CHAPTER 4

NUTRIENT DEFICIENCY SYMPTOMS OF BUCKWHEAT

4.1. INTRODUCTION

In evaluating the fertility status of soils, the ability to recognise deficiency symptoms of plants is critical. If such plant growth problems are detected early in the season, appropriate amounts of additional fertiliser can be applied. Some deficiency symptoms appear at an early stage and then disappear, while others which, become manifest at a later stage and may be associated with yield reductions as large as 50%. The deficiency symptoms for almost all nutrients have been defined for many plants. Buckwheat is among those plants for which the nutrient deficiency symptoms are not well known. Due to this lack of knowledge it was decided in this initial study to develop deficiency symptoms and describe them by the omission of different nutrients using the double-pot technique as described by Janssen (1974).

The technique for the assessment of nutritional stress in plants was first used by Bouma and Dowling (1966) and was further developed by Janssen (1974, 1990), Muller *et al.,* (1979). The principle of this technique is that plants can take up nutrients simultaneously from the soil medium in the top pot and from the nutrient solution of different composition in the bottom pot. When a nutrient is omitted from the solution, plants can take it up from the soil medium only. The difference in growth between plants on a complete solution and on a solution missing one nutrient is a measure of the availability of that nutrient in the soil. This technique was modified for the following experiment.

4.2. MATERIALS AND METHODS

The technique of double-pot was modified to a triple-pot for the current study. The use of an extra pot in the middle of two pots, one containing sand and the other a nutrient solution, was necessary for the support of the upper pot containing sand and for avoiding the touching of the nutrient solution by the base of the pot containing sand. This triple-pot experiment was conducted in a temperate glasshouse (at temperatures 12°C minimum to 26°C maximum) by strictly following the same techniques and principles as described by Janssen (1974, 1990), Muller *et al.,* (1979). Sand was used as a medium in order to avoid the supply of any of the nutrients not present in the nutrient solution. The sand was thoroughly washed and steamed for 5-6 hours to avoid any contamination. It was dried in the oven at a temperature of 80°C overnight.

The triple-pot technique consisted of three pots with a diameter of 11 cm each and height of 9 cm for the top pot (called first pot in Figure 4.1), 5 cm for the middle supporting pot (called second pot in Figure 4.1) and 10.5 cm for the bottom pot (called third pot in Figure 4.1). The top pot containing 600 grams of the sand was connected to the pot containing nutrient solution by means of an absorbent filter passed through a hole punched in the bottom of the upper pot and middle pot. A schematic representation is shown in Figure (4.1).

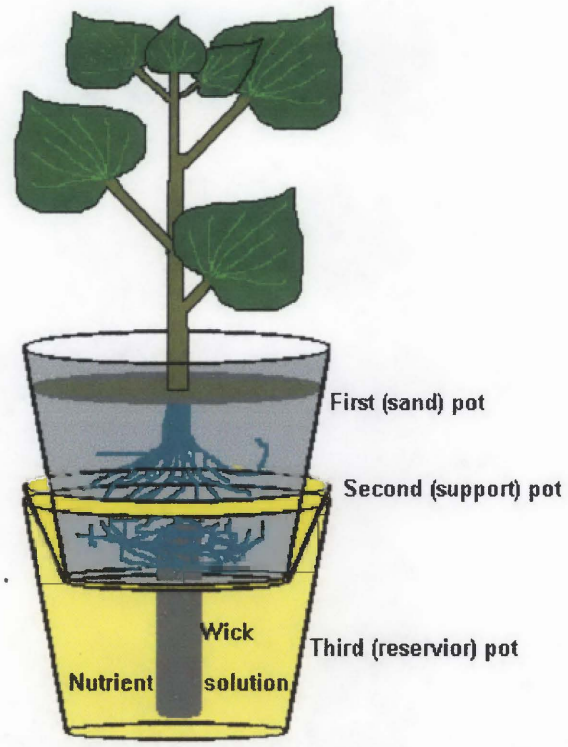


Figure 4.1. Schematic representation of triple-pot technique.

The lower pots were half-filled with distilled water and were covered with aluminium foil to prevent algal growth. The pot containing sand was then placed on to the supporting pot and then on lower pots such that the filter coming from the upper pot touched the base of the lower pot. In this way, moisture was continuously drawn through the filter into the sand culture above keeping the sand constantly moist. All the pots were shifted to the temperate glasshouse where the temperature was adjusted to 12°C as minimum and 26°C as maximum during the growing period.

Five seeds of buckwheat (*Fagopyrum esculentum* Moench, cv. Mancan) were planted in the upper plastic pot containing sand to a depth of approximately 1 cm. After the establishment of the seedlings, they were thinned up to 3 plants per pot after three or four days of germination depending upon the condition of the plants. The distilled water in the lower pots was replaced by nutrient solution after the thinning of the plants. The plants and nutrient solutions in the lower pots were monitored every day and the

nutrient solutions were replenished often enough to prevent unintended deficiencies or nutrient imbalances occurring. The pots were randomised every week. Observations on the deficiency symptoms for the omitted nutrients were recorded during the growing period.

4.2.1. Experimental design and treatments

The experiment was set up in a randomised complete block design with nine treatments, replicated three times. The treatments consisted of nine nutrient solutions, as summarised in Table (4.1). Nutrient solutions were prepared separately for each of the treatments using reagent grade chemicals. The final concentrations of all nutrients in the various solutions are summarised in Table (4.2).

Table 4.1. Nutrient solutions used in triple-pot experiments.

Solution	Description
NIL	DISTILLED WATER
+ALL	All the major (N, P, K, S, Ca, Mg) and micronutrients (Fe, Zn, Cu, B, Mn, and Mo)
+ALL-T	All the major nutrients without trace elements
-N	All the major and micronutrients except N
-P	All the major and micronutrients except P
-K	All the major and micronutrients except K
-S	All the major and micronutrients except S
Ca	All the major and micronutrients except Ca
Mg	All the major and micronutrients except Mg

Description of nutrient solutions

NIL Distilled water only (CONTROL)

+ALL The solution was prepared by mixing 60 mL of 1M $Ca(NO_3)_2$. $4H_2O$,40 mL of 1M KNO_3, 40 mL of 1M$NH_4H_2PO_4$, 20 mL of 0.75M$MgSO_4.7H_2O$, and 20 mL of 2M KCl for the macronutrients, together with 20 mL of 150 mM Fe Sequestrene (Sodium Ferric Ethylene diamine di (o-hydroxyphenyl acetate), 20 mL of 15 mM $MnCl_2.4H_2O$, 20 mL of 1.5 mM $ZnCl_2$, 20 mL of 1 mM $CuCl_2$, 20 mL of 0.50 mM H_3BO_3, and 20 mL of 0.01 mM $(NH_4)_6Mo_7O_{24}.4H_2O$ for the micronutrients. The volume of the solution was made with distilled water up to 20 litres.

+ALL-T All the nutrients were mixed in the same manner as for +ALL but excluding micronutrients.

-N This solution was prepared by mixing 20 mL of 0.75M $MgSO_4.7H_2O$, 20 mL of 2M of KCl, 40 mL of 1M KH_2PO_4, and 60 mL of 1M $Ca(CH_3COO)_2$ with 20 mL of 150 mM Fe Sequestrene (Sodium Ferric Ethylene diamine di (o-hydroxyphenyl acetate), 20 mL of 15 mM $MnCl_2.4H_2O$, 20 mL of 1.5 mM $ZnCl_2$, 20 mL of 1 mM $CuCl_2$, 20 mL of 0.50 mM H_3BO_3, and 20 mL of 0.01 mM $(NH_4)_6Mo_7O_{24}.4H_2O$ for the micronutrients. The volume of the solution was made up to 20 litres with distilled water.

-P This was prepared by mixing 60 mL 1M Ca $(NO_3)_2.4H_2O$, 40 mL of 1M KNO_3, and 20 mL of 0.75M $MgSO_4.7H_2O$, 20 mL of 2M KCl, and 40 mL of 0.5M NH_4NO_3 for the macronutrients, together with 20 mL of 150 mM Fe Sequestrene (Sodium Ferric Ethylene diamine di (o-hydroxyphenyl acetate), 20 mL of 15 mM $MnCl_2.4H_2O$, 20 mL of 1.5 mM $ZnCl_2$, 20 mL of 1 mM $CuCl_2$, 20 mL of 0.50 mM H_3BO_3, and 20 mL of 0.01 mM $(NH_4)_6Mo_7O_{24}.4H_2O$ for the micronutrients. The volume of the solution was made up to 20 litres with distilled water.

-K By mixing the nutrient solution of 60 mL of 1M $Ca(NO_3)_2.4H_2O$, 40 mL of 1M $NH_4H_2PO_4$, 20 mL of 0.75M $MgSO_4.7H_2O$, and 20 mL of 2M NH_4Cl for the macronutrients, together with 20 mL of 150 mM Fe Sequestrene (Sodium Ferric Ethylene diamine di (o-hydroxyphenyl acetate), 20 mL of 15 mM $MnCl_2.4H_2O$, 20 mL of 1.5 mM $ZnCl_2$, 20 mL of 1 mM $CuCl_2$, 20 mL of 0.50 mM H_3BO_3, and 20 mL of 0.01 mM $(NH_4)_6Mo_7O_{24}.4H_2O$ for the micronutrients. The volume of the solution was made up to 20 litres with distilled water.

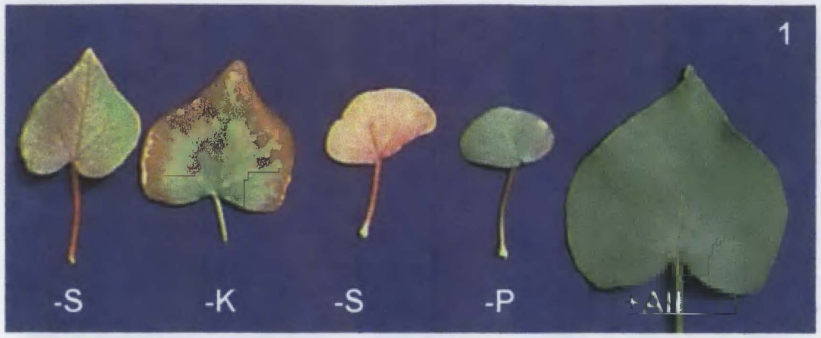
-S This was prepared by mixing 60mL of 1M $Ca(NO_3).4H_2O$, 20 mL of 2M KCl, 40 mL of 1MKH_2PO_4, 50 mL of 0.5M NH_4NO_3, and 30 mL of 0.5M $Mg(NO_3)_2.7H_2O$ for the macronutrients and 20 mL of 150 mM Fe Sequestrene (Sodium Ferric Ethylene diamine di (o-hydroxyphenyl acetate), 20 mL of 15 mM $MnCl_2.4H_2O$, 20 mL of 1.5 mM $ZnCl_2$, 20 mL of 1 mM $CuCl_2$, 20 mL of 0.50 mM H_3BO_3, and 20 mL of 0.01 mM $(NH_4)_6Mo_7O_{24}.4H_2O$ for the micronutrients. The volume of the solution was made up to 20 litres with distilled water.

Table 4.2. Final concentration of the nutrients in the solutions.

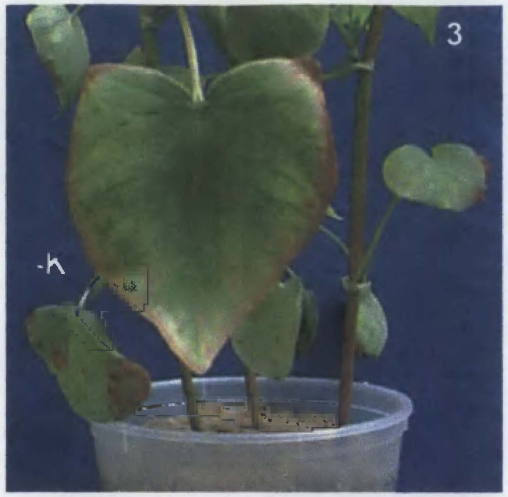
Nutrient	Macronutrient Concentration (mM)								
	NIL	+All	+ALL-T	-N	-P	-K	-S	-Ca	-Mg
N	0	10.0	10.0	0.00	10.0	10.0	10.0	10.0	10.0
P	0	2.00	2.00	2.00	0.00	2.00	2.00	2.00	2.00
K	0	4.00	4.00	4.00	4.00	0.00	4.00	4.00	4.00
S	0	0.75	0.75	0.75	0.75	0.75	0.00	0.75	0.75
Ca	0	3.00	3.00	3.00	3.00	3.00	3.00	0.00	3.00
Mg	0	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.00
Micronutrient Concentration (μM)									
Fe	0	150	0	150	150	150	150	150	150
Mn	0	15.0	0	15.0	15.0	15.0	15.0	15.0	15.0
Zn	0	1.50	0	1.50	1.50	1.50	1.50	1.50	1.50
Cu	0	1.00	0	1.00	1.00	1.00	1.00	1.00	1.00
B	0	0.50	0	0.50	0.50	0.50	0.50	0.50	0.50
Mo	0	0.07	0	0.07	0.07	0.07	0.07	0.07	0.07

-Ca 80 mL of 1M KNO_3, 40 mL of 1M $NH_4H_2PO_4$, 20 mL of 0.75M $MgSO_4.7H_2O$, 40 mL of 0.50M NH_4NO_3 and 20 mL of 2M NH_4Cl were combined for the macronutrients with 20 mL of 150 mM Fe Sequestrene (Sodium Ferric Ethylene diamine di (o-hydroxyphenyl acetate), 20 mL of 15 mM $MnCl_2.4H_2O$, 20 mL of 1.5 mM $ZnCl_2$, 20 mL of 1 mM $CuCl_2$, 20 mL of 0.50 mM H_3BO_3, and 20 mL of 0.01 mM $(NH_4)_6Mo_7O_{24}.4H_2O$ for the micronutrients. The volume of the solution was made up to 20 litres with distilled water.

-Mg Nutrient solutions for this treatment were prepared by mixing 60 mL of 1M $Ca(NO_3)_2.4H_2O$, 10 mL of 1M KNO_3, 40 mL of 1M $NH_4H_2PO_4$, 20 mL of 2M KCl, 30 mL of 0.5M K_2SO_4, and 30 mL of 0.5M NH_4NO_3 for the macronutrients with 20 mL of 150 mM Fe Sequestrene (Sodium Ferric Ethylene diamine di (o-hydroxyphenyl acetate), 20 mL of 15 mM


1
-S
-K
-S
-P
+All


2
-K


3
-K


4
+ALL
-N


5
-S


6
S


7
+ALL
-S

No. 8). The stems were thin and the number of flowers were also reduced compared to +All. A purple colouration was also observed in some plants on the lower leaves. The maturity was slow compared to the plants in +All treatment.

-K Two deficiency symptoms were observed due to lack of K, i.e., chlorosis of leaf margins and small brown necrotic (dead) spots developed while the veins were still green. Some leaves also showed a shiny surface due to K deficiency. The chlorosis of leaf margins were observed on the leaves above the first older leaves (cotyledons) in most cases of the deficiency, as shown in the photographs No. 1, 2, 3.

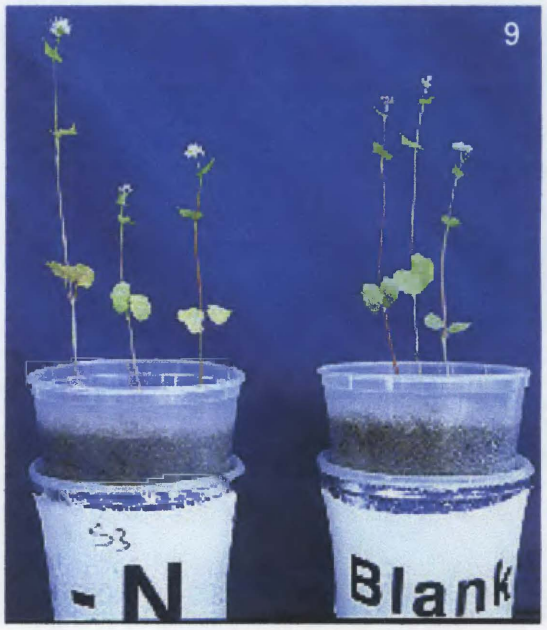
-S The deficiency of S caused a uniform yellowish green colour on the plant. A dark pinkish colour appeared on some of the pale yellowish green leaves as shown in the photographs No. 1, 5, 6, 7. The deficiency of S also produced a thin-stemmed spindly plant. The stems were dark pink in colour as shown in photograph.

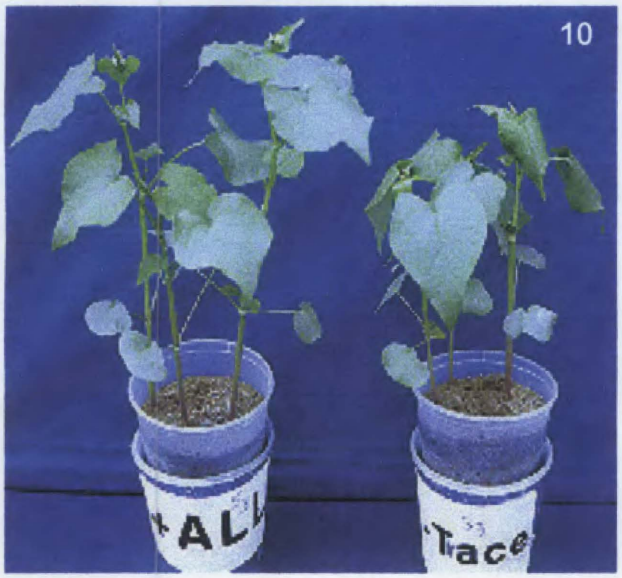
-Ca No deficiency symptoms were observed on the plants when Ca was omitted from the nutrient solution except for a reduction in plant size compared to the plants with +All. Plants were healthy and a normal green colour in appearance like the plants produced in +All (photograph No. 11).

-Mg The omission of Mg from the nutrient solution caused no deficiency symptoms on the plants. Plants were normal green and healthy and were similar in appearance to the plants where All nutrients were applied (photograph No. 11).

+ALL-T There was no deficiency symptom found on the leaves except that the plant and its leaves were smaller compared to +All (Photograph No. 10). The individual effects of the trace elements cannot be explained by these deficiencies as all these elements were applied and omitted collectively.


8
ALL
-P


9
-N
Blank


10
+ALL
-Trace


11
ALL
-Mg
-Ca

4.4. DISCUSSION

According to the principles of the double-pot technique, plants can absorb nutrients from the soil and from the nutrient solution simultaneously. In the current study, when a nutrient or all the nutrients were omitted from the nutrient solution, the plant could not get any nutrient from the soil (sand), which resulted in the deficiency symptom(s) of the omitted nutrient.

The omission of All nutrients (NIL) caused the symptoms of stunted growth and pale/ yellow plants. There was serious reduction of flowers in such plants. These results were expected in the sand culture with a non-supply of any nutrients to the plants. The deficiency symptoms that appeared on the plants were typical for the NIL treatment.

The omission of nitrogen during this study caused typical N deficiency symptoms as shown in the photographs. Because of the importance of N in the plant metabolism as a constituent of amino acids, proteins, nucleotides and chlorophyll (Robson and Snowball, 1986), its omission caused a significant and major effect on the plant growth. These deficiency symptoms of N were identical to the deficiency symptoms recorded by various researchers e.g. Thompson and Troeh (1975), Tisdale *et al.,* (1993), Grundon (1987) and Bergmann (1992) for various other plants.

Phosphorus, an important nutrient for the growth of buckwheat has shown clear deficiency symptoms in the plants. Hannan and Bluett (1996) reported that the presence of P makes a significant difference in the development of buckwheat. The development of plants was affected by the lack of P, which resulted in the deficiency symptoms. The deficiency symptoms recorded for P in crop were identical to the deficiency symptoms recognised for other plants by Tisdale *et al.*, (1993), Robson and Snowball (1986), and Bergmann (1992).

The omission of K caused clear deficiency symptoms on the leaves of buckwheat. The chlorosis of leaf margins was the typical deficiency symptom of K, which has also been identified by various researchers (Tisdale *et al.,* 1993; Robson and Snowball, 1986; Grundon, 1987; Bergmann, 1992) for different plants.

Sulfur is not readily transferred from old to young tissue when a deficiency occurs, the symptoms appear first as general yellowing over the whole plant (Grundon, 1987). In buckwheat it was observed that the plants start to turn pale green and the older leaves started to be affected with dark pink colour as shown in picture No. 6.

Other symptoms were identical to the deficiencies described by Bergmann (1992), and Tisdale *et al.*, (1993).

The omission of Ca and Mg caused no visual deficiency symptoms on the plants in the current study but their importance cannot be ignored on the basis of these results. They may show deficiency symptoms in other situations or similar studies. These nutrients have beneficial effects on the plant growth particularly when applied at lower pH levels (Schmidt, 1995; Taylor, 1996).

There were no clear deficiency symptoms observed due to the omission of trace elements during this study except that smaller plants were produced compared to +All. Due to the role of micronutrients in the plant development further investigation concerning deficiency symptoms is crucial.

CHAPTER 5

SOIL NUTRIENT DEFICIENCIES

5.1. INTRODUCTION

A considerable portion of the New England Tablelands is climatically suitable for buckwheat. However, most farmers in this region are not fully aware of their soils fertility status. This lack of knowledge on the soil fertility among other factors has resulted in year to year and field to field unstable buckwheat production in the past many years. For the successful and sustainable yield of buckwheat such knowledge is crucial. This study on the evaluation of the fertility potential of the buckwheat growing areas will be useful in predicting the fertiliser requirements on these soils. The nutrient omission technique was used in the triple-pots to investigate the nutrient requirements of buckwheat on various soil types.

5.2. MATERIALS AND METHODS

The technique used in this study was also modified from double-pot to triple-pots due to the reason explained in the materials and methods section of Chapter 3. The principles of the technique were strictly followed as described by Janssen, (1974, 1990), Muller *et al.*, (1979). Five agriculturally important soils of the New England Tablelands, New South Wales, Australia were tested in this study. These soils were a chocolate soil collected from Laureldale, University of New England (UNE) Armidale, a black earth from Clark's farm UNE, Armidale and a grey brown podsolic (Kirby-17) collected from Newholme, Guyra road, Armidale. Two other grey brown podsolic soils i.e. Clark's (C) and Uralla (U) soils collected from Clark's farm UNE, Armidale and from south of Uralla, respectively. The soils were collected to a plough depth (upper 25 cm). All these soils have different characteristics and the detailed analyses for each of these soils is given in Table (5.1). Each soil was air dried and passed through 2mm mesh. From each of the sieved bulk samples of these soils, 500 g was weighed separately into 27 plastic pots that served as the upper pots for nine treatments and three replicates. All the pots used in this experiment were of the same size as described in Chapter 3 section 3.2. The experiment was conducted in a glasshouse with a temperate regime. The procedure followed was as previously described.

Five to seven seeds of buckwheat (*Fagopyrum esculentum* Moench) cv. Mancan were planted to a depth of approximately 1 cm. Mancan is a large seeded,

high yielding, of desirable quality, preferred by the Japanese market (Campbell and Gubbels, 1979) and a commonly used variety in Australia (Hennessy, 1992) and many other buckwheat producing countries. It was developed in Canada (Gubbels and Campbell, 1986). Large-seeded varieties (Mancan) are the ones preferred for food use (Myres and Meinke, 1994). Seedlings were thinned to 3 well established plants per pot 3-4 days after germination. All other experimental procedures and techniques adopted in this experiment were the same as described in Section 3.2 of Chapter 3.

5.2.1. Experimental design and treatments

For each soil, the experiment was set up in a randomised complete block design with nine treatments and three replications. The treatments consisted of nine nutrient solutions, as described in Table 3.1. The final concentrations of all the nutrients in the various solutions are summarised in Table 3.2.

5.2.2. Soil analysis

All the soil chemical analyses were carried out at the Incitec analytical laboratories, Port Kembla, NSW, using the methods as described below.

Soil pH was determined in a 1:5 ratio of soil:water and in a 1:5 ratios of soil:$CaCl_2$ (0.01M) stirred for 1 hour. pH reading was taken using a combined electrode. The measurement of the pH is method dependent. Ideally, the measurement of soil pH should be made in soil in its natural condition but for several reasons e.g. fragility of glass electrode, this is not possible, thus widely used method is the suspension method. However, a wide ratio of soil to water increases the pH by diluting the electrolyte concentration of soil. Peech (1965) advocated the use of $CaCl_2$ as the suspension medium because it is similar in electrolyte composition to soil solution. He noted that this medium is independent of dilution over a wide range of soil suspensions. The reason of higher pH by the former method will be the dilution effect while the later method represent the actual situation, thus reference is made to the later method ($CaCl_2$) for pH values.

Organic carbon was determined by the Walkley and Black method using H_2SO_4 and $K_2Cr_2O_7$ in 1:100 dilution, and measured colorimetrically using a spectrophotometer. Nitrate-N was extracted in a 1:5 ratio of soil:water, intermittently stirred for 1 hour and nitrate was measured colorimetrically using a segmented flow analyser.

Sulfur (MCP) was extracted in 1:5 soil to solution of 0.01M Ca $(H_2PO_4)_2$, shaken vigorous for 1 hour, centrifuged and measured in segmented flow analyser.

Sulfur (KCl-40) was determined in a 3:2 ratio of soil to solution of 0.25 M KCl held at 40°C for 3 hours. The solution was filtered, oxidised and heated at 80°C for 16 hours. Sulfur was measured turbidimetrically, or by an Inductively Coupled Plasma Atomic Emission Spectrophotometer (ICP-AES).

Phosphorus (Colwell) was extracted in 1:100 soil to solution of 0.5 M $NaHCO_3$, shaken for 16 hours (end-over-end shaker), and centrifuged. The available P in the extract was measured colorimetrically by segmented flow analyser.

Exchangeable cations were measured by ICP-AES in 1:10 neutral normal ammonium acetate extracts and the CEC was calculated as the sum of exchangeable cations.

Electrical conductivity was measured in a 1:5 ratio of soil: water stirred and allowed to stand for 1 hour and read by a conductivity meter. Chloride was extracted in 1:5 ratio of soil to water sample, stirred intermittently for 1 hour, centrifuged and measured on Atomic Absorption Spectrophotometer, or ICP.

Potassium, calcium, magnesium, sodium were determined in 1:100 soil solution ratio of 0.0125 M Barium Chloride, shaken end-over-end for 16 hours and read using ICP analyser. Aluminium was extracted in 1:10 soil to solution of 1M KCl, vigorously shaken for 1 hour, centrifuged and measured on the ICP.

Micronutrients (Zn, Cu, Mn and Fe) were extracted in 1:10 ratio of soil:solution using DTPA (dietylenetriaminepentaacetic acid), triethanolamine and $CaCl_2$. After 1/2 hour of vigorous shaking it was measured on ICP-AES.

Boron was determined colorimetrically in a segmented flow analyser using 1:2 ratio soil:solution of hot water, refluxed for five minutes, and the centrifuged before reading.

Table 5.1. Chemical and physical properties of soils used in various experiments.

Properties	Chocolate (Laureldale)	Grey Brown Podsolic (Kirby-17)	Grey Brown Podsolic (Clark's)	Black earth (Clark's)	Grey brown Podsolic (Uralla)
Colour (Munsell)	Very Dark Greyish Brown	Greyish Brown	Yellowish Brown	Brown	Brown
Texture	Light Clay	Sandy Loam	Sandy Clay Loam	Medium Clay	Silty loam
pH (1:5 water)	5.4	5.8	6.0	7.7	6.0
pH (1:5 $CaCl_2$)	4.8	4.9	5.1	7.1	6.2
Organic Carbon %C	2.9	1.2	0.8	1.7	0.9
Nitrate Nitrogen mg/kg	65	11	3	<2	2.2
Sulfate Sulfur (MCP) mg/kg	15	3	-	-	4.6
Sulfate Sulfur (KCl-40) mg/kg	7	3	5	11	-
Phosphorus (Colwell) mg/kg	61	9	38	17	4
Potassium meq/100g	0.4	0.2	0.2	0.3	0.10
Calcium meq/100g	18.5	2.1	2.4	42.7	1.49
Magnesium meq/100g	13.3	1.1	0.6	15.8	0.62
Aluminium (KCl) meq/100g	0.14	0.11	<0.05	<0.05	-
Sodium meq/100g	0.27	0.07	<0.05	0.15	0.02
Chloride mg/kg	11	6	5	5	5
Electrical Conductivity dS/m	0.27	0.04	0.02	0.14	0.02
Copper mg/kg	3.2	<0.5	4.7	2.5	0.2
Zinc mg/kg	1.7	7.5	7.5	0.5	0.5
Manganese mg/kg	91	8	6	7	13
Iron mg/kg	96	41	58	19	34
Boron mg/kg	0.5	0.2	0.2	0.6	0.27

5.3. RESULTS

5.3.1. Chocolate soil

a) Plant height

The height of Mancan in chocolate soil was significantly affected by the omission of various nutrients. The highest plant height was obtained with the treatment where all the nutrients were present (+All). This was statistically similar to the height of all other treatments with the exception of –All, -N and -P. There was a range of 2-53% reduction in height due to omission of various nutrients (Figure 5.1). The largest reduction of 53% was caused by the omission of N, which was statistically similar to the reduction (49%) caused by the omission of all nutrients (NIL) and was significantly different from the rest of the reductions. The omission of P caused 17% reduction which was statistically similar to +All-T (-T is minus trace elements), -K, -S, -Ca and –Mg.

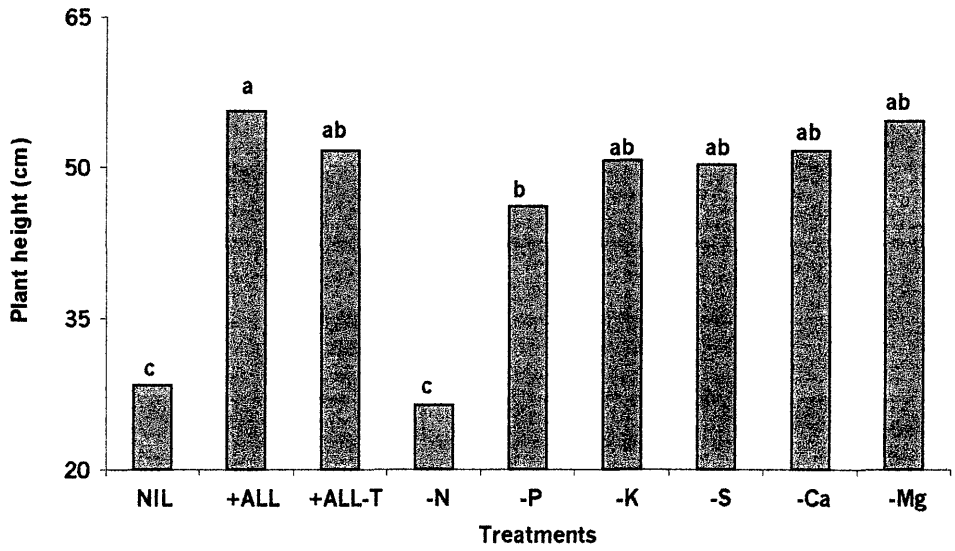


Figure 5.1. Plant height as affected by the omission of nutrients on the chocolate soil (Laureldale).
Data bars labelled with the same letters within a figure are not significantly different according to DMRT P≤0.05.

b) Dry matter yield

The biggest dry matter yield was obtained with +All nutrients, which was statistically similar to the yield obtained with –K, -Ca, and –Mg (Figure 5.2). The greatest reduction of 96% was caused by the omission of N, which was statistically similar to the reductions of 93% and 79% caused by the omission of All nutrients (NIL) and S, respectively. The omission of P reduced the dry matter yield by 53% which was statistically similar to the reduction of 37%, 47%, and 79% caused by the omission of K, trace elements, and S, respectively.

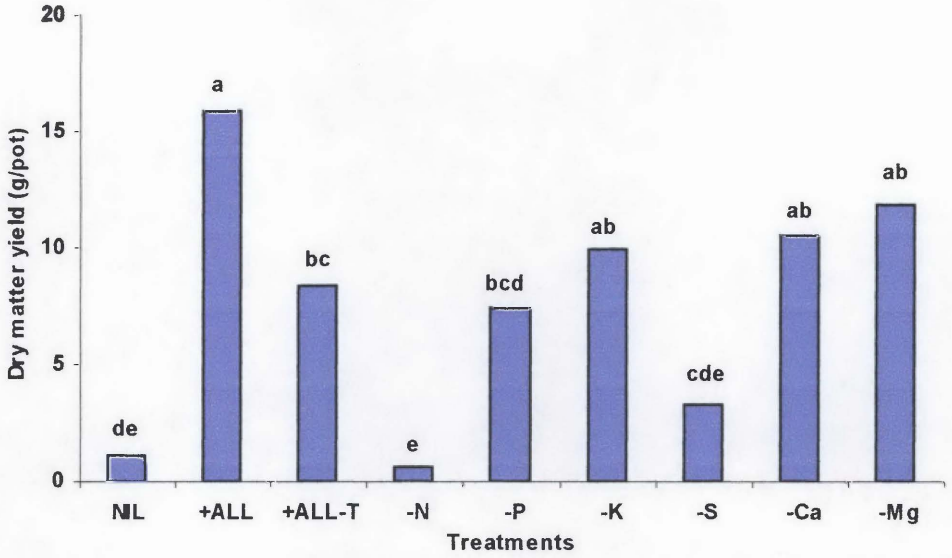


Figure 5.2. Dry matter yields as affected by the omission of nutrients on the chocolate soil (Laureldale).

Data bars labelled with the same letters within Figure are not significantly different according to DMRT P≤0.05.

c) Root dry weights

Root dry weights were also significantly affected by the omission of nutrients (Figure 5.3). The highest root dry weight was recorded in +All nutrient, which was statistically similar to the root dry weight obtained with +All-T, -P, -K, -Ca, and –Mg. The biggest reduction (97%) in root dry weight was occurred with -N, which was statistically similar to –All, -S, and -P (94%, 76%, 45%, respectively). There were no statistical differences in the reductions of root dry weight caused by the omission of All nutrients, +All-T, P, K and S.

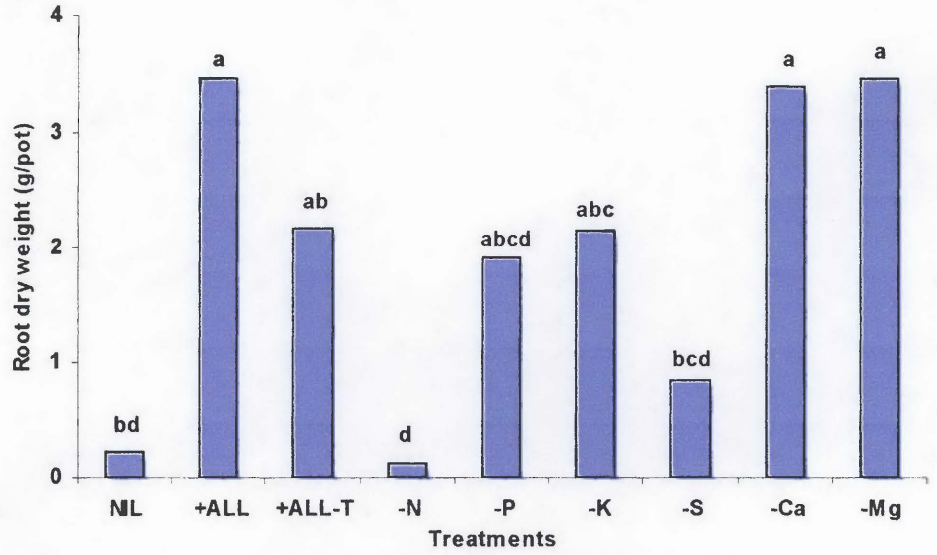


Figure 5.3. Root dry weights as affected by the omission of nutrients on the chocolate soil (Laureldale).

Data bars labelled with the same letters within a figure are not significantly different according to DMRT P≤0.05.

5.3.2. Grey brown podsolic soil (Kirby-17)

a) Plant height

The highest plants were recorded in the +All treatment, which was statistically similar to the heights obtained with +All-T, -K, -S, -Ca, and -Mg. The treatments –N and –P were the only treatment significantly different from +All (Figure 5.4).

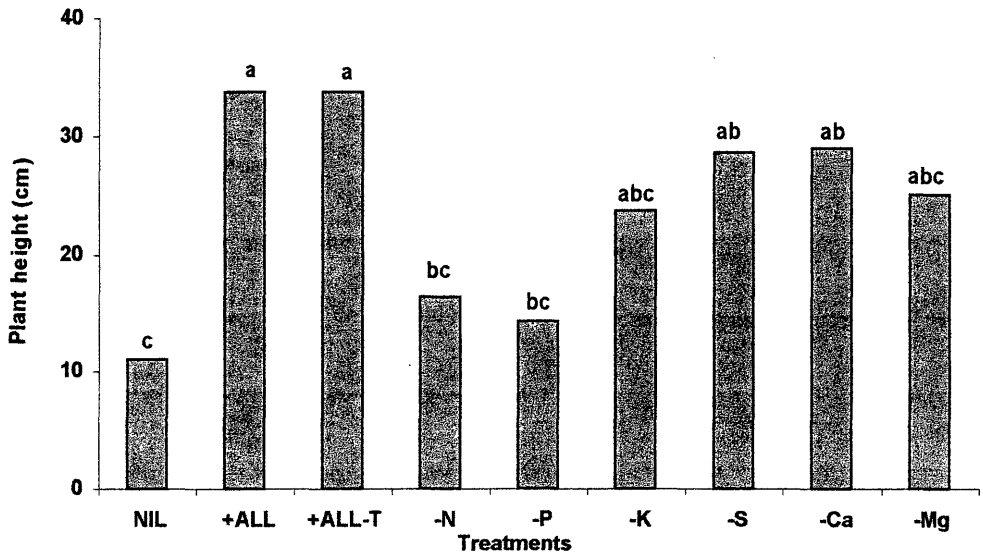


Figure 5.4. Plant height as affected by the omission of nutrients on the grey brown podsolic (Kirby-17).

Data bars labelled with the same letters within figure are not significantly different according to DMRT P≤0.05.

b) Dry matter yield

The omission of various nutrients significantly affected the dry matter yield (Figure 5.5). The highest dry matter yield (3.42 g/pot) was obtained with the +All treatment, which was statistically similar to the +All-T, -K, -Ca, and –Mg. The largest reduction (94%) in dry matter yield was recorded for NIL, which was statistically similar to the reductions (88%, 88%, 87%, 63%, 52, and 31%) caused by the omission of N, P, S, K, Ca and Mg respectively. However, the dry matter yields recorded in the +All and +All-T treatments were significantly higher than the dry matter yields produced with NIL, -N, -P, and –S.

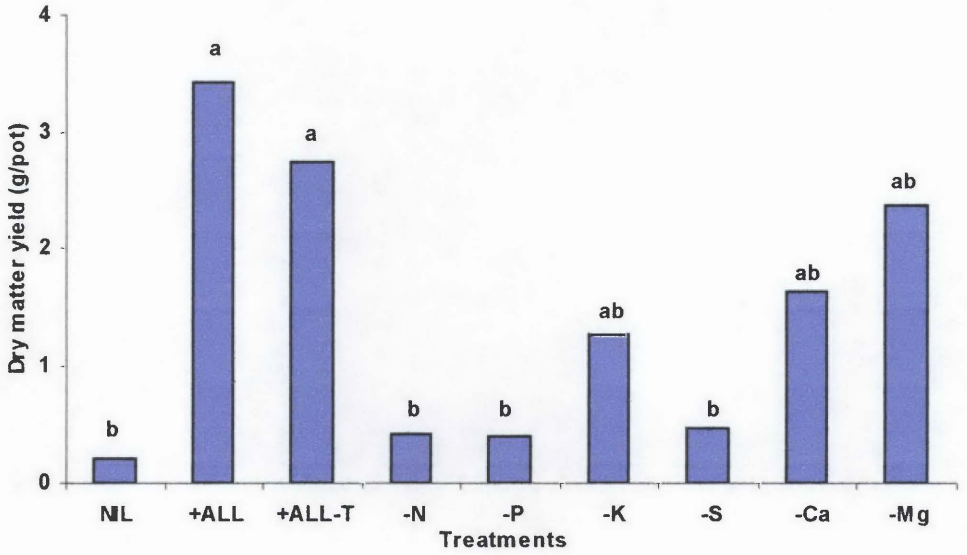


Figure 5.5. Dry matter yield as affected by the omission of nutrients on the grey brown podsolic (Kirby17) soil.

Data bars labelled with the same letters within figure are not significantly different according to DMRT P≤0.05.

c) Roots dry weight

The omission of nutrients significantly affected root dry weights as well. The highest root weight was in the treatment +All, which was statistically similar to +All-T, and –Mg. There was a range (43-80%) reductions in root dry weights (Figure 5.6) with largest (80%) occurring in -N, which was statistically similar to all other treatments except +All.

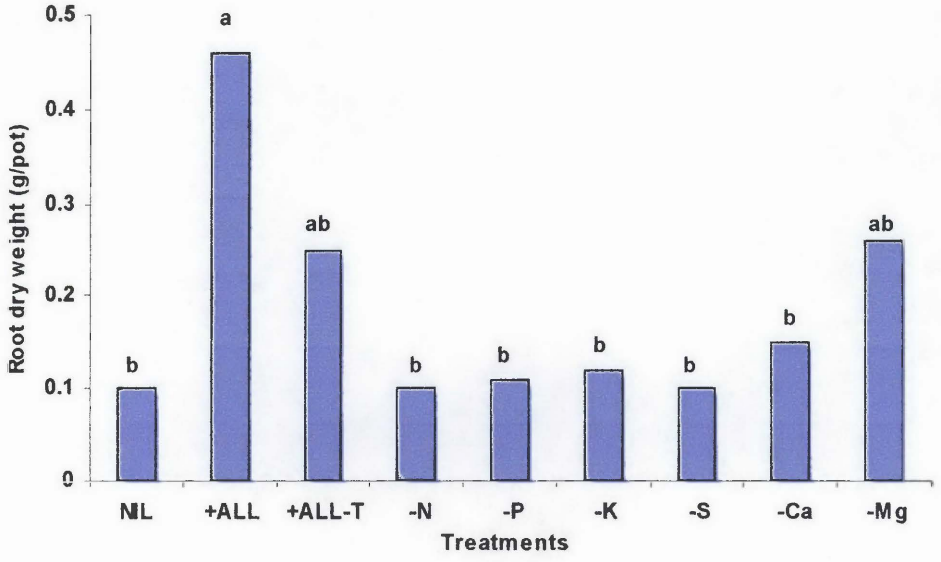


Figure 5.6. Root dry weights as affected by the omission of nutrients on the grey brown podsolic (Kirby-17) soil.

Data bars labelled with the same letters within a figure are not significantly different according to DMRT P≤0.05.

5.3.3. Black earth soil (Clark's)

a) Plant height

There were no significant treatment differences on the plant height (Table 5.2).

Table 5.2. Plant height as affected by the omission of nutrients.

Nutrients	NIL	+ALL	+ALL-T	-N	-P	-K	-S	-Ca	-Mg	Sig.
Plant Height	27.0	29.8	30.0	26.3	26.7	27.7	26.0	31.7	31.0	NS

b) Dry matter yield

The omission of a range of nutrients caused significant reduction of 2 - 82% in the dry matter yield (Figure 5.7). There were no significant differences between +All, -K, -Ca and –Mg. The omission of All nutrients caused maximum reduction, which was statistically similar to the reductions in dry matter yield due to –N and –S. There was no significant difference between the dry matter yield in –P and –S.

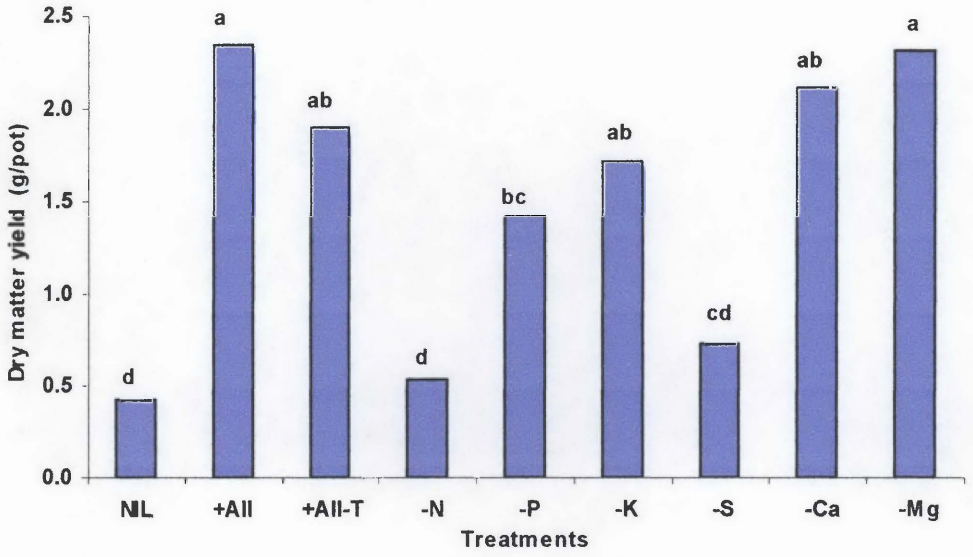


Figure 5.7. Dry matter yield as affected by the omission of nutrients on the black earth soil (Clark's).
Data bars labelled with the same letters within a figure are not significantly different according to DMRT P≤0.05.

c) Root dry weights

The root dry weights were significantly affected with the omission of various nutrients (Figure 5.8). The highest root dry weight was obtained with the application of All nutrients; this was statistically similar to the root weights produced with the omission of trace elements, P, Ca, and Mg. The largest reduction (72%) occurred in root dry weight with the omission of All nutrients (NIL) which was in turn statistically similar to the reductions caused by the omission of N, and S. The omission of K caused a reduction of 37% which was statistically similar to the reductions caused by all other treatments except NIL and +All (Figure 5.8).

In summary, the omission of All, trace, N, P, K, S, Ca, and Mg caused reductions of 72%, 30%, 58%, 28%, 37%, 63%, 19% and 30%, respectively compared to maximum yield produced by the application of All nutrients.

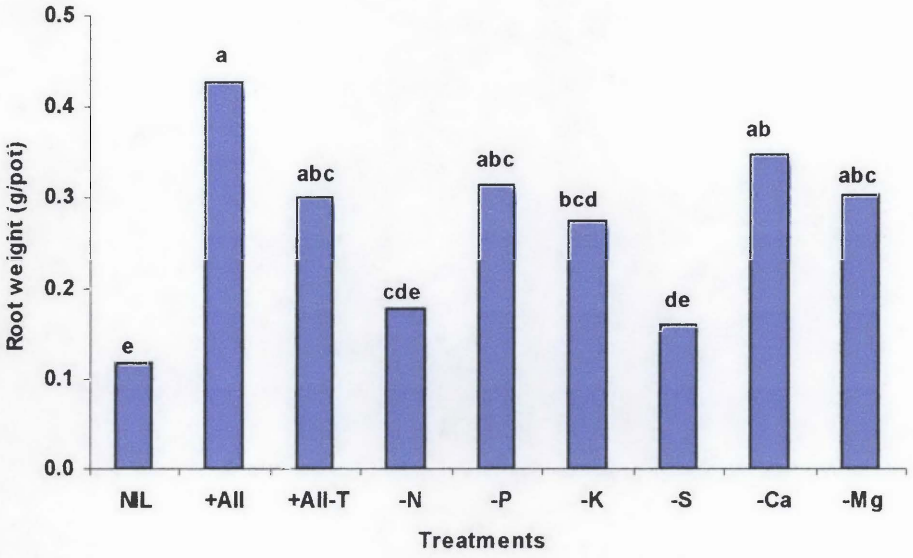


Figure 5.8. The omission of nutrients affecting the root dry weights on the black earth soil (Clark's).
Data bars labelled with the same letters within a figure are not significantly different according to DMRT P≤0.05.

5.3.4. Grey brown podsolic soil (Uralla)

a) Plant height

All the treatments produced statistically similar heights except in the treatment where P was omitted which caused significant reduction of 46% in the height compared to the maximum plant height obtained with +All (Figure 5.9).

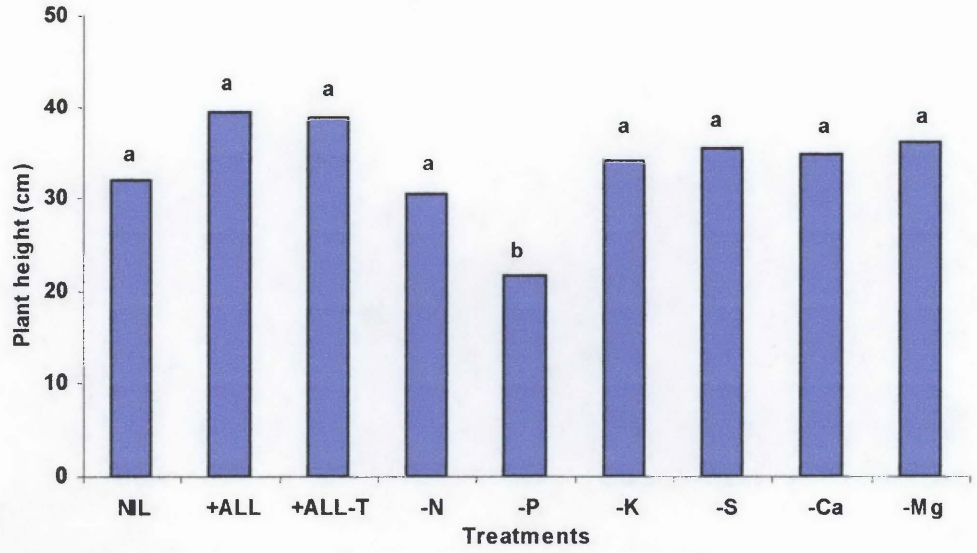


Figure 5.9. The omission of nutrients affecting the plant height on the grey brown podsolic soil (Uralla).
Data bars labelled with the same letters within a figure are not significantly different according to DMRT P≤0.05.

b) Dry matter yield

There were no statistical differences among the dry matter yields obtained with +All and with the omission of trace elements, Ca, and Mg (Figure 5.10). The omission of All, N, P, and S caused statistically similar reduction in yield. However, the yield obtained with the omission of K was significantly lower than the dry matter yield obtained with +All, +All-T, -Ca, and –Mg while significantly higher than the dry matter yields obtained with –All, -N, -P, and -S.

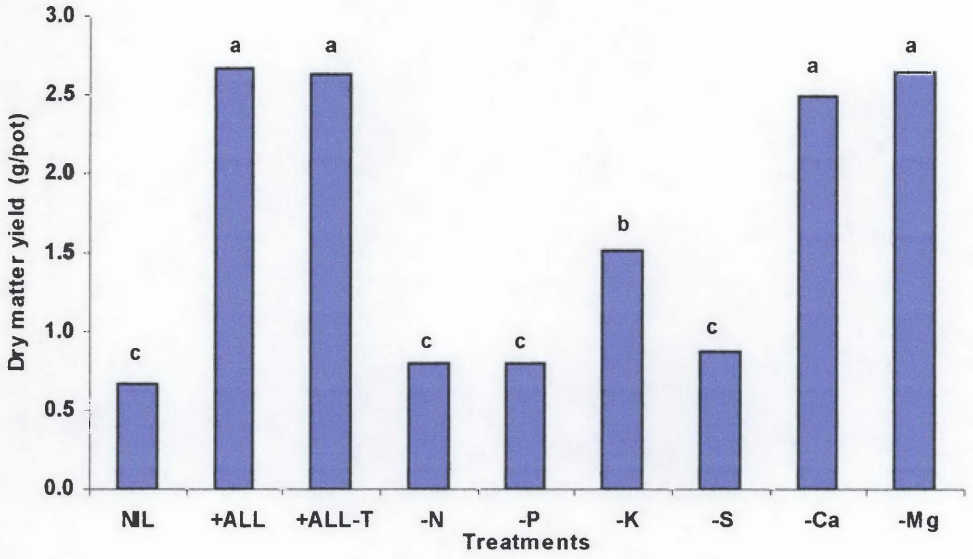


Figure 5.10. The omission of nutrients affecting the dry matter yield on the grey brown podsolic soil (Uralla).

Data bars labelled with the same letters within a figure are not significantly different according to DMRT $P \leq 0.05$.

c) Root dry weights

There was no statistical difference in the root dry weights obtained with the application of +All nutrients and omission of trace elements and Mg. The omission of Ca produced statistically similar root weights to +All and –trace elements but lower than –Mg and significantly higher than the rest of the treatments. The largest reduction (63%) was caused by the omission of N, which was not statistically different from the root dry weights obtained with -All, -P, -K and –S (Figure 5.11).

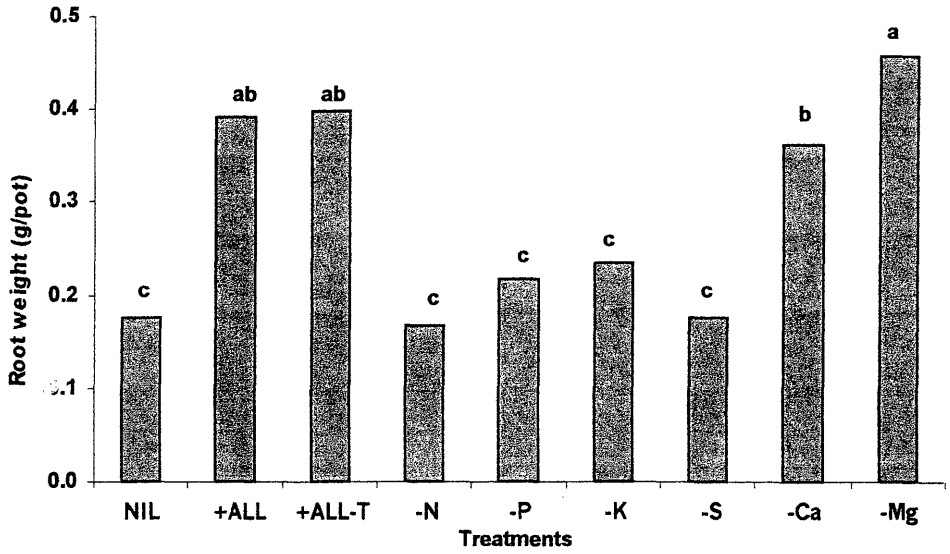


Figure 5.11. Root dry weights as affected by the omission of nutrients on the grey brown podsolic soil (Uralla).

Data bars labelled with the same letters within a figure are not significantly different according to DMRT P≤0.05.

5.3.5. Grey brown podsolic soil (Clark's)

a) Plant height

Height was reduced by 13-40% with a range of nutrient omissions (Figure 5.12). The heights obtained with +All, -trace, -P, -Ca and –Mg were statistically similar. The heights produced with the omission of K and S were statistically similar to the heights in all other treatments except –Mg. Minimum height was produced in the absence of All nutrients (NIL) which was statistically similar to heights of all other treatments except +All and –Mg.

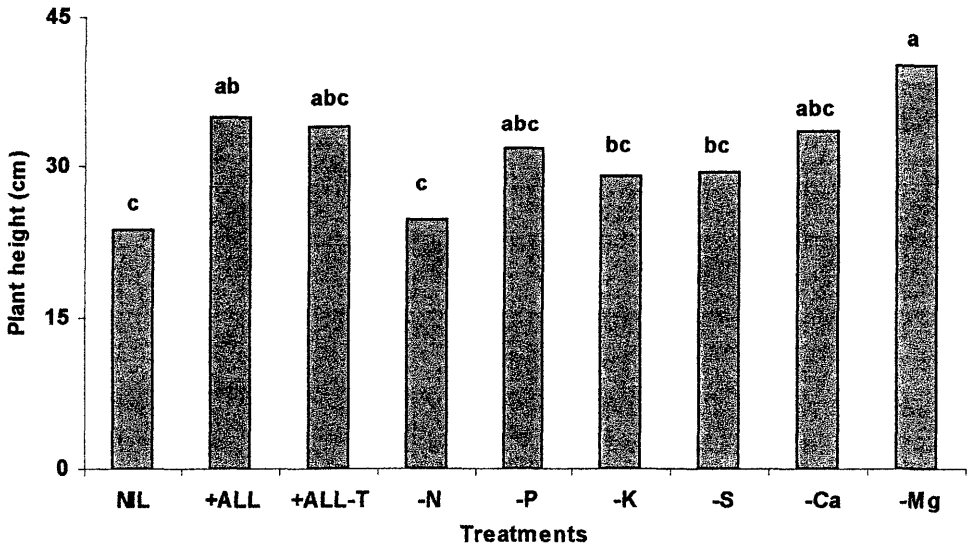


Figure 5.12. The omission of nutrients affecting the plant height on the grey brown podsolic soil (Clark's).

Data bars labelled with the same letters within a figure are not significantly different according to DMRT P≤0.05.

b) Dry matter yield

There were highly significant effects on the dry matter yields due to omission of nutrients. A range of 17- 82% reductions were caused due to the omission of a range of nutrients when compared to the dry matter yield produced with +ALL. The yields produced with +All, -trace, -P, and -Mg were statistically similar. There was no statistical difference in the reductions of dry matter yield caused by the omission of All, N, K, S, and Ca. The biggest reduction in yield was caused by the omission of N. The omission of All, N, P, K, S, and Ca reduced the dry matter yield by 79%, 82%, 18%, 46%, 62%, and 41%, respectively compared to the dry matter yield in +All (Figure 5.13).

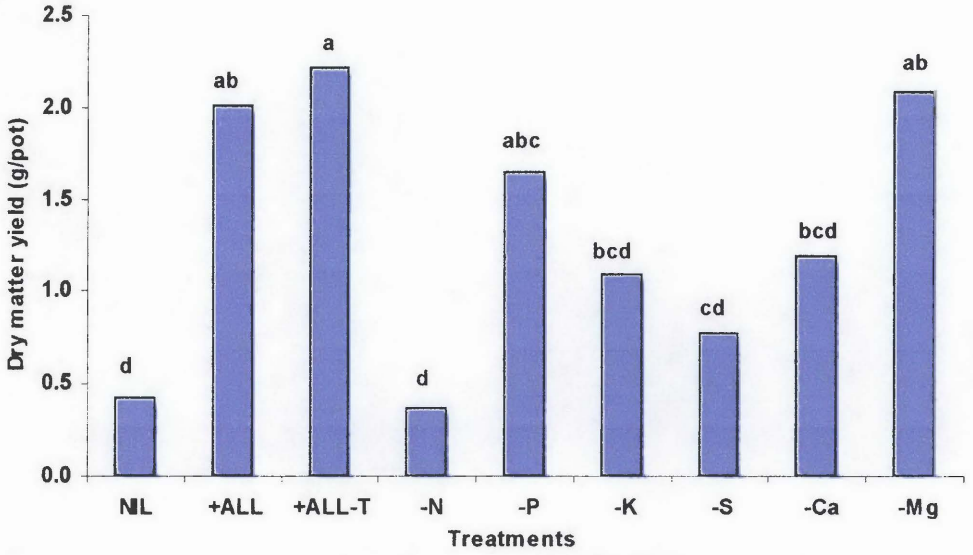


Figure 5.13. Dry matter yield as affected by the omission of nutrients on the grey brown podsolic soil (Clark's).

Data bars labelled with the same letters within a figure are not significantly different according to DMRT P≤0.05.

c) Root dry weight

Root dry weights were significantly affected by the omission of various nutrients (Figure 5.14). The highest root dry weight was obtained with the treatment where trace elements were omitted, which was in turn statistically similar to the yield produced with +All, -P and –Mg. The highest reduction in root dry weight was recorded with –N which was statistically similar to the root weights in –All, -K, -S, and –Ca. The omission of All, N, K, S and Ca caused reductions of 66%, 72%, 38%, 48%, and 41%, respectively when compared to the yield obtained with +All nutrients.

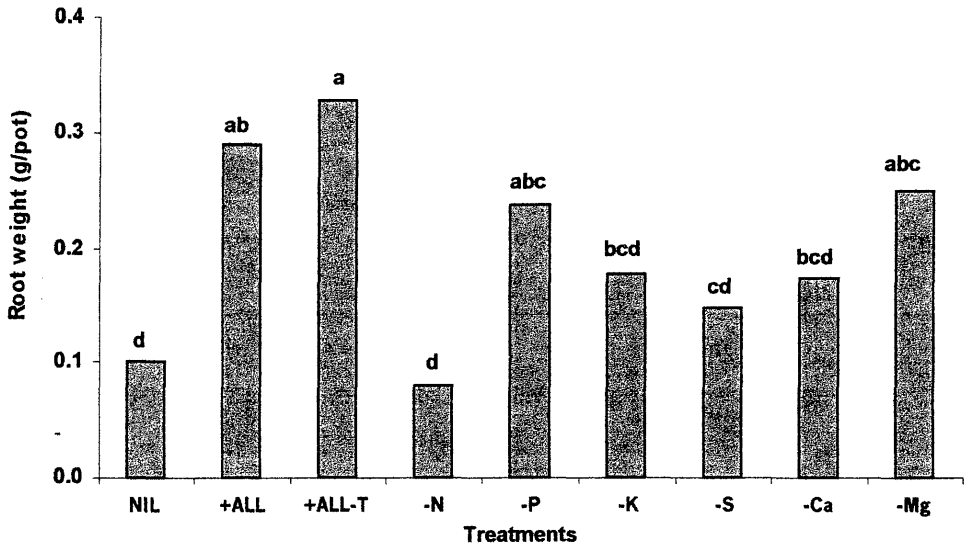


Figure 5.14. Root dry weights as affected by the omission of nutrients on the grey brown podsolic soil (Clark's).

Data bars labelled with the same letters within a figure are not significantly different according to DMRT P≤0.05.

5.4. DISCUSSION

The omission of various nutrients significantly affected all the plant parameters grown on the soils under investigation. However, with the omission of some nutrients, there were no significant differences in the plant parameters when compared to +All treatment. There are no published data on the sufficiency levels of nutrients in the soil for buckwheat, so these results are compared to the requirements of small grain crops such as wheat, oats and barley on these soils as described in the Soil Interpretation Manual (1990).

By comparing nitrogen nutrition in different soils with respect to dry matter yield and root dry weight, it is apparent from the figures that the omission of nitrogen decreased these two parameters significantly in all the soils which suggest that the addition of N fertiliser will increase the yield. It is also supported by the observation of their low initial nitrate level which is less than 11 mg/kg except chocolate soil. Moreover, plant height was not affected significantly in black earth soil and grey brown podzolic (Uralla) soil. The comparisons are made with wheat, oats and barley as described in the Soil Interpretation Manual (1990). According to that comparison, N is required for buckwheat as well.

The chocolate soil contained 65 mg/kg of NO_3-N which is sufficient to support reasonable crop yield but the response of this soils is understandable considering the mass of soil (0.5 kg) which supplied only 32.5 mg/kg NO_3-N and produced a biomass (root + shoot) of 20.5 g. Notwithstanding the possibility of denitrification in this fine textured soil under wet condition, amount of 32.5 mg of NO_3-N supplied by half kg of soil would hardly

result in the tissue concentration of 1.6 mg/g (32.5 mg/20.5 g = 1.6 mg/g) of tissue which is inadequate considering the values of 39, 4.5, and 56 mg/g for oat tops, straw, and rape, respectively (Mengal, 1971).

All the soils except grey brown podsolic (Clark's) showed reduction in dry matter yield when P was omitted. The response of grey brown podsolic (Kirby-17), Black earth and Uralla soils with low P of 9, 17, and 4 mg/kg, respectively is understandable. But reduction in yield by chocolate soil with 61 mg/kg P and no reduction in yield in Clark's soil with 38 mg/kg initial P levels needs closer analysis. The chocolate soil is a nutrient rich and has out yielded all other soils by a factor of about 5 to 10 on the basis of dry matter. Therefore, P supplied by the soil mass and the yield produced should be taken into account to understand the effect of P. The soil P level (61 mg/kg) apparently seems high, and if it is assumed that all P was bio-available, the plant tissue concentration hardly reaches to 3.39 mg/g tissue (30.5 mg P per 9 g dry matter). This suggested that the response of chocolate soil to the omission of P is basically caused by the high yield potential of limited mass of soil. Considering the value of soil pH (4.8) and the soluble Fe concentration (96 mg/kg) the possibility of formation of insoluble Fe-phosphate can not be excluded (Lindsay and Norvell, 1979). Grey brown podsolic (Clark's) soil with 38 mg/kg of P produced about 1.8 g dry matter (root + shoot) per 0.5 kg soil would maintain tissue concentration of 10.5 mg P/g dry matter. This tissue concentration of P is well above the reported values of P for most crops (Tisdale and Nelson, 1985). In view of the relationship between the soil P and plant yield, the level of P in the plant suggested that Clark's soil supplied enough P to maintain the yield of buckwheat without depending on any additional P. As such P omission in this particular soil did not cause any reduction in yield.

The omission of P from nutrient solution significantly reduced almost all the yield parameters studied. Buckwheat is a heavy user of P and responds like small grains to phosphate fertilisers (Helm and Schneiter, 1986; Smith, 1989; and Berglund, 1995).

Plant height and dry matter yield were not significantly affected when K was omitted from the nutrient solution except for the grey brown podsolic (Uralla) soil where dry matter yield and plant height was reduced significantly when compared to +All. This soil has only 0.1 meq/100 g soil initial K that may not be sufficient to supply the required amount of K.

Sulfur levels in all the soils were insufficient for buckwheat when compared to wheat, oats, and barley according to Soil Interpretation Manual (1990). Dry matter yield and dry root were significantly reduced when S was omitted from nutrient solution. Due to deficiency of S spindly stems were produced which resulted non-significant differences in plant height

compared to maximum height of +All. These results suggest that the addition of S is required for the optimum yield of buckwheat on the soils studied.

The absence of both Ca and Mg from the nutrient solution did not cause any significant differences in all the parameters studied except dry matter yield and dry root weight in grey brown podsolic (Clark's) soil which were significantly reduced when Ca was omitted from the system. From the analysis of soil (Table 5.1), the initial Ca content is very high which indicate some nutritional disturbance that might have negative impact on the plant growth (Tisdale et al., 1985; Mengal and Kirkby, 1987). Over all results suggest that all the soils under study have moderate to high level of both Ca and Mg, which are adequate for buckwheat and at near future, no additional Ca and Mg are required.

Regarding micronutrients (Zn, Cu, Mn, and Mn), the omission of these nutrients did not affect the yield significantly when compared to +All in all the soils studied. This suggests that the addition of micronutrients is not required on these soils. The no response to micronutrients addition may be the lower soil pH under which all the micronutrients are soluble (Tisdale *et al.* 1993) and hence available. Soil test analysis (Table 5.1) also shows that the micronutrients were well above the critical limits. However, to be more authentic, the comparison between individual nutrient addition and omission may be more informative than addition of all at one time. Since due to the abundance of the research work, this was not possible in the present situation.

The overall results indicated that the tissue yield in chocolate soil (regardless of individual nutrient omissions) was higher than all other soils. This soil out yielded other soils by magnitude of 5 to 10. The initially higher levels of almost all the essential nutrients (Table 5.1) suggest that this soil was rich in nutrients and having a favourable soil physical condition could be considered suitable for buckwheat production. This was evident from the field experiments conducted on this soil and as well as from the stand of buckwheat crop grown on farmer fields.

It can be concluded from this study that N, P, and S are required for higher yields while K is sufficient at present but may be needed in soils having light texture. The micronutrients are not required as the soils are acidic (low pH) and their availability will be no problem keeping in view their high concentration in soil and low pH.