 0.42 No of leaves + 1.15 K $R^2 = 0.492$.

The prediction equation above showed the importance of pH, soil texture, O.C, exchangeable K, available Cu and Fe in determining B availability.

The prediction equation for the other crop parameters are shown in Table 13.

Table 13: Prediction equation for other crop parameters

Number of Leaves:

Y = 14.50 - 40.68 CaCl B + 0.37 O.C - 0.148 avail P + 45.08 HWSB + 7.44 HCl B - 9.29 DAB - 39.62 MSB. R^2 = 74.83**%

DMY Y

Y = 7.611 + 0.62 pH $CaCl_2$ + 0.0522 avail P + 10.34 HWB - 6.678 DAB - 16.92 MSB - 0.0086 total B + 0.34 Cu R^2 = 52.93*%

RY

Y = 79.88 + 1.28 avail P + 75.67 HWB - 12.15 HCl B - 24.61 DAB - 25.20 Na R^2 = 26.55%

CR

Y = 14.80 + 12.17 $CaCl_2$ B + 0.70 pH $CaCl_2$ - 0.128 Av. P - 18.41 HWSB + 4.75 DAB - 0.44 Na + 0.079 Sand + 0.12 silt + 0.041 Fe + 0.32 Number of leaves. R^2 = 60.52*%

4.2.7 Critical Level of Boron in the Soils

The Hotwater soil tests proved more efficient in predicting B availability, hence critical levels of B in the soil were established based on the test.

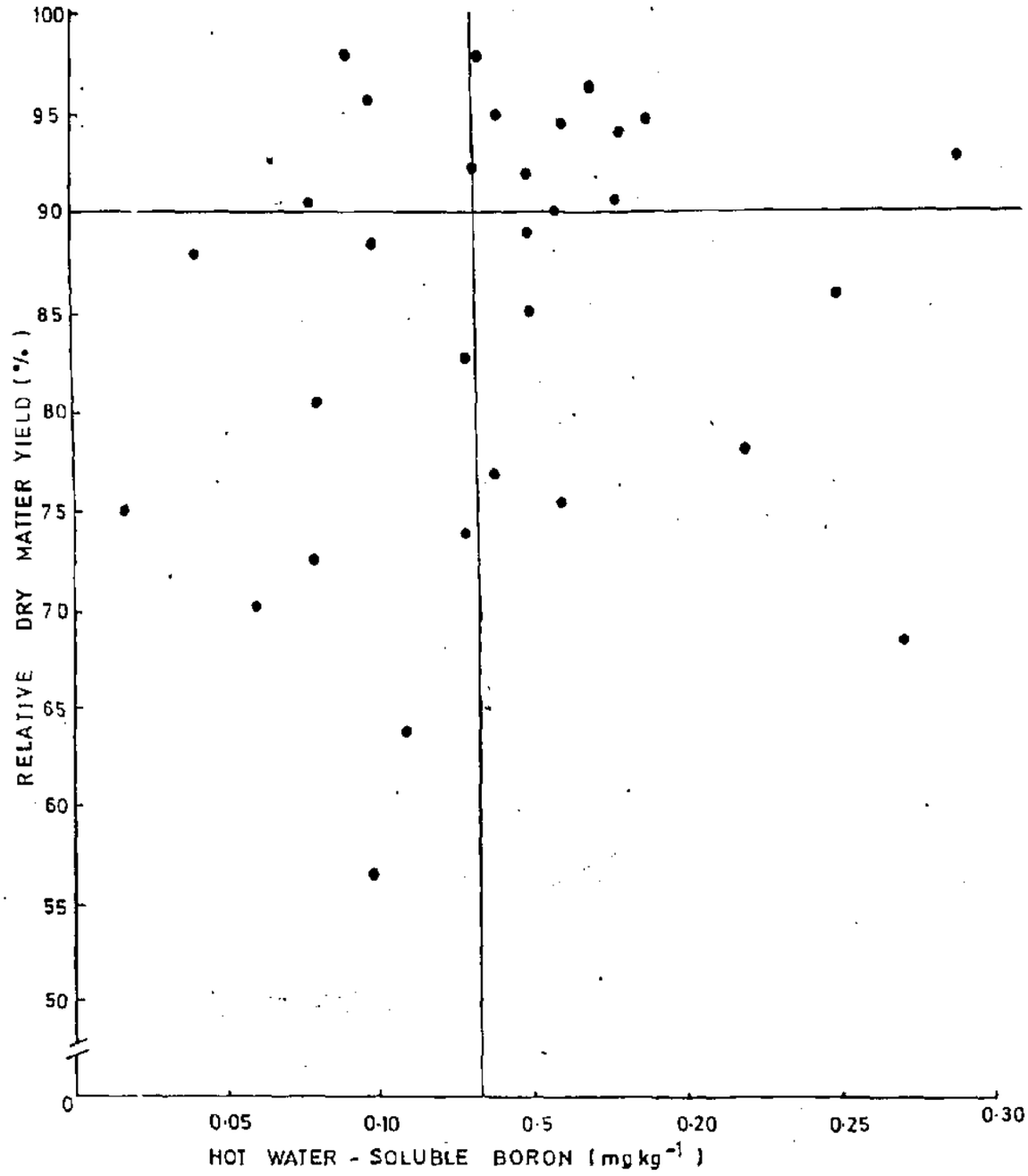
The graphical representation of relative dry matter yield (%) against Hotwater-B in all the soils studied according to the method of Cate and Nelson (1971) indicate 0.13 $mgKg^{-1}$ B (Fig. 3A) as critical concentration of B in soil.

The critical Hotwater-B have been put between 0.15 $mgKg^{-1}$ Rogers (1947) and 0.35 $mgKg^{-1}$ Dawson and Gustafson (1945) for sandy to medium-textured soils. 12 out of the 30 soil samples used in the present study fall within the range while the remaining 18 soils fall below this range Table 4). This confirms the report of Lombin (1985a) who worked with Northern Nigeria savanna soils and reported that Nigerian savanna soils B content ranged from low to very low, but could not establish any critical soil B level.

In the field, the critical B levels are expected to be lower than those of the green house. This is so because in the field, plants have a larger soil mass from which nutrients are explored. In the green house, the plant roots are restricted to the small soil mass used.

Furthermore, the critical nutrient levels are dependent upon the crop and soil type (Ulrich and Hills 1973). For tomato crop, Drews (1980a) recommended soil B levels of 0.8 - 2 $mgKg^{-1}$.

FIG.3A. SCATTER DIAGRAM OF RELATIVE DRY MATTER YIELD OF TOMATO PLANTS VS HOT WATER - SOLUBLE B.



4.2.8 Critical Boron Concentration in Plant Tissue

The Cate and Nelson method (1965) was adopted in establishing critical B concentration in plant tissue. The plot of relative yield (%) against plant tissue B concentration showed 1.06 $mgkg^{-1}$ (Fig. 3B) as critical concentration of B in tomato plant tissue. The critical level of plant tissue B concentration obtained from this study is however lower than 10-25 $mgkg^{-1}$ suggested by Drews and Frank (1980a) for tomato plants and 25-100 $mgkg^{-1}$ reported by Bradford (1966) for plants.

The very low value of the critical level of plant tissue B concentration obtained in this study could be due to low soil level B, and inability of the soils to retain B due to low adsorption capacity. This has resulted to leaching of B from the soils, which consequently make the soils to be B deficient.

4.2.9 Delineation of Soils into Boron Fertility Classes

An attempt was made to delineate the soils of tomato growing areas in Northern guinea and sudan savanna into B fertility classes. This could not be done as a result of the small area covered during sampling. However, the thirty surface soils (fallow and cultivated) has been classified either as High (H) or low (L) (Figs. 3C & 3D) based on the critical B level (0.13 $mgkg^{-1}$) developed from both laboratory and greenhouse studies.

About 67% (ten out of fifteen) of the fallow soils have soil B concentration above the critical B level, while 33% (five out of fifteen) have their B concentration below the critical B level

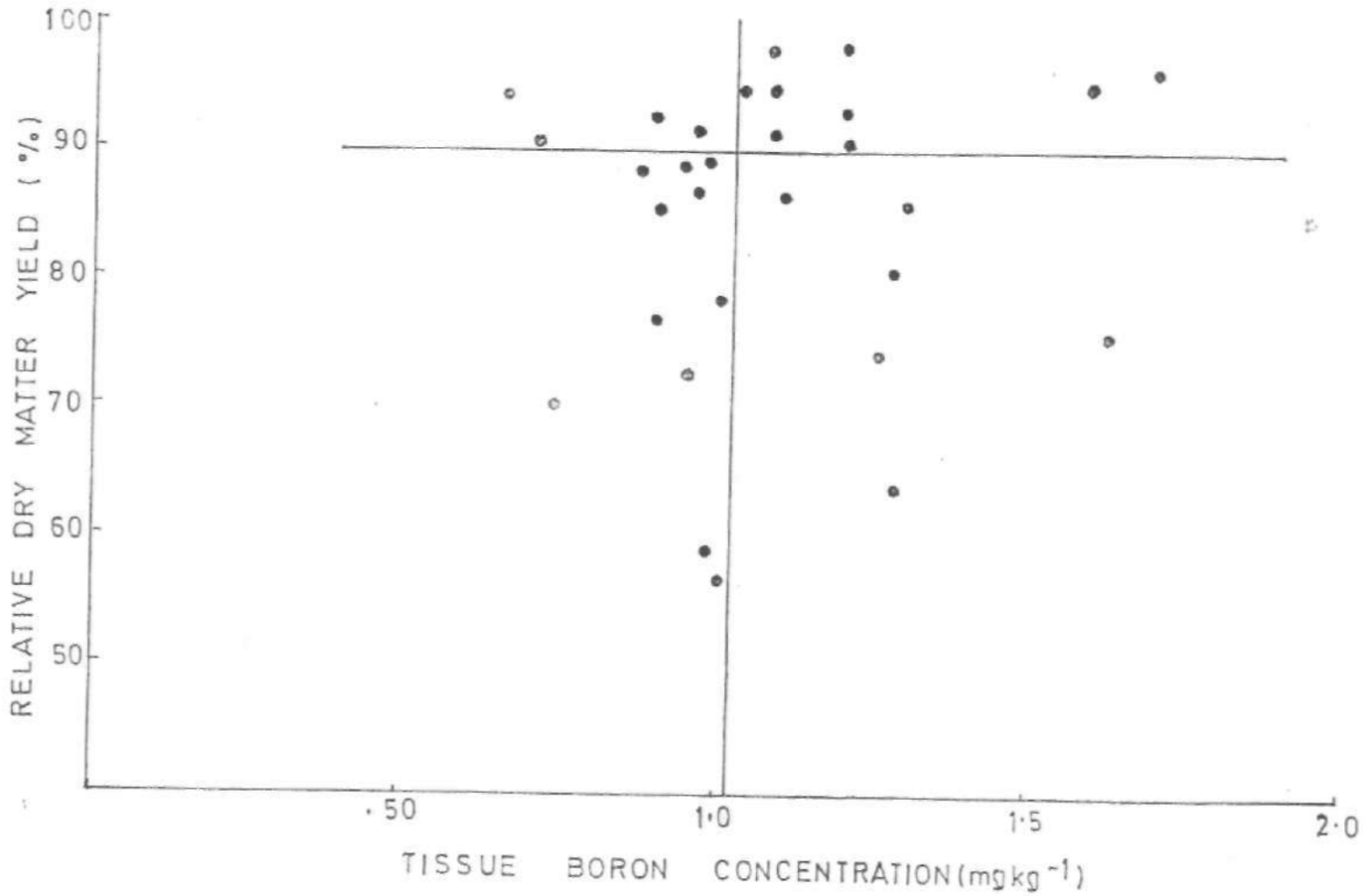


Fig.3B: Scatter diagram of relative dry matter yield of tomato plants Vs tissue B concentration.

Fig.3C: Boron fertility map of fallow soils in Northern Guinea and Sudan savanna of Nigeria.

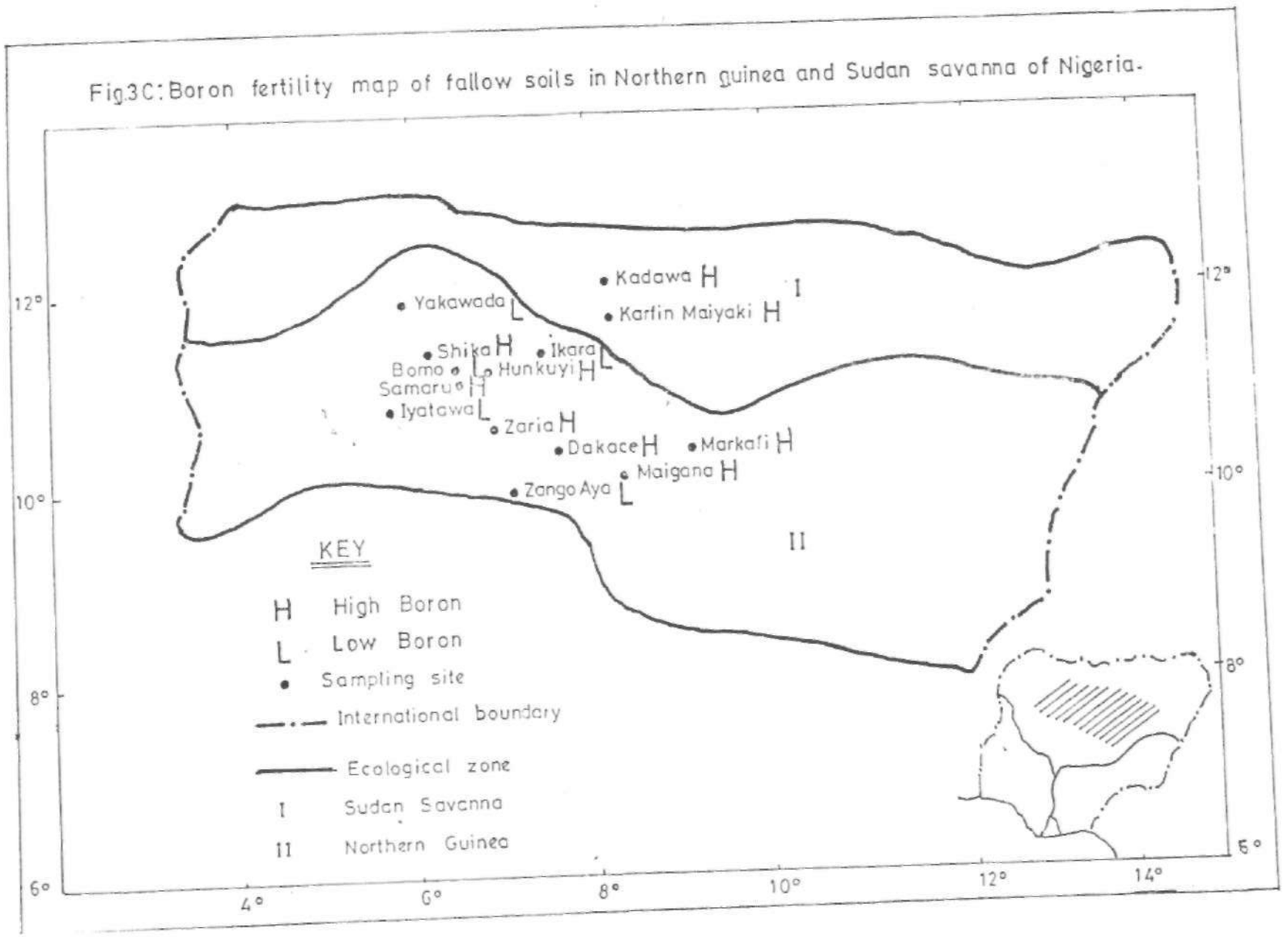
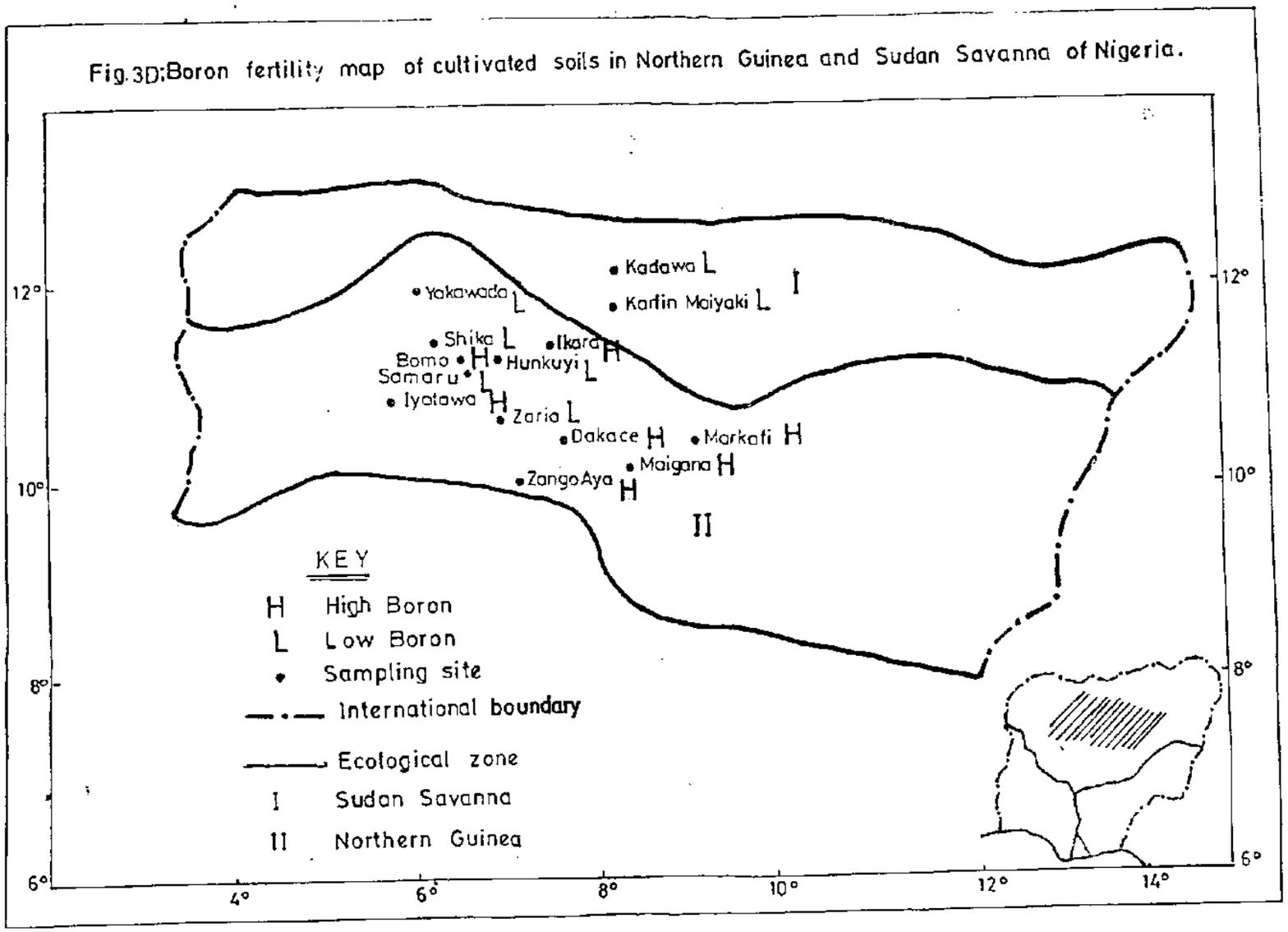


Fig.3D:Boron fertility map of cultivated soils in Northern Guinea and Sudan Savanna of Nigeria.



(Fig. 3C). Similarly, 53% (eight out of fifteen) of the cultivated soils have their soil B concentration above the critical B level, while 47% (seven out of fiteen) fell below the critical B level of 0.13 $mgKg^{-1}$ (Fig. 3D).

A more accurate delineation of the area studied would required larger number of sampling than collected in the present study. Future studies may have to look at this aspect.

4.3 FIELD STUDIES

4.3.1 Soil Characterization

The classification of the soils and main features of the locations of the study profile soils are presented in Tables 14, 15, Appendix A and B.

The soil at the Samaru site belongs to the Haplic Acrisol in FAO System and Ultic Haplustalf (fine, kaolinitic, isohyperthermic family) in soil Taxonomy. The soil is well drained, the texture is loam at the surface and clay in the subsoil.

The soil at the Kadawa site belongs to Eutric cambisol in FAO System and Typic Ustropepts (fine-loamy, mixed, Isohyperthermic family) in soil Taxonomy. The soil is moderately well drained, the texture is sandy loam, both at the surface and subsoil. Most of these soils are underlain by iron pan at depth varying from 80 to 150cm (Table 14).

Table 14: Some selected feature of the sites and classification of the soil profiles at the experimental sites

Profile	Location	Classification	Parent material	Rainfall*	
				Amount	Duration
Pedon 1	Samaru	Ultic Haplastulf (USDA) Haplic Acrisol (FAO)	Aeolian material on basement complex	1090	5
Pedon 2	Kadawa	Typic Ustropepts (USDA) Eutic Cambisol (FAO)	Thin aeolian material over granitic residum	870	4

* Source: Institute for Agricultural Research Meteorological Unit, Zaria

4.3.1.1 Selected Properties of the Soil Profile

The selected physical and chemical properties of the soil profiles are given in Table 15. The soil of Pedon 1 (Samaru) varies from loam to clay with clay content increasing consistently with depth. Whereas in Pedon 2 (Kadawa), the textural classes are sandy loam with fairly clay content throughout the pedon.

The nature and reactions of the soils are expected to be different because, they had been developed under different drainage, soil moisture conditions varied parent materials, natural influences and previous land use.

The soils of the two pedons are neutral in reaction. The O.C content in all the pedons are low, being less than 10 gkg^{-1}. The surface soils have the highest organic carbon content in the two pedons, but decreased appreciably with depth in all cases. The ECEC fall within the low to medium fertility (Table 15) with most values less than 10 $cmolkg^{-1}$. This result is in agreement with the findings of Jones and Wild (1975) and Greenland (1981) who reported that most Nigerian soils are of low reactivity as a result of the dominance of kaolinitic clay fraction

4.3.2 Physicochemical Properties of the Surface Soils of the Experimental Sites

The data on physical and chemical characteristics of the experimental sites before cropping are shown in Table 16. The soil test values suggested that both Samaru and Kadawa soils on the average, have pH (H_20) values which were slightly acid. The soils were light textured with low clay contents which varied from 90-150

Table 15: Selected physical and chemical properties of the soil profiles

Profile	Depth (cm)	Sand	Silt	Clay	pH (H_2O)	pH ($CaCl_2$)	O.C (gKg^{-1})	ECEC $cmolKg^{-1}$	BS NH_4OAc	Textural Classes
		<------- gKg^{-1} ------->								
Pedon 1	0-15	410	440	150	6.7	5.70	9.2	1.87	32.0	Loam
	15-28	410	420	170	6.9	5.72	2.8	4.42	59.0	Loam
	28-40	330	340	330	6.68	5.74	2.9	2.86	55.0	Clay loam
	40-128	310	280	410	6.66	5.76	1.3	6.88	57.6	Clay
	128-175	250	280	470	6.50	5.70	0.8	9.92	64.0	Clay
Pedon 2	0-30	570	240	190	6.83	5.30	4.2	8.19	59.0	Sandy loam
	30-45	530	280	190	6.66	5.78	2.4	6.85	56.6	Sandy loam
	45-65	550	240	210	6.58	5.78	1.8	9.78	67.5	Sandy loam
	100	570	220	210	6.34	5.78	1.0	7.96	69.7	Sandy loam

Table 16: Physicochemical properties of the soils at the experimental sites at Samaru and Kadawa

Soil Properties	1992/93		1993/94	
	Samaru (I) 0-30cm	Kadawa (I) 0-30cm	Samaru (II) 0-30cm	Kadawa (II) 0-30cm
pH (H_2O)	5.9	5.5	5.8	6.1
pH ($CaCl_2$)	5.3	5.1	5.6	5.7
Textural class	Loam	Sandy loam	Loam	Sandy loam
Sand (gkg^{-1})	440	690	390	730
Silt (gKg^{-1})	430	200	460	180
Clay (gkg^{-1})	130	110	150	90
O.C (gKg^{-1})	6.8	10.6	6.0	7.3
Available P $mgKg^{-1}$	6.7	4.32	6.70	18.84
Total N (gkg^{-1})	0.42	0.88	0.42	0.53
Exchangeable bases (cmol (±) Kg^{-1})				
Ca	2.99	7.61	2.20	4.12
Mg	0.86	1.56	0.49	1.15
K	0.29	0.29	0.17	0.23
Na	0.31	0.35	0.20	0.37
CEC	6.01	17.40	5.90	10.40
Micronutrient ($MgKg^{-1}$)				
Available B	0.05	0.12	0.13	0.22
Available Fe	15.2	16.5	15.8	16.9
Available Cu	1.8	3.2	2.0	3.6
Available Mn	8.6	10.1	10.5	11.2
Available Zn	2.5	3.5	2.8	3.9

Table 16 contd: Physicochemical properties of the soils at the experimental sites at Samaru and Kadawa

Soil Properties	1993		1994	
	Samaru (III) 0-30cm	Kadawa (III) 0-30cm	Samaru (IV) 0-30cm	Kadawa (IV) 0-30cm
pH (H_2O)	5.7	5.4	5.7	8.3
pH ($CaCl_2$)	4.8	5.0	5.3	7.5
Textural Class	Loam	Sandy loam	Loam	Sandy loam
Sand (gKg^{-1})	430	610	490	670
Silt (gKg^{-1})	420	280	400	240
Caly (gkg^{-1})	150	110	110	90
O.C ($kgKg^{-1}$)	9.8	5.9	8.0	7.0
Available P ($mgKg^{-1}$)	8.39	18.96	9.94	15.13
Total N (gKg^{-1})	0.49	0.56	0.46	0.49
Exchangeable bases (cmol (±) Kg^{-1})				
Ca	0.87	5.98	1.35	3.19
Mg	0.082	1.28	0.29	0.37
K	0.051	0.29	0.14	0.09
Na	0.086	0.70	0.15	0.30
CEC	4.20	15.20	3.00	7.40
Micronutrient ($MgKg^{-1}$)				
Available B	0.10	0.17	0.13	0.32
Available Fe	21.0	23.0	22.5	26.0
Available Cu	1.2	1.7	1.5	1.96
Available Mn	16.0	19.0	18.0	21.0
Available Zn	1.8	2.4	1.94	2.6

Samaru I 1992/93 dry season trial
Samaru II 1993/94 dry season trial
Kadawa I 1992/93 dry season trial
Kadawa II 1993/94 dry season trial
Samaru III 1993 rainfed trial
Samaru IV 1994 rainfed trial
Kadawa III 1993 rainfed trial
Kadawa IV 1994 rainfed trial

gKg^{-1}. The silt contents of Samaru soils were high and varied from 400-460 gkg^{-1}, while those of Kadawa soils varied from 180-280 gkg^{-1}. Kadawa soils were high in sand contents which varied from 610 - 730 gKg^{-1}, whereas, the sand content of Samaru soils varied from 390-490 gKg^{-1}. The soils of Samaru were loam, while those of Kadawa were sandy loam. These fall within the range of textural classes recommended for the growth of tomatoes (Simons and Sobulo 1974, Vandamme, 1978 and Vandamme and Lambert 1978).

The organic carbon contents were generally low, and varied from 6.0 gKg^{-1} to 9.8 gKg^{-1} for Samaru soils, while that of Kadawa varied from 5.9 to 10.6 gkg^{-1} as shown in Table 16. The low O.C content had earlier been reported by Jones and Wild (1975).

The least available P of 4.32 $mgKg^{-1}$ and the highest of 18.84 $mgKg^{-1}$ were obtained with Kadawa I and II soils respectively. The phosphorus content of savanna soils is known to be generally low (Jones and Wild 1975 Kowal and Kassam, 1978).

Total N contents of the soils are low and varied between 0.42 and 0.49 for Samaru soils, while those of Kadawa, varied from 0.49 to 0.88 gkg^{-1}. The total N content fall within the range (0.08 to 29 gKg^{-1}) obtained in Savanna soils (Jones and Wild 1975).

The soils of Kadawa had high exchangeable Ca, Mg and CEC than Samaru soils. Available B contents varied from 0.05 to 0.13 $mgKg^{-1}$ for Samaru soils while those of Kadawa varied from 0.12 to 0.32 $mgKg^{-1}$, as shown in Table 16. Only Kadawa IV soils had available B of 0.32 $mgKg^{-1}$ which is within the critical soil B recommended by Rogers (1947), whereas none of the soils have soil B of 0.8-2.0

recommended by Drews et al (1980a) as adequate for the growth of tomatoes.

All the soils had high Fe and Mn contents, but only Kadawa I and II soils had available Zn higher than 3.2 $mgKg^{-1}$ which is the critical soil Zn reported by Pam (1990) for 0.1N HCl extractable Zn. The Cu level varied between marginal and high (Table 16) when compared to the critical Cu levels of 1.0 $mgKg^{-1}$ set by Lombin (1983b).

The result (Table 16) showed that B, N, P and O.C contents of the soils used, fall within the low fertility classes suggested for soils of Northern Nigerian (Enwezor et al 1989 and 1990). It is expected that crops will respond to additions of these nutrients in the soils.

4.3.3 Dry Season Trials 1992/93 & 1993/94

4.3.3.1 Effect of Boron Application on Morphological Appearance of Plants

In the field, boron deficiency was observed on some plants. At Samaru, some plants in the control plots (0 kg Bha^{-1}) produced curled and chlorotic leaves near the apex as well as brittle and yellowing of older leaves, an indication of slight to moderate B deficiency. Some of these symptoms disappeared gradually, as though some persisted in some plants up to maturity.

Death of terminal bud, bushy appearance of plants; uneven ripening of fruit were observed in some control plots. These are part of symptoms of B deficiency, described previously. A similar observation was made at Kadawa. Similar observation had been made

elsewhere by Holmes (1960), Adams and Winsor (1974); Jackson and Chapman (1975), Aduayi (1978) and Gupta (1993).

Toxicity symptoms were observed in plots that received 4 and 5 kg B ha^{-1}. These symptoms manifested as leaf marginal burning and inter-veinal chlorosis, starting with the older leaves. These were symptoms described by Bergmann and Neubert (1976) and Shorrocks (1983) as evidence of B toxicity.

In 1993/94 trial, some plots manifested symptoms of nematode infection at Kadawa. This problem which was observed at fruiting stage led to slight reduction in yield.

4.3.3.2 Effect of Boron Application on Number of Leaves

In this study, leaf count is regarded as an index of the amount of vegetative growth before flowering (Epstein 1972).

The effect of boron (B) treatment on number of leaves of the two varieties was only significant at Samaru in 1993/94 (Table 17). Nevertheless, variety Dandino had greater vegetative growth as indicated by higher number of leaves than in variety Roma VF.

Boron application significantly ($P = 0.05$) increased the number of leaves per plant up to 4 kg B ha^{-1} at Samaru in 1993/94 (Table 17). This result agreed with the report of Vaganav and Sorokina (1972) and Verma et al (1973).

In 1992/93, the highest number of leaves, in each trial was obtained at 3 and 2 kg B ha^{-1}, which accounted for 48 and 16.8% increase over the control at Samaru and Kadawa respectively. In 1993/94, plants treated to 2 kg B ha^{-1} recorded the highest number of leaves at Samaru and Kadawa with increase of 66.5 and 57.2% over

Table 17: Effect of Variety and boron rates on number of leaves at Samaru and Kadawa under irrigation condition during 1992/93 and 1993/94 cropping seasons

Treatment	1992/93			1993/94		
	Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
Variety						
Roma VF	58.0	56.0	57.0	72.0b	80.0	76.0
Dandino	64.0	56.0	60.0	77.0a	88.0	84.0
LSD (0.05)	NS	NS		5.0	NS	
Boronrates (kg B ha^{-1})						
0	53.0cde	54.0	53.0	63.0c	70.0bcd	67.0
1	63.0bc	57.0	60.0	79.0b	105.0a	92.0
2	67.0ab	63.0	65.0	105.0a	110.0a	106.0
3	79.0a	57.0	68.0	80.0b	82.0b	81.0
4	60.0cd	56.0	58.0	68.0c	72.0bc	80.0
5	45.0de	56.0	50.0	51.0d	64.0cd	58.0
LSD (0.05)	14.10	NS		9.44	16.4	

Means in a given column followed by similar letters are not significantly different at P = 0.05, using DMRT

Table 18: Effect of Variety X boron rates interaction on number of leaves at Samaru and Kadawa in 1992/93 and 1993/94

Treatment (kg Bha^{-1})	Variety	1992/93			1993/94		
		Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
0		44.0	50.0	47.0	58.0fghi	68.0	63.0
1		54.0	55.0	55.0	67.0efg	95.0	81.0
2	Roma VF	60.0	57.0	59.0	107.0a	107.0	107.0
3		78.0	57.0	67.0	78.0cde	79.0	78.0
4		67.0	56.0	62.0	73.0def	68.0	70.0
5		42.0	56.0	49.0	46.0ij	60.0	53.0
0		63.0	57.0	60.0	68.0def	73.0	71.0
1		72.0	59.0	66.0	90.0bc	115.0	103.0
2	Dandino	73.0	68.0	70.0	104.0ab	112.0	108.0
3		80.0	57.0	68.0	82.0cd	84.0	83.0
4		52.0	56.0	54.0	62.0fgh	75.0	69.0
5		48.0	55.0	51.0	56.0fghij	68.0	62.0
LSD (0.05)		NS	NS		13.4	NS	

Means in a given column followed by similar letters are not significantly different at P = 0.05, using DMRT.

the control respectively.

There was no significant difference between the results obtained for plants treated to 2 and 3 kg B ha^{-1} in 1993/94 at both locations.

Furthermore, crop growth as measured by leaf number was better in 1993/94 than in 1992/93 when the weather conditions were better (Appendix D), especially prior to and during flowering. Similar findings was reported by Epstein (1972).

The increase in the number of leaves as the boron rates increased showed that B is important for vegetative growth in tomato plants. Leaves are the major source of photosynthates in the plant. Zelitch (1971) and Epstein (1972) explained that photosynthesis play a vital role in the determination of growth indices which subsequently affect dry matter yield and fruit yield.

However, the result of this work is contrary to the findings of other workers such as Blamey (1976) and Birch et al (1981) who reported that the effect exerted by B in plants is of lesser importance in vegetative life than in the reproductive life.

The interaction between B rates and variety on number of leaves was only significant (P = 0.05) at Samaru in 1993/94 (Table 18). However, variety Dandino treated to 1 kg B ha^{-1} recorded the highest number of leaves (115.0) at Kadawa in 1993/94 (Table 18).

4.3.3.3 Effect of Boron Application on Number of Days to 50% flowering

The effect of boron rates on variety was only significant (P

= 0.05) at the first year of the trial at Samaru and Kadawa. The mean number of days of the varieties in each location revealed that variety Roma VF flowered earlier than Dandino (Fig. 4). The difference in number of days over the control were 12 and 13 days in 1992/93, 8 and 10 days in 1993/94 at Samaru and Kadawa respectively.

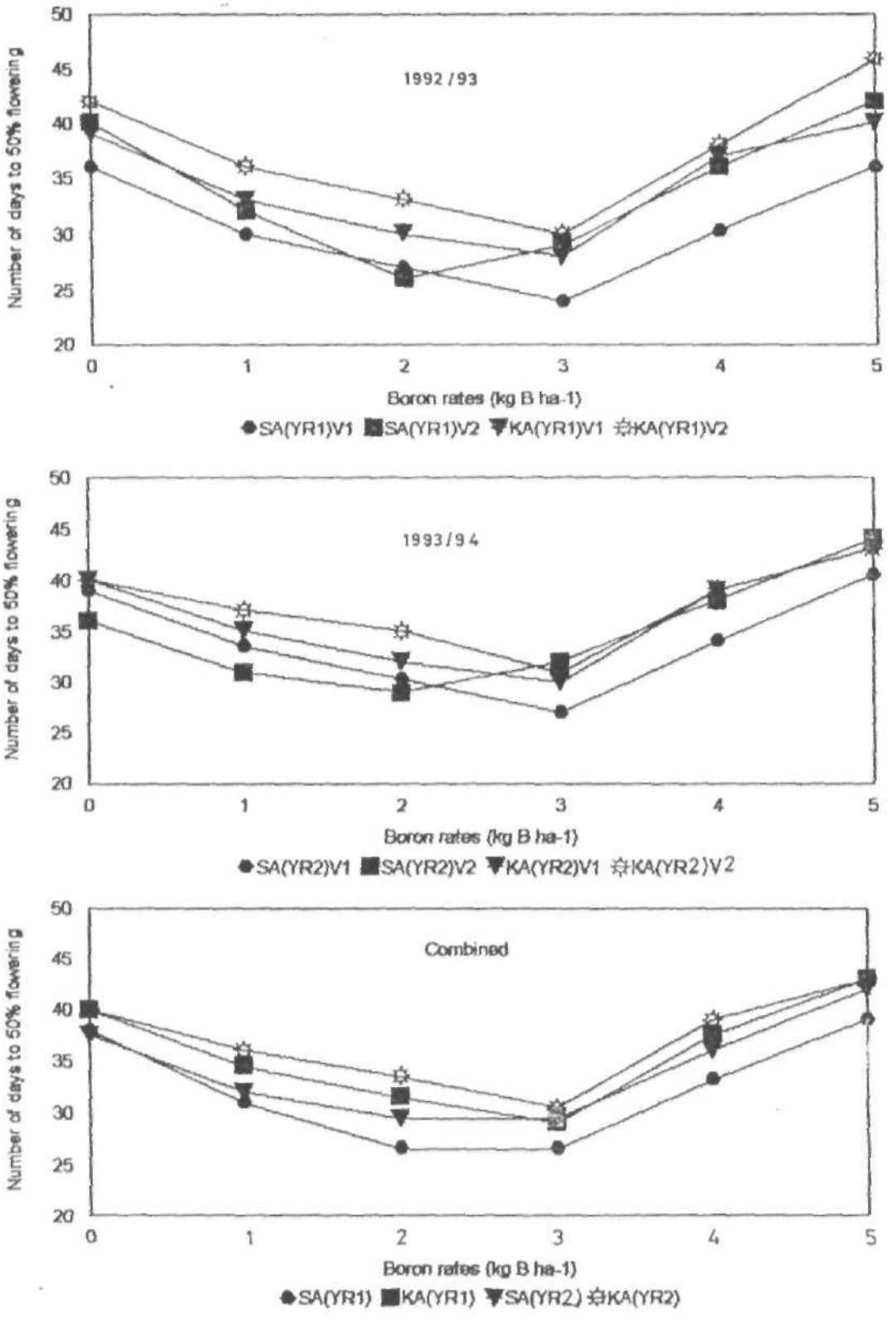
Application of increasing rates of B significantly (P = 0.05) decreased the number of days to 50% flowering up to 4 kg B ha^{-1} in both years and locations (Fig. 4). The least number of days to 50% flowering were obtained at 3 kg B ha^{-1} at Kadawa in both years, whereas at Samaru, the results of plants treated to 2 and 3 kg B ha^{-1} were at par in 1992/93 and 1993/94.

Samaru trials recorded 26.5 days as the least mean number of days to flowering whereas, Kadawa recorded 29 days (Fig. 4). The difference in number of days to flowering in both locations could be due to soil and environmental factors, as had earlier been reported that environmental and soil factors influence the morphology and development of floral parts in tomatoes (Abdalla and Verkerk 1968, Hanna and Hernandez 1982).

The interaction between B treatment and variety was not significant (P = 0.05) in both years at Samaru and Kadawa. Meanwhile, the least mean number of days to 50% flowering (24 days) was obtained with variety Roma VF treated to 3.0 kg B ha^{-1}, (Fig. 4).

The result of this study signifies the importance of B on the period of flower initiation. All B treated plants except plants

Fig. 4. Number of days to 50% flowering as influenced by variety and rates of boron at Samaru and Kadawa under irrigation conditions (1992/93 and 1993/94).



treated to 5 kg B ha^{-1} flowered earlier than the control.

4.3.3.4 Effect of B Application on Number of Flowers Per Plant

Variety Dandino produced more flowers than Roma VF in each of the trial, but the difference was only significant at Samaru in 1992/93 and 1993/94, (Table 19).

The number of flowers increased significantly (P = 0.05) with increase in boron rates up to 4 kg B ha^{-1}, at both locations in 1992/93, but only up to 2 kg B ha^{-1} in 1993/94.

Plants treated to 2.0 kg B ha^{-1} gave the highest number of flowers per plant in each of the trials (Table 19). These represent increases of 18 and 28% in 1992/93 and 18 and 7% in 1993/94 at Samaru and Kadawa respectively.

Results obtained with plants treated to 2.0 and 3.0 kg B ha^{-1} in 1992/93 were not significantly different. The highest mean number of flowers per plant obtained at Samaru was 55.22, whereas 59.5 was obtained at Kadawa.

The result of this work corroborates the findings of Blamey (1976) that the relative effect of B is exerted more in the reproductive phase. Similarly, Eriksson (1979) reported a positive linear relationship between number of flowers and B rates in tomato plants as reported in this study.

The interaction between boron rates and variety was significant both at Samaru and Kadawa in 1992/93 and only at Samaru in 1993/94 (Table 20).

Table 19: Effect of Variety and boron rates on number of flowers per plant at Samaru and Kadawa under irrigation Condition

Treatment	1992/93			1993/94		
	Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
Variety						
Roma VF	48.22b	52.61	50.42	36.55b	29.04	30.30
Dandino	50.78a	53.00	51.89	45.04a	30.85	37.95
LSD (0.05)	1.90	NS		1.93	NS	
Boron Rates (Kg B ha^{-1})						
0	46.00de	46.50e	46.25	46.83b	32.07ab	39.45
1	51.00abc	53.50bc	52.25	45.08bc	32.57ab	38.83
2	54.33a	59.50a	56.92	55.22a	34.33a	44.78
3	54.00ab	58.00ab	56.00	40.70d	28.10bc	34.40
4	48.17cd	51.83cd	50.00	33.20e	26.43cd	29.82
5	43.50e	47.50de	45.50	23.75f	26.17d	25.00
LSD (0.05)	3.30	5.25		3.35	4.11	

Means in a given column followed by similar letter(s) are not significantly different at P = 0.05, using DMRT

Table 20: Effect of Variety X boron rates interaction on number of flowers per plant at Samaru and Kadawa under irrigation condition in 1992/93 and 1993/94

Treatment (kg Bha^{-1})	Variety	1992/93			1993/94		
		Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
0		46.00efgh	45.00fghi	45.50	43.80ef	30.90	37.35
1		48.00ef	49.00defg	48.50	36.87gh	32.27	34.57
2	Roma VF	50.00cde	56.00abcd	53.00	50.97bc	31.93	41.45
3		53.00bc	60.00ab	56.50	34.27ghi	27.13	20.47
4		47.33efg	55.67cde	51.5	29.93j	26.40	28.17
5		45.00fghi	50.00def	47.50	23.42i	25.60	24.51
0		46.00efgh	48.00fgh	47.00	49.87bcd	33.23	41.55
1	Dandino	54.00ab	58.00abc	56.00	53.30b	32.87	43.09
2		58.67a	63.00a	60.84	59.47a	36.73	48.10
3		55.00ab	56.00abcd	55.50	47.13cde	29.07	38.10
4		49.00def	48.00fgh	48.50	36.40g	26.47	31.44
5		42.00hi	45.00fghi	43.5	24.03k	26.73	25.38
LSD (0.05)		4.67	7.42		4.73	NS	

Means in a given column followed by similar letters are not significantly different at P = 0.05, using DMRT.

4.3.3.5 Effect of Boron Application on Number of Fruits Per Plants

Number of fruits was influenced by the application of B (Fig. 5). Varietal difference were only significant (P = 0.05) at Kadawa in 1992/93 and Samaru in 1993/94. The trend was strongly in favour of Roma VF in 1992/93, whereas it was in favour of Dandino in 1993/94. The difference in varietal response for the two years could be due to environmental factors.

Application of boron significantly increase the number of fruits at Samaru and Kadawa in both locations.

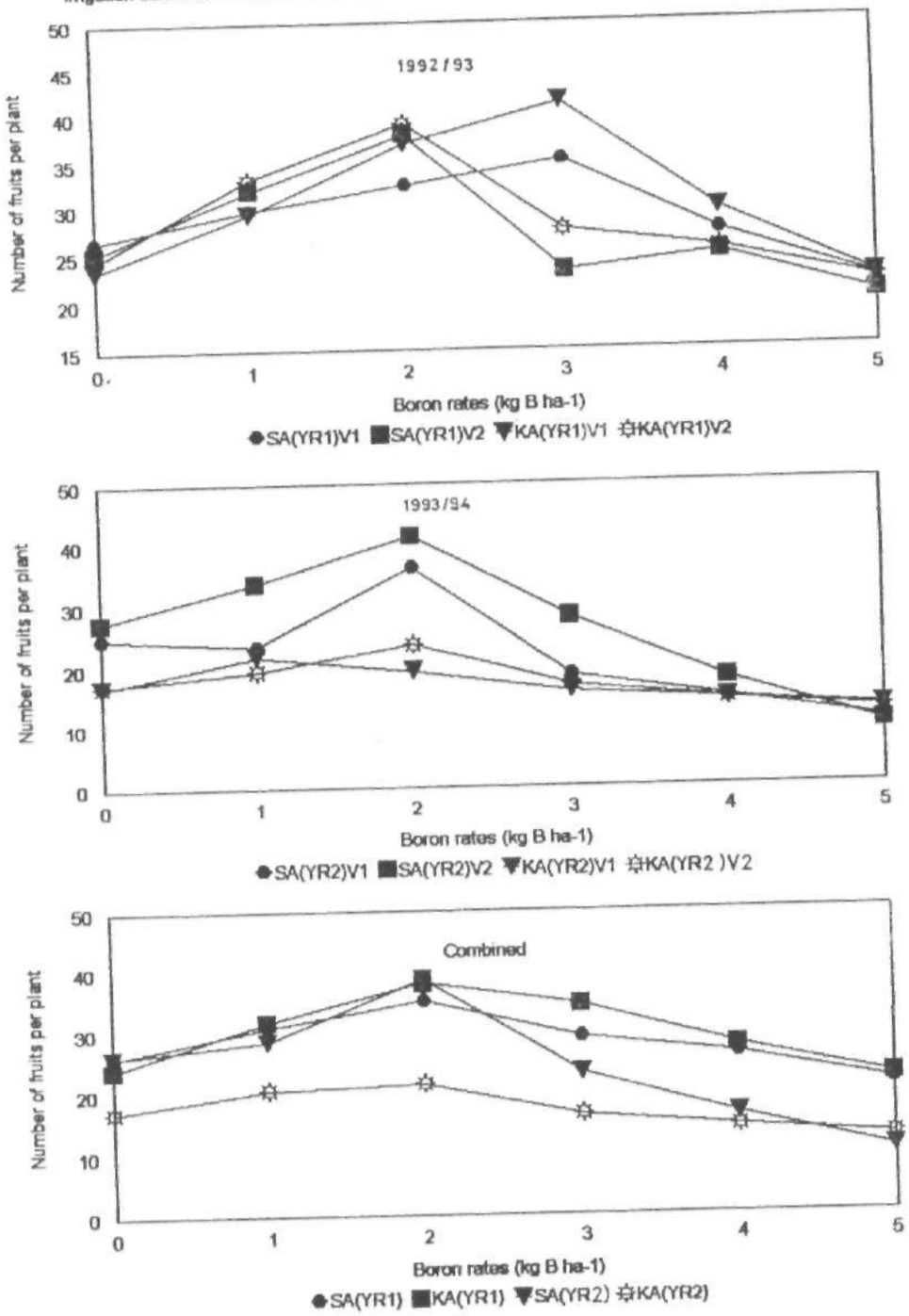
As the, B rate increased, the number of fruit per plant also increased up to a point after which a trend of gradual reduction was observed with further increase (Fig. 5). The result of this work corroborates the findings of other researchers like Pinero et al (1977), Adams et al (1978) and Adelana (1986).

This result is also in line with the report of Eriksson (1979) who reported an increase in the number of red clover fruits treated with B and attributed this effect to increase in the sugar content of the nectar, which subsequently increased the population of pollinating insects.

Plants treated to 2 kg B ha^{-1} gave the highest number of fruits in each of the trials, which accounted for increase of 35.7 and 58.7% in 1992/93 and 48.2 and 25.7% in 1993/94 relative to control at Samaru and Kadawa respectively.

The highest mean fruit number per plant (38.7) in the trials was recorded at Samaru in 1993/94 from plants treated to 2 kg B ha

Fig. 5. Number of fruits per plant as influenced by variety and rates of boron at Samaru and Kadawa under irrigation condition in 1992/93 and 1993/94.



The interaction between B treatments and variety was significant in 1992/93 at Samaru and Kadawa, and at Samaru in 1993/94. Variety Roma VF treated to 3 kg B ha^{-1} and Dandino treated to 2 kg B ha^{-1} gave the highest number of fruits per plant at Samaru and Kadawa in 1992/93. In 1993/94, variety Roma VF treated to 2 kg B ha^{-1} at Kadawa gave the highest number of fruits (Fig. 5). Dandino variety recorded the highest number of fruits at 3 kg B ha^{-1} in the same year.

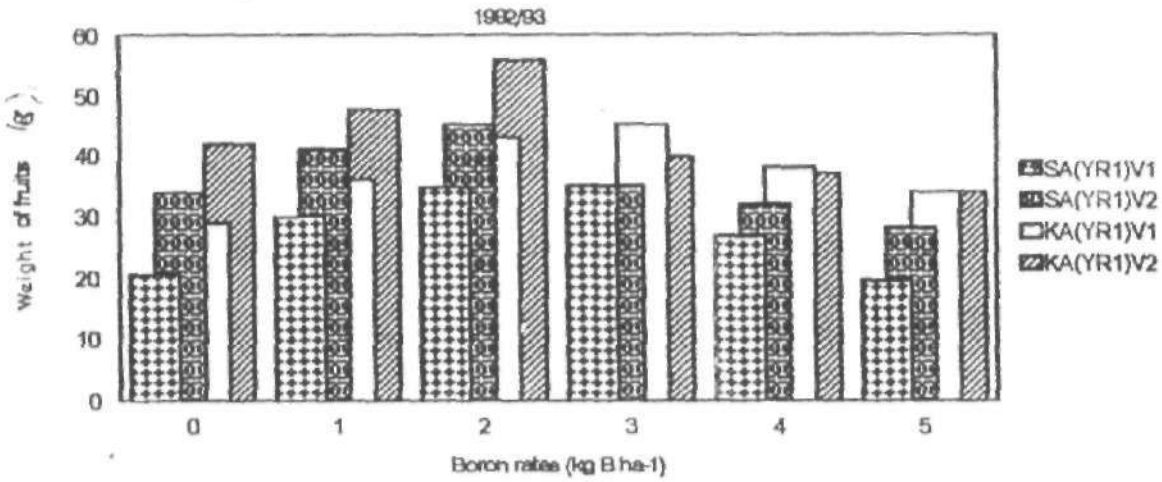
4.3.3.6 Effect of Boron Rates on Weight of Fruit

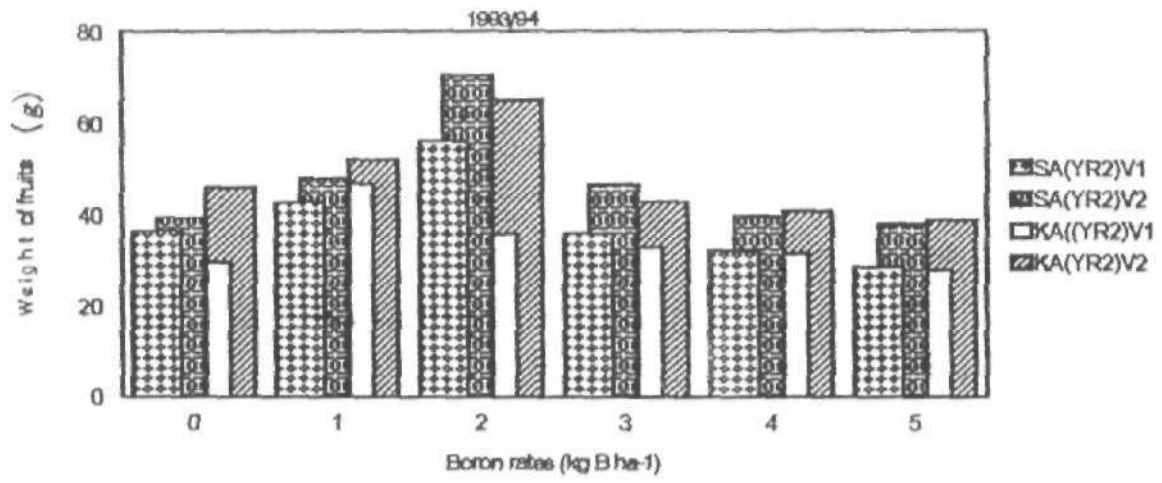
In 1992/93 and 1993/94, fruit weight of variety Dandino was significantly ($P = 0.05$) higher than that of Roma VF at Samaru and Kadawa (Fig. 6). The margin of difference was however greater in 1992/93 than in 1993/94. Dandino fruit weight was higher than Roma VF by 29 and 14% in 1992/93; 25 and 39% in 1993/94 at Samaru and Kadawa respectively.

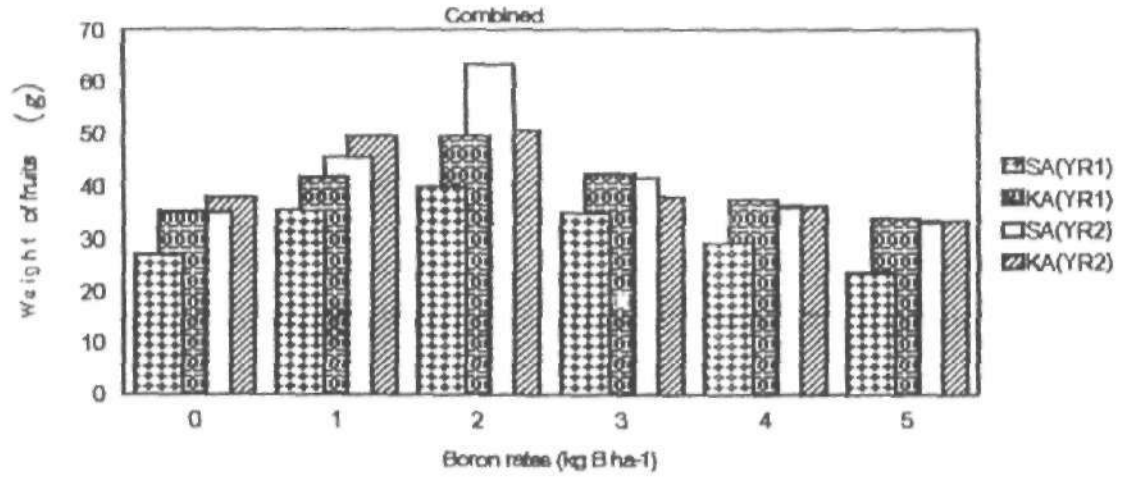
The result of this study signified that variety Dandino responded more to B fertilizer than Roma VF. Earlier studies had shown varietal response to B (Andrew and Thorne, 1962, Bradford 1966 and Tisdale et al 1985).

Boron rates significantly ($P = 0.05$) increased the weight of tomato weight at Samaru and Kadawa in 1992/93 and 1993/94. The maximum fruit weight in each trial was obtained at 2 kg B ha^{-1}, despite that the soil boron level of the experimental field were

Fig. 6 - Weight of fresh tomato fruits as influenced by variety and rates of boron at Bamaru and Kadawa under irrigation condition in 1992/93 and 1993/94.







different (Table 16) with Samaru 1992/93 site having the least (Fig. 6). Boron rate of 2 kg B ha^{-1} increased the fruit weight by 47 and 40% in 1992/93; 80 and 33% in 1993/94 at Samaru and Kadawa respectively, relative to control.

The percentage increase of the fruit weight at 2 kg B ha^{-1} over the control was more at Samaru in both years. This could be due to the low soil B level at the Samaru sites (Table 16), and the favourable weather condition at the Samaru sites during fruiting (Appendix D). Similar result was obtained by Adelana (1986) who got the highest fruit weight between 1.5 and 2.0 kg B ha^{-1} in trials conducted in different locations in South Western Nigeria.

The interaction between treatment and variety was only significant (P = 0.05) at Kadawa in 1992/93 and 1993/94 (Fig. 9). Nevertheless variety Dandino treated to 2 kg B ha^{-1} recorded the highest fruit weight of 70.33g in 1993/94 at Samaru.

4.3.3.7 Effect of Boron Rates on Marketable Fruit Yield

Varietal differences in marketable fruit yield was only significant (P = 0.05) at Samaru in 1992/93 (Table 21). Dandino out yielded Roma VF by 25 and 8.7% in 1992/93; 48.3 and 44% in 1993/94 at Samaru and Kadawa respectively.

The yield of fresh fruit increased significantly (P = 0.05) with the application of B at Samaru and Kadawa in 1992/93 and 1993/94 as shown in Table 21.

Despite the different soil B level of the experimental sites, plants treated to 2.0 kg B ha^{-1} gave the highest yield in each of

the trials. This accounted for increase of 99.9 and 121% in 1992/93; 148 and 72% in 1993/94 at Samaru and Kadawa relative to control. However, the highest tomato yield of 45.9 tons ha^{-1} was recorded at Samaru in 1993/94.

In an earlier study, Gulati et al (1980) applied different rates of B to tomatoes and recorded the highest yield of fresh tomato fruit at 1.5 kg B ha^{-1}, for irrigated tomatoes.

The yield at Kadawa in 1993/94 was slightly reduced as a result of nematode infection which manifested at fruiting stage.

High significant (P = 0.01) interactions between variety and rates of B were recorded at Samaru and Kadawa in 1992/93 and 1993/94 (Table 22). In 1992/93, Roma VF recorded its highest fruit at 3 kg B ha^{-1}, whereas Dandino recorded its highest fruit yield at 2 kg B ha^{-1} in both locations.

In 1993/94, variety Roma VF and Dandino recorded high fruit yield at 2 kg B ha^{-1} at Samaru and Kadawa relative to other treatments.

A combined analysis over two locations in 1992/93 showed that the interaction between boron rates and variety was significant (P = 0.01). The interaction between location and boron rates was significant (P = 0.05), while the interaction between location and variety was not (Appendix C).

In 1993/94, combine analysis over years showed that the interaction between variety and treatment; location and treatment, location and variety; treatment, location and variety were all highly significant (P = 0.01) (Appendix C).

Table 21: Effect of Variety and boron rates on marketable fruit yield (tons ha^{-1}) of fresh tomato fruits at Samaru and Kadawa in 1992/93 and 1993/94

Treatment	1992/93			1993/94		
	Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
Variety						
Roma VF	16.18	19.47	17.83	17.20	9.97	13.59
Dandino	20.28	21.17	20.73	25.50	14.35	19.93
LSD (0.05)	2.26	1.15		2.32	1.73	
Boron Rates (Kg B ha^{-1})						
0	14.11de	14.24de	14.18	18.51c	10.84b	14.68
1	21.80b	21.95bc	21.88	25.36b	17.14a	21.25
2	28.21a	31.44a	29.83	46.00a	18.63a	32.28
3	20.56bc	24.64b	22.60	19.77c	10.50b	15.14
4	14.97d	17.35d	16.16	11.78d	8.73bc	10.26
5	9.74e	12.28de	11.01	6.89e	7.04d	6.97
LSD (0.05)	3.92	3.01		4.02	3.01	

Means in a given column followed by similar letter(s) are not significantly different at P = 0.05, using DMRT

Table 22: Effect of Variety X boron rates interaction on yield of fresh tomato fruits at Samaru and Kadawa in 1992/93 and 1993/94

Treatment (kg Bha^{-1})	Variety	1992/93			1993/94		
		Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
0		10.99fg	11.32hij	11.16	15.36fg	8.50efghi	11.93
1		17.31d	17.49def	17.40	18.43ef	17.26b	17.82
2	Roma VF	22.17bc	26.41bc	24.29	40.52b	11.76def	26.14
3		24.87bc	30.99b	27.93	13.32fg	8.72efgh	11.02
4		13.88def	18.87d	16.38	9.39hij	7.64fghij	8.52
5		7.85ij	11.73hij	9.79	6.19jk	5.96ghijk	6.08
0		17.23d	17.17defg	17.20	21.66de	13.18bcd	17.42
1		26.29bb	26.41bcc	26.35	32.29c	17.02bc	24.66
2		34.25a	36.46a	35.36	51.34a	25.53a	38.44
3	Dadino	16.24def	18.28de	17.26	26.22d	12.28def	19.20
4		16.06defg	15.84defgh	15.95	14.17fgh	9.83defg	12.00
5		11.62efghi	12.84hi	12.23	7.601jk	8.12efgij	7.86
LSD (0.05)		5.54	4.25		5.69	4.25	

Means in a given column followed by similar letters are not significantly different at P = 0.05, using DMRT.

The response of tomato plants to boron rates at Samaru and Kadawa might be due to low levels of soil B in the soils of the experimental sites.

4.3.3.8 Effect of Boron Rates on Dry Matter Yield (DMY) of Tomato Plants

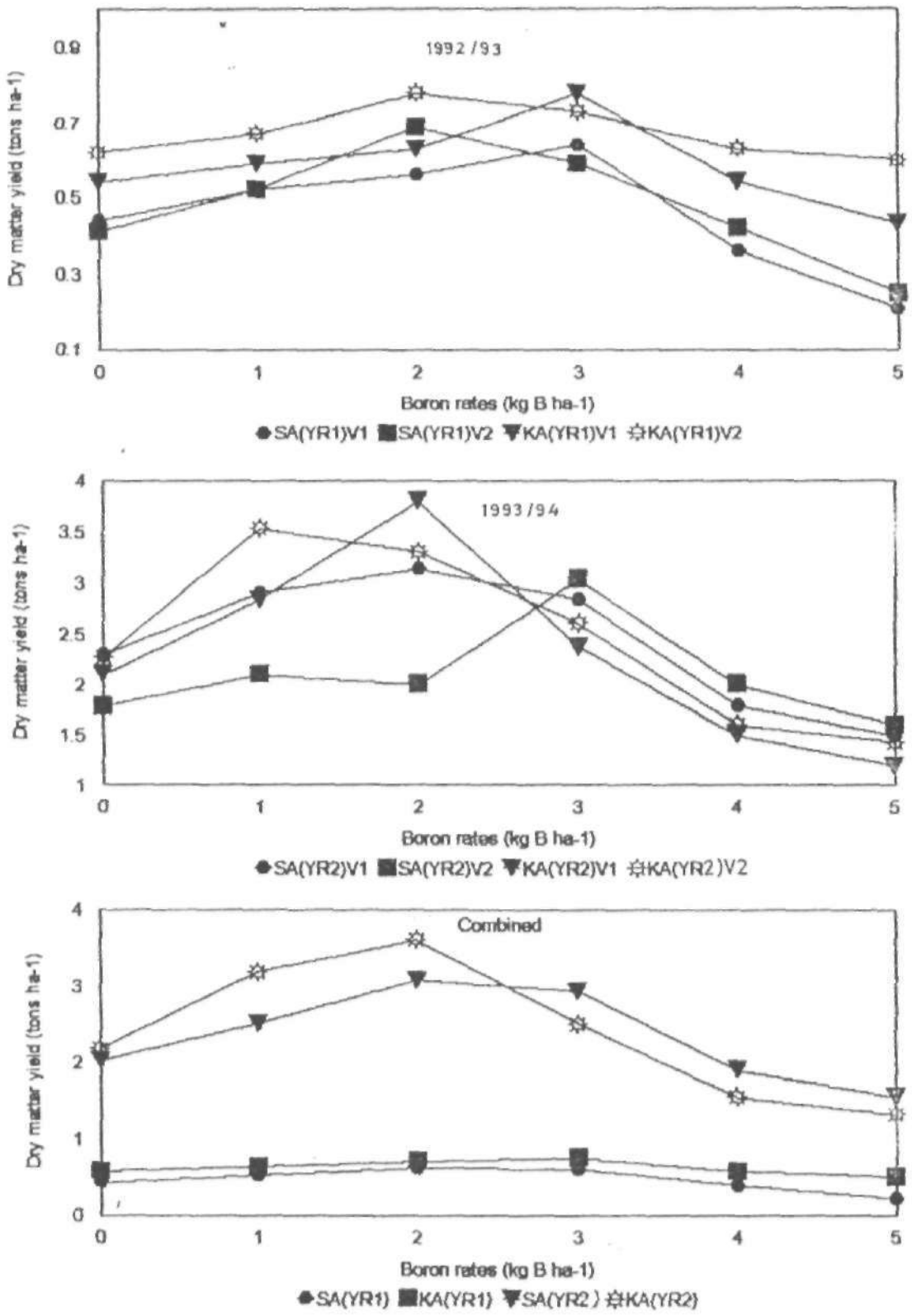
Variety Dandino recorded higher DMY than Roma VF, with the trend strongly in favour of 1993/94 trials (Fig. 7). However, the difference was only significant at Kadawa in 1992/93. The observed differences were 5.5 and 14% in 1992/93; 6.6 and 7.0% in 1993/94 at Samaru and Kadawa respectively.

There was a highly significant effect of B application on dry matter yield of tomato plants. Plants treated to 2 kg B ha^{-1} gave the highest DMY at Samaru in 1992/93 trials, whereas the highest yield was obtained with plants treated to 3 kg B ha^{-1} at Kadawa. The highest DMY for the 1993/94 trial at Samaru and Kadawa were recorded with plants treated to 2 kg B ha^{-1} (Fig. 7).

Results indicated that 1993/94 trials proved superior to 1992/93. The increase in dry matter yield of plants treated to 2 kg B ha^{-1} over the control were 46.5 and 21.5% for 1992/93 trials, 50.8 and 62.8% for 1993/94 trials at Samaru and Kadawa respectively.

Earlier studies have shown that DMY is affected by number of leaves. Khan and Sagar (1967) reported that more than half of the plants dry matter was retained in the leaves. Similarly, Thomas et al (1973) found that more than 90% of the dry matter in plants are

Fig. 7. Dry matter yield as influenced by variety and rates of boron at Samaru and Kadawa under *irrigation conditions in 1992/93 and 1993/94.*



products of photosynthesis.

There appears to be no significant interactive effect of variety X boron rates on DMY. However, what is evident from the data is that, at the highest level of B, DMY reduced significantly.

It was also observed that DMY varied with locations, the highest occuring at Kadawa. This difference may be due to differences in the inherent fertility and productivity of the soils of the two experimental locations.

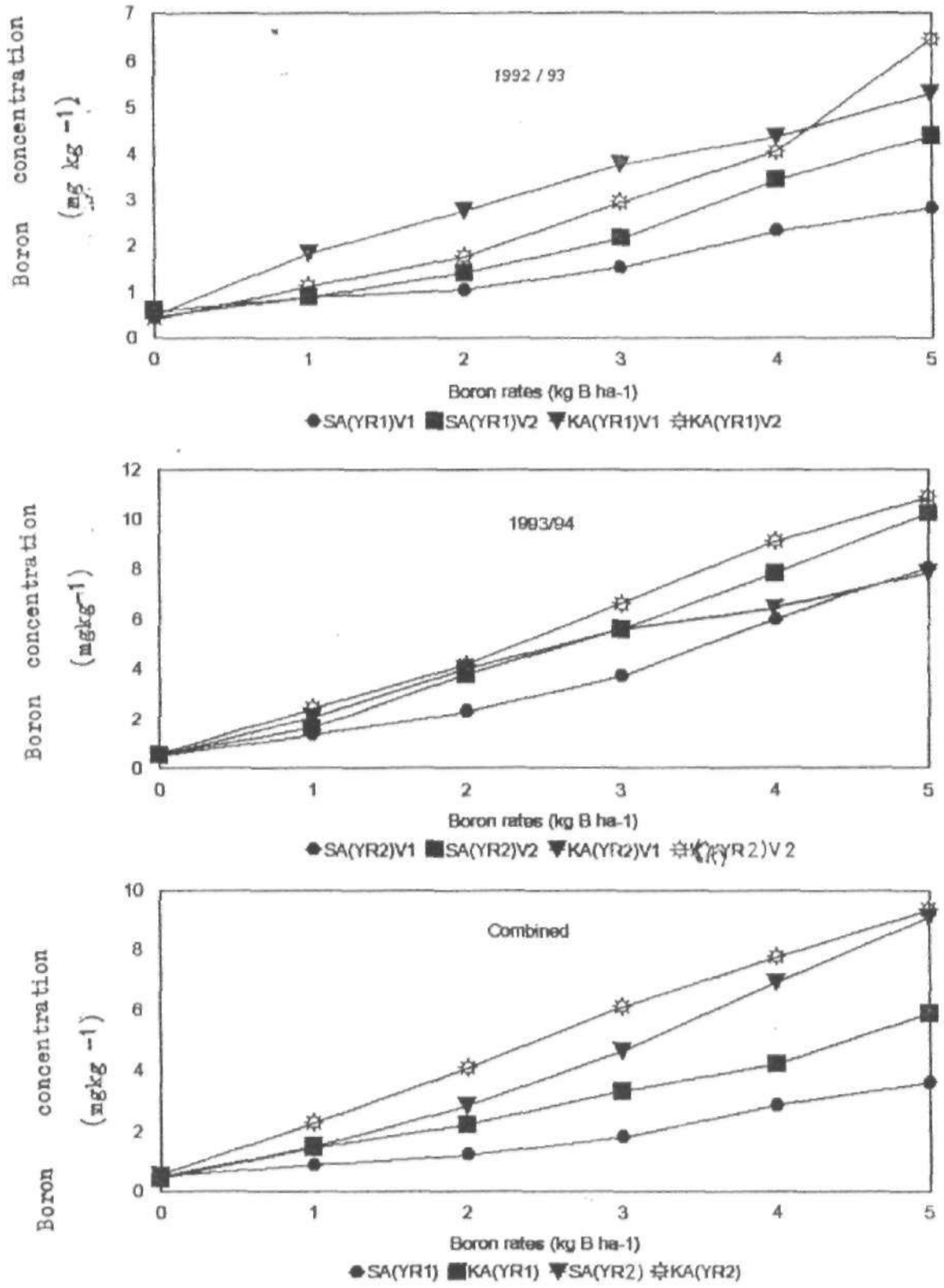
4.3.3.9 The Effect of Boron Rates on Boron Concentration in Tomato Plants

Varietal differences in B concentration were significant (P = 0.05) in 1992/93 at Samaru, and at Samaru and Kadawa in 1993/1994 (Fig. 8). Dandino recorded higher B concentration than Roma VF. The differences were to the tune of 41.9% at Samaru in 1992/93; 25.3 and 28.2% in 1993/94 at Samaru and Kadawa respectively.

The varietal differences obtained in this study confirm the report of other workers that crop species and varieties have specific B requirements (Andrew and Thorne 1962; Brown et al 1972 and Gupta 1993).

Boron concentration significantly increased as the boron rates increased (Fig. 8). The 5 kg B ha^{-1} treatment resulted in significantly greater concentration than the other treatments. B concentration was higher in 1993/94 at both locations than in 1992/93. This could be due to higher soil B level, number of leaves and DMY values in 1993/94.

fig 8. Boron concentration in plant tissue as influenced by variety and rates of boron at Samaru and Kadawa under irrigation conditions in 1992/93 and 1993/94.



However, the B concentration in the plant tissue obtained in this study (0.45-9.40 $mgkg^{-1}$) were lower than the value for normal plants as reported in literature. Neubert et al (1970) recommended a range of 30 to 75 $mgkg^{-1}$ B, whereas Drews and Frank (1980a) recommended a range of 30-35 $mgkg^{-1}$ B in plant tissues of tomato plant as sufficient.

The low values of plant tissue B could be due to low adsorption capacity of the soils which could make the soil B susceptible to leaching losses.

The interactive effect of variety X boron rates on the B concentration was significant (P = 0.01) at Samaru and Kadawa in 1992/93 and 1993/94 (Fig. 8). Dandino variety treated to 5 kg B ha^{-1} recorded the highest B concentration. In contrast, control plots gave the least B concentration in the trials.

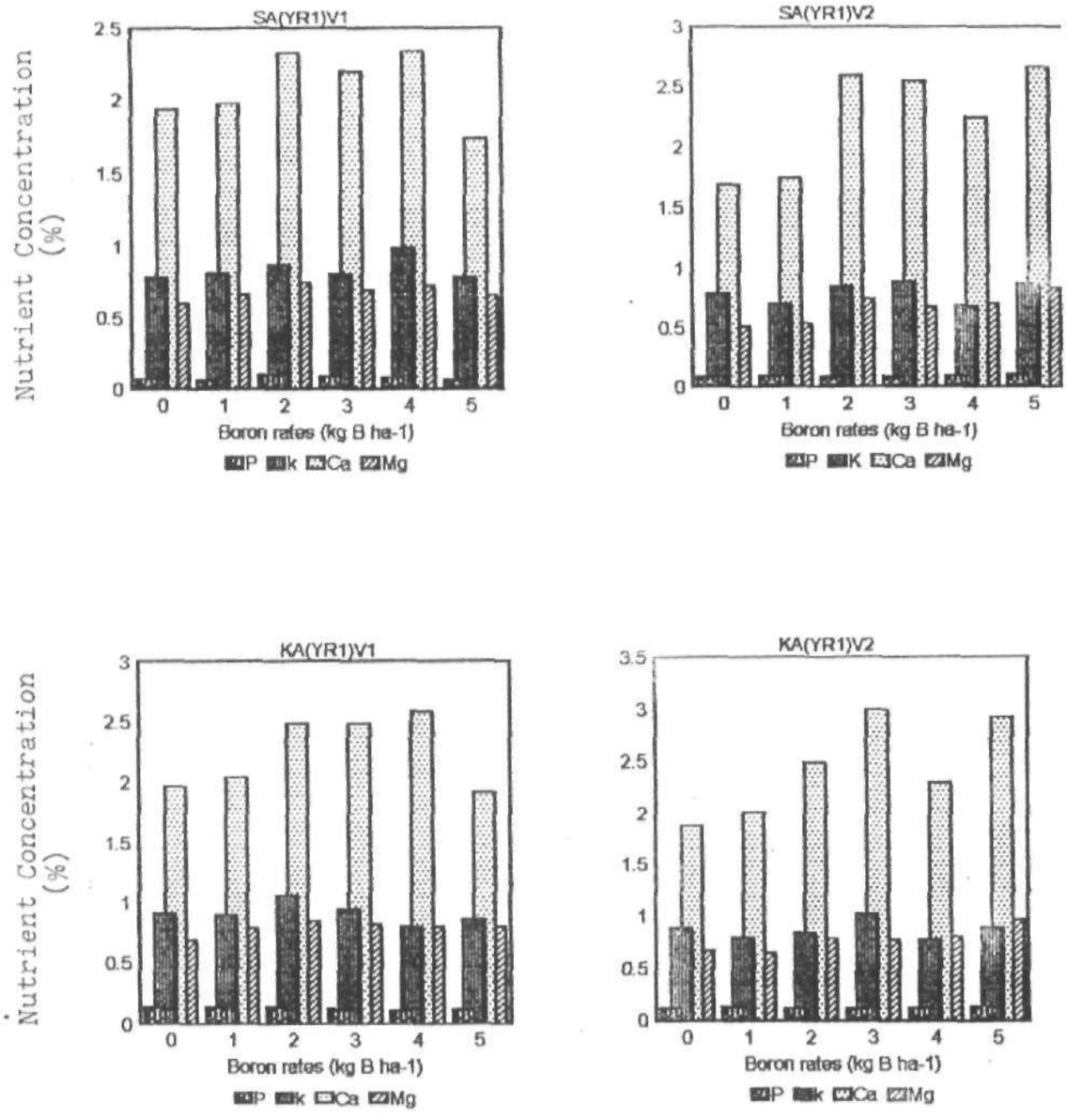
4.3.3.10 Effect of Boron Rates on the Macronutrient (K, P, Ca & Mg) Concentration

Potassium (K)

The effect of B treatments over varieties on K concentration was only significant (P = 0.01) at Kadawa in 1993/94 (Fig. 9 & 10). However, K concentration was higher in Dandino than Roma VF.

Boron application had significant (P = 0.05) effect on potassium concentration at Samaru and Kadawa in 1992/93 and at Samaru in 1993/94 (Fig. 11). The K concentration values which varied from 0.68 to 1.00% in 1992/93 and 2.28 to 2.79% in 1992/93 fall within the low to medium critical level for K in tomato plant tissue.

Fig. 9. Plant Macronutrient Concentration as Influenced by Variety and Boron Rates at Samaru and Kadawa in 1992/93



KEY:

SA = Samaru YR1 = Year 1 KA = Kadawa V1 = Variety 1 V2 = Variety 2

Fig. 10. Plant macronutrient concentration as influenced by variety and boron rates at Samaru and Kadawa in 1993/94.

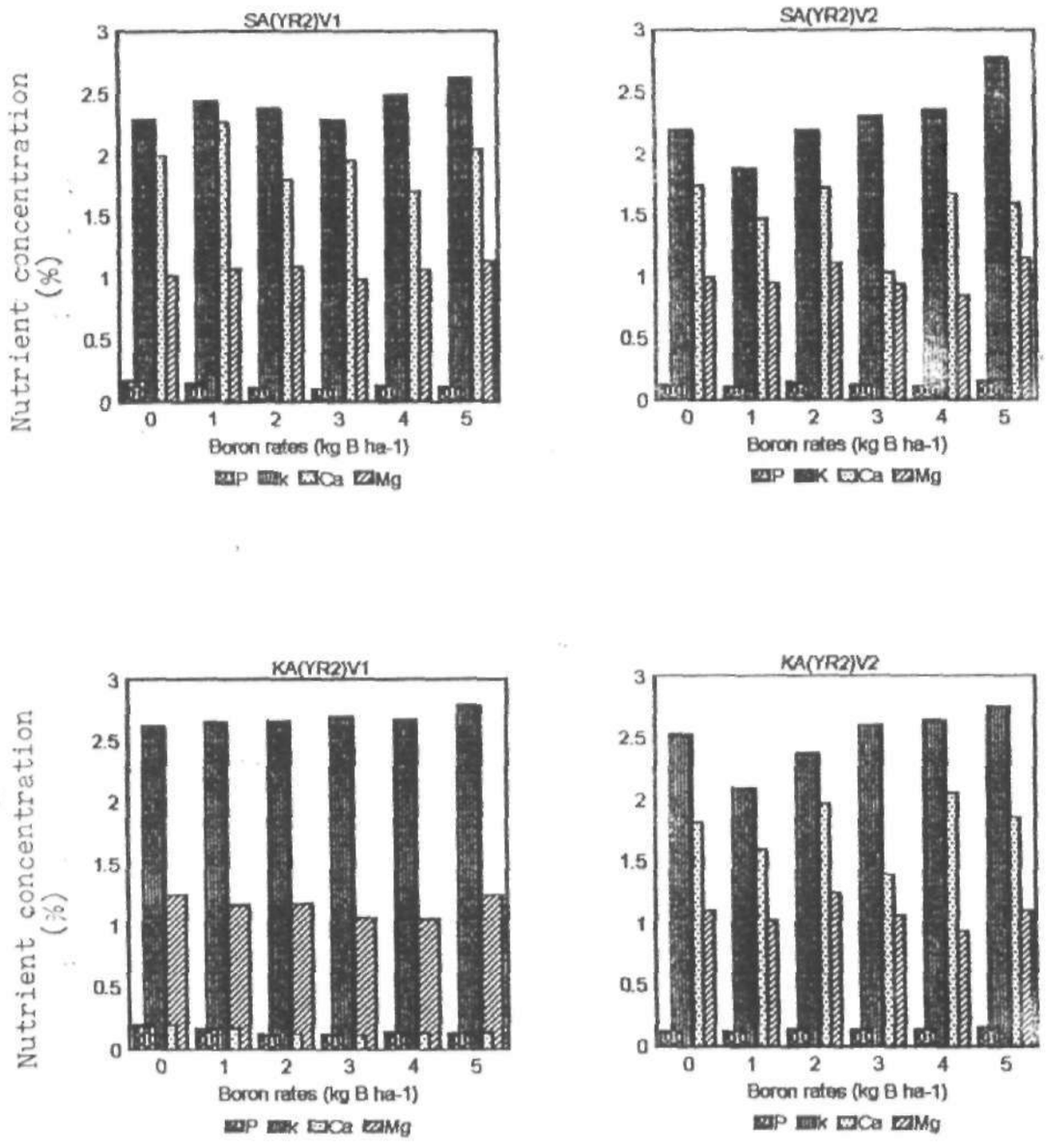
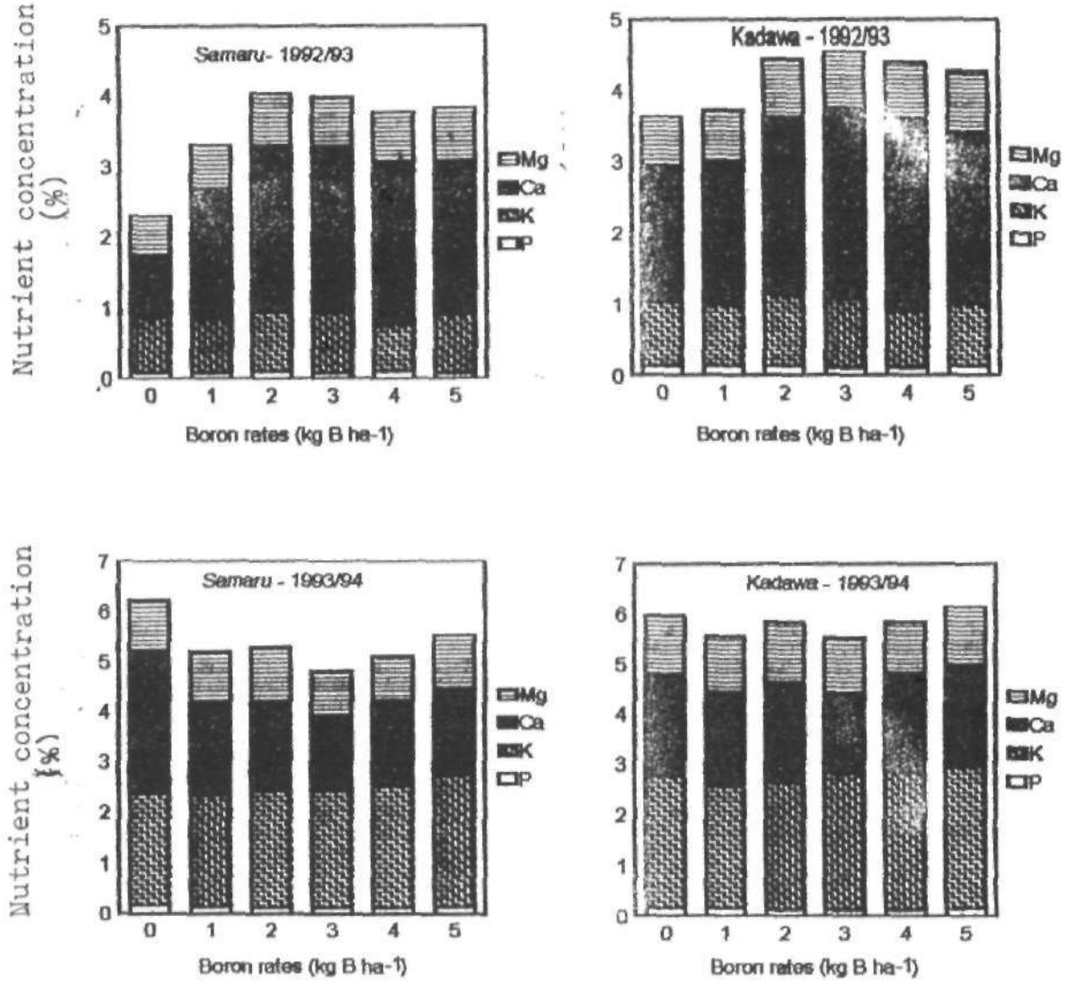


Fig. 11. Effect of boron rates on macronutrient concentration at Samaru and Kadawa in 1992/93 and 1993/94.



Zobel (1966) had reported that tomato plant absorbs and utilizes a large amount of K and that more K is absorbed than any other nutrients. Also Gould (1974), Adams et al (1978) reported that good quality tomato fruit is dependent upon adequate and proper potash fertilization.

It is worthwhile to note that K concentration was higher in 1993/94 than in 1992/93 (Fig. 11). This could also be the reason why the yield parameters were higher in 1993/94.

Variety X B treatment interaction for K concentration was not significant in both years (Figs. 9 and 10).

Phosphorus (P)

Dandino variety had significantly ($P = 0.05$) higher phosphorus concentration than Roma VF at Samaru in 1992/93 (Fig. 9). In 1993/94, P concentration for Roma VF was more than Dandino in both locations (Fig. 10) although the difference was not significant ($P = 0.05$). This discrepency could be due to the soil P level of the soils in the sites.

The effect of B rates on P concentration was only significant ($P = 0.05$) at Samaru in 1993/94 (Fig. 11). Phosphorus concentration was higher in 1993/94 (0.11-0.16 $mgKg^{-1}$) than in 1992/93 (0.08-0.13 $mgKg^{-1}$). The P range for both years is below the critical range of 0.4-0.6 $mgKg^{-1}$ reported by Roorda and Smilde (1981) for tomato plants.

The higher P concentration in 1993/94 was associated with high dry matter content at harvest. The interaction between B rates and

variety for P concentration was significant (P = 0.05) at Samaru in 1992/93 and 1993/94 (Figs. 9 and 10).

Calcium (Ca)

Calcium concentration in Dandino was greater than that of Roma VF in 1992/93, but lower than Roma VF in 1993/94. The difference in Ca concentration was significant at Kadawa in 1992/93 (Fig. 9), and at Samaru in 1993/94 (Fig. 10).

Boron rates significantly enhanced Ca concentration up to 3 kg B ha^{-1} at Samaru in 1992/93 (Fig. 11). Ca concentration in plant tissue in 1992/93 (1.80 - 2.7%) was higher than in 1993/94 (1.5-2.0%) at both locations. This could be due to the high exchangeable Ca in the soils of the experimental site (before planting) in 1992/93 (Table 16) than 1993/94.

The interaction between B rates and variety for concentration was only significant at Kadawa in 1992/93.

Magnesium (Mg)

Magnesium concentration in Roma VF was higher than that in Dandino, although no significant difference was observed (Fig. 9 & 10).

The effect of B rates on Mg concentration in the plant tissue was only significant (P = 0.05) at Samaru and Kadawa at the first year of the trial. However, Mg concentration was higher in 1993/94 (0.95-1.14) than 1992/93 (0.5-0.87%). The Mg concentration values for both years are within the range of 0.36 to 0.85% obtained by

Roorda and Smilde (1981) for healthy tomato plants.

The interaction between B rates and variety on concentration was only significant in 1992/93 at Samaru and Kadawa (Figs. 9 & 10).

4.3.3.11 Effect of Boron Rates on The Micronutrients (Zn, Mn, Fe and Cu) Concentration

Zinc (Zn)

The effect of boron rates over variety on Zn concentration was significant ($P = 0.01$) at Samaru and Kadawa in 1993/94 but not in 1992/93 (Fig. 12). However, variety Roma VF produced higher Zn concentration than Dandino.

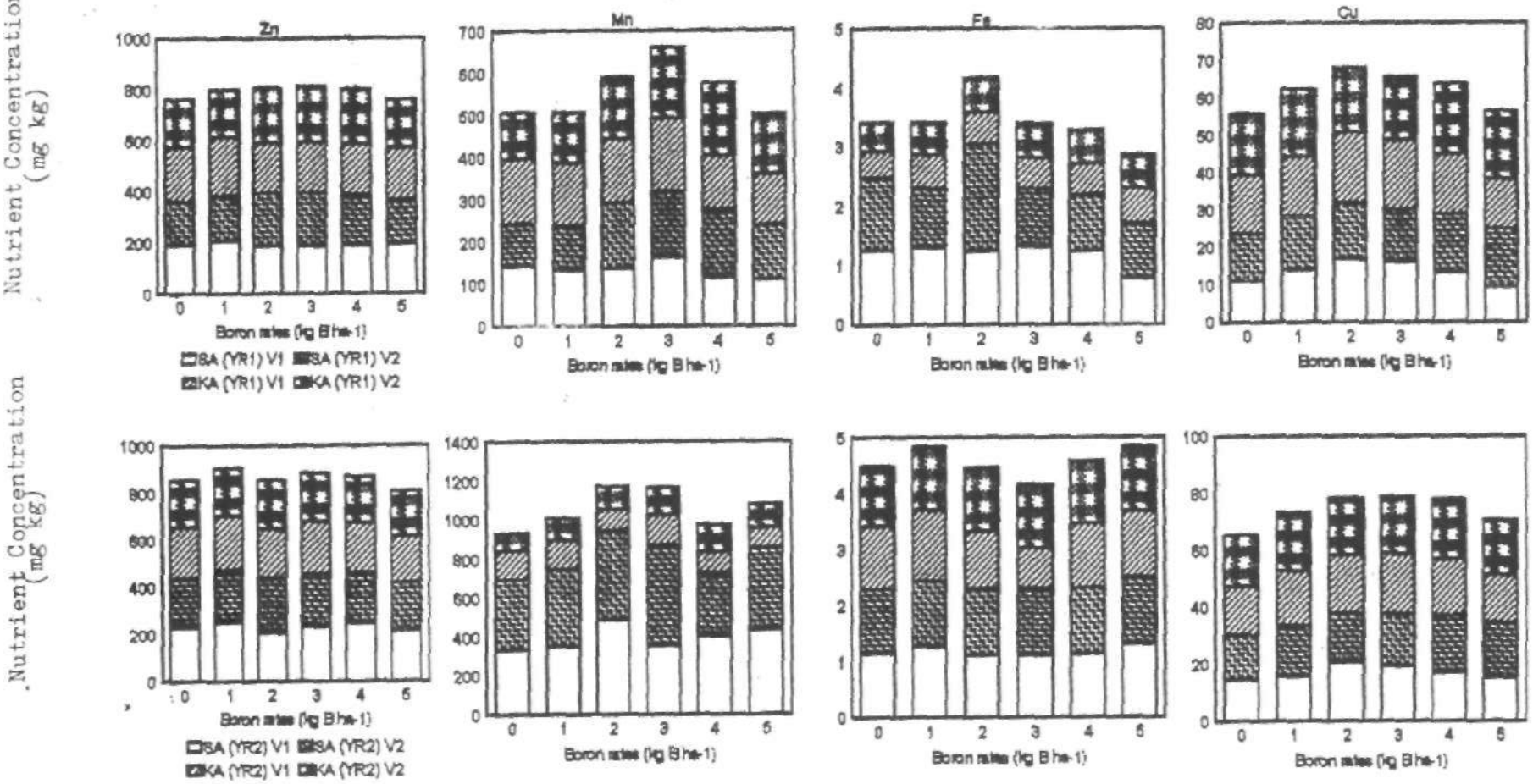
Boron rates had significant effect on Zn concentration at Samaru and Kadawa in 1993/94 (Fig. 13). The values of Zn concentration which varied from 183 to 240 $mgkg^{-1}$ is within the recommended range of 20-350 $mgkg^{-1}$ (Jones, 1972).

The highest Zn concentration of 240 $mgkg^{-1}$ was obtained at 1.0 kg B ha^{-1} at Samaru in 1993/94. This could be due to the high DMY recorded at 1.0 kg B ha^{-1} in 1993/94 (Fig. 7).

The interaction between B rates and variety on Zn concentration was significant ($P = 0.01$) in each of the trial except at Kadawa in 1993/94 (Fig. 12).

The result signifies the importance of Zn in the nutrition of tomato (Winsor and Adams 1986).

Fig. 12. Micronutrient Concentration as Influenced by Variety and Boron Rates at Samaru and Kadawa in 1992/93 and 1993/94



KEY:

SA = Samaru KA = Kadawa YR1 = Year 1 YR2 = Year 2 V1 = Variety 1 V2 = Variety 2

Manganese (Mn)

The effect of variety over B treatment on Mn concentration was not significant in all the trials (Fig. 12).

Boron rates did not influence the Mn concentration in plant tissue significantly in both locations and years (Fig. 13). The Mn concentration varied from 110 to 470 $mgkg^{-1}$. These values are within the sufficiency range of 20 to 500 $mgkg^{-1}$ recommended by Jones (1972) but was higher than a range of 55-220 $mgkg^{-1}$ reported by Roorda and Smilde (1981). Although, there are limited data to show when toxicity occurs, levels in excess of 500 $mgkg^{-1}$ are probably toxic for many plants.

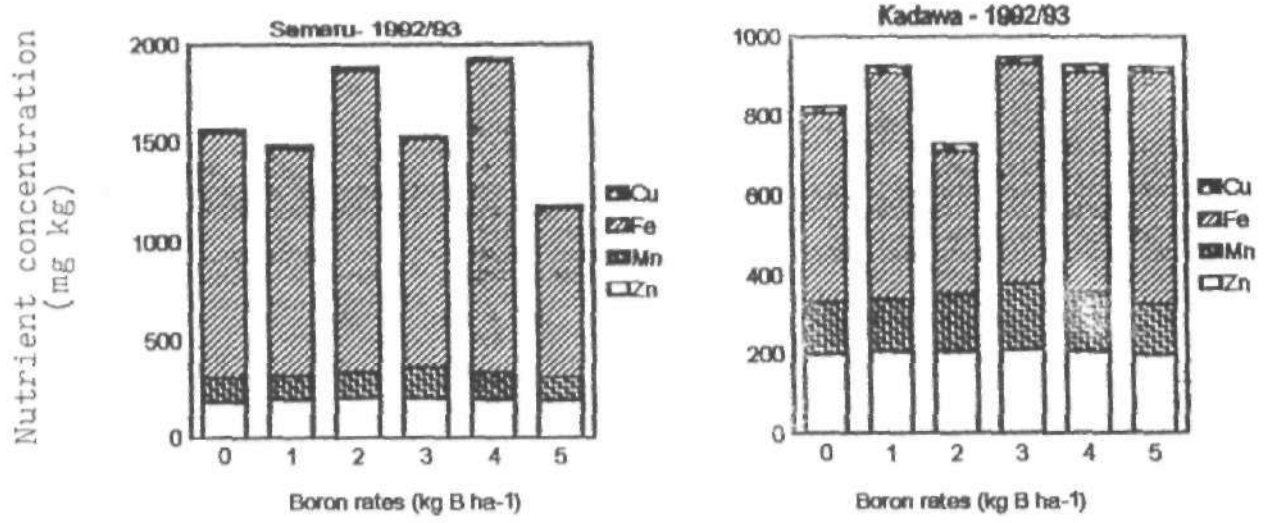
The interaction between variety and treatment on Mn concentration was not significant in all the trials (Fig. 12).

Iron (Fe)

The effect of varieties over treatment on the concentration of Fe was not significant (P = 0.05). However, Dandino appears to be superior in Fe concentration than Roma VF (Fig. 12).

Application of B had significant influence on the Fe concentration at Samaru and Kadawa in 1992/93 but not in 1993/94 (Fig. 13). The Fe concentration varied from 354 to 1535 $mgkg^{-1}$. This is above the sufficiency range of 50-250 $mgkg^{-1}$ reported by Neubert et al (1970) and Roorda and Smilde (1981). The high values could be as a result of contamination from the soil and tyupe of fertilizer used.

Fig. 13. Effect of boron rates on micronutrient concentration in plant tissue at Samaru and Kadawa in 1992/93 and 1993/94.



Gould (1974) reported that Fe is the most important mineral present in tomatoes in terms of providing adequate nutrition because the Fe is in the reduced ferrous state.

Copper (Cu)

The effect of variety over B rates on the concentration of Cu was not significant (P = 0.05) in any of the trials (Fig.12). However, variety Dandino proved superior to Roma VF in terms of Cu concentration.

Copper concentration in the plant tissue was significantly influenced by B rates at Samaru in 1992/93 and 1993/94 but not at Kadawa (Fig. 13). The Cu concentration of 12 to 21 $mgkg^{-1}$ was within the sufficiency range of 5-20 $mgkg^{-1}$ recommended by Jones (1972).

The effect of variety X boron treatment interaction on the Cu concentration was only significant at Samaru in both years but not at Kadawa (Fig. 12).

4.3.3.12 The Effect of Boron Rates on Boron Uptake in Tomato Plant

The effect of boron (B) rates on uptake of boron of the two varieties was significant in 1993/94 at Samaru and Kadawa (Table 23), nevertheless, variety Dandino had greater mean B uptake than Roma VF.

Application of boron significantly increased B uptake over the control at Samaru and Kadawa in 1992/93 and 1993/94. In 1992/93, plants treated to 3 kg B ha^{-1} recorded highest uptake of 1.11 and

2.67 gha^{-1} at Samaru and Kadawa respectively. Similarly, in 1993/94, the highest B uptake of 14.28 and 15.43 gha^{-1} were recorded at Samaru and Kadawa respectively, as shown in Table 23.

The interaction between boron rates and variety on boron uptake of tomato plants was significant in each of the trials as shown in Table 24. However, in 1992/93, Dandino variety treated to 4 kg B ha^{-1} produced the highest B uptake of 1.38 gha^{-1} at Samaru while Dandino plants treated to 5 kg B ha^{-1} produced the highest B uptake of 3.82 gha^{-1} at Kadawa.

The results of 1993/94 revealed that Dandino variety treated to 3 kg B ha^{-1} recorded highest B uptake of 16.95 and 17.48 gha^{-1} at Samaru and Kadawa respectively.

Boron uptake obtained in 1993/94 were higher than that of 1992/93. This could be due to higher DMY recorded in 1993/94 (section 4.3.3.8) trials.

Boron uptake obtained in this study (0.196-16.95 gha^{-1}) were low compared with the results of Pinero et al (1977), Gulati et al (1980) and Garate et al (1984a). However, Gulati et al (1980) had reported that plant uptake of B can be regulated by controlling the application of irrigation as well as the amount of nutrient to the soil. Similarly, Adams and Winsor (1970) has reported that uptake of nutrients in tomatoes varies with many factors such as light intensity, temperature, humidity, aeration and with the health of the plant.

Table 23: Effect of Variety and boron rates on boron uptake (gha^{-1}) in tomato plants at Samaru and Kadawa under irrigation condition in 1992/93 and 1993/94

Treatment	1992/93			1993/94		
	Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
Variety						
Roma vf	0.60	1.80	1.20	7.55b	9.05b	8.30
Dandino	0.89	1.78	1.40	10.81a	11.90a	11.36
LSD (0.05)	NS	NS		3.12	2.25	
Boron Rates (Kg B ha^{-1})						
0	0.22d	0.25e	0.23	1.02e	1.18d	1.10
1	0.45cd	0.88d	0.67	3.72d	7.33c	5.53
2	0.75bc	1.50c	1.13	9.25c	14.44a	11.85
3	1.11a	2.67a	1.89	13.58ab	15.43a	14.51
4	1.10a	2.40ab	1.80	13.23b	11.92b	12.58
5	0.84b	2.06b	1.45	14.28a	12.56b	13.42
LSD (0.05)	0.36	0.42		0.88	0.96	

Means in a given column followed by similar letter(s) are not significantly different at P = 0.05, using DMRT

Table 24: Effect of Variety X boron rates interaction on boron uptake in tomato plants at Samaru and Kadawa under irrigation conditions in 1992/93 and 1993/94

Treatment (kg Bha^{-1})	Variety	1992/93			1993/94		
		Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
0		0.196ghijk	0.263ij	0.230	1.13h	1.04i	1.09
1		0.471fghi	1.020fgh	0.746	4.03g	5.85g	4.94
2	Roma VF	0.569defg	1.74cdef	1.16	7.15f	15.09bc	11.12
3		0.968abcd	3.18a	2.074	10.21e	13.39cde	11.80
4		0.814bcdef	2.31bc	1.562	10.84cde	9.59f	10.22
5		0.564defg	2.29bcd	1.430	11.94c	9.36fg	10.65
0		0.238ghijk	0.232ij	0.234	0.91h	1.33i	1.12
1		0.434fghij	0.734igh	0.584	3.42	8.81fg	6.12
2		0.935abde	1.260fg	1.098	11.34cd	13.78bcde	12.56
3	Dandino	1.126ab	2.140bcde	1.633	16.95a	17.48a	17.22
4		1.38a	2.48b	1.93	15.63ab	14.25bcd	14.94
5		1.11abc	3.82a	2.47	16.61ab	15.76ab	16.19
LSD (0.05)		0.45	0.62		1.42	2.20	

Means in a given column followed by similar letters are not significantly different at P = 0.05, using DMRT.

4.3.3.13 Simple Correlation Matrix (r) Among Yield Parameters and Nutrient Concentration in 1992/93 Trials

Results indicated that number of leaves was related negatively to number of days to 50% flowering (r = -0.509**) but positively with number of flowers (r = 0.358**), number of fruits (r = 0.400**), fruit weight (r = 0.499**), fruit yield (r 0.478**) and DMY (r = 0.326**) at Samaru (Table 25). At Kadawa, number of leaves was only related to Fe concentration (r = 0.393**). The correlation between these parameters and number of leaves signifies the important contribution of number of leaves to the parameters.

Number of days to 50% flowering was related negatively with number of flowers per plant (r = -0.497**), number of fruits per plant (r = -0.500**), fruit yield (r = -0.579**) and positively with B concentration (r = 0.330*). For Kadawa trials, number of days to 50% flowering correlated negatively with number of flowers per plant (r = -0.347*), number of fruits per plant (r = -0.623**), fruit yield (r = -0.465**), DMY (r = 0.439**) and K concentration (r = -0.306*) as shown in Table 25. The number of flowers per plant was strongly related to number of fruits (r = 0.564**), fruit weight (r = 0.556**), fruit yield (r = 0.688**), DMY (r = 0.556**), Zn and Cu concentration (r = 0.560** and 0.394** respectively) at Samaru. Number of flowers per plant was strongly related to number of fruit (r = 0.738**), fruit weight (r = 0.708**) and fruit yield (r = 0.772**) as shown in Table 25. The relationship between number of flowers and other yield parameters agreed with the report of Winsor and Adams (1974) and Gupta (1979).

At Samaru, number of fruits correlated with fruit weight (r =

0.556**), fruit yield (r = 0.841**), DMY (r = .503**), Fe, concentration (r = 0.401**), Cu and B concentrations (r = 0.314* and 0.400** respectively). Also at Kadawa, strong relationship existed between number of fruits and fruit size (r = 0.709**) and fruit yield (r = 0.921**).

The fruit weight was related to fruit yield (r = 0.879**), DMY r = 0.451**), Fe and Cu concentrations (r = 0.356** and 0.430** respectively), at Samaru. However, fruit weight was only related, though strongly with fruit yield (r = 0.916**) at Kadawa (Table 25).

The fruit yield, correlated with DMY (r = 0.568**), Fe concentration (r = 0.412**), Cu concentration (r = 0.440**) and negatively with B concentration (r = -0.319**) at Samaru; while there was no correlation between fruit yield and other parameters at Kadawa as shown in Table 25.

As the DMY increased, the B concentration decreased (r = -0.463**) at Samaru. For Kadawa trials, Zn and P concentrations decreased as the DMY increased (r = -0.352* and -0.411** respectively).

Significant relationship existed between B and Ca concentration (r = 0.369**), Mg concentration (r = 0.546**) at Samaru, Na, Ca, Mg and Fe concentraions (r = 0.356**, 0.480**, 0.666** and 0.434** respectively) at Kadawa (Table 25).

Potassium concentration was significantly correlated with Mg concentration (r = 0.339*); while Na concentration significantly correlated with Ca, Mg and Cu concentrations (r = 0.377**, 0.454**

Table 25: Simple correlation matrix (r) among yield parameters and nutrient concentraion in 1992/93 dry season at Samaru

	No of leaves	No of days to 50% Flowering	No of flowers per plant	No of fruits per plant	Fruit weight	Fruit yield	Dry matter yield	<---------- Nutrient concentration ----------									
								B	S	Na	Ca	Mg	Zn	Mn	Fe	Cu	P
Number of leaves	-																
Number of days to 50% flowering	-0.509**	-															
Number of flowers per plant	0.358**	-0.497**	-														
Number of fruits per plant	0.400**	-0.500**	0.564**	-													
Fruit weight	0.499**	-0.273*	0.556**	0.556**	-												
Fruit yield	0.479**	-0.455**	0.589**	0.641**	0.879**	-											
Dry matter yield	0.326*	-0.579**	0.550**	0.503**	0.451**	0.566**	-										
B Concentration	-0.171	0.330*	-0.293*	-0.430**	-0.151	-0.319*	-0.463**	-									
S "	-0.027	-0.077	0.153	-0.078	0.162	0.106	0.172	-0.031	-								
Na "	-0.174	-0.131	-0.060	0.150	-0.157	0.071	0.086	0.201	0.075	-							
Ca "	0.232	0.029	0.093	-0.016	0.165	0.080	0.009	0.389**	0.294*	0.377**	-						
Mg "	-0.085	-0.104	0.037	-0.104	-0.033	-0.031	-0.091	0.548**	0.339*	0.456**	0.893**	-					
Zn "	-0.008	-0.294*	0.560**	0.141	0.122	0.140	-0.195	-0.051	-0.192	0.131	0.116	0.279*	-				
Mn "	0.143	-0.039	0.178	0.070	0.030	0.024	0.194	0.126	0.225	0.187	0.548**	0.397**	0.337*	-			
Fe "	0.063	-0.092	0.217	0.401**	0.356**	0.412**	0.254	0.059	-0.187	0.104	0.259	0.114	0.200	0.425**	-		
Cu "	0.146	-0.191	0.394**	0.314*	0.430**	0.440**	0.323*	0.062	0.161	0.364**	0.417**	0.360**	0.129	0.436**	0.413*	-	
P "	0.039	0.231	0.161	-0.306	0.221	0.256	0.090	0.201	0.227	0.050	0.423**	0.303*	-0.097	0.305*	0.193	0.455**	-

Table 23 cont'd: Simple correlation coefficients among yield parameters and nutrient concentration in 1992/93 dry season at Ibadan

	No of leaves	No of days to 50% flowering	No of flowers per plant	No of fruits per plant	Fruit weight	Fruit yield	Dry matter yield	Nutrient Concentration: B	K	Na	Ca	Mg	Zn	Mn	Fe	Cu	P
Number of leaves	-																
Number of days to 50% flowering	0.028	-															
Number of flowers per plant	0.105	-0.247**	-														
Number of fruits per plant	0.147	-0.609**	0.736**	-													
Fruit weight	0.072	-0.247	0.709**	0.709**	-												
Fruit yield	0.165	-0.495**	0.772**	0.921**	0.915**	-											
Dry matter yield	0.140	-0.439**	-0.097	0.144	0.047	0.126	-										
B Concentration	0.196	0.222	-0.110	0.132	0.235	-0.123	-0.154	-									
K "	-0.223	-0.326*	0.150	0.289*	0.175	0.261	0.159	-0.137	-								
Na "	-0.124	-0.152	-0.017	0.206	-0.133	0.062	-0.273*	0.355**	0.235	-							
Ca "	0.057	-0.121	0.158	0.214	0.093	0.110	0.144	0.462**	0.159	0.144	-						
Mg "	0.178	0.135	-0.038	0.039	-0.014	0.015	-0.106	0.666**	-0.158	0.330*	0.545**	-					
Zn "	0.086	-0.175	0.232	0.250	0.062	0.110	-0.352*	-0.106	0.068	0.141	0.001	0.019	-				
Mn "	-0.154	-0.124	0.052	0.144	-0.123	0.060	-0.013	0.102	0.155	0.0752	0.321*	0.134	0.332*	-			
Fe "	0.395**	0.236	0.242	0.222	0.178	0.097	-0.103	0.454**	0.023	-0.093	0.261	0.243	0.372**	0.246	-		
Cu "	0.159	-0.171	0.151	0.230*	0.206	0.275*	-0.065	0.242	0.113	0.2835	0.128	0.193	0.311*	0.121	0.183	-	
P "	0.058	0.151	0.157	0.193	0.187	0.122	-0.412	-0.019	-0.168	0.155	-0.150	0.156	0.343*	0.336	-0.169	0.372**	-

and 0.364** respectively) at Samaru and Mg concentration (r = 330*) at Kadawa.

Calcium concentration was significantly correlated with Mg, Mn, Cu and P concentrations (r = 0.690**, 0.548** 0.417**, and 0.423** respectively) at Samaru; while Ca concentraion correlated with only Mg concentration (r = 0.331*) at Kadawa.

The relationship between Mg, Mn and Cu concentrations were significant (r = 0.397** 0.360, respectively) at Samaru.

Zinc (Zn) concentration was only related significantly to Mn concentration (r = 0.337*) at Samaru, and to Fe, Cu and P (r = 0.372**, 0.311* and 0.340* respectively) at Kadawa as shown in Table 25.

There were significant relationship between Mn concentration and Fe (r = 0.428*) Cu (r = 0.416**) and P (r 0.305*) concentrations at Samaru. Also Fe correlated with Cu concentrations (r = 0.413*) at Samaru. Copper (Cu) concentration correlated with P concentration (r = 0.455** and 0.371**) at Samaru and Kadawa respectively (Table 25).

The relationship between B and other macro and micronutrients had been reported in literature (Magalhaes and Monnerat, 1978; Graves et al 1978; Adams and Grimmet, 1981).

4.3.3.14 Simple Correlation Matrix (r) Among Yield Parametes and Nutrient Concentration in 1993/94 Trials

At Samaru, there was negative relationship between number of leaves and number of days to 50% flowering (r = -0.679**), B, K, Fe and P concentrations (r = -0.396**, -0.342*, -0.347* and -0.318*

respectively) as shown in Table 26. Also as the number of leaves increased the following parameters also increased: number of flowers, (r = 0.702**), number of fruits (r = 0.776**) fruit weight (r = 0.806**), fruit yield (r = 0.835**), DMY (r = 0.574**), Mn and Cu concentrations (r = 0.439**, 0.373*).

There were negative relationship between number of leaves, B and K concentrations (r = -0.318* and -0.461**); but positive relationship existed with number of flowers (r = 0.506**), number of fruits (r = 0.689**), fruit weight (r = 0.618**), fruit yield (r = 0.677**), DMY (r = 0.661**), and Na concentration (r = 0.395**) at Kadawa (Table 26).

Number of days to 50% flowering at Samaru correlated negatively with number of flowers (r = -0.446**), number of fruits (r = -0.511**) fruit weight (r = -0.463**), fruit yield (r = -0.522**), DMY (r = -0.471**), Zn and Cu concentrations (r = -0.343*, -0.312* respectively), but positively with B concentration (r = 0.456**) and K concentration (r = 0.373*).

At Kadawa, number of days to 50% flowering correlated with number of flowers, (r = -0.321*), number of fruits (= 0.442**), fruit yield (r = -0.327*), DMY (r = -0.389*), Mn and Cu concentrations (r = -0.359* and -0.349* respectively) as shown in Table 26.

The number of flowers correlated negatively with B and Fe concentrations (r = -0.665** and -0.310* respectively), whereas it correlated positively with number of fruits, (r = 0.970**) fruit weight (r = 0.756**) and DMY (r = 483**) at Samaru.

Table 24: Simple correlation matrix (r) among yield parameters and nutrient concentration in 1993/94 trials at Samaru

		No of leaves	No of days to 50% Flowering	No of flowers per plant	No of fruits per plant	Fruit weight	Fruit yield	Dry matter yield	Nutrient Concentration								
									N	K	Na	Ca	Mg	Zn	Mn	Fe	Cu
Number of leaves		-															
Number of days to 50% flowering		-0.673**	-														
Number of flowers per plant		0.707**	-0.646**	-													
Number of fruits per plant		0.776**	-0.511**	0.970**	-												
Fruit weight		0.805**	-0.463**	0.756**	0.829**	-											
Fruit yield		0.835**	-0.522**	0.891**	0.946**	0.926**	-										
Dry matter yield		0.574**	-0.471**	0.463**	0.569**	0.532**	0.631**	-									
N Concentration		-0.356**	0.456**	-0.665**	-0.661**	-0.249	-0.469**	-0.360**	-								
P	*	-0.342*	-0.373**	0.426**	-0.381**	-0.263	-0.338*	-0.113	0.417**	-							
K	*	-0.249	0.248	0.129	0.093	0.352*	0.191	-0.078	0.456**	0.197	-						
Na	*	-0.153	0.095	-0.134	-0.052	-0.163	-0.169	0.005	-0.163	0.456**	-0.202	-					
Ca	*	-0.024	0.049	-0.138	-0.062	0.0270	-0.035	-0.116	0.172	0.644**	0.103	0.630**	-				
Mg	*	0.013	-0.349*	0.0329	0.078	-0.045	-0.004	0.174	-0.247	0.186	-0.152	0.315*	0.052	-			
Zn	*	0.439**	-0.071	0.172	0.227	0.352**	0.355**	0.252	0.224	-0.015	0.169	-0.269	0.138	-0.407**	-		
Mn	*	-0.347*	0.158	-0.310*	-0.251	-0.096	-0.237	-0.110	0.202	-0.002	0.149	0.115	0.078	-0.123	-0.145	-	
Fe	*	0.378**	-0.312*	0.197	0.142	0.333*	0.185	0.133	0.139	0.162	0.092	0.065	0.173	0.085	0.069	-0.278*	-
Cu	*	-0.318*	0.301*	-0.029	-0.037	-0.117	-0.134	-0.153	-0.074	0.530**	0.231	0.297*	0.577**	0.424**	-0.299*	-0.050	-0.0
P	*																

Table 26 contd: Simple correlation matrix (r) among yield parameters and nutrient concentration in 1993/94 trials at Zadawa

		No of leaves	No of days to 50% Flowering	No of flowers per plant	No of fruits per plant	Fruit weight	Fruit yield	Dry matter yield	Nutrient Concentration: B	K	Na	Ca	Mg	Zn	Mn	Fe
Number of leaves		-														
Number of days to 50% flowering		-0.273*	-													
Number of flowers per plant		0.506**	-0.321*	-												
Number of fruits per plant		0.593**	-0.442**	0.866**	-											
Fruit weight		0.613**	-0.246	0.636**	0.750**	-										
Fruit yield		0.677**	-0.327*	0.797**	0.910**	0.951**	-									
Dry matter yield		0.661**	-0.389**	0.509**	0.657**	0.394**	0.512**	-								
B Concentration		-0.315**	0.141	-0.502**	-0.573**	-0.221	-0.372**	-0.435**	-							
K	*	-0.461**	0.107	-0.353*	-0.351*	-0.439**	-0.449**	-0.130	0.502*	-						
Na	*	0.395**	-0.177	0.195	0.193	0.096	0.129	0.166	0.006	-0.105	-					
Ca	*	-0.026	0.103	-0.005	0.022	-0.158	-0.082	0.023	-0.008	0.558**	0.011	-				
Mg	*	-0.060	0.099	0.010	0.122	-0.042	0.065	0.059	-0.220	0.177	-0.131	0.353*	-			
Zn	*	0.056	-0.220	0.102	0.257	-0.144	0.025	0.241	-0.255	0.314*	-0.193	0.302*	0.042	-		
Mn	*	0.171	-0.353**	-0.069	0.126	0.153 *	-0.041	0.376**	0.037	0.268	0.119	0.183	-0.097	0.423**	-	
Fe	*	-0.110	0.028	-0.071	0.026	-0.004	0.006	0.075	0.082	0.071	-0.322**	0.070	0.055	0.218	0.137	-
Cu	*	0.171	-0.349*	-0.037	0.074	0.118	0.097	0.240	0.148	0.002	0.147	-0.042	0.010	0.229	0.158	-0.101
P	*	-0.209	0.149	-0.048	0.009	-0.119	-0.048	0.089	-0.225	0.240	-0.204	0.175	0.191	0.384**	0.206	0.212

At Kadawa, number of flowers correlated positively with number of fruits (r = 0.866**), fruit weight (r = 0.696**), fruit yield (r 0.792**) and DMY (r = 0.509**) but negatively with B and K concentrations (r = -0.501** and -0.353*).

The number of fruits increased as the B and K concentrations decreased (r = -0.661** and -0.380* respectively) at Samaru and at Kadawa (r = -0.573** and -0.350* respectively). Nevertheless, the following parameters increased with increase in fruit number - fruit weight (r = 0.829**), fruit yield (r = 0.946**), DMY (r = 0.569**) at Samaru and fruit weight (r = 0.760**), fruit yield (r = 0.910**) and DMY (r = 0.657**) at Kadawa (Table 26).

Fruit size increased with increase in fruit yield (r = 0.926**), DMY (= 0.532**), Na concentration (r = 0.352*) and Mn concentration (r = 0.382*) at Samaru. Similarly at Kadawa, fruit weight increased with increase in fruit yield (r 0.951**) and DMY (r = 0.394*), and decreased with K concentration (r = -0.499**).

Fruit yield correlated positively with DMY (r = 0.531**), Mn concentration (r = 0.355*) and negatively with B and K concentrations (r -0.466** and -0.356*) at Samaru. Fruit yield also correlated positively with DMY (r = 0.512**) and negatively with B and K concentrations (r = 0-0.372* and -0.449**), at Samaru.

Dry matter yield (DMY) correlated negatively with B concentration (r = -0.360* and -0.455**) at Samaru and Kadawa respectively.

Boron concentration correlated with potassium (K) concentration (r = 0.417**), Na concentration (r = 0.458**) at

Samaru and B concentration at Kadawa (= 0.302*).

Potassium (K) concentration increased as Ca, Mg and P concentration increased (r = 0.466**, 0.644** and 0.530** respectively) at Samaru. Whereas at Kadawa, K concentration correlated with Ca and Zn concentrations (r = 0.558** and 0.314* respectively).

At Samaru, Ca concentration increased as Mg and Zn concentrations (r = 0.600** and 0.315* respectively) increased (Table 26). Whereas at Kadawa Ca concentration increased with increase in Mg concentration (r = 0.353*) as shown in Table 26.

Magnesium (Mg) concentration correlated with P concentration (r = 0.377*) at Samaru, whereas Zn concentration correlated with Mn concentration (r = 0.407**, 0.429**) and P concentration r = 0.424**, 0.384) at Samaru and Kadawa respectively (Table 26). The result of this study agreed with the report of Adams and Winsor (1974) and Alvarez-Tinaut et al (1979).

The various relationship observed in the study suggested that application of B exerted postive effect on growth and productivity of tomatoes (Abo-Elshaod et al 1980), and that the yield is related to the content of the micronutrient in dry matter (Graves et al 1978 and Winsor and Adams 1986).

FRUIT ANALYSIS RESULTS

4.3.3.15 Effect of Boron Rates on the Ascorbic Acid (AA) Contents of Tomato Fruits

The effect of boron application on ascorbic acid contents of varieties was not significant (P = 0.05) in any of the trials, though Dandino gave the highest mean ascorbic acid content at Kadawa in 1992/93; and also at Samaru and Kadawa in 1993/94 (Table 27).

The non significant effect between varieties had earlier been reported by Gould (1974) who stated that statistical differences between varieties seldom occur in field experiments. He emphasized the relationship between a particular variety and the environmental conditions in determining ascorbic acid content of tomato fruit.

Ascorbic acid contents of fruits increased significantly (P = 0.05) with increased B rates in both years and locations (Table 27).

Plants treated with 2 kg B ha^{-1} gave the highest AA contents in each of the trials. These accounted for increase of 34.9 and 28% in 1992/93; 34.7 and 31.1% in 1993/94 above the control at Samaru and Kadawa respectively.

The content of AA obtained in this study is higher than the values obtained by Gould (1974).

There was no significant difference between the results obtained with B applied at 2 and 3 kg ha^{-1} at Samaru and Kadawa in 1993/94.

The interaction effect between B rates and variety was not significant in 1992/93, and 1993/94 at both locations (Table 28).

Table 27: Effect of Variety and boron rates on acid contents (%) of ripe tomato fruits at Samaru and Kadawa in 1992/93 and 1993/94

Treatment	1992/93			1993/94		
	Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
Variety						
Roma VF	24.92	25.43	25.18	25.78	26.14	25.96
Dandino	24.12	27.47	25.80	26.33a	27.27a	26.80
LSD (0.05)	NS	NS		NS	NS	
Boron Rates (Kg B ha^{-1})						
0	21.75cd	25.65bcd	2.370	25.00bc	25.67cd	25.34
1	26.50b	29.00abc	27.75	30.00ab	32.92ab	31.46
2	29.33a	32.90a	31.12	33.67a	33.70a	33.69
3	27.67ab	31.75ab	29.71	25.00bc	28.40ab c	26.70
4	22.50c	21.50de	22.00	23.67cd	20.70de	22.19
5	19.50d	7.90e	13.70	19.00d	18.70e	18.90
LSD (0.05)	4.62	6.8		6.25	6.12	

Means in a given column followed by similar letter(s) are not significantly different at P = 0.05, using DMRT

Table 28: Effect of Variety X boron rates interaction on ascorbic acid contetnts (%) of ripe tomato fruits at Samaru and Kadawa in 1992/93 and 1993/94

Treatment (kg Bha^{-1})	Variety	1992/93			1993/94		
		Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
0		21.50	23.50	22.50	24.00	25.00	24.50
1		25.00	26.00	25.50	28.00	32.83	30.00
2	Roma VF	27.67	28.80	28.24	31.33	30.90	31.12
3		29.33	33.50	31.42	26.00	28.80	27.40
4		24.00	22.00	23.00	25.33	20.80	23.10
5		22.00	18.80	20.40	20.00	18.50	19.25
0		22.00	27.80	26.00	26.00	26.33	26.16
1		28.00	32.00	30.00	31.90	33.00	32.50
2	Dandino	31.00	37.00	36.00	36.30	36.30	36.15
3		26.00	30.00	28.00	24.10	28.00	26.05
4		21.00	21.00	21.00	22.00	20.60	21.30
5		17.00	17.00	17.00	18.00	18.90	18.45
LSD (0.05)		NS	NS		NS	NS	

4.3.3.16 Effect of Boron Rates on Total Soluble Solids (TSS) of Tomato Fruits

Total soluble solids is an important component in the overall flavour intensity in tomato fruits.

The effect of B rates on TSS contents of varieties was only significant ($P = 0.05$) in 1993/94 at Kadawa (Fig. 14). Nevertheless, variety Dandino produced fruits with higher TSS contents than Roma VF.

TSS increased significantly ($P = 0.05$) with the application of B at Samaru and Kadawa in 1992/93 and at Kadawa in 1993/94 (Fig. 14). In 1992/93, plants treated to 2 kg B ha^{-1} gave the highest TSS contents at Samaru and Kadawa which resulted in increase of 22.8 and 20.5% above the control. Whereas in 1993/94 the highest TSS contents were recorded at 1.0 kg B ha^{-1} and 2.0 kg B ha^{-1} at Samaru and Kadawa respectively, with increase of 20.1 and 18.7% above the control.

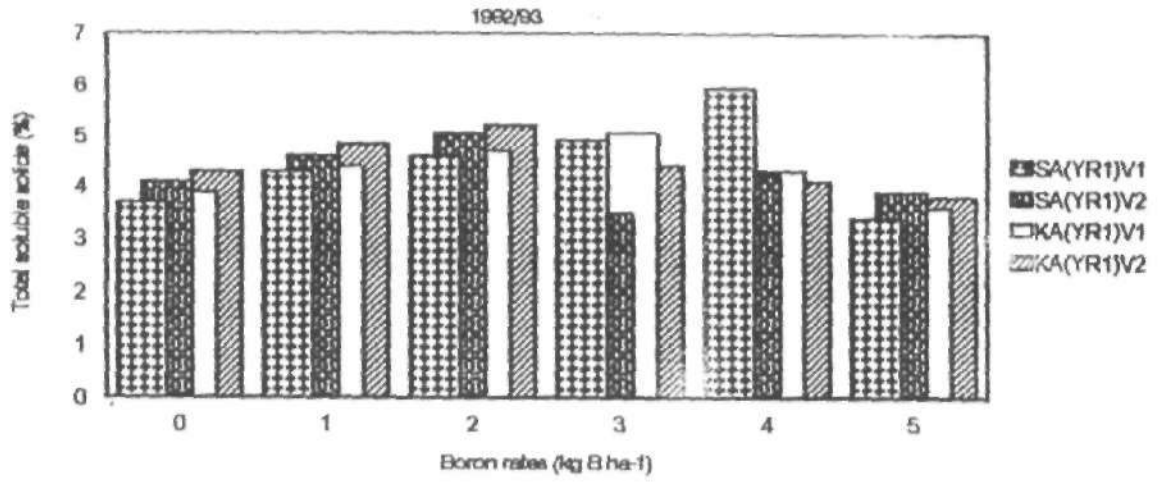
The interaction between B rates and variety was significant at Kadawa in both years.

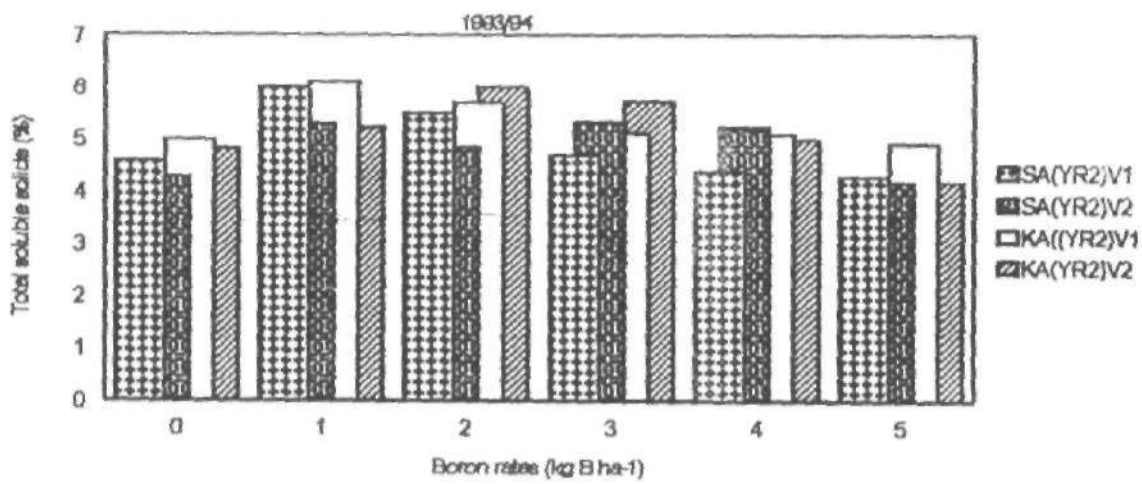
4.3.3.17 Effect of Boron Rates on Titratable Acidity (TA)

Significant ($P = 0.05$) varietal response was recorded at Samaru in 1992/93 and 1993/94 but not at Kadawa. Nevertheless the highest TA of 4.3% was recorded at Kadawa in 1993/94 (Fig. 15). The discrepancies could be due to soil type and environmental factors.

Boron application significantly ($P = 0.05$) increased the TA

Fig. 14. *Total soluble solids (TSS) contents of tomato fruits as influenced by variety and rates of boron at Samaru and Kadawa under irrigation condition in 1992/93 and 1993/94.*





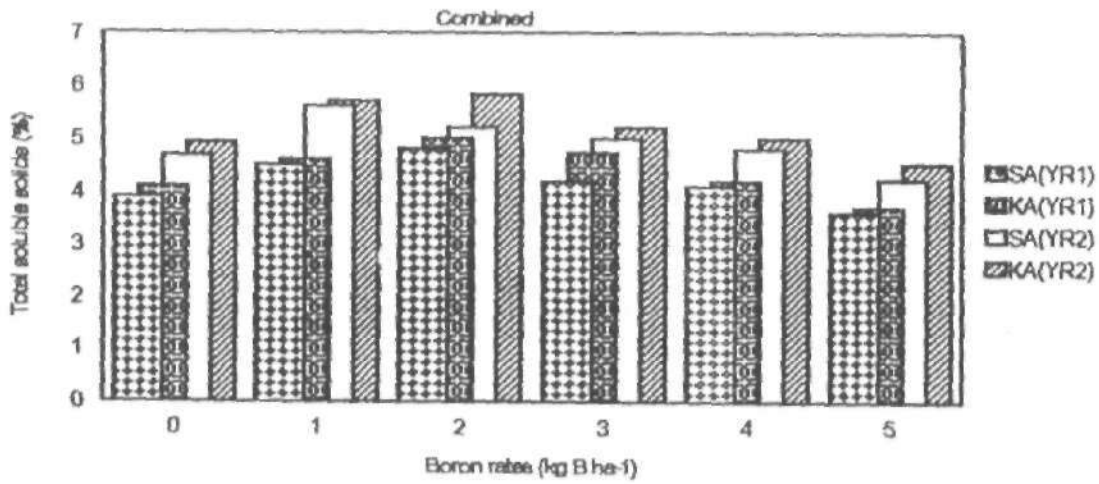
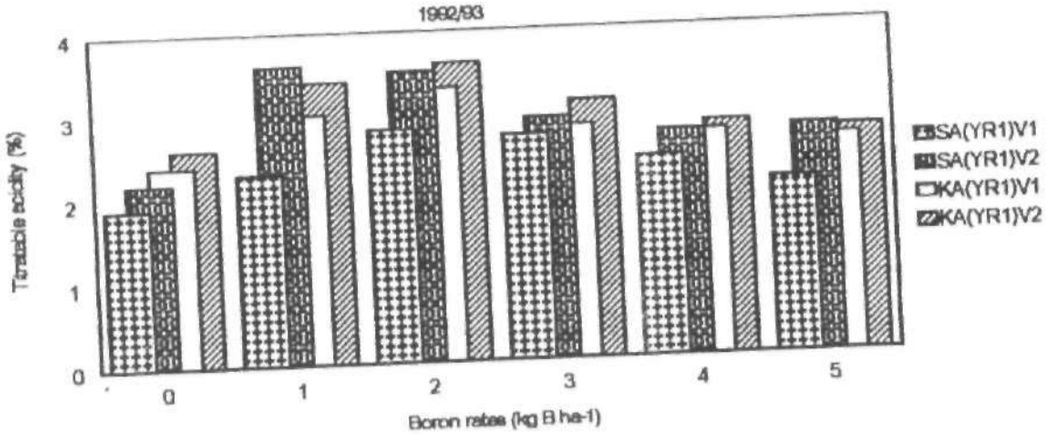
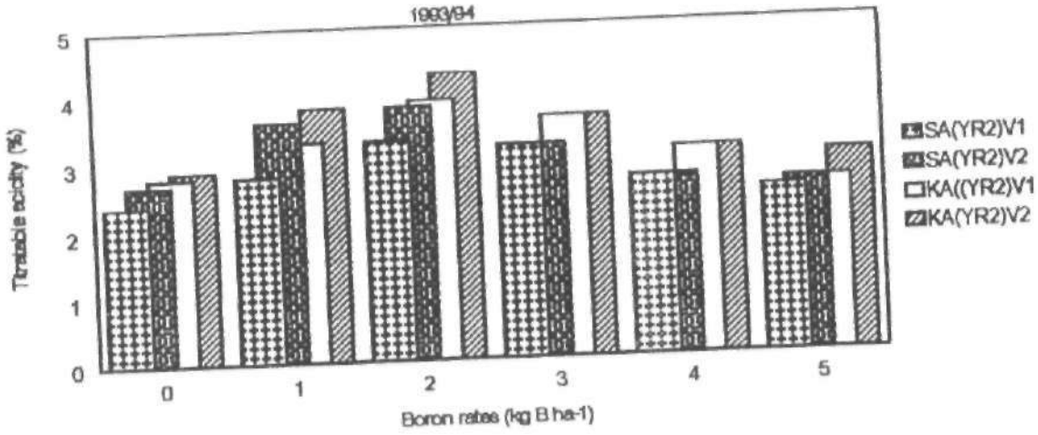
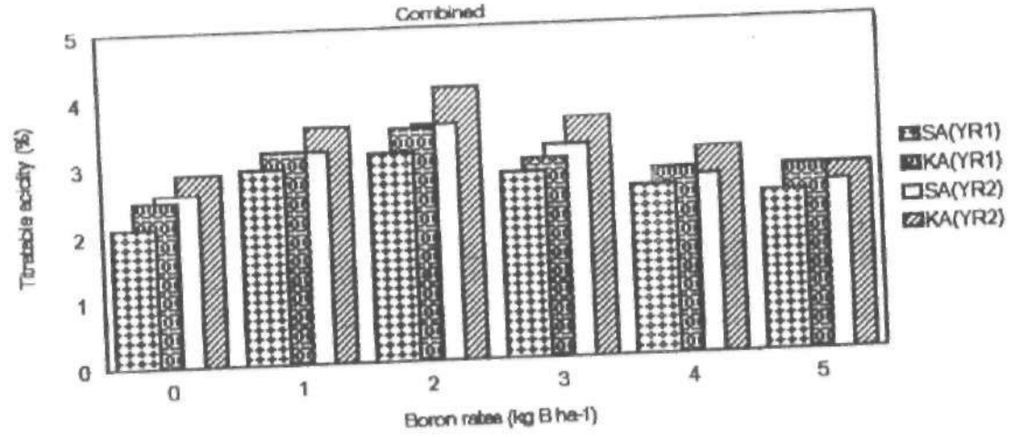


Fig. 15. Titratable acidity contents of tomato fruits as influenced by variety and rates of boron at Bamenu and Kadawa under irrigation conditions in 1992/93 and 1993/94.







contents of tomato fruits at Samaru and Kadawa in 1992/93 and 1993/94 (Fig.15).

4.3.3.18 Effect of Boron Rates on pH of Tomato Fruits

The effect of varieties over B rates on pH of tomato fruit was only significant (P = 0.05) at Samaru in 1992/93 (Table 29).

The pH of tomato fruits which ranged from 3.97 to 4.59 did not follow a particular trend. Wolf et al (1979) determined the pH of 107 varieties of tomatoes and found that the pH of most cultivars did not exceed 4.6. He reported that the pH of fruit increased as the tomato matured, and that the growing location appeared to affect the pH of the cultivars.

The interaction between B rates and varieties was not significant at Samaru and Kadawa in 1992/93 and 1993/94 (Table 30).

The non significant difference that existed among the treatments signifies that the pH of the fruit alone cannot be used as indicator of fruit acidity, but also may require the determination of titratable acidity.

4.3.3.19 Effect of Boron Rates on Reducing Sugars (RS)

Variety Dandino produced fruits with higher RS contents in both years, at Samaru and Kadawa (Fig. 16). Although the difference was only significant (P = 0.05) in 1992/93 at Samaru and Kadawa. Nevertheless, the highest RS content was recorded with Dandino at Kadawa in 1993/94.

Table 29: Effect of Variety and boron rates on pH of ripe tomato fruits at Samaru and Kadawa in 1992/93 and 1993/94

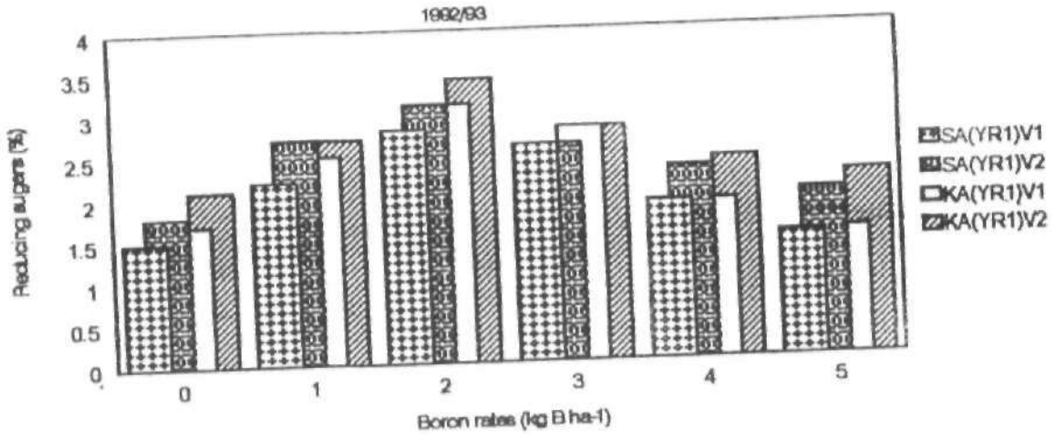
Treatment	1992/93			1993/94		
	Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
Variety						
Roma VF	3.95ab	4.31	4.13	4.11	4.31	4.21
Dandino	4.05a	4.24	4.15	4.11	4.24	4.18
LSD (0.05)	0.10	NS		NS	NS	
Boron Rates (Kg B ha^{-1})						
0	3.97	4.25	4.11	4.03	4.25	4.14
1	3.97	4.27	4.12	4.10	4.27	4.18
2	4.03	4.59	4.31	4.15	4.38	4.27
3	4.03	4.30	4.17	4.15	4.30	4.23
4	4.03	4.25	4.14	4.10	4.25	4.18
5	3.97	4.22	4.10	4.17	4.22	4.20
LSD (0.05)	NS	NS		NS	NS	

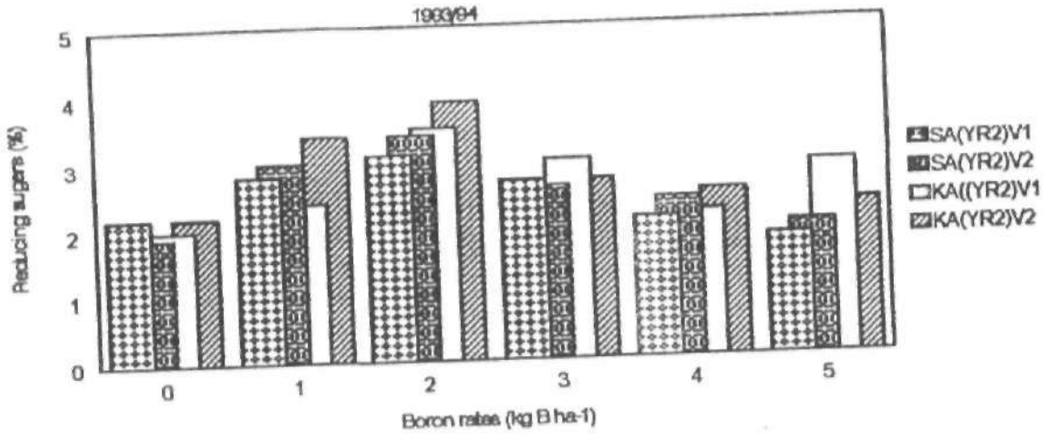
Means in a given column followed by similar letter(s) are not significantly different at P = 0.05, using DMRT

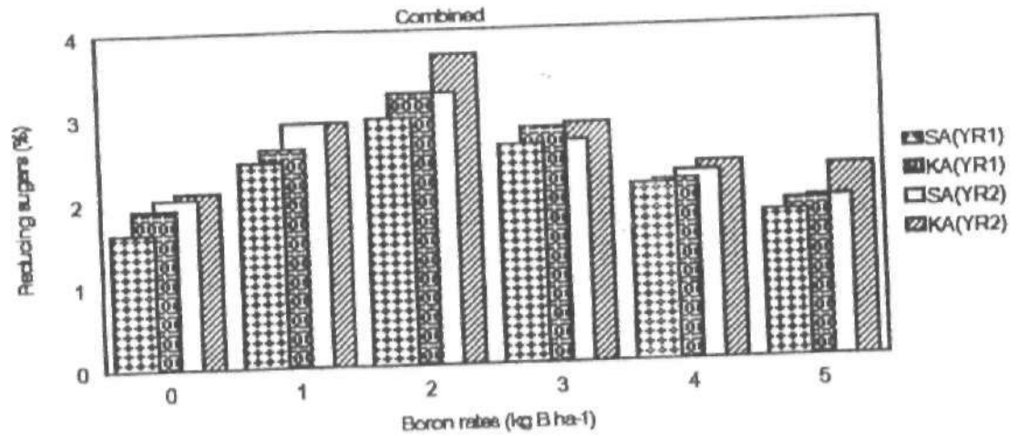
Table 30: Effect of Variety X boron rates interaction on pH of ripe tomato fruits at Samaru and Kadawa in 1992/93 and 1993/94

Treatment (kg Bha^{-1})	Variety	1992/93			1993/94		
		Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
0		3.93	4.33	4.13	4.10	4.33	4.22
1		3.97	4.23	4.10	4.13	4.23	4.18
2	Roma VF	4.03	4.37	4.20	4.10	4.37	4.24
3		3.93	4.43	4.18	4.10	4.43	4.27
4		3.97	4.20	4.09	4.13	4.20	4.17
5		3.87	4.30	4.09	4.10	4.30	4.40
0		4.00	4.17	4.08	3.97	4.17	4.07
1		3.97	4.30	4.14	4.07	4.30	4.18
2	Dandino	4.03	4.40	4.22	4.20	4.40	4.30
3		4.13	4.17	4.15	4.20	4.17	4.18
4		4.10	4.30	4.20	4.07	4.30	4.18
5		4.07	4.13	4.10	4.13	4.14	4.14
LSD (0.05)		NS	NS		NS	NS	

Fig. 16. Reducing sugars of tomato fruits as influenced by variety and rates of boron at Samaru and Kadawa in 1992/93 and 1993/94.







Boron application had high significant effect on RS in each of the trials (Fig. 16). Plants treated to 2 Kg B ha^{-1} recorded the highest yield in each of the trials, whereas, plants treated to 0 and 5 kg B ha^{-1} performed poorly. Similar findings had been reported by Verma et al (1973) and Abo-Elshaod (1980) who ascribed the increase in RS of some B treated plants to rapid translocation of metabilies from the leaves to the fruits.

The interaction between treatment and variety on RS was only significant in 1992/93 (Fig. 16).

4.3.3.20 Simple Correlation Among Fruit Components

Ascorbic acid (AA) correlated with TSS, RS and yield (r = 0.535**, 0.645** and 0.797** respectively) at Samaru, whereas it correlated with TSS (r = 0.599**) TA (r = 0.481*) fruit yield (r = 0.605**) at Kadawa (Table 31).

Total soluble solids (TSS) correlated with TA (r = 0.0500**, 0.500**), RS (r = 0.635**, 0.701**) and yield (r = 0.708**, 0.880**) both Samaru and Kadawa respectively. This result agreed with the report of Stevens et al (1979).

Titratable acidity (TA) correlated with RS (r = 0.661**) and yield (r = 0.604**) at Samaru, but correlated with pH (r = 0.423*), RS (r = 0.442*) fruit yield (r = 0.535*) at Kadawa (Table 31).

pH did not correlate with any of the fruit components at Samaru. This confirms the report of Lambeth et at (1966).

Reducing sugars correlated with yield (r = 0.681** and 0.576**) at Samaru and Kadawa respectively. The results of this

study confirmed the report of Kader et al (1978) who got strong correlation among the fruit components.

It is interesting to note that yield correlated with all the fruit components in both locations except at Samaru, where it did not correlate with pH. This signifies the importance of these fruit components in the tomato fruit.

Table 31: Simple Correlation among fruit components in Samaru and Kadawa under irrigation condition.

	Ascorbic Acid	Total soluble solids	Titratable Acidity	pH	Reducing sugars	Yield
SAMARU						
Ascorbic Acid	-					
Total soluble solids	0.533**	-				
Titratable Acidity	-	0.500**	-			
pH	-	-	-	-		
Reducing Sugars	0.645**	0.635**	0.661**	-	-	
Yield	0.797**	0.708*	0.604**	0.681**	-	-
KADAWA						
Ascorbic Acid	-					
Total soluble solids	059	-				
Titratable Acidity	0.481*	0.500**	-			
pH	-	-	0.423*	-		
Reducing Sugars	0.439*	0.701**	0.442*	-	-	
Yield	0.605*	0.880**	0.533**	0.430*	0.576**	-

4.3.4 RAINFED TRIALS (1993 AND 1994)

4.3.4.1 Effect of Boron Application on Morphological Appearance of Tomato Plants During the Wet Season

Boron application influenced the vegetative growth of plants. This was easily noticed in plants receiving 0.5 to 1.5 kg B ha^{-1}, whose growth was rapid from 2 WAP to the time of flowering.

In 1994, there was excessive rainfall in the month of August and September (Appendix D). This resulted in fruit loss as a result of fruit cracking and decay. Recently Peet and Willits (1995) reported fruit cracking in tomato which resulted into serious economic losses as a result of excess water.

Boron deficiency symptoms characterised by brittleness yellowing of leaves and bushy appearance of plants were observed in the control (0 kg B ha^{-1}) plots which resutled in reduction in yield, at both locations and years.

Toxicity symptoms which also included, marginal burning and interveinal chlorosis, starting with the older leaves were also observed in plots receiving 2.0 and 2.5 kg B ha^{-1}.

4.3.4.2 Effect of Boron Fertilizer Rates on Number of Leaves under Rainfed Conditions

Varieties did not vary significantly with respect to number of leaves per plant (Table 32). The mean number of leaves of Dandino was higher than that of Roma VF in 1993 and 1994 at Samaru and Kadawa. The differences were to the tune of 6.5 and 3.1% in 1993; 4.3 and 3.4% in 1994 at Samaru and Kadawa respectively.

Application of B significantly ($P = 0.05$) increased the number

Table 32: Effect of Variety and boron rates on number of leaves at Samaru and Kadawa under rainfed condition in 1993and 1994

Treatment	1993			1994		
	Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
Variety						
Roma VF	61.0	71.0	66.0	77.0	85.0	81.0
Dandino	65.0	73.0	69.0	80.0	88.0	84.0
LSD (0.05)	NS	NS		NS	NS	
Boron Rates (Kg B ha^{-1})						
0	55.0cd	61.0de	58.0	69.0cd	80.0c	74.0
0.5	70.0b	75.0bc	72.0	79.0b	91.0b	85.0
1.0	78.0a	89.0a	84.0	93.0a	97.0a	95.0
1.5	71.0a	82.0ab	77.0	90.0a	96.0ab	93.0
2.0	56.0c	68.0cd	62.0	76.0bc	85.0c	80.0
2.5	50.0cde	55.0e	52.0	63.0de	70.0d	67.0
LSD (0.05)	8.4	10.6		7.5	5.5	

Means in a given column followed by similar letter(s) are not significantly different at P = 0.05, using DMRT

Table 33: Effect of Variety X boron rates interaction on number of leaves at at Samaru and Kadawa in 1993 and 1994

Treatment (kg Bha^{-1})	Variety	1993			1994		
		Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
0		51.7ghijk	56.7fghijk	54.2	67.0	76.7fgh	71.9
0.5		66.7bcde	72.3cdefg	69.5	73.0	89.0bcd	81.0
1.0	Roma VF	69.3bcd	80.3bc	74.8	88.0	90.3bc	89.0
1.5		77.7ab	90.3ab	84.0	94.0	101.0a	97.5
2.0		56.0efgh	72.7cdef	64.4	77.0	85.7cde	81.4
2.5		46.0ghijkl	51.0hijkl	48.5	61.7	67.3i	64.5
0		58.7de	66.0cdefgh	62.4	70.7	83.3cdefg	77.0
0.5		72.3bc	77.3bcd	74.8	85.0	93.7b	89.4
1.0	Dandino	87.3a	97.0a	92.2	98.0	104.0a	101.0
1.5		64.3cd	74.3cde	69.3	86.3	90.3bc	88.3
2.0		55.3efghi	63.0defghi	59.2	75.7	84.0cdef	79.9
2.5		53.4fghij	59.0efghij	56.2	64.7	73.3hi	69.0
LSD (0.05)		11.9	15.0		NS	7.7	

Means in a given column followed by similar letters are not significantly different at P = 0.05, using DMRT.

of leaves with the trend being strongly in favour of 1 kg B ha^{-1} in 1993 and 1994 at Samaru and Kadawa (Table 32).

Despite differences in the B soil tests values of the experimental sites, the highest number of leaves for each trial was recorded at the same rate of 1 kg B ha^{-1}. The increase above the control were 41.8 and 45.1% in 1993, 35.2 and 21.5% in 1994.

There was no significant difference obtained in the result of plants treated to 1 kg B ha^{-1} and 1.5 kg B ha^{-1} at Samaru and Kadawa in 1993 and 1994.

The significant response to B application indicates that B supports the growth of tomato plants, by increasing the number of leaves. In his study, Epstein (1972) reported that leaves can be used to measure the vegetative growth before flowering, since they are the major sources of photosynthates in the plant.

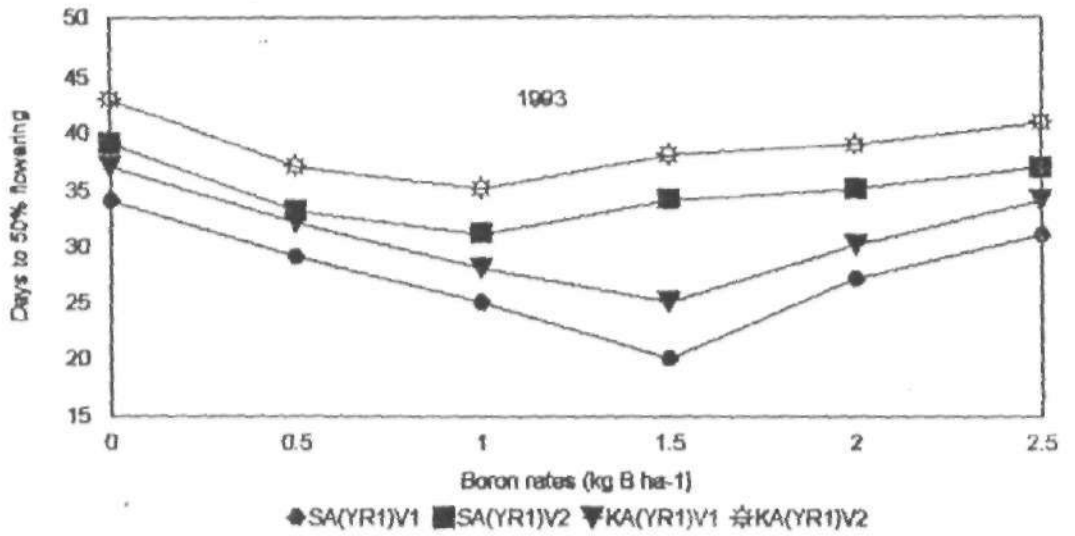
The interactions between treatments and variety were significant in 1993 at Samaru and Kadawa, and also at Kadawa in 1994 (Table 33).

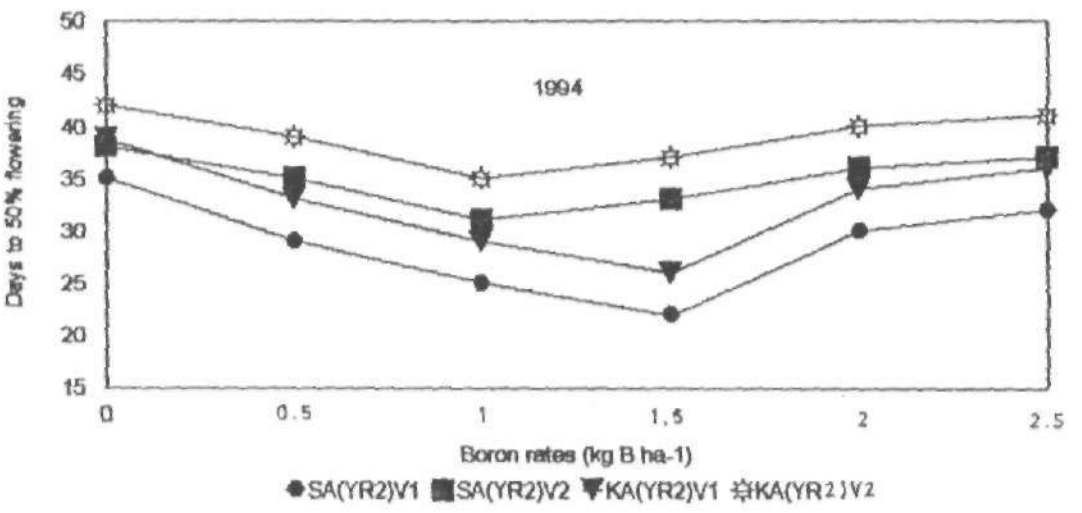
4.3.4.3 Effect of Boron Rates on Days to 50% Flowering

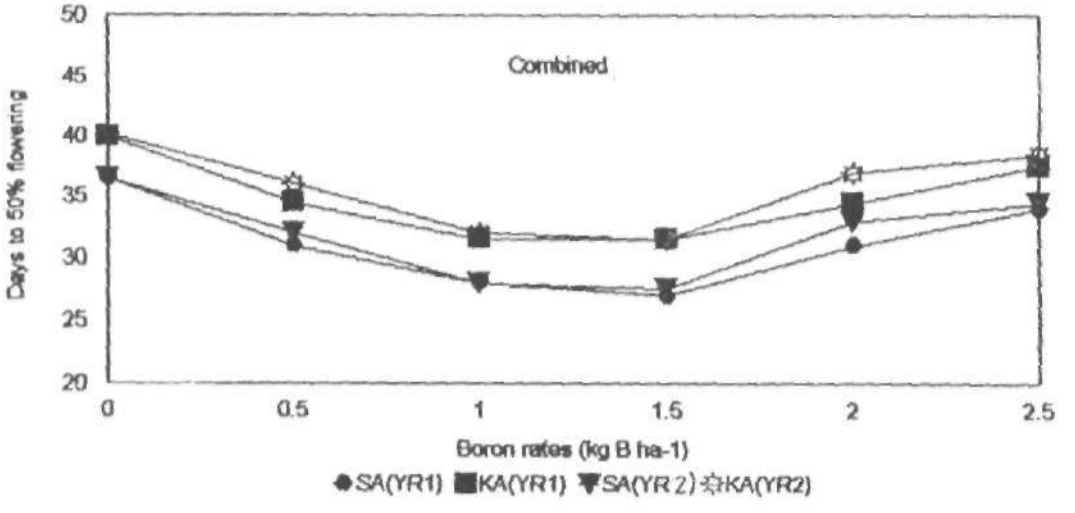
Application of boron significantly (P = 0.05) influenced the number of days to 50% flowering. Variety Roma VF recorded the least number of days to 50% flowering at Samaru and Kadawa in 1993 and 1994 (Fig. 17). The difference in mean number of days to flowering for variety Roma VF over Dandino were 7.2 and 7.0 days in 1993; 8.0 and 7.0 days in 1994 at Samaru and Kadawa respectively.

The superiority of Roma VF over Dandino in number of days to

Fig. 17. Number of days to 50% flowering as influenced by variety and rates of boron, under rainfed conditions at Samaru and Kadawa in 1993 and 1994.







50% flowering may be explained by the fact that the characters was genetically controlled.

Increasing B rates significantly decreased the number of days to flowering in each of the experimental locations as shown in Fig. 17. Plants treated to 1.5 kg B ha^{-1} recorded the least days to flowering in each of the trial. However, there was no significant difference obtained in the results of plants treated to 1.0 and 1.5 kg B ha^{-1} at Samaru and Kadawa in 1993 and 1994.

The least number of days, 27 days after transplanting (DAT) to flowering was recorded at Samaru in 1993 when the atmospheric temperature was within the optimal temperature for flowering. Similar findings were reported by Learner and Wittwer (1953) and Wittwer (1963).

The interaction between treatment and varieties on days to 50% flowering was only significant at Samaru in 1993. However Roma VF plants treated with 1.5 kg B ha^{-1} recorded the least number of days (20) to 50% flowering at Samaru in 1993 (Fig. 17).

4.3.4.4 Effect of Boron Rates on Number of Flowers

Dandino produced significantly ($P = 0.05$) more flowers than Roma VF in 1993 at Samaru and in 1994 at both locations (Table 34). The increase was to the tune of 26 and 25.3% in 1993; 11.4 and 19.2% in 1994 at Samaru and Kadawa respectively. Kadawa trials gave more mean number of flowers per plant (50 and 51) than Samaru (47 and 46) in 1993 and 1994 respectively.

Table 34: Effect of Variety and boron rates on number of flowers per plant at Samaru and Kadawa under rainfed condition in 1993 and 1994

Treatment	1993			1994		
	Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
Variety						
Roma VF	43.7	47.3	45.5	40.5	48.4	44.5
Dandino	46.9	49.8	48.4	46.5	50.9	48.7
LSD (0.05)	3.2	NS		4.0	1.0	
Boron Rates (Kg B ha^{-1})						
0	38.7de	44.5de	41.6	38.5de	45.4d	42.0
0.5	47.0bc	49.5bc	48.3	46.4abc	51.4ab	48.9
1.0	53.0a	55.0a	54.0	51.00a	55.1a	53.1
1.5	51.5ab	52.5ab	52.0	48.00ab	52.5b	50.3
2.0	43.5cd	47.8bc	45.7	41.98bcd	50.3c	46.1
2.5	38.3de	42.0e	40.2	35.00def	43.5de	39.3
LSD (0.05)	5.5	4.6		6.9	1.8	

Means in a given column followed by similar letter(s) are not significantly different at P = 0.05, using DMRT

Table 35: Effect of Variety X boron rates interaction on number of flowers per plant at Samaru and Kadawa under rainfed condition in 1993 and 1994

Treatment (kg Bha^{-1})	Variety	1993			1994		
		Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
0		38.0	43.0	40.5	36.0	44.0ghi	40.0
0.5	Roma VF	42.0	47.0	44.5	40.8	47.7f	44.3
1.0		49.0	51.0	50.0	45.0	52.7cd	48.9
1.5		52.0	54.0	53.0	47.0	53.6bc	50.3
2.0		44.0	48.0	46.0	41.0	50.2de	45.6
2.5		37.2	41.0	39.1	33.0	42.4hi	37.7
0		39.3	46.0	42.7	41.0	46.8fg	43.9
0.5	Dandino	52.0	52.0	52.0	52.0	55.0ab	53.5
1.0		57.0	59.0	58.0	57.0	57.5a	57.3
1.5		51.0	51.0	51.0	49.0	51.4cde	50.2
2.0		43.0	47.7	45.4	43.0	50.3de	46.7
2.5		39.3	43.0	41.0	37.0	44.5fgh	40.8
LSD (0.05)		NS	NS		NS	2.52	

Means in a given column followed by similar letters are not significantly different at P = 0.05, using DMRT.

Increasing B rates significantly increased the number of flowers per plant at Samaru and Kadawa in 1993 and 1994 (Table 34). There was no significant difference in the result of plants treated to 0.5 and 1.5 kg B ha^{-1}. Plants treated to 2.5 kg B ha^{-1} gave the least number of flowers in all the trials signifying toxicity effect of the B level (Table 34).

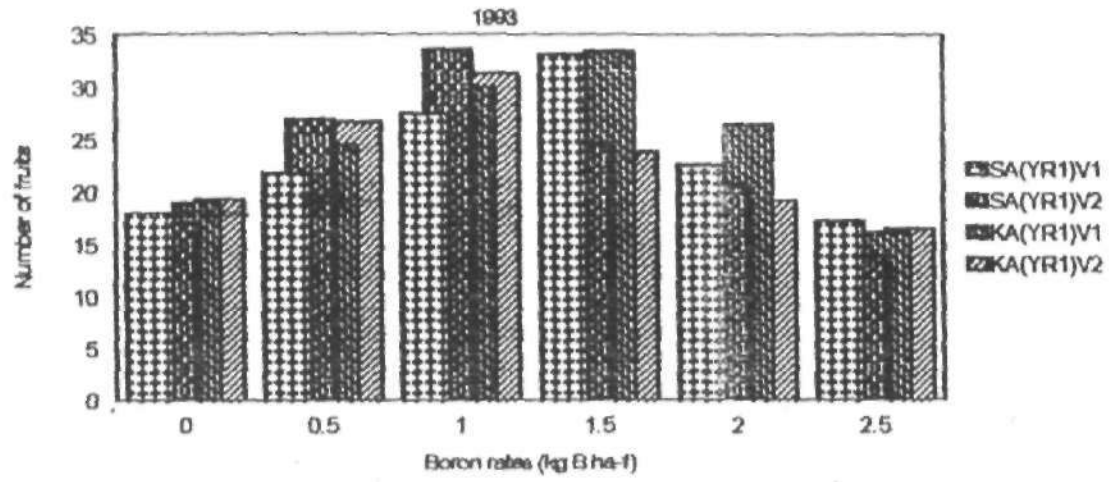
The result on number of flowers obtained in both locations are very similar. Studies have shown that temperature among other environmental factors influenced the morphology and development of floral parts in tomato. Learner and Wittwer (1953) and Wittwer (1963) had variously reported that the process of flower formation in the tomato are influenced by prevailing temperature. Similarly, Huxley (1962) reported that temperature influences the number of flowers per inflorescence.

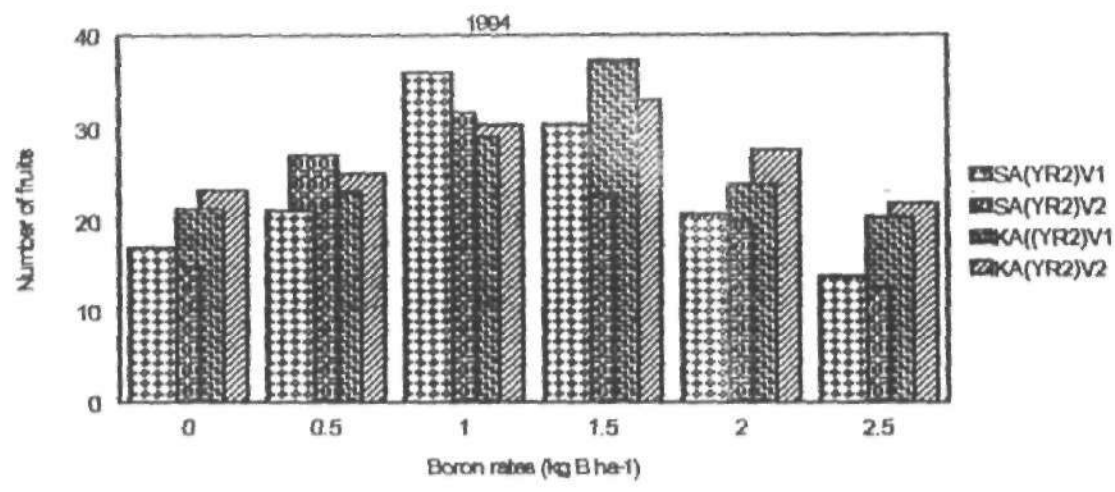
The interaction between variety and boron rates on number of flowers was only significant (P = 0.01) at Kadawa in 1994 (Table 35). However, Dandino variety treated to 1.5 kg B ha^{-1} gave the highest number (59) of flower in all the trials.

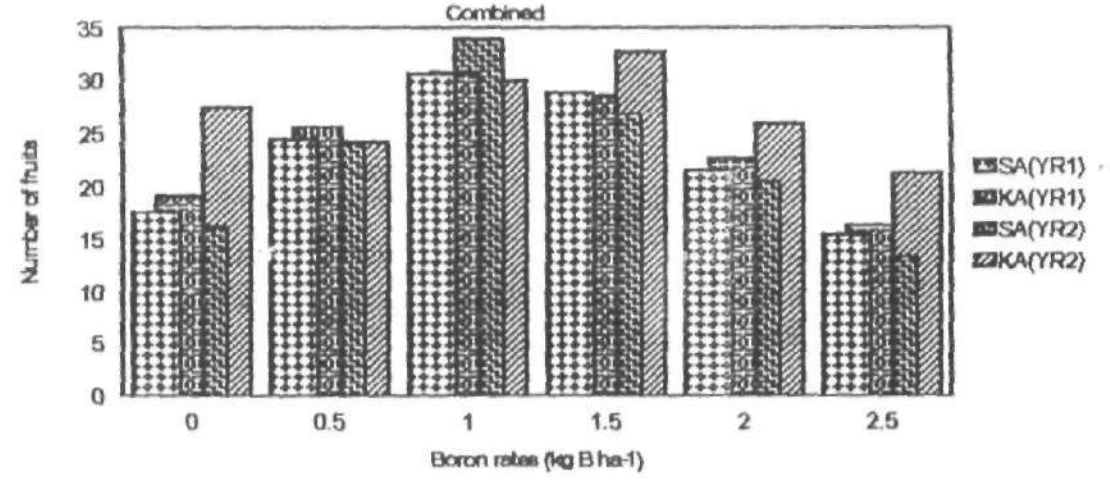
4.3.4.5 Effect of Boron Rates on Number of Fruits Per Plant

Boron application had significant effect on varieties at Kadawa in 1993 and 1994 (Fig. 18). Variety Roma VF recorded more fruits than Dandino in all the trials except in 1994 at Kadawa, where Dandino produced more fruits. This discrepancy could be due to environmental and soil factors which also control the number of flowers that set fruits. Boron Application significantly

Fig. 18. Number of fresh tomato fruits as influenced by variety and rates of boron under rainfed conditions at Samaru and Kadawa in 1993 and 1994.







increased the number of fruits per plant in all the locations (Fig. 18). The highest number of fruit was recorded at 1.0 kg B ha^{-1} in each of the trials except at Kadawa in 1994 where plants treated to 1.5 kg B ha recorded the highest number of fruits, despite the fact that soil test value of 0.32 mg Kg^{-1} was higher than the critical soil B of 0.13 mg Kg^{-1} (Fig. 3) obtained from the greenhouse study.

The least number of fruits in each trial was recorded at 2.5 kg B ha^{-1}. This could be due to toxicity effect as a result f excess B. Similar result has been reported by other workers (Abo-Elshaod et al 1980 and Adelana 1986).

The interaction between B rates and variety was only significant in the first year of the trial, at Samaru and Kadawa.

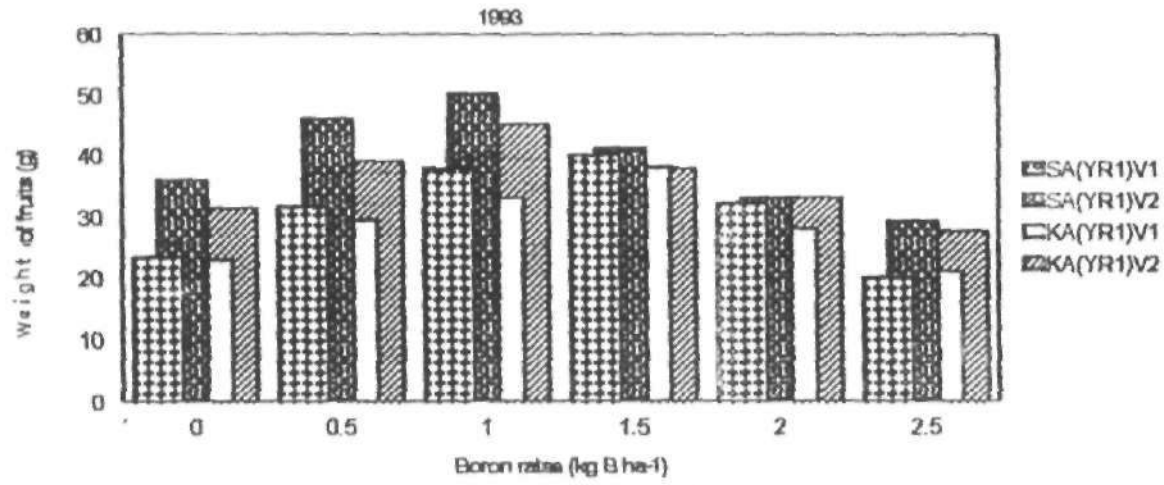
4.3.4.6 Effect of Boron Rates on Fruit Weight

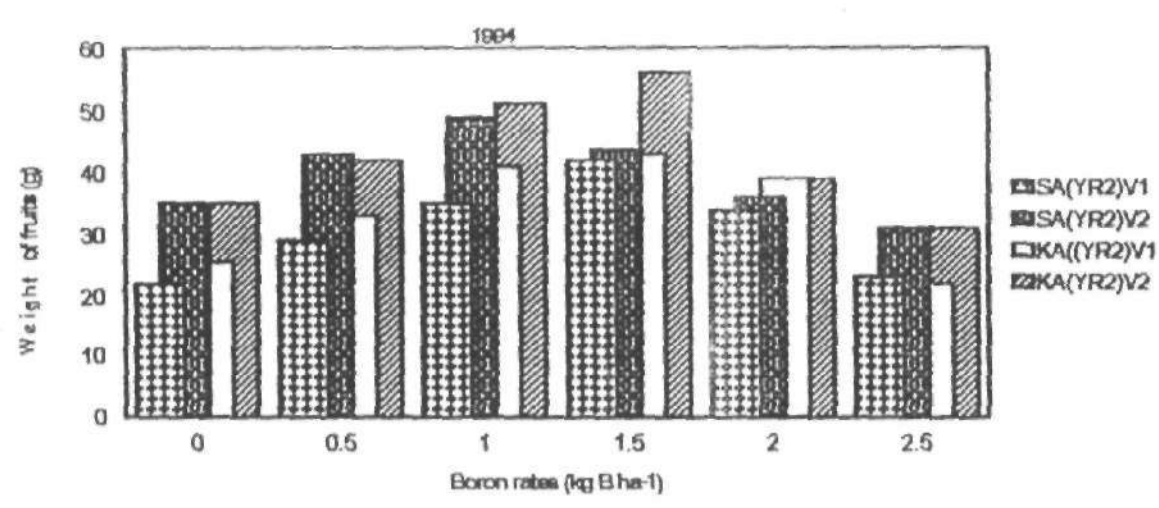
The effect of B rates over variety was significant (P = 0.01) in each of the trials. Variety Dandino produced significantly bigger fruits than Roma VF (Fig. 19). The increases were to the tune of 27.3 and 23.9% in 1993; 28.5 and 24.7% in 1994 at Samaru and Kadawa respectively.

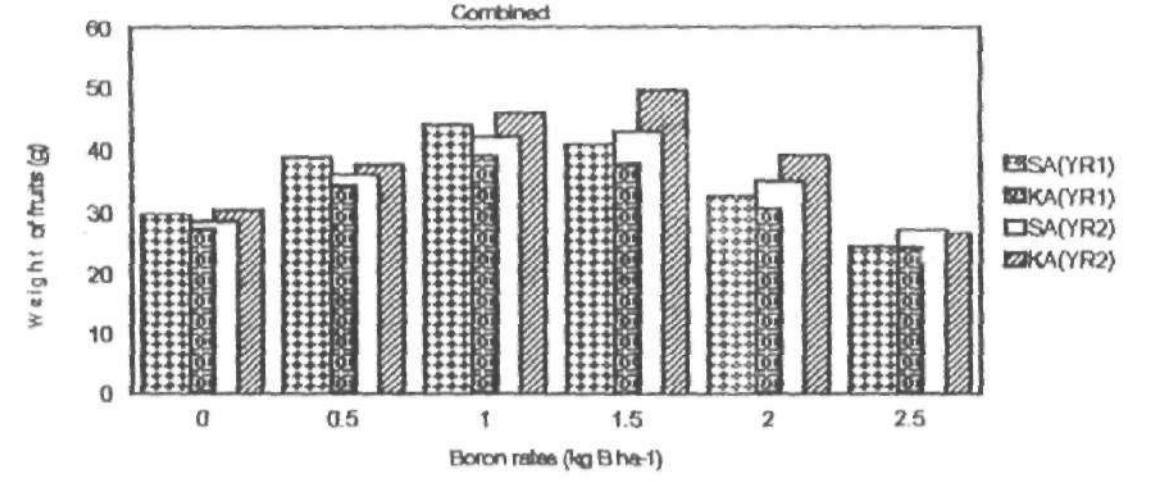
Weight of fruit increased with increasing B rates up to 2.0 kg B ha^{-1} in 1993 and 1994 at Samaru and Kadawa (Fig. 19). Fruit weight decline at B rates of 2.5 kg B ha^{-1}, due to B toxicity on the plants. Similar decline in fruit weight had earlier been reported (Aduayi 1978 and Adelana 1986) who found that high rates of B was toxic to tomato plants.

In 1993, the highest fruit weight in each trial was obtained

Fig.19. Weight of fresh tomato fruits as influenced by variety and rates of boron at Bamaru Bamaru and Kadawa under rainfed conditions in1993 and 1994.







with 1.0 kg B ha^{-1} boron rate, with Samaru having the highest fruit weight of 43.9g; whereas in 1994, the highest fruit weight of 49.5g was obtained at Kadawa (Fig. 19).

The interaction between B rates on weight of fruit was significant only at Samaru in 1993, (Fig. 19). Meanwhile, the biggest fruit weight of 56g was recorded with Dandino variety treated to 1.5 kg B ha^{-1}.

4.3.4.7 Effect of Boron Rates on Marketable Fruit Yield

The effect of varieties over treatments on fruit yield was significant (P = 0.05) at Samaru in 1993 and at Samaru and Kadawa in 1994 (Table 36). Variety Dandino out-yielded Roma VF by margins of 27.5 and 11.9% in 1993; 19.1 and 33.5% in 1994 at Samaru, and Kadawa respectively, though, varietal difference was not observed at Kadawa in 1993. The higher fresh fruit yield of Dandino is attributed to its higher number of leaves at flowering.

Application of B significantly increased the yield of fresh tomato fruit at Samaru and Kadawa in 1993 and 1994 (Table 36). The yield of tomato fruit increased as the B rates increased up to 2 kg B ha^{-1}, after which there was a corresponding decrease with increasing rates. Similar findings have been reported by Aduayi (1978), Pandita et al (1979) and Adelana (1986).

In 1993, the highest yield of tomato in each of the trial, were obtained at 1 kg B ha^{-1} with increase of 165.0 and 128.7% above the control at Samaru and Kadawa respectively (Table 36).

In 1994, the highest fresh fruit yield were obtained at 1 kg

B ha^{-1} at Samaru and 1.5 kg B ha^{-1} at Kadawa. These accounted for increase of 177.9 and 136.3% above the contro.

The highest yield of 28.18 tons ha^{-1} was recorded at Samaru in 1993, despite the higher number of leaves, flowers and fruits previously recorded in 1994 trials. The discrepancy could be due to environmental factors as suggested Snyder and Carlson (1984) who reported that in considering the yield of tomato plant, there is need to account for environmental factors such as relative humidity, temperature and rainfall.

Temperature and relative humidity were optimal during the trial period (1993 & 1994) but in 1994, there was excessive rainfall at the two sites and it was worse at Kadawa (Appendix D). These reasons could account for slightly low yield obtainable at Samaru.

Further more, the Kadawa trial of 1994 was established late as the seedlings were washed away with the excessive rainfall.

High significant (P = 0.01) interaction existed between boron rates and varieties in all the trials with regards to fruit yield except at Kadawa in 1994 (Table 37).

A combined analysis over locations showed that in 1993 boron rates; varieties, boron rates x varieties were significant at (P = 0.01) while location x boron rates and location x varieties were significant at (P = 0.05). Meanwhile the interaction between location x variety x boron rates was not significant (Appendix C).

Table 36: Effect of Variety and boron rates on marketable fruit yield (tons ha^{-1}) of tomato at Samaru and Kadawa under rainfed condition in 1993 and 1994

Treatment	1993			1994		
	Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
Variety						
Roma VF	15.3b	12.6b	14.0	15.1b	14.8b	15.0
Dandino	19.5a	14.1a	16.8	17.9a	19.8a	18.9
LSD (0.05)	1.7	NS		2.4	2.5	
Boron Rates (Kg B ha^{-1})						
0	10.6c	8.8cd	9.7	9.2d	11.5cd	10.4
0.5	20.5b	14.7b	17.6	18.0bc	15.3bc	16.7
1.0	28.2a	20.1a	24.2	25.5a	23.2a	24.4
1.5	23.7b	18.3a	21.0	22.8ab	27.2a	25.0
2.0	13.8c	11.4bc	12.6	16.3c	16.9b	16.6
2.5	7.5d	6.7d	7.1	7.2d	9.6d	8.4
LSD (0.05)	3.0	3.3		4.1	4.3	

Means in a given column followed by similar letter(s) are not significantly different at P = 0.05, using DMRT

Table 37: Effect of Variety X boron rates interaction on marketable fruit yield of tomato at Samaru and Kadawa under rainfed condition in 1993 and 1994

Treatment (kg Bha^{-1})	Variety	1993			1994		
		Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
0		8.6hijk	7.4hijk	8.0	7.7hi	9.1	8.4
0.5		13.3fg	12.0efg	12.7	12.6fg	12.9	12.7
1.0	Roma VF	22.2d	16.0cd	19.1	19.8cd	20.0	19.9
1.5		26.6bc	21.5ab	24.1	25.6ab	23.4	24.5
2.0		14.5f	12.4def	13.5	18.3cde	15.7	17.0
2.5		6.3jkl	5.8hijk	6.1	6.5ki	7.7	7.1
0		12.7ghi	10.2fghi	11.5	10.7fgh	13.9	12.3
0.5		27.6b	17.3bc	22.5	23.5bc	17.8	20.7
1.0	Dandino	34.2a	23.4a	28.8	31.2a	26.4	28.8
1.5		20.7de	15.2cde	18.0	19.9cd	31.1	25.5
2.0		13.1efgh	10.4fgh	11.8	14.4def	18.1	16.3
2.5		8.7hij	7.7hij	8.2	7.9ghi	11.5	9.7
LSD (0.05)		4.3	4.6		5.8	NS	

Means in a given column followed by similar letters are not significantly different at P = 0.05, using DMRT.

In 1994, the result of combined analysis over locations shows that boron rates, variety, and boron rates x variety were highly significant (P = 0.01). While interaction between locations x boron rates x variety was significant at 5% level. The interaction between location treatment and location x variety were not significant at 5% level (Appendix C).

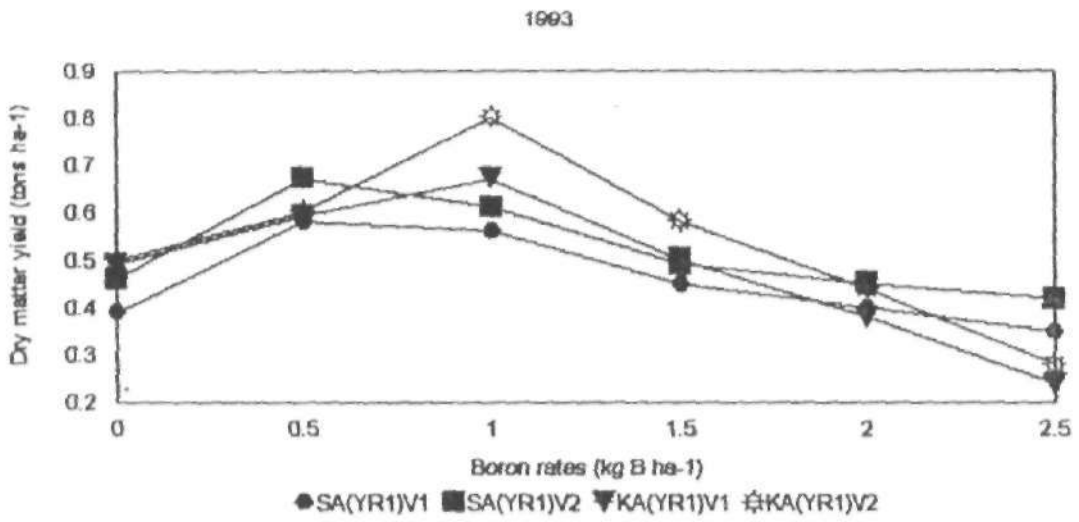
4.3.4.8 Effect of Boron Rates on Dry Matter Yield of Tomato Plants

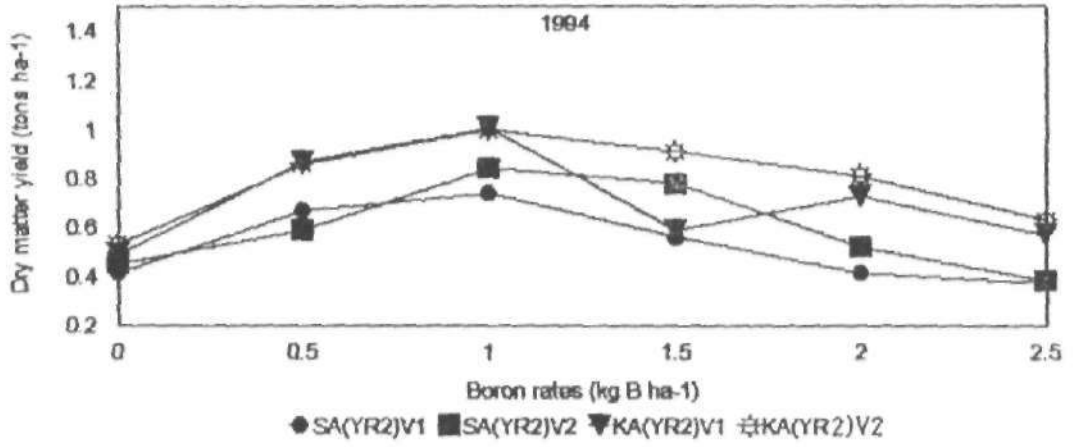
The effect of boron rates on varieties was only significant (P = 0.05) at Samaru in 1994. However, variety Dandino consistently produced higher dry matter yield (DMY) than Roma VF in each of the trials (Fig. 20). The percentage increase of DMY of Dandino over Roma VF was to the tune of 12.7 and 11.5% in 1993, 12.7 and 13.4% in 1994 at Samaru and Kadawa respectively.

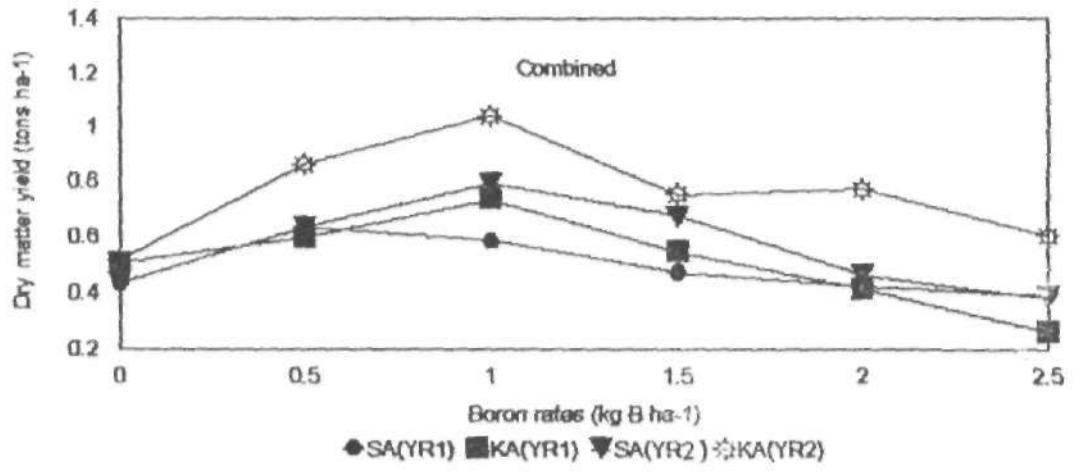
High significant differences (P = 0.01) existed among the mean dry matter yield. Plants treated to 1.0 kg B ha^{-1} gave the highest DMY of tomato plants at Samaru and Kadawa in 1994, whereas in 1993, the highest DMY for each trial were recorded with plants treated to 0.5 and 1.0 kg B ha^{-1} at Samaru and Kadawa respectively (Fig. 20). The significant response of DMY to application of B was due to response of no of leaves to B application, as the former contributes to the DMY (Thomas et al 1973).

The least DMY was obtained with plants treated to 2.5 kg B ha^{-1} in each of the trials except at Kadawa in 1994 where the control (0 kg B ha^{-1}) gave the least DMY.

Fig. 20. Dry matter yield as influenced by variety and rates of boron at Samaru and Kadawa under rainfed conditions in 1993 and 1994.







The result of this work corroborated with the report of Chude (1983) who got maximum DMY when 1.0 mg kg^{-1} was applied to two cacao varieties.

The interaction between treatments and variety on DMY was not significant at 5% (Fig. 20).

4.3.4.9 Effect of Boron Rates on the Concentration of Boron in the Plant Tissue

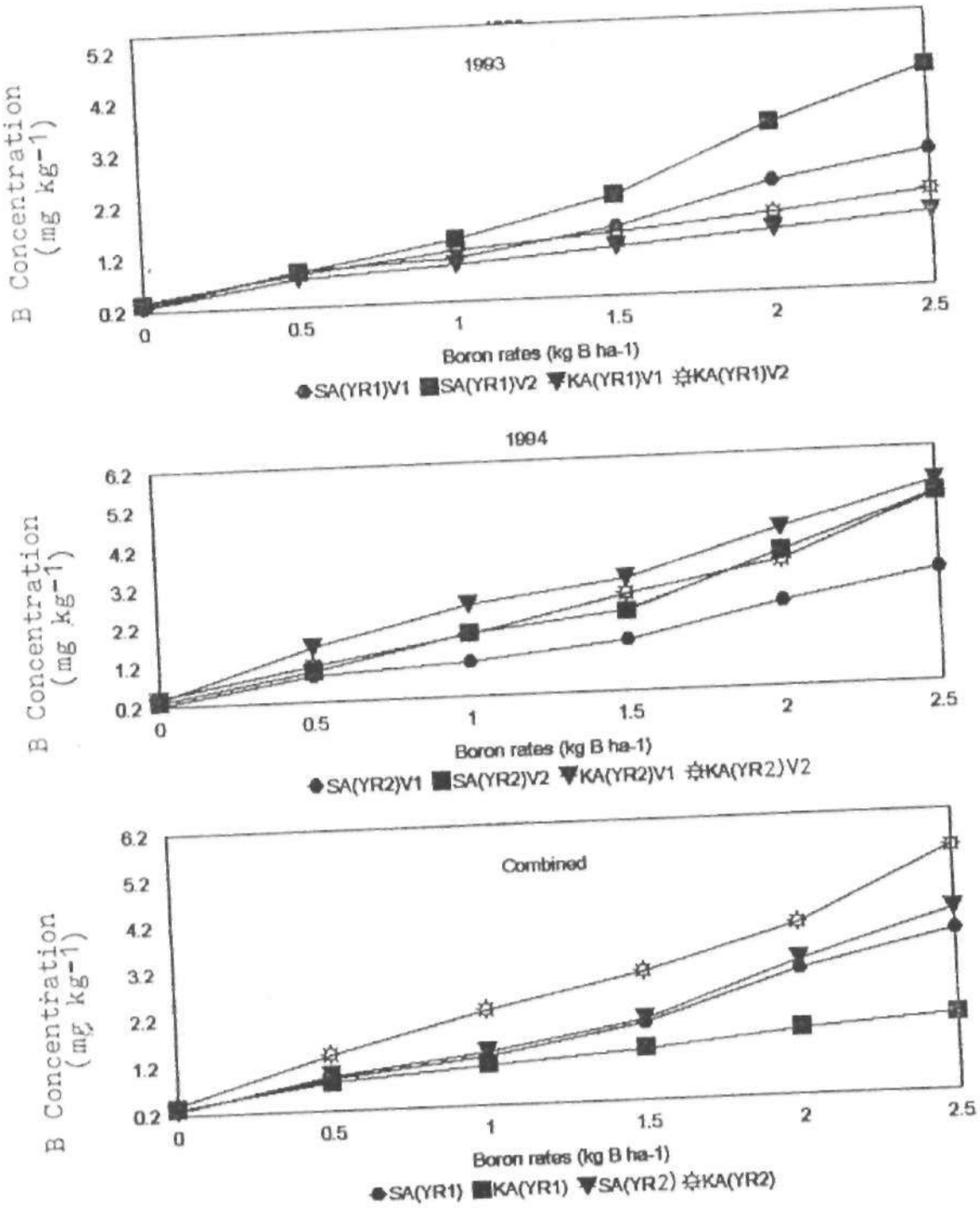
The effects of boron rates over variety on B concentration was significant (P = 0.01) at Samaru and Kadawa in both years (Fig. 21). This signifies that the two varieties differ in their ability to absorb and utilize applied B. Hence the two varieties responded to B treatments differently, with Dandino having the higher concentration in each of the trials except in 1994 at Kadawa, where Roma VF recorded higher B concentration (Fig. 21).

Application of B significantly increased B concentration of tomato plant tissue with 2.5 kg B ha^{-1} treatment producing the highest B concentration (Fig. 21).

The boron concentration recorded for both years at Samaru ranged from 0.26 to 3.60 mg kg^{-1} with a mean of 1.84 mg kg^{-1}, while for Kadawa trials, B concentration ranged from 0.32 to 5.42 mg kg^{-1} with a mean of 1.90 mg kg^{-1}.

The values of the B concentration recorded in this study were low compared with the ones obtainable from Literature. Drews and Frank (1980a) got a range of 30-80 mg kg^{-1} and pointed out that a range of 30-35 mg kg^{-1} B leaf content is adequate for tomato plants.

Fig. 21. Boron concentration in plant tissue as influenced by variety and rates of boron at Samaru and Kadawa under rainfed conditions in 1993 and 1994.



The low content of B concentration in plant tissue obtained in this study could be due to leaching as Borax fertilizer is soluble and it is also capable of reversing into insoluble forms (adsorption). However, plants containing B concentration in the range of 1.035 to 2.18 mg kg^{-1} gave the highest fruit yield in the trials. According to Shorrocks (1974), Adams et al (1978), a range of less than 10 mg kg^{-1} is deficient; whereas, Smilde et al (1968) reported a range of 5 to 11 mg kg^{-1} as deficient.

The interaction of boron x variety on B concentration was only significant at Samaru in both years, but not at Kadawa (Fig. 21).

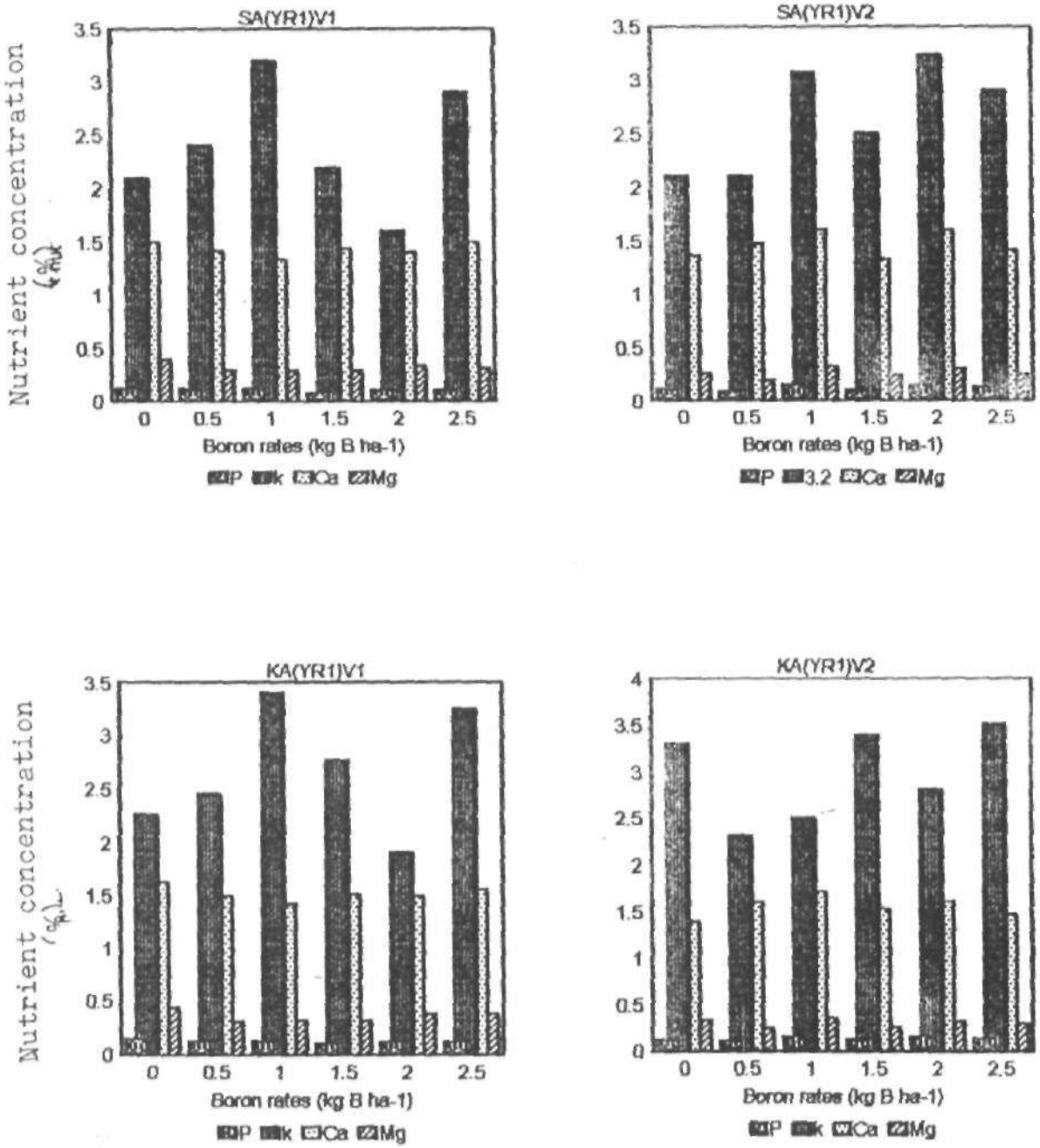
4.3.4.10 Effect of Boron Rates on the Concentration of Macronutrients

Phosphorus (P)

The effect of B rates over varieties was only significant (P = 0.01) at Samaru and Kadawa in 1994 but not in 1993 (Fig. 22 & 23). P concentration for variety Dandino was slightly higher than Roma VF in 1993, whereas the reverse was the case in 1994. The reason for this discrepancy could be due to the soil P level (Table 16) and the type of NPK fertilizer used for the trials.

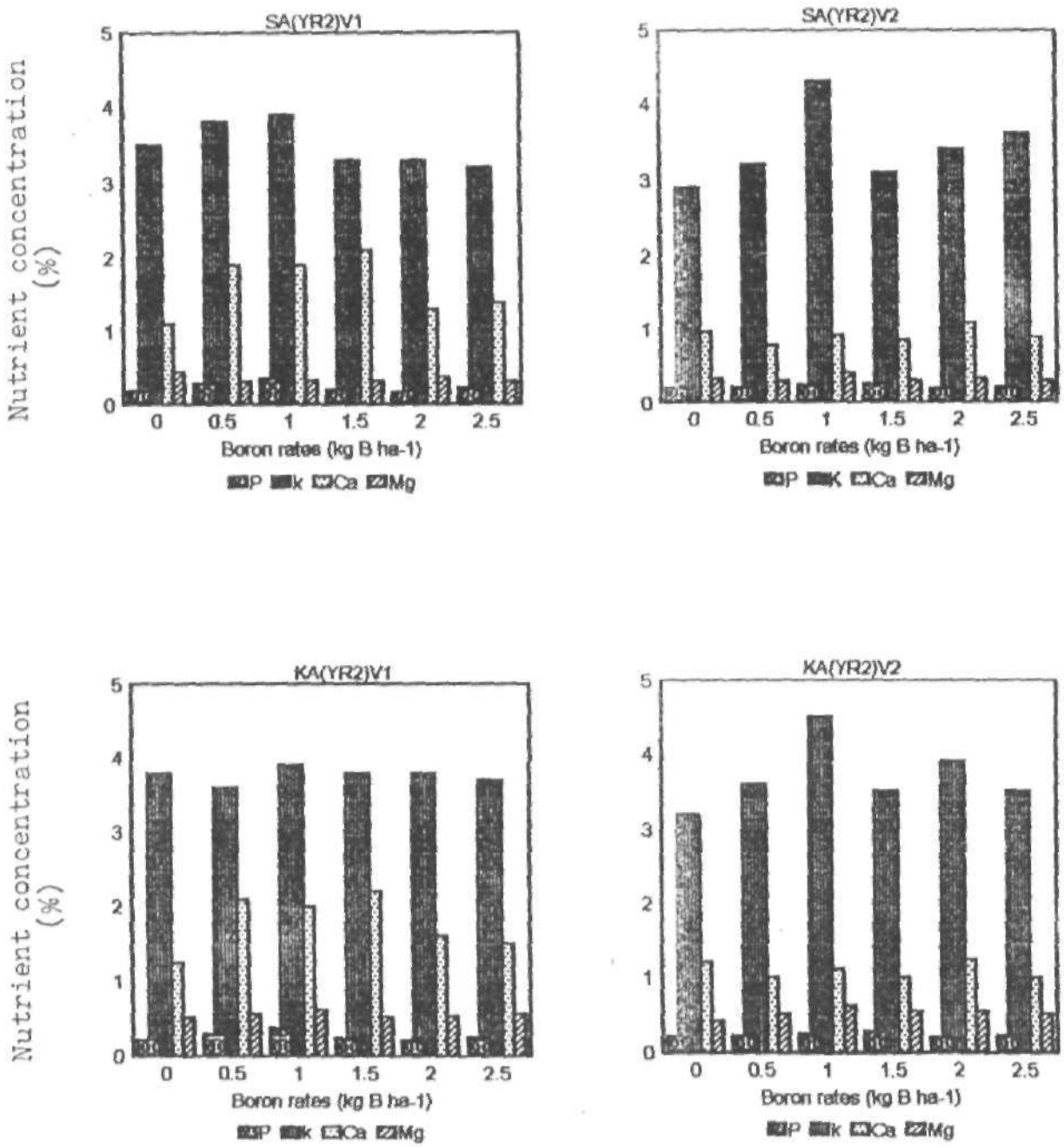
In 1993, application of B rates had significant (P = 0.05) effect on P concentration at Samaru whereas in 1994, the effect was significant (P = 0.01) at Samaru and Kadawa (Fig. 24). However, the highest P concentration in the trials were recorded at B rates of between 1.0 and 1.5 kg ha^{-1}. Massey and Winsor (1980), Purvis and Carolus (1964) had emphasised the importance of P in the

Fig. 22. Plant nutrient concentration as influenced by variety and boron rates at Samaru and Kadawa under rainfed conditions in 1993



KEY:
SA = Samaru YR1 = Year 1 KA = Kadawa V1 = Variety V2 = Variety 2

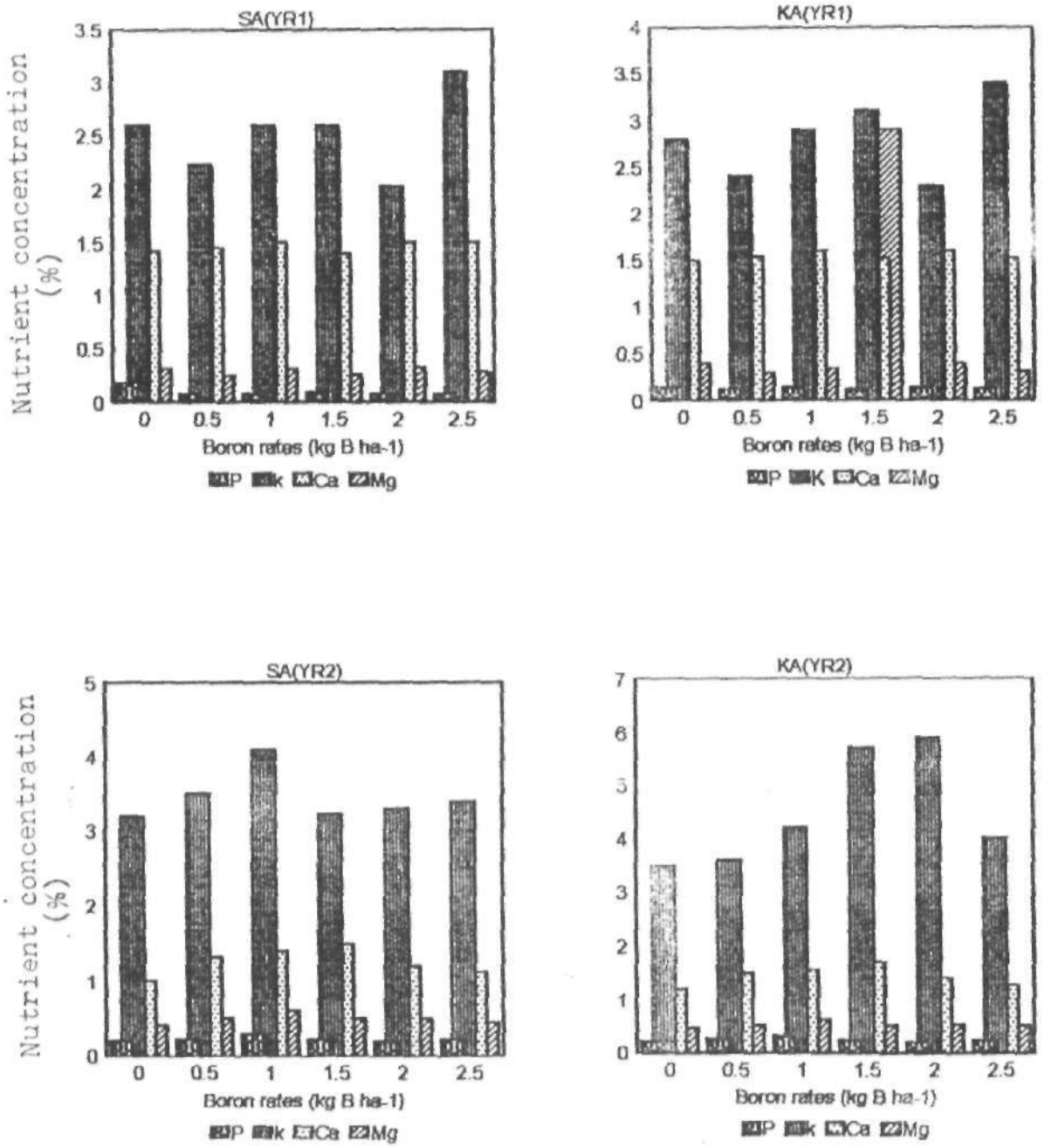
Fig. 23. Plant nutrient concentration as influenced by variety and boron rates at Samaru and Kadawa under rainfed conditions in 1994.



KEY:

SA = Samaru YR2 = Year 2 KA = Kadawa V1 = Variety 1 V2 = Variety 2

Fig. 24. Effect of boron rates on macronutrient concentration in plant tissue at Samaru and Kadawa in 1993 and 1994.



KEY:

SA = Samaru YR2 = Year 2 KA = Kadawa

nutrition of tomatoes.

The interaction between variety and B rates is only significant (P = 0.05) at Kadawa in 1993; Samaru and Kadawa in 1994.

Potassium (K)

Boron rates did not significantly (P = 0.05) influenced K concentration in the two varieties in any of the trials (Fig. 22). However, variety Dandino proved more superior than Roma VF by having higher K concentration.

The effect of B rates on K concentration was not significant (P = 0.05) at Samaru and Kadawa in both years (Fig. 24). K uptake in the plant tissue which varied from 2.0 to 5.9% is within the range recommended by Roorda et al (1981) for healthy tomato plants. However, K concentration was higher in 1994 trials than 1993. This could be due to increase DMY obtained in 1994.

Potassium concentration for the treatments did not follow a specific trend, however, what is evident is that high values of K concentration were obtained at the highest rate of B in 1993 trials. Similar findings was reported by Reeve and Shive (1944) for tomato plants.

The interaction between variety and B rates on K concentration was only significant at Samaru in 1993.

Calcium (Ca)

Varietal effect was significant (P = 0.01) with boron application at Samaru and Kadawa in 1994. Variety Dandino proved more superior in calcium concentration in 1993, but not in 1994 when Roma VF proved more superior (Fig. 22 & 23).

Application of B rates had significant effect on Ca concentration in 1994 at both locations, but not in 1993 (Fig. 24). The reason for the disparity in the result could be due to the different soil type and inherent fertility status of the soils of the two locations. Also the strong relationship that has been reported in Literature that exist betwen Ca and B was not observed in this study.

The interaction between variety and B rates on Ca concentration was significant (P = 0.01) at Samaru in 1993 and 1994 and also at Kadawa in 1993 (Fig. 22 & 23).

Magnesium (Mg)

Varietal differences in magnesium concentration was significant (P = 0.05) at Samaru and Kadawa in 1993 but not in 1994 (Fig. 22). However, variety Roma VF proved superior in Mg concentration in each of the trials.

The effect of B rates on Mg concentration was significant (P = 0.05) at Samaru and Kadawa in 1993 and 1994 (Fig. 24). This signifies the importance of Mg in the nutrition of tomatoes (Purvis and Carolus 1964).

The interaction between B rates and variety was only significant at Samaru in 1993 (Fig. 22 & 23).

4.3.4.11 Effect of Boron Rates on the Concentration of Micronutrients (Zn, Mn, Fe and Cu)

Zinc (Zn)

The effect of B rates over variety on Zn concentration was significant (P = 0.01) in each of the trials (Fig. 25). However, variety Roma VF contained more Zn in the plant tissue than Dandino.

Application of B significantly (P = 0.01) increased concentration of Zn in tomato plants (Fig. 26). The Zn concentration values which varied from 150 to 292 mg kg^{-1} are within the sufficiency range cited by Adams and Grimmet (1981) for the growth of tomato plants. The high significant effect of B rates on Zinc concentration of tomato plants in this study signifies the importance of Zn in the nutrition of tomato.

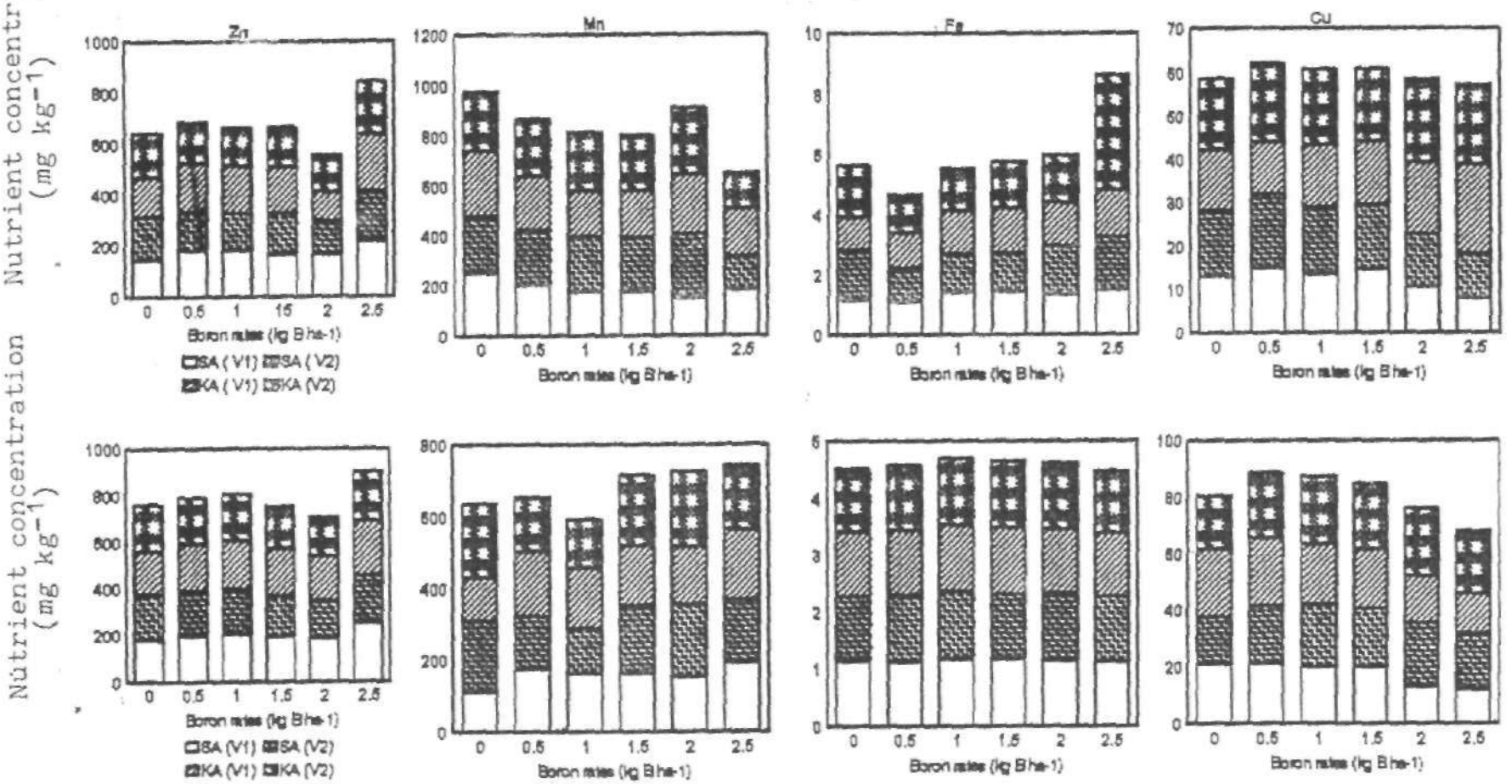
The interaction effect of B rates and variety on the Zn concentration was significant (P = 0.05) in 1993 but not in 1994 (Fig. 25).

Manganese (Mn)

The effect of B treatment over variety on Mn concentration was significant (P = 0.01) at Samaru and Kadawa in 1994 but not in 1993 (Fig. 25). However variety Dandino recorded more Mn concentration than Roma VF.

B rates had significant (P = 0.01) effect on Mn concentration at Samaru and Kadawa in 1993 and 1994 (Fig. 26). The Mn concentration values which varied from 144 to 252 mg kg^{-1} is within the sufficiency range of 50 to 500 mg kg^{-1} recommended by Jones

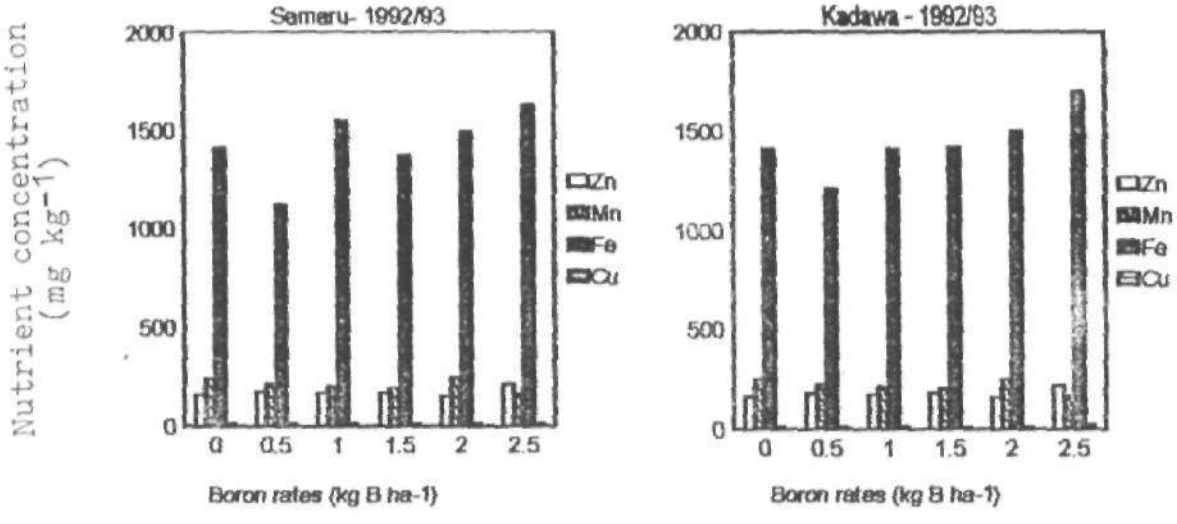
Fig. 25. Micronutrient concentration as influenced by variety and boron rates at Samaru and Kadawa in 1993 and 1994.

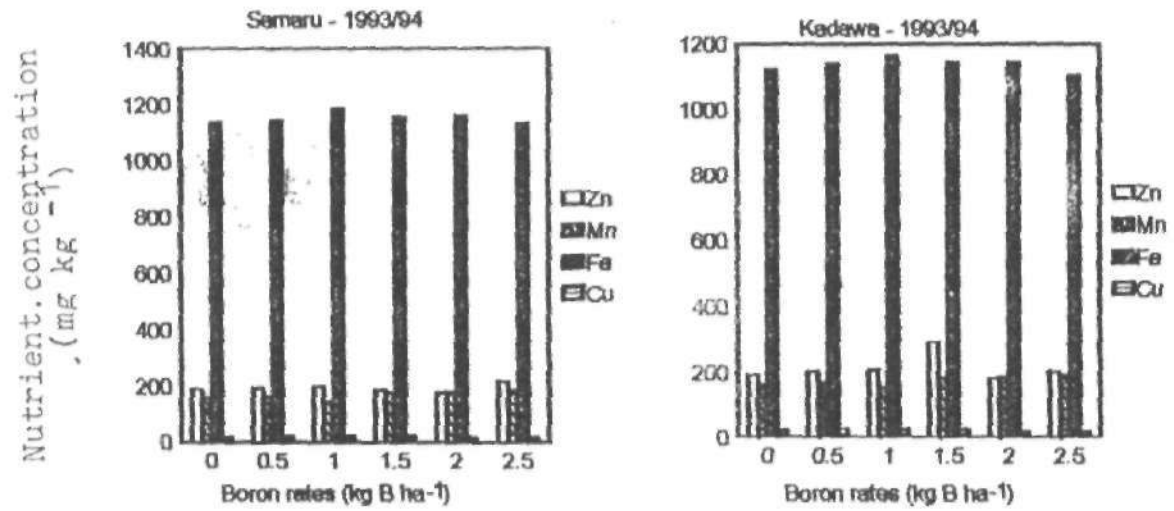


KEY:

SA = Samaru KA = Kadawa V1 = Variety 1 V2 = Variety 2

Fig. 26. Effect of boron rates on micronutrient concentration in plant tissue at Samaru and Kadawa in 1993 and 1994.





(1972); and a range of 55 to 220 mg kg^{-1}, 0 mg kg^{-1} obtained in tomato healthy plants (Roorda et al 1981).

The interactive effect of B rates x variety on Mn concentration was significant (P = 0.01) only in 1994 at both locations (Fig. 25).

Iron (Fe)

Although the Fe concentration in the tomato plants were high, there was no significant varietal influence of B rates on Fe concentration (Fig. 25). Variety Dandino recorded higher Fe concentration than Roma VF in both years.

The effect of B rates on Fe concentration was only significant (P = 0.05) at Samaru in 1994 (Fig. 26). The Fe concentration varied from 1104 to 1697 mg kg^{-1}. This range is above the sufficiency range recommended by Neubert et al (1970). Nevertheless, the values obtained in this study is within the range obtained by Agbenin (1987) who worked on cowpea with similar soils. The high values of Fe concentration in the plants could be due to soil Fe and fertilizer contamination. It has also been reported that tropical soils are high in Fe (Pam 1991).

The non significant (P = 0.05) effect of B rates on Fe concentration corroborates the work of Gomez et al (1981).

The interaction between B rates and variety on Fe concentration was only significant (P = 0.05) at Samaru in 1994 (Fig. 25).

Copper (Cu)

Varietal differences in copper concentration was not significant (P = 0.05) in none of trials (Fig. 25). Although variety Dandino absorbs more Cu than Roma VF.

The effect of B rates on copper concentration was not significant at Samaru and Kadawa in 1993 and 1994 (Fig. 26). The Cu concentration which varied from 12.6 mg kg^{-1} to 23.5 mg kg^{-1} are within the sufficiency range of 5-20 mg kg^{-1} recommended by Jones (1972).

The effect of variety x boron rates interaction on Cu concentration was significant (P = 0.05) at Samaru and Kadawa in 1993 but not in 1994 (Fig. 25).

4.3.4.12 The Effect of Boron Rates on Boron Uptake in Tomato Plant

Varietal differences in B uptake were significant (P = 0.05) at Samaru and Kadawa in 1993 and at Samaru in 1994 (Table 38). Variety Dandino recorded higher B uptake in the trials than Roma VF.

Boron uptake increased significantly (P = 0.05) with the application of B at Samaru and Kadawa in 1992/93 and 1993/94 as shown in Table 39. Plants treated to 2.5 and 1.0 kg B ha^{-1} produced the highest B uptake of 1.414 and 0.771 g ha^{-1} at Samaru and Kadawa respectively in 1993. Similarly, in 1994, plants treated to 2.5 kg B ha^{-1} recorded the highest B uptake of 1.54 and 3.32 gha^{-1} at Samaru and Kadawa respectively.

The interaction between boron rates and variety (Table 39)

were all significant at Samaru and Kadawa in both years. Dandino plants treated to 2.5 and 1.0 kg B ha^{-1} produced the highest B uptake of 1.803 and 0.938 gha^{-1} at Samaru and Kadawa respectively in 1993. Similarly, in 1994, Dandino plants treated to 2.5 kg B ha^{-1} recorded highest yield of 1.940 and 3.680 gha^{-1} at Samaru and Kadawa respectively.

The values of B uptake recorded in this study are low compared with the result of other workers (Alvarez-Tinaut et al 1979 and Gulati 1980). This could be due to low B concentrations in the plant tissues (Section 4.3.4.9).

Table 38: Effect of Variety and boron rates on boron uptake (gha^{-1}) in tomato plants at Samaru and Kadawa under rainfed condition in 1993 and 1994

Treatment	1993			1994		
	Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
Variety						
Roma VF	0.620b	0.439b	0.53	0.744b	2.02a	1.382
Dandino	0.984a	0.625a	0.805	1.26a	1.99a	1.63
LSD (0.05)	.134	.119		.362	NS	
Boron Rates (Kg B ha^{-1})						
0	0.123d	0.157e	0.140	0.106e	0.192e	0.149
0.5	0.537c	0.461d	0.500	0.569d	1.174d	0.872
1.0	0.715bc	0.771a	0.743	1.05b	2.25c	1.65
1.5	0.825b	0.691ab	0.758	1.30abc	2.20c	1.75
2.0	1.200a	0.682abc	0.941	1.45ab	2.92b	2.19
2.5	1.414a	6.485bc	0.950	1.54a	3.32a	2.43
LSD (0.05)	.283	.210		.382	.351	

Means in a given column followed by similar letter(s) are not significantly different at P = 0.05, using DMRT

Table 39: Effect of Variety X boron rates interaction on bron uptake in tomato plants at Samaru and Kadawa under rainfed condition in 1993 and 1994

Treat-ment (kg Bha^{-1})	Variety	1993			1994		
		Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
0		0.107ghij	0.134fghijk	0.12	0.089i	0.167i	0.128
0.5		0.510defghi	0.432defghi	0.471	0.576fgh	1.39gh	0.983
1.0	Roma VF	0.594cdefgh	0.604bcd	0.600	0.813efg	2.62bcde	1.720
1.5		0.616cdefg	0.565bcdef	0.591	0.835def	1.970fg	1.403
2.0		0.868cde	0.516cdefgh	0.692	1.00cde	3.030a	2.010
2.5		1.024bcd	0.384efghij	0.704	1.15cd	2.970bc	2.06
0		0.138ghij	0.179fghijk	0.159	0.123i	0.220i	0.172
0.5		0.563cdefgh	0.490defgh	0.527	0.560fgh	0.960h	0.76
1.0	Dandino	0.837cdef	0.938a	0.888	1.280b	1.870g	1.58
1.5		1.032ab	0.817ab	0.925	1.770ab	2.440bcdef	2.10
2.0		1.528ab	0.740abc	1.134	1.890ab	2.820bcd	2.36
2.5		1.803a	0.585bcde	1.194	1.940a	3.680a	2.81
LSD (0.05)		0.48	0.64		0.36	0.58	

Means in a given column followed by similar letters are not significantly different at P = 0.05, using DMRT.

4.3.4.13 Simple Correlation Among Yield Parameters and Nutrient Concentration in 1993 Rainfed Trials

At Samaru, the number of leaves correlated negatively with the number of days to flowering (r = -0.349*) (Table 40) B concentration (r = -0.381*), but positively with number of flowers (r = 0.619**), fruit number (r = 0.730**), weight fruit (r = 0.761**), fruit yield (r = 0.803**) and DMY (r = 0.610**).

At Kadawa, number of leaves correlated with number of flowers (r = 0.625**), number of fruits (r = 0.645**), fruit yield (r 0.742**) and DMY (r = 0.616**) as shown in Table 40. The relationship between number of leaves and other parameters emphasized the importance of number of leaves in the determination of these parameters.

Number of days to 50% flowering increased, as the number of fruit decreased (r = -0.454**) and Na concentration increased (r = 0.310*) at Samaru. At Kadawa number of days to 50% flowering correlated significantly with the number of flowers (r = -0.394*), number of fruit (r = -0.606**) and yield (r = -0.391*).

The number of flowers correlated significantly with number of fruit (r = 0.763**), weight fruit (r = 0.752**), fruit yield (r = 0.826**) and DMY (r = 0.306*) at Samaru. Similarly, at Kadawa, number of flowers correlated significantly (Table 40) with number of fruit (r = 0.781**), weight fruit (r = 0.807**), fruit yield (r = 0.846**), DMY (r = 0.739**) and Ca concentration (r = 0.331**). Number of flowers correlated negatively with Zn concentration at Samaru and Kadawa (r = -0.412** and -0.365* respectively) as shown in Table 40. This result corroborates the report of Adams and

Table 40: Simple correlation matrix (r) among yield parameters and nutrient concentration in 1993 trials at Sanaru

	No of leaves	No of days to 50% Flowering	No of flowers per plant	No of fruits per plant	Fruit weight	Fruit yield	Dry matter yield	Nutrient Concentration								
								B	K	Na	Ca	Mg	Zn	Mn	Fe	Cu
Number of leaves	-															
Number of days to 50% flowering	-0.349*	-														
Number of flowers per plant	0.619**	-0.273	-													
Number of fruit per plant	0.732**	-0.454**	0.763**	-												
Fruit weight	0.761**	-0.019	0.752**	0.737**	-											
Fruit yield	0.803**	-0.269	0.826**	0.886**	0.924**	-										
Dry matter yield	0.601**	-0.177	0.306*	0.294*	0.442**	0.429**	-									
B Concentration	-0.381**	0.157	-0.129	-0.304*	-0.220	-0.270	-0.328*	-								
K "	-0.128	0.273*	-0.173	-0.279*	-0.106	-0.233	-0.039	0.174	-							
Na "	-0.206	0.310*	0.049	-0.189	0.065	-0.097	-0.364**	-0.156	0.203	-						
Ca "	0.228	0.063	0.020	0.080	0.026	0.061	0.170	0.113	-0.382	-0.142	-					
Mg "	-0.067	-0.250	-0.239	-0.060	-0.307*	-0.165	-0.206	-0.026	0.199	0.013	0.401**	-				
Zn "	-0.281*	-0.129	-0.412**	-0.346*	-0.465**	-0.416**	-0.209	0.217	0.328*	-0.122	-0.330*	-0.075	-			
Mn "	-0.052	0.122	-0.033	-0.110	0.051	0.001	0.035	-0.201	-0.326*	0.379*	0.192	0.464**	-0.553**	-		
Fe "	-0.033	0.245	-0.252	-0.266	-0.111	-0.234	-0.095	0.340*	0.213	-0.073	0.113	-0.128	0.213	-0.312*	-	
Cu "	-0.006	0.191	-0.088	-0.072	0.006	-0.037	-0.068	0.305*	0.128	-0.020	-0.132	-0.074	-0.135	-0.155	0.218	-
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.224	0.137	0.216	0.338*	0.559**	-0.169	0.436**	-0.058	0.1

Table 40 contd: Simple correlation matrix (r) among yield parameters and nutrient concentration in 1993 trials at Kadawa

	No of leaves	No of days to 50% Flowering	No of flowers per plant	No of fruits per plant	Fruit Size	Fruit yield	Dry matter yield	← Nutrient Concentration → B	K	Na	Ca	Mg	Zn	Mn	Fe	Cu	P
Number of leaves	-																
Number of days to 50% flowering	-0.290*	-															
Number of flowers per plant	0.625**	-0.394**	-														
Number of fruits per plant	0.760**	-0.607**	0.781**	-													
Fruit weight	0.645**	-0.114	0.807**	0.684**	-												
Fruit yield	0.742**	0.391**	0.846**	0.912**	0.906**	-											
Dry matter yield	0.615**	-0.201	0.740**	0.802**	0.647**	0.650**	-										
B Concentration	-0.112	0.030	-0.055	-0.174	-0.021	-0.091	-0.413**	-									
K "	-0.224	-0.135	-0.131	-0.156	-0.101	-0.124	-0.061	0.256	-								
Na "	-0,264	-0.067	0.053	-0.079	-0.112	-0.112	-0.142	-0.101	-0.101	-							
Ca "	0.149	-0.059	0.331*	0.096	0.214	0.199	0.241	0.129	-0.345*	0.155	-						
Mg "	-0.179	-0.153	-0.158	-0.057	-0.346**	-0.169	-0.043	0.321*	0.022	0.493**	0.144	-					
Zn "	-0.252	-0.136	-0.365**	-0.280	-0.381*	-0.286*	-0.476**	0.273*	0.194	-0.417**	-0.434**	-0.221	-				
Mn "	-0.089	0.007	0.112	-0.057	-0.002	-0.056	0.207	-0.384**	-0.202	0.570**	0.282*	0.432**	-0.593**	-			
Fe "	-0.016	0.226	-0.135	-0.229	-0.056	-0.158	-0.296*	0.461**	0.146	-0.296*	-0.147	-0.260	0.302*	-0.351*	-		
Cu "	0.108	0.045	0.041	-0.003	0.053	0.009	0.002	0.176	0.151	-0.017	-0.054	-0.183	-0.090	-0.182	0.166	-	
P "	-0.057	0.120	-0.028	-0.076	0.064	-0.053	-0.606	0.032	0.076	0.165	0.253*	0.475**	-0.242	0.423**	-0.201	0.162	-

Winsor (1974).

The number of fruit increased as the B and Zn concentration decreased (r = -0.304* and -0.346* respectively); but increased with increase in weight fruit (r = 0.737**) and fruit yield (r = 0.886**) at Samaru. Similarly at Kadawa, number of fruits correlated with weight fruit (r = 0.684**) fruit yield (r = 0.911**) and DMY (r = 0.606**).

The weight fruit increased as the Mg and Zn concentrations decreased (r = -0.307* and -0.465** respectively) at Samaru, and also at Kadawa (r = -0.345* and -0.381** respectively). High significant correlation (Table 40) existed between weight fruit and tomato fruit yield (r = 0.924**), DMY (r = 0.441**) at Samaru, and at Kadawa (r = 0.906** and 0.647** respectively). The relationship between weight fruit and Mg and Zn concentrations implies that these nutrients are important for the modification of weight fruit (Adatia and Winsor, 1971 and Winsor and Adams 1986).

Fruit yield correlated negatively with Zn concentration (r = -0.416**) at Samaru, but positively with DMY (r = 0.429** and 0.650**) at Samaru and Kadawa respectively.

Dry matter yield (DMY) increased with decrease in B and Na concentrations (r = -0.328*, -0.364* respectively) at Samaru; B and Zn concentrations at Kadawa (r = 00.411** and -0.476**).

Boron (B) concentration correlated with Fe and Cu concentration (r = 0.340; 0.305* respectively) at Samaru but negatively with Mg (r = -0.321*) Mn (r = -0.348*) and Fe concentrations (r = -0.441**) at Kadawa (Table 40).

Potassium concentration correlated with Zn (r = 0.328*) and Mn (r = -0.326*) concentration at Samaru, but correlated with Ca concentration (r = -0.341*) at Kadawa.

Sodium (Na) concentration correlated with Mn concentration (r = 0.379*) at Samaru; Zn, Mg, and Mn concentrations (r = -0.417**, 0.451** and 0.570** respectively) at Kadawa.

The Ca concentration correlated with Mg (r = 0.401**), P (r = 0.338*) concentrations at Samaru; and Zn concentration (r = -0.434**) at Kadawa (Table 40).

At Samaru and Kadawa, the Mg concentration correlated with Mn (r = 0.464**; 0.432** respectively) and P concentrations (r = 0.559** and 0.475** respectively).

Zinc (Zn) concentration increased as the Mn concentration decreased (r = -0.559**) at Samaru and also at Kadawa (r=-0.593**). The Mn concentration correlated negatively with Fe (r = -0.312* and -0.351*) at Samaru and Kadawa. Phosphorus (P) concentration correlated with Mn concentration (r = 0.436** and 0.423** respectively) at Samaru and Kadawa (Table 40).

The relationship between the yield parameters and the nutrient concentrations signified the importance of these nutrients in the nutrition of tomato crop. This result is in line with the report of other workers (Graves et al 1978 and Penalosa et al 1987). The negative relationship between some nutrients concentrations corroborated with the report of Adams and Winsor (1974), (1979) and Adams and Grimmett (1981).

4.3.4.14 Simple Correlation Among Yield Parameters and Nutrient Concentration in 1994 Rainfed Trials

The number of leaves increased with decrease in number of days to 50% flowering (r = -0.524*) but increase in number of flowers (r = 0.716**), fruit weight (r = 0.788**), fruit yield (r = 0.868**), DMY (r = 0.543**), Mg and Fe concentrations (r = 0.331* and 0.507** respectively) at Samaru (Table 41).

At Kadawa, number of leaves correlated also negatively with number of days to 50% flowering (r = -0.327*), and B concentration (r = -0.339*), but positively with number of flowers (r = 0.860**), number of fruits (r = 0.741**), fruit weight (r = 0.736**), fruit yield (r = 0.747**) DMY (r = 0.587**), K and Fe concentrations (r = 0.312* and 0.434** respectively) as shown in Table 41.

The number of days to 50% flowering correlated at both Samaru and Kadawa with number of fruits (r = -0.487**, -0.392*), fruit yield (r = -0.368*, -0.310*), Ca concentration (r = -0.615**, -0.657**), Mg concentration (r = -0.354*, -0.342*) and P concentration (r = -0.380*, -0.387*) at Samaru and Kadawa respectively.

Number of flowers per plant correlated with number of fruits (r = 0.675**), fruit weight (r = 0.784**), fruit yield (r = 0.799**) DMY (r = 0.572**), Fe and Cu concentrations (r = 0.561** and 0.344*) at Samaru. Whereas at Kadawa number of flowers also correlated with number of fruits (r = 0.788**), fruit weight (r = 0.809**) DMY (r = 0.797**), K and Fe concentrations (r = 0.393* and 0.400** respectively as shown in Table 41. This result is in agreement with the report of Winsor et al 1967, Gould 1974 and

Table 41: Simple correlation matrix (r) among yield parameters and nutrient concentration in 1994 rainfed trials at Samaru

	No of leaves	No of days to 50% flowering	No of flowers per plant	No of fruits per plant	Fruit Size	Fruit yield	Dry matter yield	Nutrient Concentration: B	K	Na	Ca	Mg	Zn	Mn	Fe	Cu	P
Number of leaves	-																
Number of days to 50% flowering	-0.524**	-															
Number of flowers per plant	0.716**	-0.142	-														
Number of fruits per plant	0.756**	-0.487**	0.675**	-													
Fruit weight	0.769**	-0.187	0.785**	0.596**	-												
Fruit yield	0.869**	-0.369*	0.799**	0.797**	0.802**	-											
Dry matter yield	0.563**	-0.218	0.572**	0.579**	0.520**	0.600**	-										
B Concentration	-0.264	0.165	-0.228	-0.325*	-0.261	-0.269	-0.256**	-									
K "	-0.162	-0.190	0.103	0.117	0.056	0.089	0.056	0.022	-								
Na "	0.215	0.025	0.182*	0.045	0.343*	0.263	0.110	0.628**	0.077	-							
Ca "	0.182	-0.615**	-0.186	0.282*	-0.024	0.054	0.028	-0.198	0.156	-0.250	-						
Mg "	0.333*	-0.354**	0.174	0.378**	0.252	0.199	0.277**	0.065	0.143	0.109	0.349*	-					
Zn "	-0.151	-0.166	-0.166	-0.085	-0.313*	-0.219	-0.265	-0.004	-0.094	-0.091	0.231	0.014	-				
Mn "	-0.276*	0.151	-0.214	-0.245	-0.123	-0.327*	-0.248	0.397**	-0.304*	0.197	0.062	-0.146	0.247	-			
Fe "	-0....	-0....	-0....	-0....	-0....	-0....	-0....	-0....	0....	0....	-0....	-0....	-0....	-0....	-		
Cu "	0.291*	0.038	0.349*	0.281	0.265	0.242	0.412**	-0.067	-0.237	-0.238	-0.153	-0.232	-0.185	-0.202	0.245	-	
P "	0.267	-0.378**	0.128	0.457**	0.234	0.168	0.502**	-0.178	0.178	-0.231	0.439**	0.469**	0.243	0.264	0.099	0.279	-

Table 41 contd: Simple correlation matrix (r) among yield parameters and nutrient concentration in 1994 rainfed trials at Kadawa

	No of leaves	No of days to 50% flowering	No of flowers per plant	No of fruits per plant	Fruit Size	Fruit Yield	Dry matter yield	<---------- Nutrient Concentration ----------									
								B	P	Na	Ca	Mg	Zn	Mn	Fe	Cu	P
Number of leaves	-																
Number of days to 50% flowering	-0.327*	-															
Number of flowers per plant	0.860**	-0.290*	-														
Number of fruits per plant	0.761**	-0.352**	0.789**	-													
Fruit weight	0.736**	-0.245	0.809**	0.545**	-												
Fruit yield	0.747*	-0.310*	0.797**	0.351**	0.956**	-											
Dry matter yield	0.567**	-0.102	0.608**	0.431**	0.552**	0.511*	-										
B Concentration	-0.339*	-0.031	-0.231	-0.070	-0.134	-0.101	-0.050	-									
P "	0.312*	-0.119	0.395**	0.291*	0.222	0.250	0.297*	0.199	-								
Na "	-0.008	0.235	0.092	0.133	0.160	0.212	0.234	0.386**	0.369**	-							
Ca "	0.226	-0.457**	0.116	0.162	-0.145	0.024	0.063	0.122	0.361	-0.205	-						
Mg "	0.177	-0.342*	0.253	0.203	0.229	0.203	0.349*	0.160	0.250	0.111	0.227	-					
Zn "	-0.203	-0.216	-0.259	-0.334*	-0.387**	-0.345*	-0.093	0.229	-0.026	-0.078	0.257	0.335	-				
Mn "	-0.283	0.171	-0.225	-0.092	-0.012	-0.023	-0.077	0.295*	-0.280*	0.092	0.025	-0.079	0.024	-			
Fe "	0.434**	-0.166	0.400**	0.292*	0.156	0.215	0.382**	-0.181	0.026	0.060	0.185	0.233	-0.095	-0.229	-		
Cu "	0.136	0.067	0.053	0.046	0.180	0.099	0.144	-0.241	0.297*	0.076	-0.107	0.037	-0.244	-0.122	0.123	-	
P "	0.152	-0.367**	0.140	0.260	0.155	0.224	0.638**	-0.027	0.059	0.092	0.439**	0.467**	0.207	0.040	0.159	0.057	-

Adams et al (1978).

Number of fruits correlated with weight of fruit (r = 0.596**), fruit yield (r = 0.797**), DMY (r = 0.579**), B concentration (r = -0.325*) Mg, Fe and P concentration (r = 0.376*, 0.584** and 0.457** respectively) at Samaru. Similarly, at Kadawa, number of fruits correlated with fruit weight, (r = 0.845**), fruit yield (r = 0.950**) and DMY (r = 0.431**).

Fruit weight correlated with fruit yield (r = 0.850**) DMY (r = 0.520**) Na, Zn and Fe concentrations (r = 0.348*, -0.303* and 0.447** respectively) at Samaru. However at Kadawa, it correlated with fruit yield (r = 0.956**), DMY (r = 0.552**) and Zn concentration (r = -0.387*) as shown in Table 41.

At Samaru, fruit yield correlated with DMY (r = 0.599**) Fe concentration (r = 0.598**). Also at Kadawa, fruit yield correlated with DMY (r = 0.511**) and Zn concentration (r = 0.341**).

Dry matter yield (DMY) increased with increase in Cu and P concentrations (r = 9.411** and 0.500** respectively) at Samaru; Mg, Fe and P concentration (r = 0.549**, 0.382* and 0.438** respectively) at Kadawa.

Boron concentration correlated with Na and Mn concentrations (r = 0.628**, 0.397** respectively) at Samaru and Na concentration (r = 0.386*) at Kadawa.

Potassium concentration was related to Mn concentration (r = -0.305*) at Samaru and Na concentration at Kadawa (r = 0.365*) as shown in Table 41.

Calcium (Ca) concentration correlated (Table 41) with Mg and P concentrations (r = 0.345* and 0.435**) at Samaru and P concentration (r = 0.433**) at Kadawa. Magnesium concentration correlated with P concentration at Samaru and Kadawa (r = 0.484** and 0.467** respectively) (Table 41).

The various relationship observed in this study, agreed with the report of other researchers such as Adams and Winsor (1974) and Graves et al (1978). This study has also shown that B fertilizer exerted positive effect on growth and productivity of tomato crop. Also Elshaod et al (1980).

4.3.4.15 Effect of Boron Application on Ascorbic Acid (AA) Content of Tomato Fruits

The effect of boron (B) rates over variety on ascorbic acid (AA) contents was only significant at Samaru in 1993 (Table 42). However, variety Dandino produced fruits with higher ascorbic acid content in 1993 and 1994 at Samaru and Kadawa. This results agree with those of Gould (1974) and Brown (1979) who reported that the content of AA vary with varieties of tomato.

Boron application significantly increased the AA contents of tomato fruits at Samaru and Kadawa in 1993 and at Kadawa in 1994 (Table 42). The highest AA content were recorded at 1.5 and 1.0 kg B ha^{-1} at Samaru and Kadawa respectively in 1993. This accounted for increases of 33 and 50% over the control at Samaru and Kadawa respectively.

In 1994, plants treated to 1.0 kg B ha^{-1} recorded the highest AA contents. The corresponding increases above the control were

Table 42: Effect of Variety and boron rates on ascorbic acid contents (%) of fruits at Samaru and Kadawa in 1993 and 1994

Treatment	1993			1994		
	Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
Variety						
Roma VF	21.8b	22.9	22.4	25.6	25.5	25.6
Dandino	23.8a	25.2	24.5	28.7	28.3	28.5
LSD (0.05)	2.1	NS		NS	NS	
Boron Rates (Kg B ha^{-1})						
0	20.3cde	20.8d	20.5	23.5	23.0bcde	23.3
0.5	23.5bc	27.0abc	25.3	27.5	28.5ab	28.0
1.0	26.3ab	31.0a	28.7	33.0	33.5a	33.3
1.5	27.0a	28.3ab	27.7	26.9	28.0abc	27.5
2.0	21.3cd	19.6e	20.5	27.5	26.8bcd	27.2
2.5	18.7de	17.5ef	18.1	24.5	23.5bcde	24.0
LSD (0.05)	3.6	5.0		NS	6.2	

Means in a given column followed by similar letter(s) are not significantly different at P = 0.05, using DMRT

Table 43: Effect of Variety X boron rates interaction on ascorbic contents of fruits at Samaru and Kadawa under rainfed condition in 1993 and 1994

Treatment (kg Bha^{-1})	Variety	1993			1994		
		Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
0		18.6	19.5	19.1	23.0	22.0	22.5
0.5		22.0	25.0	24.0	27.0	26.0	26.5
1.0	Roma VF	24.0	28.0	26.0	30.0	31.0	30.5
1.5		28.6	30.6	29.6	20.8	27.0	23.9
2.0		23.0	18.0	20.5	28.0	25.0	26.5
2.5		16.7	16.0	16.3	25.0	22.0	23.5
0		22.0	23.0	22.5	24.0	24.5	24.3
0.5	Dandino	25.0	29.0	27.5	28.0	31.0	29.5
1.0		28.7	34.0	31.4	36.0	35.0	35.5
1.5		25.5	26.0	25.8	33.0	29.0	31.0
2.0		21.7	21.0	21.4	27.0	26.0	26.5
2.5		20.7	19.0	19.9	24.0	25.0	24.5
LSD (0.05)		NS	NS		NS	NS	

40.4 and 45.6% at Samaru and Kadawa respectively. Similar findings has been reported elsewhere (Jelenic et al 1958 and Rachkouskaya 1973).

It is interesting to note that, there was no significant (P = 0.05) difference in the results obtained for plants treated to 1.0 and 1.5kg B ha^{-1} in each of the trials.

The interaction of variety x boron rates on AA contents was not significant in each of the trials (Table 43).

In his study Gould (1974) found that soil condition and plant nutrition alter the AA contents of tomatoes. In other studies, cultivation practices and light intensity previous to maturity as well as treatment with growth regulators and insecticides had been shown to alter AA contents (Umale 1969 and Oza and Rangneda, 1972). Reports have also indicated that maturity of tomato fruits and environmental conditions have marked influence upon AA contents.

4.3.4.16 Effect of B Application on Total Soluble Solids (TSS) of Tomato Fruits

The effect of B treatment over varieties on TSS content of fruits was only significant at Kadawa in 1994 (Fig. 27). Nevertheless, variety Dandino gave the highest TSS contents in each of the trials except at Samaru in 1994, where Roma VF recorded the highest TSS. This result is contratry to the report of Brecht et al (1976), who reported a significant varietal influence on TSS contents of tomato fruits.

Total soluble solids contents increased with increasing B

applications at Samaru and Kadawa in 1993 and 1994 up to 2.0 kg B ha^{-1} (Fig. 27) but declined at B rates of 2.5 kg B ha^{-1}d, as recorded for other parameters. This signifies that B level of 2.5 kg B ha^{-1} was toxic to the tomato plants and fruits.

In 1993, plants treated to 1.0 kg B ha^{-1} recorded the highest TSS contents, which gave an increase of 23.5 and 26.4% above the control at Samaru and Kadawa respectively. In 1994, plants treated to 1.0 kg B ha^{-1} also recorded the highest TSS at Samaru, whereas, at Kadawa the highest TSS contents was obtained with plants treated to 0.5 kg B ha^{-1}. An increase of 20.5 and 14.7% over the control were obtained in 1994 at Samaru and Kadawa respectively.

Reports from literature have shown that there is a strong relationship between leaf number and TSS of fruits. McCollum and Skok (1960) and Brecht et al 1976 had variously reported that greater photosynthetic capabilities in the plants due to their increased leaf number could feasibly allow for a greater photosynthate movement to the fruit and hence a higher soluble solids contents.

The interaction effect of variety x boron level was only significant (P = 0.05) at Samaru in 1993 (Fig. 27).

4.3.4.17 Effect of Boron Application on Titratable Acidity (TA)

Titratable acidity (TA) comprises of the potential acidity and the pH of the tomato fruit. TA influences the degree of sourness and consequently the flavour of tomato fruit (Lambeth et al 1964).

Variety Dandino significantly produced fruits with higher TA

Fig. 27. Total soluble solids (TSS) contents of tomato fruits as influenced by variety and rates of boron under rainfed conditions at Samaru and Kadawa in 1993 and 1994.

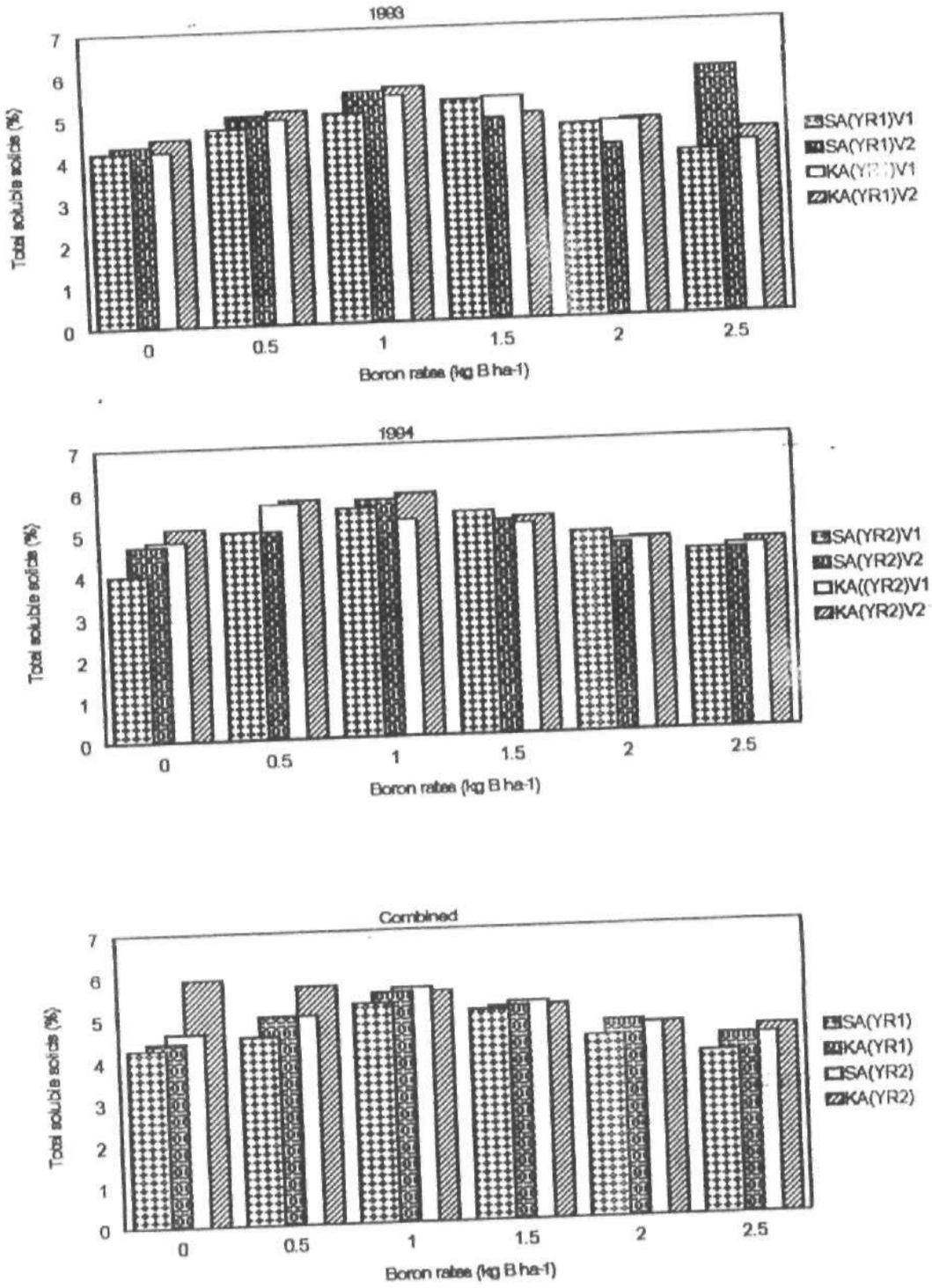
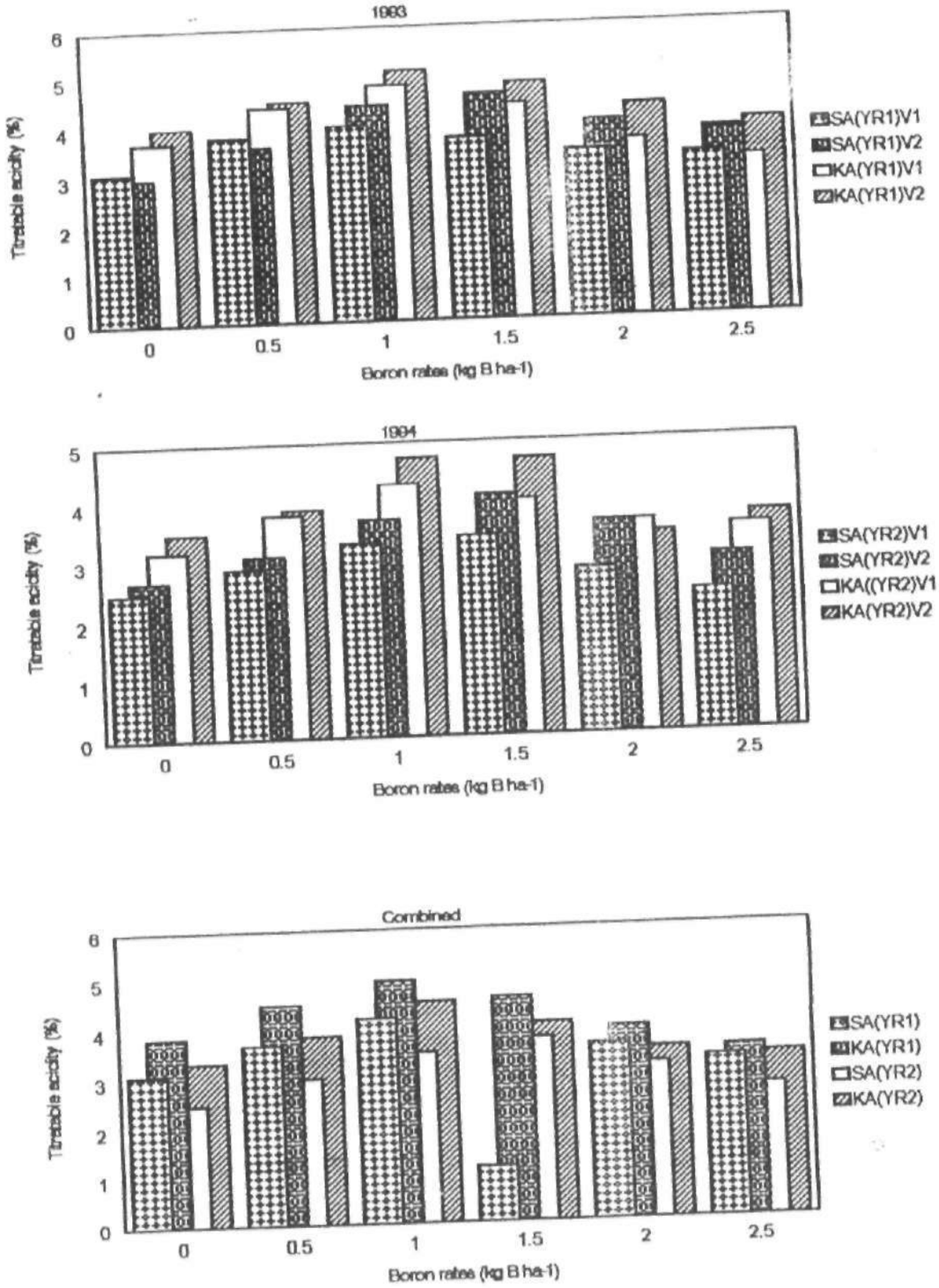


Fig. 28. Titratable acidity contents of tomato fruits as influenced by variety and rates of boron at Samaru and Kadawa in 1993 and 1994.



than Roma VF in each of the trial (Fig. 28) and the difference was significant at Kadawa in 1993 and Samaru in 1994. Earlier report have shown that TA varies with cultivar, and in the various sections of the tomato fruits, with the locular jelly having the highest TA contents (Bohart 1940; MacGillavray and Clemente 1956 and McCollum and Shock1956).

Boron application significantly increased the TA contents of tomato fruits in all the trial except at Samaru in 1993 (Fig. 28) plants treated to 1.5 kg B ha^{-1} gave the highest TA contents at Samaru in 1994, whereas others recorded their highest TA contents at 1.0 kg B ha^{-1}.

In spite of the absence of any statistical significance (P = 0.05) influence of variety x boron rates interaction on TA of fruits, there were indications that some levels of B either increased or depressed TA contents. For instance, while 1.0 kg B ha^{-1} produced the highest TA for Roma VF, in contrast 1.5 kg B ha^{-1} application on Dandino resulted in the highest TA while control gave the lowest values (Fig. 28).

4.3.4.18 Effect of Boron Application on pH of Tomato Fruits

Application of boron did not have any varietal influence on the pH of the fruit in each of the trials (Table 44).

Application of B had no significant (P = 0.05) effect on the pH of the tomato fruits, in 1993 and 1994 at Samaru and Kadawa (Table 44). This result agrees with the report of Brecht et al (1976) who did not obtain any consistent trend in differences in pH

of fruits that could be attributed to growth habit of tomato.

The interaction between boron treatment and variety on pH of fruits was not significant in each of the trials (Table 45).

The non significant values obtained in this study could be due to the fact that pH alone cannot be used for the determination of acidity in tomato fruits. The degree of sourness in tomato fruit is determined by its degree of acidity, which is determined from titratable acidity and pH. This is in agreement with Anderson (1957) who had earlier reported that pH and TA in tomato fruit influenced the degree of sourness.

4.3.4.19 Effect of Boron Application on Reducing Sugar (RS) Contents of Tomato Fruit

A comparison of the RS of the two varieties showed that variety Dandino significantly (P = 0.05) produced fruits with higher RS than Roma VF, at Samaru and Kadawa in 1993, and at Samaru in 1994 (Fig. 29).

Reducing sugars (RS) of tomato fruit was singificantly influenced by the B rates in each of the trials. Plants treated to 1.0 kg B ha^{-1} gave the highest RS contents, whereas the least for each trial were obtained with the control. The corresponding increases over the control were 86.4 and 71.0% in 1993; 73.3 and 70.8% in 1994 at Samaru and Kadawa respectively. The result of this study is in agreement with the report of Jelenic et al (1958) and Verma et al (1973).

Table 44: Effect of Variety and boron rates on pH of tomato fruits at Samaru and Kadawa in 1993 and 1994

Treatment	1993			1994		
	Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
Variety						
Roma vf	3.0	4.1	3.6	4.1	4.0	4.1
Dandino	4.1	4.0	4.1	4.1	4.2	4.2
LSD (0.05)	NS	NS		NS	NS	
Boron Rates (Kg B ha^{-1})						
0	4.0	4.1	4.1	4.0	4.0	4.0
0.5	4.1	4.0	4.1	4.1	4.2	4.2
1.0	4.2	4.0	4.1	4.1	4.1	4.1
1.5	4.1	4.1	4.1	4.1	4.1	4.1
2.0	4.0	4.0	4.0	4.1	4.0	4.1
2.5	4.0	4.1	4.1	4.1	4.1	4.1
LSD (0.05)	NS	NS		NS	NS	

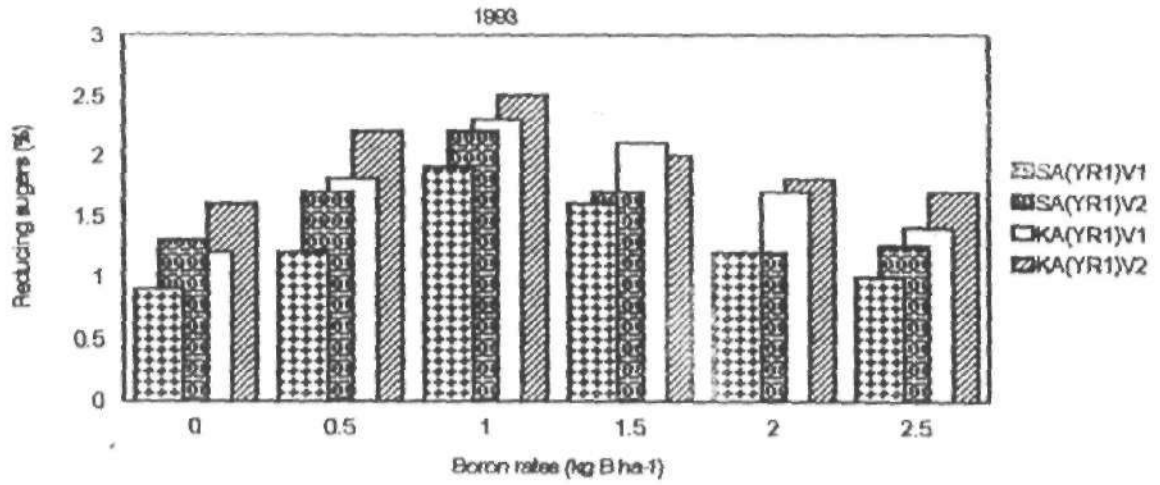
NS = Not significant

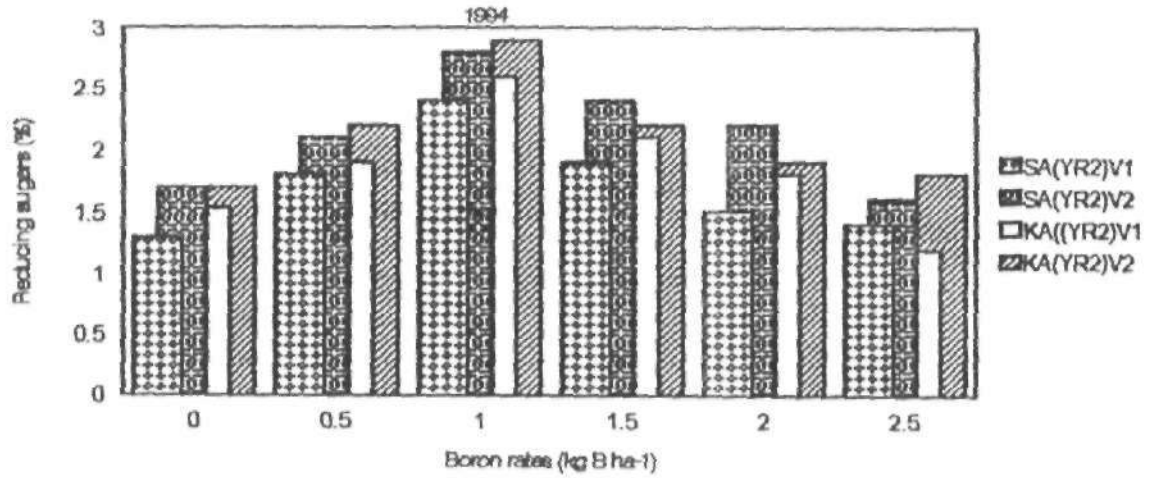
Table 45: Effect of Variety X boron rates interaction on pH of tomato fruits at Samaru and Kadawa in 1993 and 1994

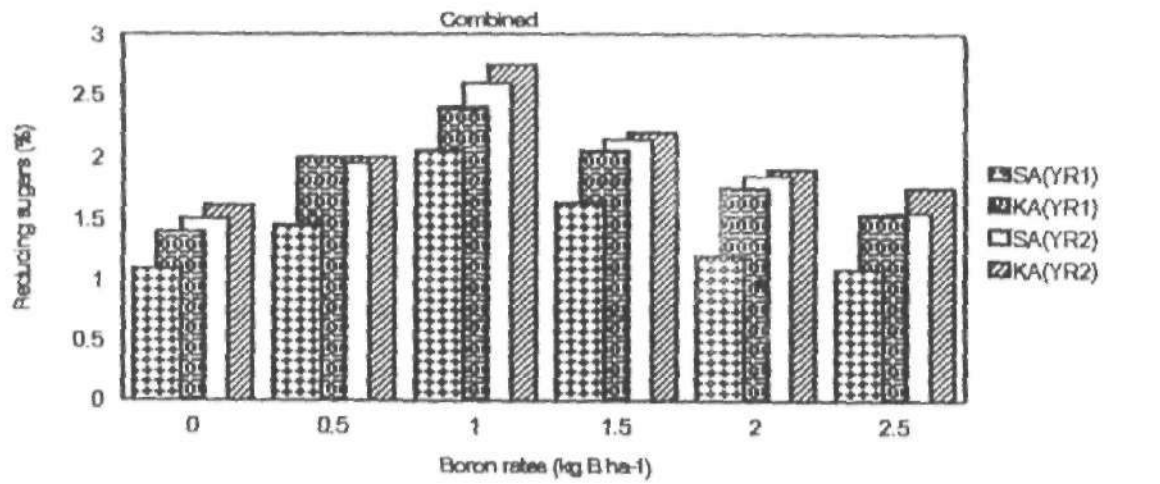
Treatment (kg Bha^{-1})	Variety	1993			1994		
		Samaru	Kadawa	Mean	Samaru	Kadawa	Mean
0		3.9	4.1	4.0	4.0	4.0	4.0
0.5		4.1	4.0	4.1	4.1	4.0	4.1
1.0	Roma VF	4.1	4.1	4.1	4.2	3.9	4.1
1.5		4.1	4.1	4.1	4.1	4.1	4.1
2.0		4.0	4.0	4.0	4.1	4.0	4.0
2.5		4.1	4.0	4.1	4.1	4.0	4.0
0		4.0	4.1	4.1	4.0	4.1	4.1
0.5		4.2	4.0	4.1	4.1	4.3	4.2
1.0	Dandino	4.2	3.9	4.0	4.0	4.2	4.1
1.5	"	4.0	4.1	4.1	4.1	4.2	4.2
2.0		4.0	4.0	4.0	4.1	4.0	4.1
2.5		3.9	4.2	4.0	4.1	4.2	4.2
LSD (0.05)		NS	NS		NS	NS	

NS = Not Significant

Fig. 29. Reducing sugars of tomato fruits as influenced by variety and rates of boron at Samaru and Kadawa in 1993 and 1994.







Esteban et al (1985) reported an accumulation of protein and RS in the tomato roots of B deficient plants.

When the effect of variety x boron rate interaction on reducing sugar contents of tomato fruit was considered, in both locations, the two varieties recorded the highest RS content at 1.0 kg B ha^{-1}. However, Dandino variety treated to 1.0 kg B ha^{-1} at Kadawa in 1994, recorded the highest RS contents of 2.9% (Fig. 29) in all the trials.

4.3.4.20 Relationship Among Fruit Components

Ascorbic acid (AA) correlated with TSS (r = 0.557**), RS (r = 0.508**) and yield (r = 0.724**) at Samaru. Similarly, at Kadawa AA was strongly related to TSS (r = 0.597**), TA (r = 0.607**), RS (r = 0.747**) and yield (r = 0.771**), as shown in Table 46.

Titratable acidity did not correlate with any of the fruit components at Samaru, but with RS (r = 0.527**) and yield (r = 0.679**) at Kadawa.

pH correlated with TSS at Samaru (r = 0.440*) but not at Kadawa (Table 46).

Reducing sugars correlated with fruit yield in both locations (r = 0.805** and 0.654** at Samaru and Kadawa respectively). TSS correlated with RS (0.820** and 0.397*) and yield (r = 0.881** and 0.644**) at Samaru and Kadawa respectively.

Fruit yield of tomatoes correlated with all the fruit components except pH in both locations. This emphasised the importance of these fruit components in the tomato fruit.

Table 46: Simple correlation among fruit components at Samaru and Kadawa under rainfed condition

	Coefficient of correlation (r)					
	Ascorbic Acid	Total soluble solids	Titratable Acidity	pH	Reducing sugars	Yield
SAMARU						
Ascorbic Acid	-					
Total soluble solids	0.557**	-				
Titratable Acidity	-	-	-			
pH	-	0.440*	-	-		
Reducing Sugars	0.508**	0.820**	-	-	-	
Yield	0.724**	0.881*	-	-	0.805**	-
KADAWA						
Ascorbic Acid	-					
Total soluble solids	0.597**	-				
Titratable Acidity	0.607**	0.601**	-			
pH	-	-	-	-		
Reducing sugars	0.747*	0.397**	0.527**	-	-	
Yield	0.771**	0.644**	0.679**	-	0.654**	-

* = Significant at 5% level
** = Significant at 1% level

pH did not correlate with any of the fruit components and yield at Kadawa. The result obtained in this study agreed with the report of Stevens et al (1977, 1979) and Kader et al (1978).

4.3.4.21 Effect of Boron Rates on the Distribution of Boron in Different Tomato Plant Parts

There were variations in B distribution among plant parts in the two tomato varieties (Fig. 30).

Leaves

Application of B signiicantly (P = 0.01) increased the concentration of B in both Roma VF and Dandino leaves. The concentration of B in the leaves of Roma VF variety varied from 0.60 to 9.40 mg kg^{-1} with a mean of 3.84 mg kg^{-1}, while that of variety Dandino varied from 1.05 to 10.90 mg kg^{-1} with the mean of 6.94 mg kg^{-1}.

Stem

Application of B significantly (P = 0.01) increased the concentration of B in the stem. The B concentration of Roma VF variety varied from 0.58 to 1.23 with the mean of 0.91 mg kg^{-1}, while for Dandino it varied from 0.70 to 1.82 mg kg^{-1} with the mean of 1.30 mg kg^{-1} (Fig. 30). The interaction between variety and B rates was significant (P = 0.05).

Roots

Application of B did not have any significant (P = 0.01)

effect on the concentration of B in the roots. However, the concentration of boron in the roots of Roma VF variety varied from 0.31 to 0.98 mg Kg^{-1} with the mean of 0.68 mg kg^{-1} (Fig. 30). Similarly, the B concentration of Dandino variety varied from 0.35 to 1.60 with the mean being 0.85 mg kg^{-1}.

Results of this work signified that variety Dandino consistentoy recorded higher B concentration in the various ploant parts than Roma vf. This is in line with the report of Andrew and Thorne (1962) and Brown et al (1972), that crop species and variety vary in B requirement.

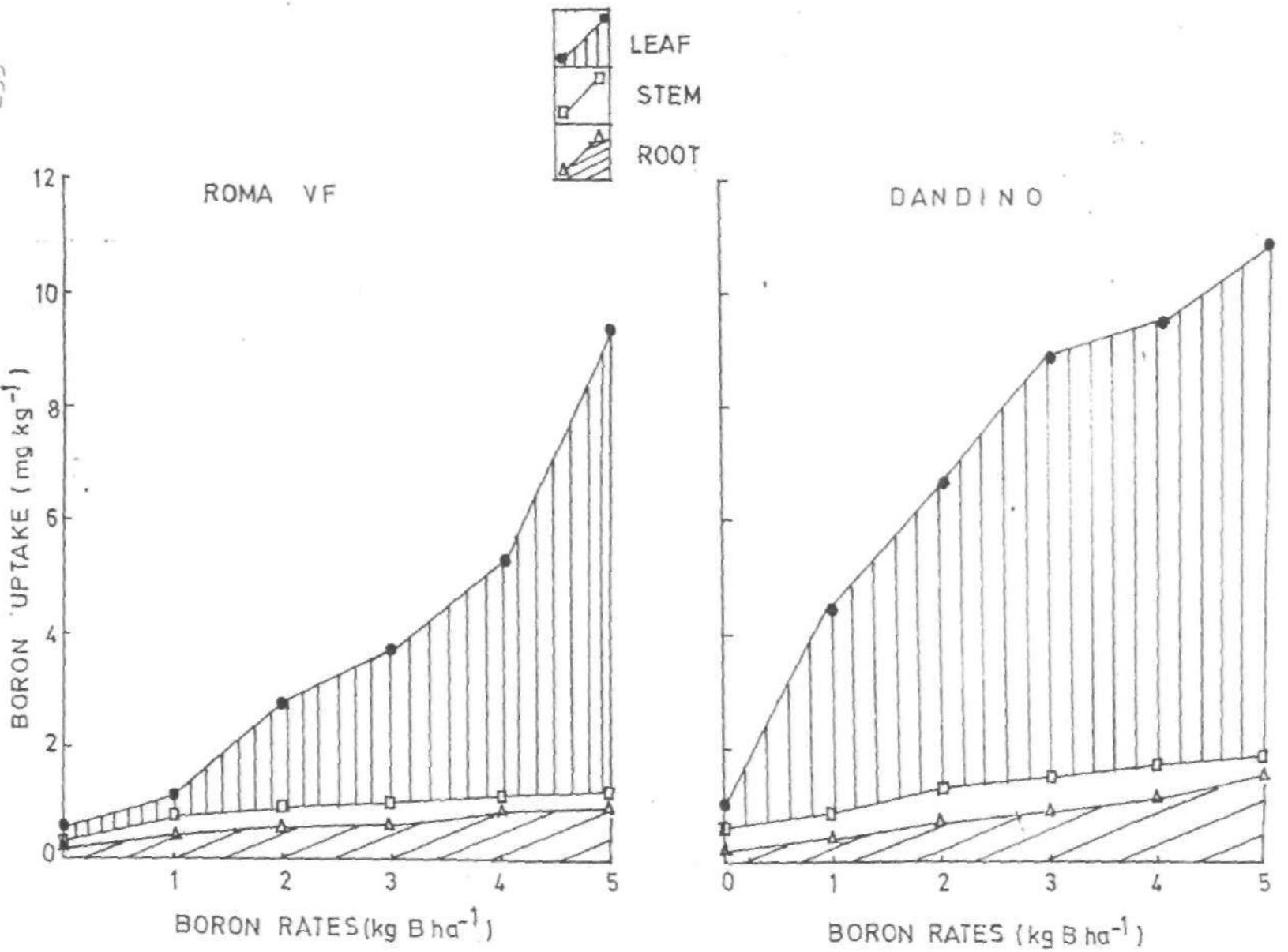
The concentration of B was highest in the leaves in both varieties. This was followed by the stem. Roots had the least B concentration. This result agreed with the report of Magalhaes et al (1978), Drews and Frank (1980b) and Garate et al (1984a). Similarly, Garate et al (1984b) reported that the B concentration in roots stem and fruits were generally much lower than those in the leaves, and that the concentration of B in the entire plant tended to average about half of that in the leaves.

The non-significant difference of B treatment on the roots agreed with the report of Esteban et al (1987).

4.4. GENERAL DISCUSSION

The critical concentration of B established in the soils from the greenhouse was 0.13 mg kg^{-1}. Although, there was response to higher B level in the field, this is contrary to the widely held view that the critical B level in the field is lower than that of

FIG.30: BORON DISTRIBUTION IN TWO TOMATO VARIETIES.



the greenhouse.

This is because, in the field, plants have a larger soil mass from which nutrients are explored. In the greenhouse, plants are planted under control situations, the plant roots are restricted to the small soil mass used and the growth duration was shorter.

There were increases in all parameters - yield, yield components, and fruit components determined with increae in B rates up to a particular boron level after which there was corresponding decline in the parameters, in dry and wet (rainfed) seasons. The only exception was with B uptake which increased with increase in B rates.

Although, different rates of B were applied to the dry and wet season trials, there was need to compare the performance of the crop in both season.

In the field, plants responded to B rates up to 4 kg ha^{-1} in the dry season and 1.5 kg B ha^{-1} in the wet season.

The number of leaves was more during the dry season than wet season. This could be due to severe fungi attack which is always encountered during the wet season.

Plants flowered earlier in the wet season than in the dry season, due to better weather conditions during the wet season (May to September) as shown in Appendix D.

In terms of number of flowers, the dry season trials recorded more flowers than wet seaosn, with variety Dandino having more flowers than Roma VF. The mean number of fruit for dry season was more than that of wet season, with variety Roma VF having more

fruit than Dandino (Figs. 5 & 18) in both seasons. Also the average fruit weight for the dry season trial 70.33g was more than the wet season trials - 56.00g. Both were recorded by Dandino variety.

The highest marketable fruit yield of 46 tons ha^{-1} was recorded during the dry season as against 35-40 tons recorded on farmers field in the area. While 28.18 ton ha^{-1} was recorded for wet season trials; contrary to 20-25 tons ha^{-1}, recorded on farmer field. The usally unavoidable fungal attack of tomato leaf in the wet season and other environmental factors are responsible for the difference in the yield.

Dry season trial also recorded higher DMY of 3.07 tons ha^{-1} than wet season 1.04 tons ha^{-1}. This was due to more number of leaves recorded in the dry season than wet season as explained by Zelitch (1971) and Epstein (1972).

In both seasons, there were increases in the B concentration with the rates of B (Fig. 8 and 21). Dry season recorded more B concentration than wet season. This was expected as the B treatment of dry season was more than wet season. In both dry season trials the order of macronutrient concentration was in this order

$$Ca > K > Mg > P.$$

The only exception to the wet season trial was at Kadawa in 1993 where 1.5 kg B ha^{-1} recorded high Mg concentration (Fig. 24).

The high Ca and K concentration could be due to the type of

fertilizers applied (CAN and NPK). Since similar fertilizer rates were applied at the same season (except borax), the soil Ca and K level before planting could be responsible for the difference in concentration.

The order of micronutrient concentration during the dry season was Fe > Mn > Zn > Cu as shown in Fig. 13. The first year wet season trials also followed the same trend as the dry season with Fe concentration as the highest and Cu concentration, the least (Fig. 26). However, at the second year wet season trial (1994), Fe concentration was the highest, followed by Zn concentration in this order

Fe > Zn > Mn > Cu.

In terms of fruit analysis, the AA, TSS, pH and RS contents were higher in the dry season. Wet season trials recorded more TA than dry season. This explained why the wet season tomato fruits are Sour (Luk'Yanenko and Luk'Yanenko 1981).

Analysis of B in different parts of tomato plants revealed that, the leaves contained more B than any other part, which confirmed the findings of other researchers Drews (1980a) and Garate et al (1984).

Boron adsorption and desorption studies carried out on the thirty surface soils revealed that twenty nine out of thirty soils best fit the Langmuir adsorption isotherm, whereas only one best fit the Freundlich equation. Desorption reactions were irreversible in all the soils.

Findings from the present study are in line with the widely held view that (1) boron fertilizer increases the fruit yield of tomato and modifies the fruit composition by improving the flavour of the fruit (Aduayi 1978, Gulati 1980 and Adelana 1986) (2) the B level in Northern Nigerian Savanna soils are low (Anande-kur 1976, Lombin 1985a and 1985b).

CHAPTER 5

SUMMARY AND CONCLUSION

This study was initiated as a result of B deficiency reported to be the most widely micronutrient deficiency on farmers fields in Northern Nigeria.

The B status of 30 surface soils (Cultivated and fallow) from the Sudan and Northern guinea savanna were studied using six different extractants to determine their suitability for the predictions of plant available B to tomatoes.

The available B in the soils obtained from various extracts are low. This could be due to low B content in the parent material. The total B content compared favourably with the values obtainable elsewhere.

Results obtained in this study indicated that less than 1% of total B is in the available forms. The B extracted by the different soil tests correlated with soil O.C., E.A., Exchangeable K, available P, total N, available Fe and total B. Plant B uptake related only to pH.

Boron uptake did not correlate significantly with any of the soil test methods, however, other yield components such as relative yield, number of leaves correlated significantly with some soil test methods. The critical concentration of B in the soil was established as 0.13 mg kg^{-1} from the hot water test.

Two tomato varieties were used for the field calibration studies. Response to B application was observed. Visual

deficiency symptoms were also observed in some control plots.

The least number of days to flowering, and highest number of flowering, fruit weight and yield were obtained between 2 and 3 kg B ha^{-1} during the dry season in both locations.

High yield and yield parameters were recorded between 1.0 and 1.5 kg B ha^{-1} during the wet seasons. Yield was higher in the dry seasons than in wet seasons. It has been proved that dry season favours the production of tomatoes than wet season probably because the low incidence of disease uring the dry season. The two tomato varieties responded to B level differently.

The ripe fresh tomato fruits were also analysed for titratable acidity, total soluble solids, pH, ascorbic acid, and reducing sugars. Application of B increased these components in the fruits, but high levels of B 2.5 and 5.0 kg ha^{-1} for wet and dry seasons respectively were toxic for the tomato plants as all the fruit components contents declined at these B rates. Mean titratable acidity was higher in the wet season than dry season, whereas reducing sugars was more during the dry season than wet season.

The B uptake in the plant tissue increased with the increase in B rates. It also varied within the plant, with the leaves having more B than the stem; the least B content was recorded in the roots.

The macro and micronutrients concentration in the plant tissue were high. This could be due to contamination from the soil and fertilizers used in this study. Also the concentration of these nutrients in the plant tissues depend on the time of sampling,

method of analysis, and part of the plant being sampled (Mortvedt et al 1972). The present study also supports the study conducted by Graves et al (1978) that the yield of tomato is related to the content of the micronutrient in the leaves of the crop.

Boron adsorption and desorption studies were carried out on the thirty soils to know the soils which will respond to B, and to show long term residual effects from applied B. Twenty nine out of thirty soils best fit the Langmuir adsorption isotherm, whereas, only one best fit the freundlich equation. The values of K and b for the soils were low. This could be due to the sandy nature and low clay content of the soils used in this study. The B adsorption and desorption reactions are irreversible in all the soils.

In conclusion, the hot water B test is recommended for routine analysis of available B in the Northern Nigerian savanna soils.

In the field, the application of 1.0 kg B ha^{-1} during the wet season and 2.0 kg B ha^{-1} during the dry season are recommended for optimum yield of tomato in the savanna agro-ecology. Furthermore, for ease of application, the recommended amount of B should be incorporated as a fixed ratio in already existing macronutrient compound (NPK) formulations.

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APPENDIX A: PROFILE DESCRIPTIONS

Profile No. : S1

General Site Information:

Location	:	IAR Horticultural Garden, Samaru, Area C.
Taxonomic classification	:	Ultic Haplustalf (USDA) Haplic Acrisol (FAO)
Soil parent material	:	Thin aeolian materials over basement complex rocks. Saprolite.
Geology	:	Basement complex rocks.
Geomorphology	:	Undulating plain within the Kaduna plains
Topography	:	Mid-slope; gently sloping 2-4% slope.
Vegetation	:	Northern Guinea Savanna
Landuse	:	Fallow after tomatoes/peppers the previous years
Soil erosion	:	Slight sheet erosion
Drainage	:	Well drained
Depth to wate table	:	Not encountered
Depth to inpenetrable layer	:	Not encountered
Surface characteristics	:	No remarkable features
Described by	:	T. Kparmwang and E.Y. Oyinlola
Date sampled	:	24th January, 1994

Horizontal Description

Horizon	Depth (cm)	Description
Ap	0-15	Dark brown (7.5YR 4/4 moist light brown (7.5YR 6/4 dry) loam week corase subangular blocky structure, non-sticky (wet) friable (moist slightly hard (dry); common medium pores; common medium and few coarse roots; common fine mica/quartz; clear smooth boundary.
AB	15-28	Strong brwon (7.5YR 5/8 moist) reddish yellow (7.5YR 6/8 dry) loam; weak coarse subangular blocky structure slightly sticky (wet), firm (moist) slightly hard (dry) few medium pores; common fine and few medium roots; common fine mica/quartz; clear smooth boundary.
Bt1	28-40	Yellowish red (5YR 5/8 moist) clay loam moderate coarse subangular blocky structure; sticky (wet) firm (moist) slightly hard (dry) common medium pores; and few medium roots; common fine mica/quartz; gradual smooth boundary.
Bt2	40-128	Yellowish red (5YR 5/8 moist) clay, strong very coarse subangular blocky structure; sticky (wet) friable (moist) slightly hard (dry); common medium pores and few coarse voids; common fine mica/quart; gradual smooth boundary.
Bt3	128-175	Strong brown (7.5YR 5/8 moist) clay with common medium faint, light yellowish brown (2.5Y 6/4) mottles; moderate coarse subangular blocky structure; slightly sticky (wet) friable (moist) hard (dry); few medium pores; few fine roots; common fine mica/quartz; few fine soft root nodules.

Profile No. : K2

General Site Information:

Location	:	IAR Irrigation Station Kadawa
Taxonomic classification	:	Ustostic Dystropept (USDA) Eutric cambisol (FAO)
Soil parent matrial	:	Thin aeolian material over ganitic residuim
Geology	:	Basement complex rocks.
Geomorphology	:	Nearly flat plain within the Kano plains
Topography	:	Upper slope; nearly flat 0-2% slope
Vegetation	:	Northern Guinea savanna zone.
Landuse	:	Rice, the previous year.
Soil erosion	:	None.
Drainage	:	Moderately well drained.
Depth to water table	:	Seepage at 65cm from a perched water table due to retroplinthite at 130cm depth.
Depth to impenetrable layer	:	Petroplinthite layer at 130cm.
Surface Characteristics	:	No remarkable features.
Described by	:	T. Kparmwang and E.Y. Oyinlola
Date sampled	:	27th January, 1994.

Horizontal Description

Horizon	Depth (cm)	Description
Ap	0-30	Dark brown (10YR 4/3 moist) sandy loam with common fine faint dark brown (7.5YR 4/4) root pore mottles; moderate coarse subangular blocky structure; non-sticky (wet) friable (moist) few medium pores; common fine roots; many fine mica/quartz; gradual smooth boundary.
AB	30-45	Dark yellowish brown (10YR 4/4 moist) sandy loam; weak coarse subangular blocky structure; non-sticky (wet) friable (moist) few soft coarse iron concretions; many fine mica/quartz; gradual smooth boundary.
BA	45-65	Yellowish brown (10YR 5/8 moist) sandy loam; medium and coarse subangular blocky structure slightly sticky (wet); many fine pores; common fine roots; many fine mica/quartz; gradual smooth boundary.
Bw1	65-100	Yellowish brown (10YR 5/6 moist) sandy loam; slightly sticky (wet) friable (moist); many fine mica/quartz; horizon sampled with auger.
Bw2	100-130	Light yellowish brown (10YR 6/4 dry), (10YR 5/4 moist) loam; yellowish brown, slightly sticky (wet) common hard iron/manganese concretions horizon sampled by auger.
Bv	130+	Petroplinthite layer. Not sampled.

APPENDIX B: PARTICLE-SIZE DISTRIBUTION

Horizon	Depth (cm)	Particle-Size Distribution			
		Sand (%)	Silt (%)	Clay (%)	Textural Class
SAMARU					
Ap	0-15	41.0	44.0	15.0	Loam
AB	15-28	41.0	42.0	17.0	Loam
Bt1	28-40	33.0	34.0	33.0	Clay loam
Bt2	40-128	31.0	28.0	41.0	Clay
Bt3	128-175	25.0	28.0	47.0	Clay
KADAWA					
Ap	0-30	57.0	24.0	19.0	Sandy loam
AB	30-45	53.0	28.0	19.0	Sandy loam
BA	45-65	55.0	24.0	21.0	Sandy loam
B	100	57.0	22.0	21.0	Sandy loam

Appendix B: Soil Chemical Properties

Horizon	Depth (cm)	pH		Exchangeable Bases					Exch. Acidity	CEC		Clay	Base Saturation		O.C	TN	Av. P
		H_2O	$CaCl_2$	Ca	Mg	K	Na	TEB		NH_4OAc	ECEC		NH_4OAc	ECEC	<------ g/kg ------>		
SAMARU																	
Ap	0-15	6.70	5.70	1.923	0.182	0.115	0.152	1.472	0.4	4.60	1.87	9.2	32	79	9.2	0.70	4.67
AB	15-28	6.90	5.72	3.044	0.699	0.26	0.217	4.22	0.2	7.50	4.42	38.4	59	96	2.8	0.42	4.51
Bt1	28-40	6.68	5.74	1.75	0.370	0.13	0.209	2.46	0.4	5.20	2.86	12.70	47	86	2.9	0.35	3.56
Bt2	40-128	6.66	5.76	4.69	1.36	0.37	0.26	6.68	0.2	11.60	6.88	27.18	58	97	1.3	0.21	3.15
Bt3	128-175	6.50	5.70	5.49	2.92	1.06	0.304	9.77	0.2	15.20	9.92	31.74	64	99	0.8	0.35	3.94
KADAWA																	
Ap	0-30	6.83	5.30	4.12	2.95	0.41	0.313	7.793	0.4	13.20	8.19	61.14	59	95	4.2	0.39	5.45
AB	30-45	6.56	5.78	4.87	1.152	0.148	0.283	6.453	0.4	11.40	6.85	55.58	56	94	2.4	0.39	3.56
BA	45-65	6.58	5.78	6.99	1.85	0.197	0.339	9.376	0.4	13.90	9.78	63.19	68	96	1.8	0.28	3.19
B	100	6.34	5.78	5.74	1.52	0.194	0.304	7.758	0.12	11.30	7.96	52.14	69	98	1.0	0.25	5.85

Appendix C: Combine analysis of variance for assessing the effect of boron rates on marketable fruit yield over locations

Source of Variation	DV	SS	1992/93 Trials		
			SS %	MS	F
Location	1	78.43	1.62	78.43	0.75
Residual	4	420.900	8.72	105.23	12.41**
Total	5	499.33	10.34	99.87	11.78
Treatments	5	2797.11	57.95	559.42	65.99**
Varieties	1	151.36	3.14	151.36	17.86**
Treatments x varieties	5	925.43	19.17	185.09	21.83**
Location x varieties	1	25.99	0.54	25.99	3.07*
Location x Treatments x varieties	5	15.33	0.32	3.07	0.36
Residual	44	372.98	7.73	8.48	
Total	66	4327.57	89.66	65.57	
Grand Total	71	4826.90	100.00		
				1993 Trials	
Location	1	294.54	6.57	294.54	3.96*
Residual	4	297.29	6.63	74.32	10.75**
Total	5	591.83	13.21	118.37	17.12
Treatments	5	2656.69	59.28	531.34	76.83**
Varieties	1	145.08	3.24	145.09	20.98**
Treatments x varieties	5	583.75	13.03	116.16	16.88**
Location x Treatments	5	119.31	2.66	23.86	3.45*
Location x varieties	1	34.52	0.77	34.52	4.99*
Location x treatments x variety	5	46.07	1.03	9.21	1.33
Residual	44	304.29	6.79	6.92	
Total	66	3889.71	86.79	58.94	
Grand Total	71	4481.53	100.00		

Appendix C contd: Combine analysis of variance for assessing the effect of boron rates on marketable fruit yield over locations

Source of variation	DF	SS	1993/94 Trials		
			SS %	MS	F
Location	1	1532.38	16.32	1552.38	94.44**
Residual	4	64.90	0.69	16.23	1.85
Total	5	1597.29	17.01	319.46	36.32
Treatments	5	4875.34	51.93	975.07	111.02**
Varieties	1	725.93	7.73	725.92	82.65**
Treatments x varieties	5	206.87	2.20	41.37	4.71**
Location x treatments	5	1368.06	14.57	273.61	31.15**
Location x varieties	1	71.44	0.76	71.43	8.13**
Location x treatments x varieties	5	157.09	1.67	31.42	3.58**
Residual	44	386.44	4.12	8.79	
Total	66	7791.15	82.99	118.05	
Grand Total	71	9388.44			
			1994 Trials		
Location	1	11.96	0.27	11.96	0.197
Residual	4	242.98	5.44	60.75	4.93
Total	5	254.94	5.71	50.99	4.14
Treatments	5	2839.32	63.55	567.56	46.10**
Varieties	1	276.86	6.20	276.86	22.48**
Treatments x varieties	5	218.31	4.89	43.66	3.54**
Location x treatments	5	120.20	2.69	24.04	1.95
Location x variety	1	19.93	0.45	19.93	1.62
Location x treatment x variety	5	195.95	4.39	39.19	3.18*
Residual	44	542.01	12.13	12.32	
Total	66	4212.58	94.29	63.83	
Grand Total	71	4467.52	100.00		

Appendix Table D: Weather data during the period of the trial at Samaru

Month	Rainfall (mm)	Temperature (°C)		Relative Humidity (%)	Sunshine (hours)
		Min	Max		
1992					
Nov	2.6	15.1	29.7	32.4	6.9
Dec	-	12.3	29.6	25.1	7.9
1993					
Jan	-	11.6	26.3	23.6	4.0
Feb	-	14.6	31.8	19.5	N/A
Mar	-	18.5	34.4	31.5	N/A
Apr	8.3	23.5	36.5	42.7	N/A
May	113.6	22.0	37.8	62.9	8.2
June	.139.2	20.3	31.7	72.7	7.3
July	260.0	20.2	29.5	78.4	6.6
Aug	300.7	20.0	28.4	82.0	5.0
Nov	-	14.1	33.6	NA	8.6
Dec	-	14.1	29.1	31.0	6.2
1994					
Jan	-	13.8	29.6	6.1	6.8
Feb	-	16.0	31.6	13.8	5.9
Mar	-	19.9	37.3	19.7	6.4
Apr	-	22.4	35.8	49.0	5.9
May	120.1	22.4	33.5	71.7	7.0
June	231.9	19.7	30.9	77.4	6.2
July	169.2	20.4	28.9	84.3	6.2
Aug	215.9	20.4	27.4	85.0	3.8
Sept	82.5	19.5	29.1	82.8	5.1

Source: Meteorological Office, IAR, Samaru, Zaria.

Appendix Table D: Weather data during the period of the trial at Kadawa

Month	Rainfall (mm)	Temperature (°C)		Relative Humidity (%)	Sunshine (hours)
		Min	Max		
1992					
Dec	-	19.6	32.9	56.7	9.2
1993					
Jan	-	15.8	28.7	30.5	7.5
Feb	-	19.1	33.6	23.6	6.1
Mar	-	23.3	37.6	53.9	N/A
Apr	-	29.8	38.4	56.0	4.6
May	816.0	27.7	38.5	79.5	2.4
June	391.1	28.0	38.8	79.2	7.3
July	104.3	21.9	32.9	83.6	N/A
Aug	272.2	23.9	34.3	85.0	N/A
Sept	127.3	29.1	34.4	85.4	N/A
Oct	7.6	23.6	34.3	84.9	N/A
Nov	-	16.2	33.0	75.5	N/A
Dec	-	13.9	28.6	60.5	N/A
1994					
Jan	-	13.6	29.1	62.2	N/A
Feb	-	15.4	24.5	45.6	N/A
Mar	-	18.3	37.1	48.6	N/A
Apr	8.1	23.2	37.0	64.5	N/A
May	50.1	23.9	37.6	70.1	N/A
June	149.5	22.7	34.9	78.5	N/A
July	119.7	23.0	33.9	81.7	N/A
Aug	371.7	21.3	31.0	84.1	N/A
Sept	279.5	20.8	31.1	85.4	N/A
Oct	55.1	19.9	33.4	85.4	N/A
Nov	-	12.8	32.5	66.9	N/A
Dec	-	9.4	24.5	53.9	N/A

Source: Meteorological Office, IAR, Samaru, Zaria.