CHAPTER 8

RESPONSE OF BUCKWHEAT TO APPLICATION OF MICRONUTRIENTS (Zn, Cu, B, AND Mo)

8.1. INTRODUCTION

The effects of major nutrients on the various parameters of buckwheat are discussed in other chapters. Microunutrients are also essential plant nutrients and although required by the plants in relatively small amounts, they play a variety of different roles in biochemical reactions in plants (Thompson and Troeh, 1975; Katyal & Rattan, 1990; Tisdale *et al.* 1993). A deficiency of any one of the micronutrients can restrict plant growth as surely and as severely as a deficiency of nitrogen. Interest in micronutrients has increased in the last few years because of recent research demonstrating that they play important roles in plant disease resistance and in root-stress resistance (Graham and Webb, 1991; Miller *et al.*, 1991; Van Campen, 1991; Nielsen, 1992). The effects of micronutrients in the nutrition and development of various plant species are reported by many scientists (Nicholas and Egan, 1975; Hewitt, 1979, 1983, 1984; Lepp, 1981; Robb and Pierpoint, 1983; Shkolnik, 1984; Marschner, 1986; Cauderon, 1990; Mortvedt *et al.*, 1991; Kabata-Pendias and Pendias, 1992).

Very little research has been conducted on the micronutrient requirements of buckwheat as related to soil conditions. The work reported here was set out to investigate the effects of micronutrients on the growth of buckwheat and grain yield. Commonly, the effect of a micronutrient deficiency is only detected in grain production.

8.2. MATERIALS AND METHODS

A pot experiment to evaluate the effects of copper (Cu), zinc (Zn), boron , and molybdenum (Mo) on the plant growth of buckwheat (*Fagopyrum esculentum* Moench) was conducted in the glasshouse of Division of Agronomy and Soil Science, University of New England, Armidale, Australia. Two agriculturally important soils of the New England Tablelands namely chocolate and grey brown podsolic (Kirby-17) were used in this study. These soils were collected and prepared according to the procedures as described in chapter 5, section 5.2. The analysis of these soils is presented in Table (8.3). Plastic pots with surface area of 132.66 cm^2, lined with plastic bags were filled with these soils. Basal rate of 50 kg N, 40 kg P, 50 kg K, and 60 kg S as ammonium sulphate, triple-super phosphate, potassium chloride and sodium sulphate, respectively were applied to each pot. All these nutrients were mixed thoroughly with the soil in all the pots before sowing. Five seeds of Mancan variety were sown in each pot and were thinned to 2 plants/pot after establishment. All the pots were monitored for water requirements and were kept at field capacity throughout the growing period by weighing each of them prior to water application. Plant height was recorded 35 days after germination. The plants were harvested at maturity and were placed in paper bags and dried in a forced draught oven at 80°C for 48 hours. Data on the straw and grain yields were recorded after harvesting and drying of the plants.

8.2.1. Experimental design and treatments

Micronutrients, i.e. copper (Cu), Zinc (Zn), boron, and molybdenum (Mo), were applied at rates of 0 and 5 kg/ha as $CuSO_4$. $5H_2O$, $ZnCl_2$, H_3BO_3, and $Na_2MoO_4.2H_2O$, respectively in solution form after thinning. All these nutrients were applied alone and in all their possible combinations according to the experimental plan (Table 8.1). All the treatments were replicated thrice. All the pots were arranged according to a randomised complete block design (RCBD) in the temperate glasshouse. Fertiliser calculations for an individual treatment are presented in Table 8.2.

Table 8.1. Treatments description

Treatment ID	Micronutrients Added	Treatment ID	Micronutrients Added
T_1	Zn_0 Cu_0 B_0 Mo_0	T_9	Zn_0 Cu_0 B_0 Mo_5
T_2	Zn_5 Cu_0 B_0 Mo_0	T_{10}	Zn_5 Cu_0 B_0 Mo_5
T_3	Zn_0 Cu_5 B_0 Mo_0	T_{11}	Zn_0 Cu_5 B_0 Mo_5
T_4	Zn_5 Cu_5 B_0 Mo_0	T_{12}	Zn_5 Cu_5 B_0 Mo_5
T_5	Zn_0 Cu_0 B_5 Mo_0	T_{13}	Zn_0 Cu_0 B_5 Mo_5
T_6	Zn_5 Cu_0 B_5 Mo_0	T_{14}	Zn_5 Cu_0 B_5 Mo_5
T_7	Zn_0 Cu_5 B_5 Mo_0	T_{15}	Zn_0 Cu_5 B_5 Mo_5
T_8	Zn_5 Cu_5 B_5 Mo_0	T_{16}	Zn_5 Cu_5 B_5 Mo_5

8.2.2. Data presentation and statistical analysis

The data were analysed as a 2^4x3 replicates factorial separately for each soil by Neva (version 3.3) analysis of variance computer program (Burr, 1980) and means were separated using Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$. The data are presented as the mean for each treatment together with DMRT on each plant parameter.

Table 8.2. Fertiliser calculations for the treatments (micronutrients) and basal rates (g/pot)

Treatment	**Zn**	**Cu**	**B**	**Mo**	**N**	**P**	**K**	**S**
ID	$ZnCl_2$	$CuSO_4.5H_2O$	H_3BO_3	$Na_2MoO_4.2H_2O$	$(NH_4)_2SO_4$	TSP	KCl	Na_2SO_4
T_1	0	0	0	0	0.316	0.303	0.127	0.18
T_2	00.013	0	0	0	0.316	0.303	0.127	0.18
T_3	0	0.026	0	0	0.316	0.303	0.127	0
T_4	0.0138	0.026	0	0	0.316	0.303	0.127	0
T_5	0	0	0.037	0	0.316	0.303	0.127	0.18
T_6	0.0138	0	0.037	0	0.316	0.303	0.127	0.18
T_7	0	0.026	0.037	0	0.316	0.303	0.127	0
T_8	0.0138	0.026	0.037	0	0.316	0.303	0.127	0
T_9	0	0	0	0.017	0.316	0.303	0.127	0.18
T_{10}	0.0138	0	0	0.017	0.316	0.303	0.127	0.18
T_{11}	0	0.026	0	0.017	0.316	0.303	0.127	0
T_{12}	0.0138	0.026	0	0.017	0.316	0.303	0.127	0
T_{13}	0	0	0.037	0.017	0.316	0.303	0.127	0.18
T_{14}	0.0138	0	0.037	0.017	0.316	0.303	0.127	0.18
T_{15}	0	0.026	0.037	0.017	0.316	0.303	0.127	0
T_{16}	0.0138	0.026	0.037	0.017	0.316	0.303	0.127	0

8.2.3. Soil analysis

The chemical analysis of the chocolate and grey brown podsolic soils were carried out at the Incitec analytical laboratories, Port Kembla, NSW. The methods used for these analyses are described in chapter 5, section 5.2.2.

Table 8.2. Soil analysis of the chocolate and grey brown podsolic soils.

Properties	Chocolate (Laureldale)	Grey Brown Podsolic (Kirby-17)
Colour (Munsell)	Very Dark Greyish Brown	Greyish Brown
Texture	Light Clay	Sandy Loam
pH (1:5 water)	5.4	5.8
pH (1:5 $CaCl_2$)	4.8	4.9
Organic Carbon %C	2.9	1.2
Nitrate Nitrogen mg/kg	65	11
Sulfate Sulfur (MCP) mg/kg	15	3
Sulfate Sulfur (KCl-40) mg/kg	7	3
Phosphorus (Colwell) mg/kg	61	9
Potassium meq/100g	0.4	0.2
Calcium meq/100g	18.5	2.1
Magnesium meq/100g	13.3	1.1
Aluminium (KCl) meq/100g	0.14	0.11
Sodium meq/100g	0.27	0.07
Chloride mg/kg	11	6
Electrical Conductivity dS/m	0.27	0.04
Copper mg/kg	3.2	<0.5
Zinc mg/kg	1.7	7.5
Manganese mg/kg	91	8
Iron mg/kg	96	41
Boron mg/kg	0.5	0.2

8.3. RESULTS

8.3.1. Chocolate soil

Table 8.4, 8.5 and 8.6 represent data for the plant height, straw yield and grain yield, respectively as affected by the main effects of zinc (Zn), copper (Cu), boron (B), and molybdenum (Mo) each applied at the rate of 0 and 5 kg/ha. The values represent the mean (n=32) of a given nutrient averaged across its two levels.

The interaction of Mo x B x Cu and Mo x Cu x Zn are provided in Figures 8.1 and 8.2, respectively. Each bar represents average data for 8 observations for given levels of the respective interactions of micronutrients. Individual results regarding plant height, straw yield, and grain yield are presented in the following section.

a) Plant height

Plant height was not significantly affected by the main effects of Zn, Cu, B, and Mo each applied at the rate of 5 kg/ha as compared to Nil and as well as to the zero levels of the respective nutrients (Table 8.4).

Table 8.3. Average (n=32) plant height (cm) as affected by the application of micronutrients on the chocolate soil.

Rate	0 kg/ha	5 kg/ha
Nutrients		
Nil	46.67	-
Zinc	48.13	49.42 NS[a]
Copper	49.04	48.5 NS
Boron	48.96	48.58 NS
Molybdenum	48.46	49.08 NS

NS[a] = Non-significant

b) Straw yield

Application of 5 kg/ha of B caused a significant decrease in the straw yield as compared to control and as well as with 0 level of B (Table 8.5). Addition of Zn caused a non-significant decrease as compared to 0 level of Zn but the difference with Nil was significant. Addition of Cu and Mo caused non-significant increases in the straw yield.

Table 8.4. Average (n=32) straw (g/pot) as affected by the application of micronutrients on the chocolate soil.

Rate	0 kg/ha	5 kg/ha
Nutrients		
Nil	8.59	-
Boron	7.89a	6.81b
Zinc	7.54a	7.16a
Copper	6.93a	7.77a
Molybdenum	7.16a	7.54a

Numbers followed by the same letters within a row are not significantly different according to DMRT $P \leq 0.05$.

Mo x B x Cu interaction

On the basis of statistical analysis the interaction of Mo x B x Cu significantly affected the straw yield (Figure 8.1). The highest yield was produced with the application of 5 kg Cu/ha alone, which was significantly higher than Cu + B and Mo + B treatments. Addition of Mo and Cu at 0 level of B showed no significant difference in the straw yield, however, in the presence of 5 kg/ha each of B and Mo, Cu significantly increased the straw yield over 0 level of Cu (Fig. 8.1).

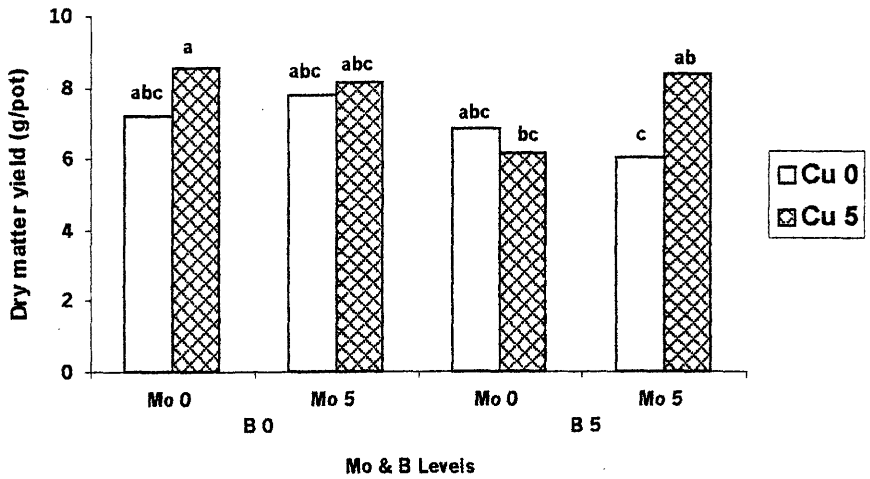

Figure 8.1. Straw yield (g/pot) as affected by the interaction of Mo x B x Cu on the chocolate soil. *Data bars labelled with the same letters within a figure are not significantly different according to DMRT $P \leq 0.05$.*

c) Grain yield

The main effects of the micronutrients in Table 8.6 each applied at the rate of 5 kg/ha indicate that there were no significant effects on the grain yield with the application of any of these nutrients with the exception of B, which has reduced the grain yield significantly by 21% compared to 0 kg B/ha.

As compared to Nil, the absence of B, Zn, Cu, and Mo showed a decrease in the yield, while addition of B and Mo tried to enhance the decreasing effect by of 43% and 37%, respectively in the grain yield whereas addition of Zn and Cu tended to minimise the decreasing effect caused by their absence from the system (Table 8.6).

Table 8.5. Average (n=32) grain yield (g/pot) as affected by the application of micronutrients on the chocolate soil.

Rate	0 kg/ha	5 kg/ha
Nutrients		
Nil	3.66	-
Boron	2.61a	2.07b
Zinc	2.25a	2.43a
Copper	2.20a	2.48a
Molybdenum	2.39a	2.29a

Numbers followed by the same letters within a row are not significantly different according to DMRT $P \leq 0.05$.

Mo x Cu x Zn interaction

Figure (8.2) compares the interactive effects of Mo x Cu x Zn on grain yield at two levels (0, 5 kg/ha) of each. At 0 level of Cu and at 5 kg/ha of Zn, addition of Mo caused a significant increase in the grain yield. However, the yield obtained at this interaction was equivalent to the grain yield obtained at Zn_0 x Cu_0 x Mo_0 and with the Cu_5 x Zn_5 x Mo_0. Although the rest of the interactive effects were non-significant, however, the data indicated that in case of Zn_0 x Cu_0 x Mo_5 tended to depress the grain yield, while Cu_0 x Zn_5 x Mo_5 increased the yield suggesting the positive interaction between Zn and Mo. Similar trend was observed with the addition of Cu_5 x Zn_5 x Mo_0.

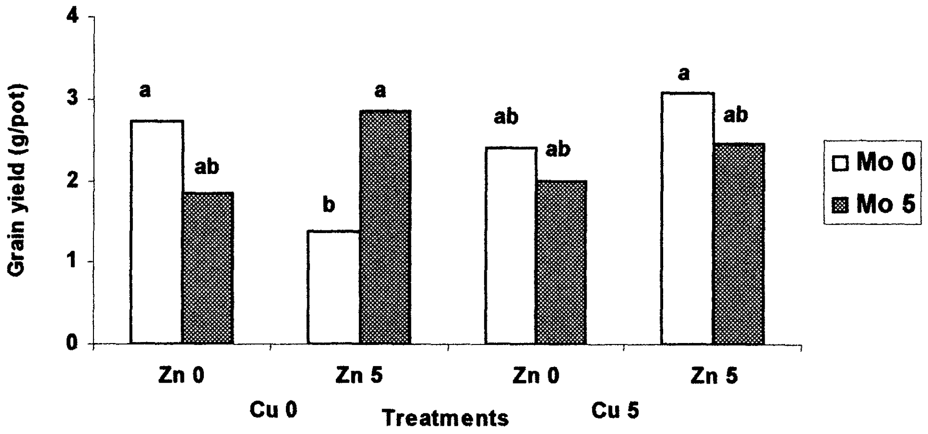

Figure 8.2. Grain yield (g/pot) affected by the interaction of Mo x Cu x Zn on the chocolate soil. *Data bars labelled with the same letters within a figure are not significantly different according to DMRT $P \leq 0.05$.*

Zn x Cu x B x Mo interaction

The interactive effects of Zn x Cu x B x Mo (Figure 8.3) indicated that the highest grain yield of 3.66 g/pot was obtained in the Nil treatment which was statistically similar to the grain of all the treatments with the exception of Zn, Cu, B, Zn + B, Mo, and Mo + Cu + B, which were statistically similar to each other. The lowest grain yield of 1.32 g/pot was obtained with the application of Zn + B which was equivalent to Zn alone and also to Cu x B x Mo.

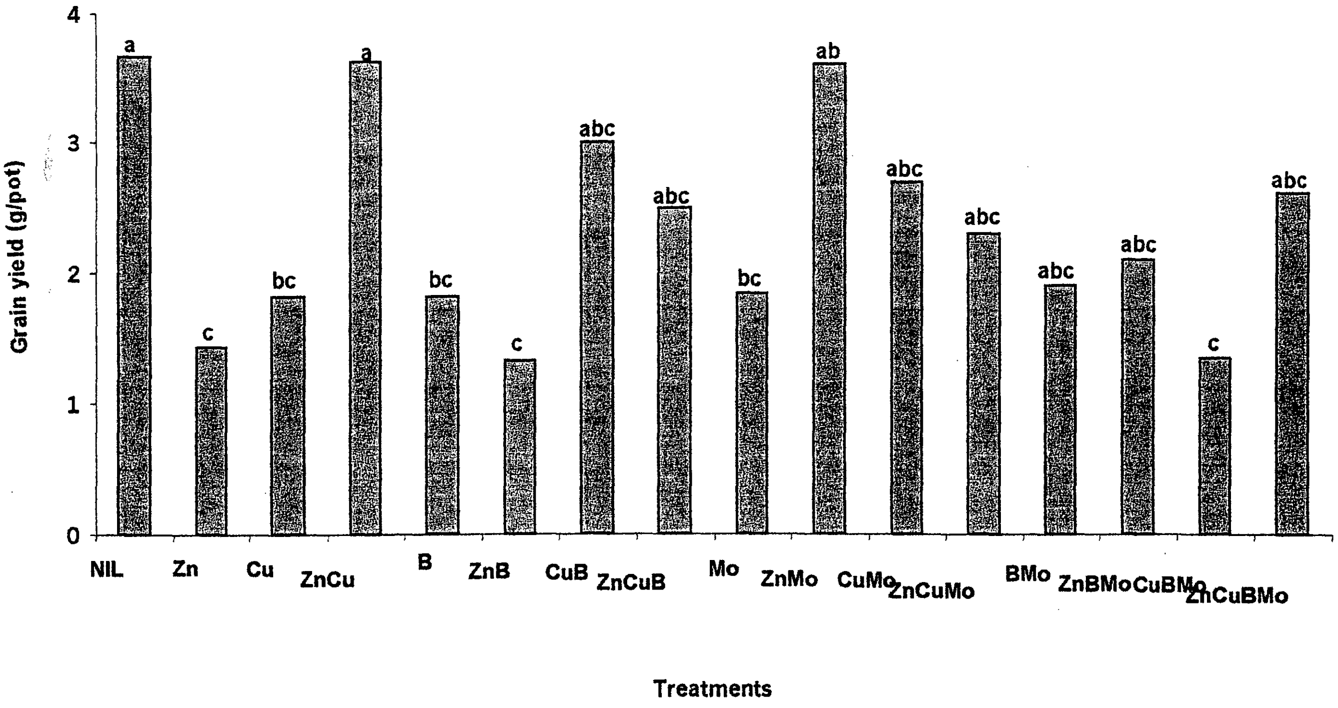

Figure 8.3. Grain yield as affected by the application of micronutrients on the chocolate soil.

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

8.3.2. Grey brown podsolic soil

a) Plant height

The main effects (Table 8.7) of the applied micronutrients each at the rate of 5 kg/ha when compared with their 0 level indicated that there was no significant effect due to the application of these nutrients except B, which has significantly depressed the plant height by 15%. When compared with Nil, the plant height decreased in the absence of B (14.5%), Zn (18%), Cu (16%), and Mo (16%) while their addition at 5 kg/ha further aggravated the magnitude of the decrease by 27.5, 23.5, 26, and 26%, respectively.

Table 8.6. Average (n=32) plant height (cm) as affected by the application of micronutrients on the grey brown podsolic soil.

Rate	0 kg/ha	5 kg/ha
Nutrients		
Nil	48.0	-
Boron	41.04a	34.79b
Zinc	39.2a	36.7a
Copper	40.3a	35.6a
Molybdenum	40.1a	35.8a

b) Straw yield

The main effects of 5 kg/ha each of Zn, Cu, B, and Mo on the straw yield (Table 8.8) indicated that the effects due to Mo and Zn were non-significant. The application of Cu significantly increased the straw yield by 12%, while B application depressed the yield by 21% compared to 0 kg Cu and 0 kg B/ha, respectively. When compared to Nil, the straw yield in the absence of B, was higher (15%) which decreased with the addition of B by 10%.

Table 8.7. Average (n=32) straw yield as affected by the application of micronutrients on grey brown podsolic soil.

Rate	0 kg/ha	5 kg/ha
Nutrients		
Nil	6.29	-
Copper	6.09b	6.83a
Boron	7.23a	5.69b
Zinc	6.40a	6.53a
Molybdenum	6.36a	6.56a

Numbers followed by the same letters within a row are not significantly different according to DMRT $P \leq 0.05$.

c) Grain yield

The data presented in Table 8.9 show the main effects of 5 kg/ha each of Zn, Cu, B, and Mo on the grain yield compared to 0 level of each nutrient. These figures have shown that the application of Zn and Mo had no significant effect on the grain yield while Cu significantly increased (19%) the yield whereas B decreased (16%). The data further revealed that in the absence of Cu, the grain yield decreased by 14% as compared to Nil while the absence of B, Zn, and Mo did not affect the yield (Table 8.9).

Table 8.8. Average (n=32) grain yield (g/pot) as affected by the application of micronutrients on the grey brown podsolic soil.

Rate	0 kg/ha	5 kg/ha
Nutrients		
Nil	2.66	-
Copper	2.29b	2.73a
Boron	2.78a	2.24b
Zinc	2.67a	2.34a
Molybdenum	2.51a	2.50a

Numbers followed by the same letters within a row are not significantly different according to DMRT $P \leq 0.05$.

Zn x Cu x Mo

The trend in Figure 8.4 indicated that the highest grain yield was obtained with the combination of Cu_5x Mo_5xMo_0 which was statistically similar to all the other treatments except Zn_5 x Mo_0 x Cu_0 and Zn_5 x Mo_5 x Cu_0 which had relatively lower yields than all the treatments.

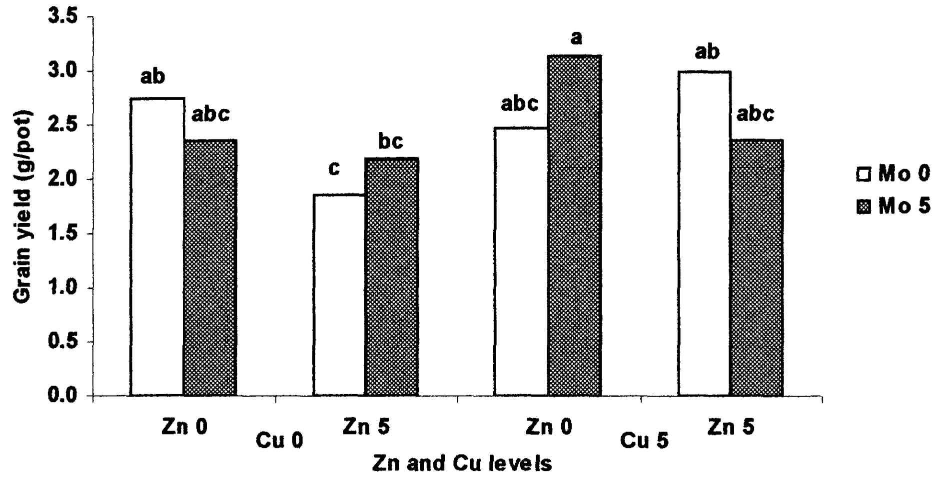

Figure 8.4. Grain yield as affected by the interaction of Zn x Cu x Mo on the grey brown podsolic soil.

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

8.4. DISCUSSION

The chocolate soil contained 3.2, 1.7, 91, 96 and 0.5 mg/kg Cu, Zn, Mn, Fe, and B, respectively with the pH value 4.8 (1:5 $CaCl_2$) is favourable for the solubility and bioavailability of these micronutrients (Lindsay and Norvell, 1978). The results indicated that the Nil (where no micronutrients were added) produced the highest straw and grain yields in this soil (Table 8.5 and 8.6). The main effects of micronutrients suggested that when B, Zn, Cu, and Mo each were not added, the straw and grain yields were lower than the Nil (original soil level). This observation suggested that the addition of all the three and absence of one micronutrient might have imbalanced the plant nutrition and hence the yield decreased. The result also indicated that addition of 5 kg/ha of B caused significant decreases (14 and 21%) in straw and grain yields, respectively as compared to B_0 (Table 8.5 and 8.6).

The behaviour of grey brown podsolic soil was identical to the chocolate soil in terms of response to microunutrients (Table 8.8 and 8.9). The depressing effect of B caused significant reductions in straw and grain yields by 21% and 19%, respectively which is similar in magnitude to chocolate soil. The addition of Cu_5 caused significant increase in straw and grain yields of grey brown podsolic soil and non-significant increase in chocolate soil. The difference in response to Cu in the two soils is associated with the initial levels of Cu. The chocolate soil contained 3.2 mg/kg Cu and grey brown podsolic soil contained < 0.5 mg/kg Cu (Table 8.3). Having an initial level of <0.5 mg/kg Cu and pH value of 4.9 and sandy loam texture, grey brown podsolic soil will be prone to Cu deficiency than heavy textured chocolate soil (Adriano, 1986).

From the overall interactive effect of Mo, Cu, Zn, and B, it is obvious that Cu_5 alone tended to improve the yields while Zn_5 and B_5 and Mo_5 tended to depress the yield. Addition of Zn x Cu, Cu x B, and Zn x Mo showed additive effects on the grain yield in chocolate soil as compared to Nil (Figure 8.3). This observation suggested positive interactive effect of Zn x Cu, Cu x B and Zn x Mo. The application of Zn alone or Zn x B and Cu x B x Mo had adverse effect on the yield and produced minimum yield compared to Nil and other interactions. The application of Cu with B and Zn tended to minimise the adverse effect of Zn and B by stimulating the yield indicating the yield stimulation by Cu as discussed earlier (Figure 8.3 and 8.4). Although statistically non-significant but similar trend was observed regarding the additive interactive effects of Cu x Zn and Mo x Zn in case of grey brown podsolic soil (Figure 8.4).

Interactions of macro and micronutrients are complex phenomena and various researchers using different levels under different conditions have reported inconsistent interactions (Adriano, 1986). Although the positive interactive effects of Cu on Zn, B, and to some extent on Mo observed in this study are supported by the information compiled by Kabata-Pendias and Pendias (1986) however antagonistic effect of Cu on Zn and Mo have been quoted by Adriano (1986).

Since the addition of micronutrients to chocolate and grey brown podsolic soil did not increase the yields over Nil where no micronutrients were added. It will not be advisable to recommend addition of micronutrients to these soils. However, since the soils are acidic and the solubility of micronutrients is high, the current levels may become critically low because of leaching in case of coarse textured soils and continuos removal by high yielding crops. The periodic soil analysis for micronutrients is recommended to determine the future need of these soils for sustainable crop production.

CHAPTER 9

THE EFFECTIVENESS OF P-SOURCES FOR THE OPTIMUM YIELD OF BUCKWHEAT UNDER PHOSPHORUS DEFICIENT SOILS

9.1. INTRODUCTION

In Australian soils, phosphorus deficiency ranks next in importance to nitrogen deficiency (McLachlan, 1976). As the deficiency is so widespread, production by a plant often depends on its ability to extract and use phosphorus. Plant species and even varieties of the same species differ in their feeding power for P (Thomas, 1930; Smith, 1934; Lyness, 1936; Rabideu, 1950). Differences in feeding power are attributed to many causes, one of which is the area of the root-absorbing surface (Fried, 1953), while differences between varieties in feeding power are usually associated only with the relative size of root-absorbing surface. Soper and Kalra (1969) suggested that there are two possible reasons for this variability, i.e. (i) variability among crops in root development in fertiliser reaction zone and (ii) crop variability in inherent efficiency for P absorption. Absorption of P is different when compared with other nutrients e.g. Nye (1968) indicated that zone of nutrient disturbance around a single root for P is small relative to the zone of disturbance for either K or NO_3^-. He suggested that when the nutrient depletion zone is small, root morphology play an important role in nutrient absorption. Buckwheat (*Fagopyrum esculentum* Moench) is reported as a heavy user of phosphorus (Smith *et al.*, 1989) and its application gives the most consistent increases in the yields (Marshall, 1969). There are various sources of phosphatic fertilisers that differ widely in their solubility in water and citrate solution (Chien *et al.*, 1990). It is commonly observed that crop responses to P fertilisers vary widely under the same soil and crop conditions due to the variation in P fertiliser solubility. Van Ray and van Diest (1979) compared six plant species including buckwheat to investigate the utilisation of phosphate from different sources by these species. Buckwheat showed an exceptional behaviour in utilising all the phosphates. This study aimed to examine the effectiveness of different sources of P fertilisers on the yield of buckwheat for two P-deficient soils of the New England Tablelands.

9.2. MATERIALS AND METHODS

A pot experiment was conducted in the glasshouse of Division of Agronomy and Soil Science, University of New England, Armidale, to study the effectiveness of phosphorus sources for the production of buckwheat. A reverse dilution technique was used (Shedley *et al.*, 1979) and the soil was labelled with radioactive phosphorus ^{32}P (half-life of 14.7 days) as KH_2PO_4 and three P fertiliser sources were applied to assess their efficiency to supply P to the crop.

Two P-deficient soils, namely, Coventry (yellow podsolic) and Kirby (grey brown podsolic) with 9 and 6 mg/kg Colwell P, respectively were used. Three fertiliser sources i.e. partially acidulated rock phosphate (PARP) of North Carolina, phosphate rock (PR) from the Duchess mine and triple-super phosphate (TSP) were applied at the four rates (0, 10, 40, 80 kg P/ha). Since SSP is widely used in the New England region thus the comparisons were made with TSP to get more information.

Nitrogen, potassium and sulfur were applied as a basal dressing at the rate of 61, 50 and 50 kg/ha, respectively. The experiment was conducted with two replicates. Approximately 2 kg soil weighed, air dried and passed through 2 mm sieve was placed in two plastic bags and then in PVC pots with 0.0184 m^2 surface area. Soil was moistened to half of the field capacity and then labelled with ^{32}P solution at the rate of 5 ml per pot, which was equivalent to 6950 MBq/g P. Each bag was thoroughly mixed and incubated for one week to attain the equilibrium. After 4 days these bags were again thoroughly shaken and mixed.

Fertiliser treatments and basal dressing were applied and thoroughly mixed with the soil. Ten seeds of buckwheat (Mancan cv.) were sown in each pot, which were thinned to six plants per pot. Pots were maintained at field capacity by weighing them throughout the growing period.

First plant sampling was done at the start of flowering, 18 days after sowing. Three plants from each pot were harvested and dried in a forced draught oven at 80°C. After grinding these plant samples were analysed for total P by the ICP after a chamber digest method as described by Anderson and Handerson (1986) and for ^{32}P by the liquid scintillation counter as described by Shedley *et al.*, (1979).

The crop was harvested at maturity. The plants were cut approximately 1 cm above the soil surface and were dried in a similar way as described earlier at 80°C and dry matter was recorded. The plant tops (including grain) were ground and passed through 2mm sieve. Samples were digested and analysed for total P by ICP and radioactive P by liquid scintillation counting.

9.2.1. Specific Activity Ratio

Radioactive data is in MBq/mg of dry matter, which is then converted to specific activity (SA) in MBq/mg of P. As all the pots including control have same amount of ^{32}P, so all the fertiliser treatments were divided by their control to get the effect of fertilisers, which is specific activity ratio (SAR). 1-SAR gave the actual percentage of P coming from different sources of P fertilisers.

9.2.2. Statistical analysis

The data were analysed as a 2x4x3x2 (2 soils, 4 P rates, 3 P sources, and 2 replicates) for the dry matter yield, P uptake and specific activity ratio (SAR) for the first and final harvests by NEVA analysis of variance computer program (Burr, 1980). Means were compared for significant differences by using Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$.

9.2.3. Soil analysis

All the chemical analysis of Coventry and Kirby soils (Table 9.1) were carried out at the Incitec analytical laboratories, Port Kembla, NSW. The detail of the methods used for these analyses is described in Chapter 5, Section 5.2.2.

Table 9.1. Soil analysis of Coventry and Kirby.

Properties	Coventry	Kirby
Soil Type	Yellow Podsolic	Grey Brown Podsolic
Colour (Munsell)	Pale brown	Greyish brown
Texture	Coarse Sandy Clay Loam	Sandy loam
pH (1:5 water)	5.5	5.8
pH (1:5 $CaCl_2$)	4.5	4.9
Organic Carbon %C	1.1	1.2
Nitrate Nitrogen mg/kg	<2	11
Sulfate Sulfur (MCP) mg/kg	-	3
Sulfate Sulfur (KCl-40) mg/kg	4	3
Phosphorus (Colwell) mg/kg	6	9
Potassium meq/100g	0.16	0.2
Calcium meq/100g	1.2	2.1
Magnesium meq/100g	0.5	1.1
Aluminium (KCl) meq/100g	0.33	0.11
Sodium meq/100g	<0.05	0.07
Chloride mg/kg	<5	6
Electrical Conductivity dS/m	0.02	0.04
Copper mg/kg	0.20	<0.5
Zinc mg/kg	0.10	7.5
Manganese mg/kg	9.0	8
Iron mg/kg	74.0	41
Boron mg/kg	0.30	0.2

9.3. RESULTS

9.3.1. First harvest (Coventry soil)

1) Dry matter yield

The effect of P sources on the dry matter yield (Figure 9.1) showed that triple super phosphate (TSP) gave significantly higher yield when compared with partially acidulated rock phosphate (PARP) and phosphate rock (PR), which in turn were non-significant when compared among themselves. The yield increased significantly up to 40 kg P/ha with the increase in the application rate but after that a non-significant effect was observed (Figure 9.2).

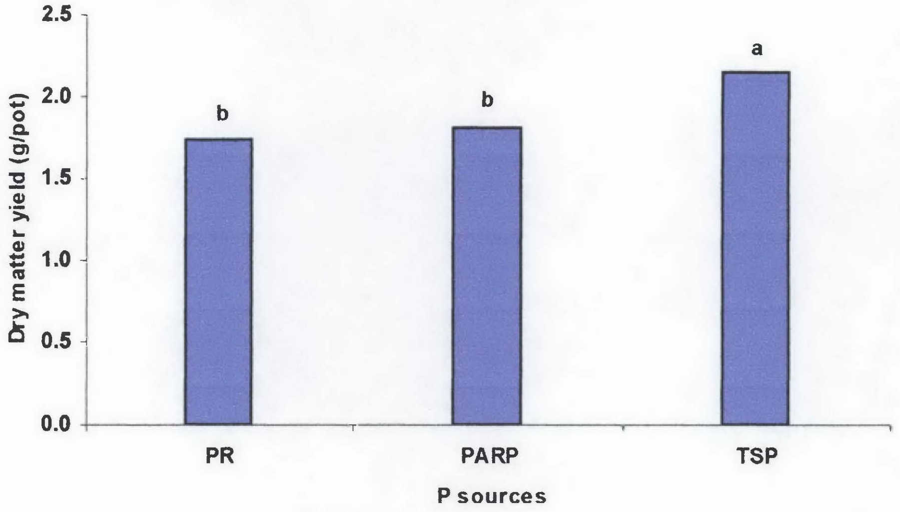

Figure 9.1. Dry matter yield in the first harvest as influenced by the sources of P for Coventry soil.

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

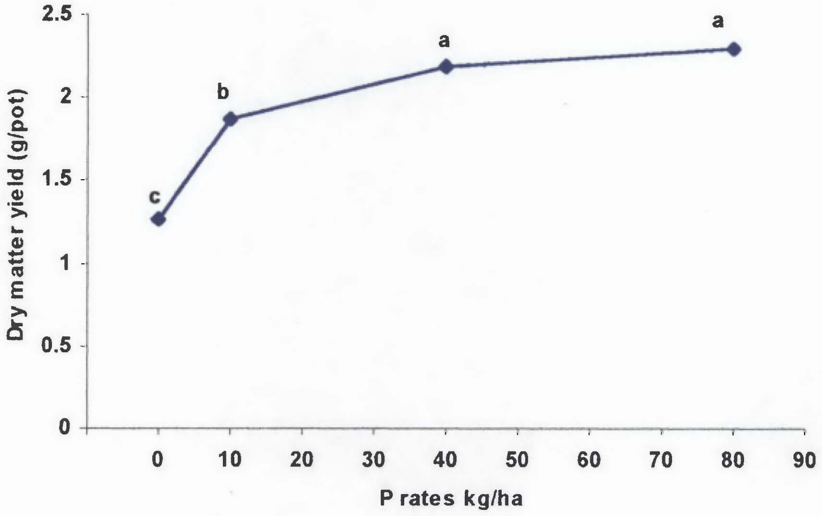

Figure 9.2. Dry matter yield in the first harvest as affected by P rates for Coventry soil.

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

2) P-uptake

There was a significantly higher P uptake from triple super phosphate at 40 and 80 kg P/ha, whereas there were no significant differences between the three sources at 10 kg P/ha (Figure 9.3). Partially acidulated rock phosphate and phosphate rock showed statistically similar behaviour in the uptake of P when compared with TSP. The uptake of P increased significantly with increasing levels of P application up to 40 kg P/ha in the case of TSP, whereas there was a non-significant increase in the case of

PARP and PR. The uptake from PARP was significantly higher at 80 kg P/ha when compared with control (0 kg P/ha) whereas it was statistically similar when compared with the uptake from 10 and 40 kg P/ha.

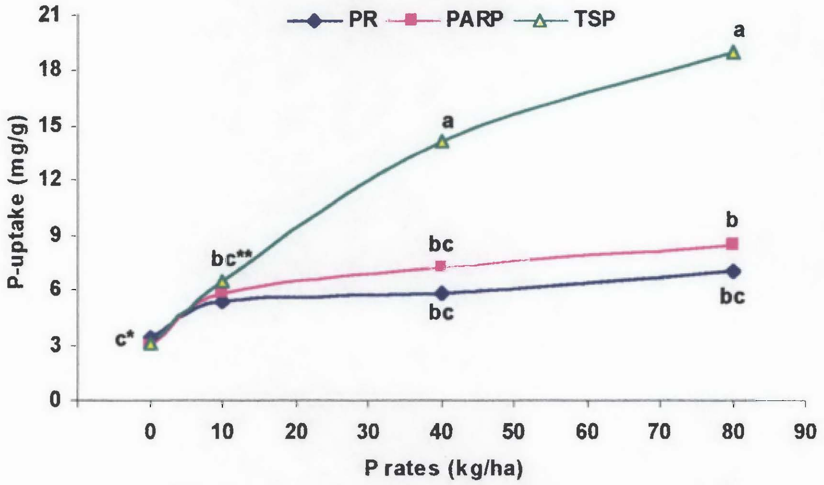

Figure 9.3. Phosphorus uptake in the first harvest as affected by P-sources and rates for Coventry soil.

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

* = Letter applies to all 0 kg P/ha data points ** = Letters apply to all 10 kg P/ha data points

3) Specific activity ratio (SAR)

The contribution of P from TSP fertiliser (Figure 9.4) was significantly higher when compared with PARP and PR at all the levels of application and PARP in turn was significantly higher than PR at all the levels. The level of application has a little effect on P percentage. In the case of TSP, 80 kg P/ha gave significantly higher P when compared with 10 kg P/ha but was statistically similar to 40 kg P/ha, which in turn was similar to 10 kg P/ha. In the case of PARP 40 kg P/ha was significantly higher than 10 kg P/ha but was similar to 80 kg P/ha, whereas in the case of PR 10 and 40 kg P/ha were statistically similar but were significantly lower than at 80 kg P/ha.

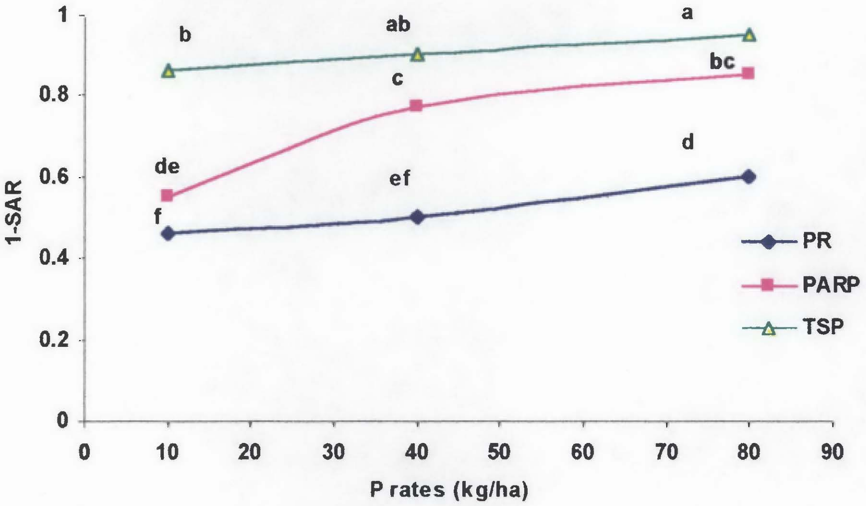

Figure 9.4. Specific activity in the first harvest as affected by P-sources and rates for Coventry soil.

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

9.3.2. Kirby soil

1) Dry matter yield

Dry matter yield data (Figure 9.5) showed that at 10 kg P/ha, TSP gave significant higher yield when compared with PR but was statistically similar to PARP which in turn was similar to PR. However, at 40 and 80 kg P/ha yield due to TSP was significantly higher than PARP and PR, which in turn were statistically similar at both the rates. In the case of TSP, dry matter yield increased significantly with the level of application whereas in the case of PARP it increased up to 40 kg P/ha and after that a non-significant effect was observed. In the case of PR, 40 and 80 kg P/ha showed similar effect towards yield and were significantly higher than 10 kg P/ha which in turn was similar to 0 kg P/ha.

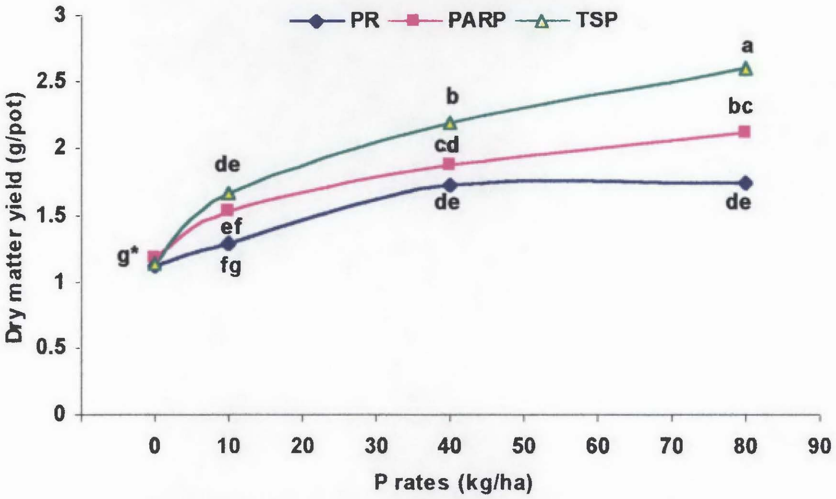

Figure 9.5. Dry matter yield in the first harvest as affected by P sources and rates for Kirby soil.

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

* = Letter applies to all 0 kg P/ha data points

2) P-uptake

The uptake of P from TSP (Figure 9.6) was significantly higher when compared with the uptake from PARP and PR at all the levels of application. The uptake of P increased significantly with increasing the rates of P application in the case of TSP, whereas in the case of PARP and PR, it showed a non-significant effect among the two sources at all the rates of P application. At the level of 40 and 80 kg P/ha PARP and PR showed significantly higher P uptake when compared with 0 and 10 kg P/ha which were in turn statistically similar.

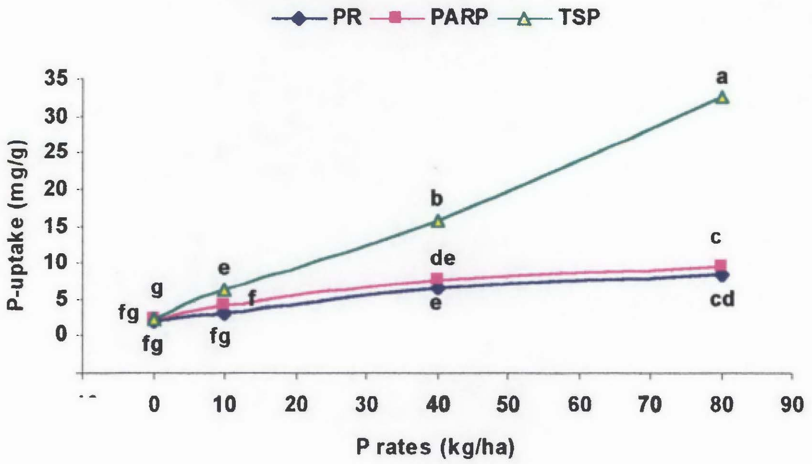

Figure 9.6. Phosphorus uptake in the first harvest as affected by P-sources and rates for Kirby soil.

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

3) Specific activity ratio (SAR)

Kirby soil showed similar trend as observed in Coventry soil for TSP fertiliser (Figure 9.7). The percentage of P from TSP was significantly higher at all the levels of application when compared with PARP and PR which were statistically similar at all levels of application. The contribution of P from fertiliser increased significantly up to 40 kg P/ha in the case of TSP and 80 kg P/ha in the case of PARP and PR.

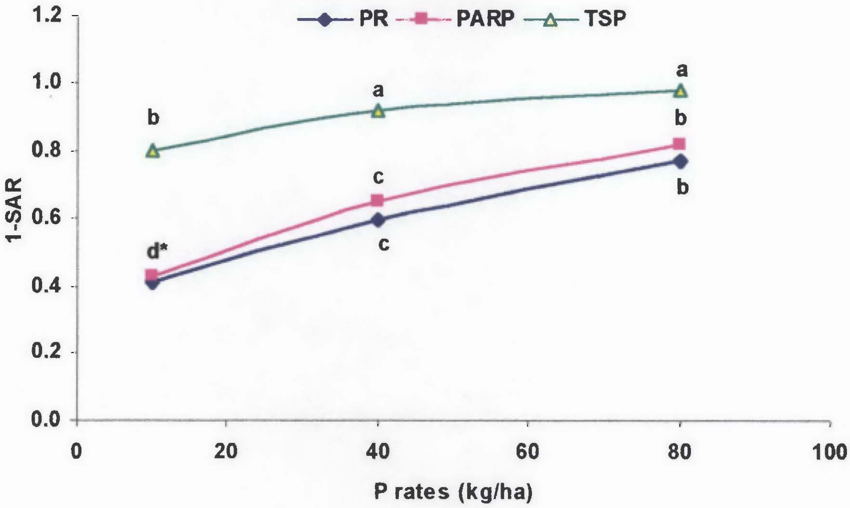

Figure 9.7. Specific activity in the first harvest as affected by P-sources and rates for Kirby soil. *Data points labelled with the same letters within a figure are not significantly different according to DMRT $P \leq 0.05$.*

* = Letter applies to both 0 kg P/ha data points

9.3.3. Final harvest (Coventry soil)

1) Dry matter yield

Data (Figure 9.8) indicated that TSP gave significantly higher dry matter yield at all the rates applied when compared with PARP and PR which were statistically similar to all levels except at 40 kg P/ha where PARP was significantly better than PR with respect to yield. The yield increased significantly with application levels of fertiliser up to 40 kg P/ha in the case of TSP and PARP after which no effect was observed, while in the case of PR it increased up to 80 kg P/ha but 10 and 40 kg P/ha rates showed similar behaviour towards the yield.

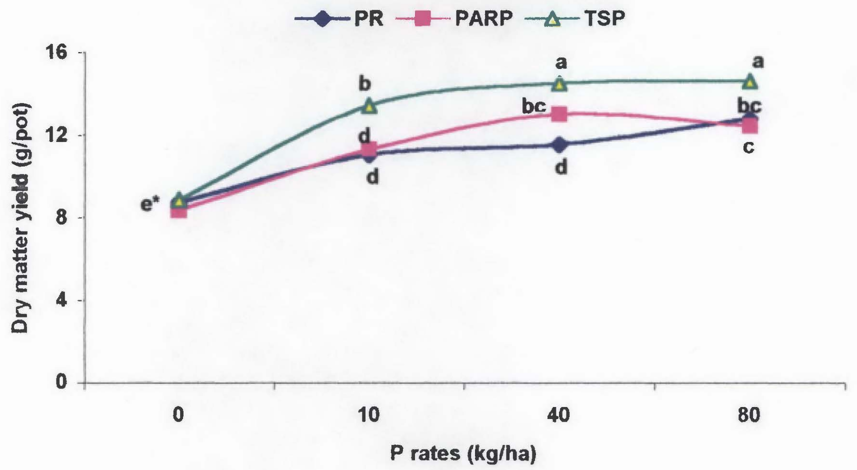

Figure 9.8. Dry matter yield at maturity as affected by P-sources and rates for Coventry soil. *Data points labelled with the same letters within a figure are not significantly different according to DMRT* $P \leq 0.05$.

* = Letter applies to all 0 kg P/ha data points

2) P-uptake

Uptake of P from different fertiliser sources (Figure 9.9) showed that at maturity TSP and PARP behaved similarly at all the levels of application but the P uptake from PR was significantly lower at the levels of 40 and 80 kg P/ha when compared with other sources. All the three sources were statistically similar at 10 kg P/ha. In the case of TSP the uptake of P increased significantly with the increasing level of application and was maximal at 80 kg P/ha, whereas in the case of PARP it increased significantly between 10 and 40 kg P/ha and after that a non-significant effect was observed. The uptake at 10 kg P/ha of PARP was statistically similar to control (0 kg P/ha). PR also showed a non-significant effect towards P-uptake at the level of 10 kg P/ha when compared with control but after that uptake of P increased significantly with the increase in the rate of P application and was maximised at 80 kg P/ha.

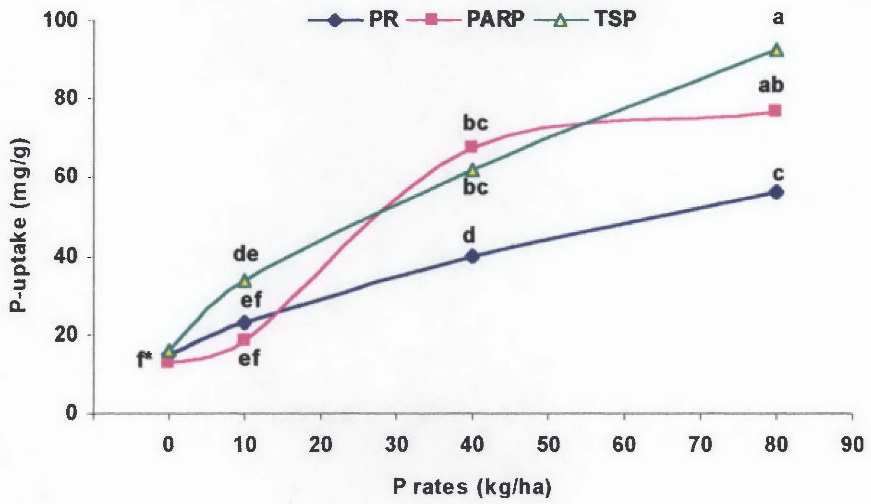

Figure 9.9. Phosphorus uptake at maturity as affected by P-sources for Coventry soil.

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

* = Letter applies to all 0 kg P/ha data points

3) Specific activity ratio (SAR)

The effects of various P sources on the percent contribution indicated that triple-super phosphate contributed a significantly higher proportion of P when compared with PARP, which in turn was significantly higher than PR (Figure 9.10). So these sources were ranked in the order of TSP > PARP > PR. The effect of P rates on the percentage of P from different sources increased significantly with the increase in the rate of application being a maximum at 80 kg P/ha (Figure 9.11).

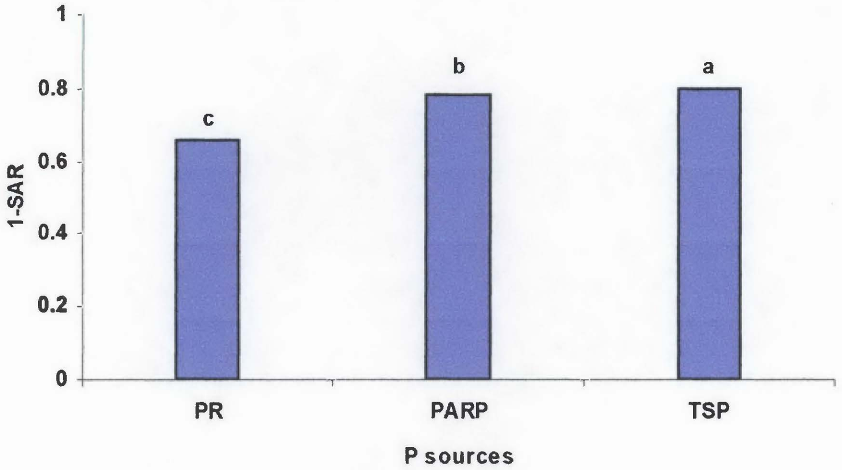

Figure 9.10. Specific activity ratio at maturity as affected by P sources for Coventry soil.

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

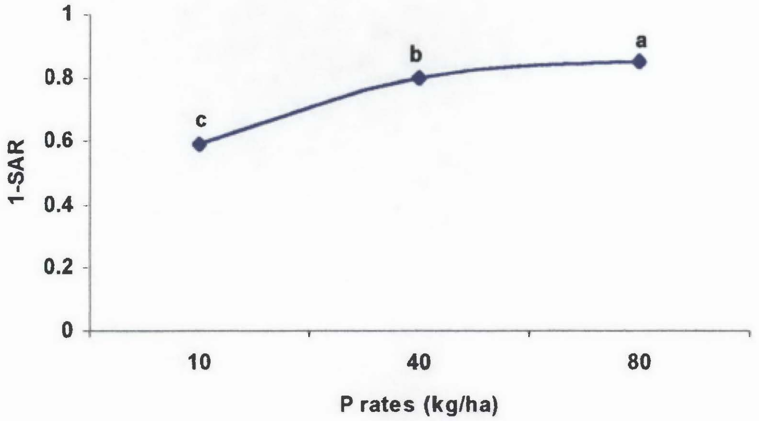

Figure 9.11. Specific activity ratio at maturity as affected by P rates for Coventry soil.

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

9.3.4. Kirby soil

1) Dry matter yield

The application of P sources showed a similar trend as observed in the Coventry soil (Figure 9.12). The dry matter yield due to TSP was significantly higher than PARP at all the levels of application, which in turn was significantly higher than PR at 40 and 80 kg P/ha and similar at 10 kg P/ha. The yield increased significantly with the increased rates of application up to 40 kg P/ha in the case of TSP and 80 kg P/ha in the case of PARP and PR but in the case of PR 10 and 40 kg P/ha gave statistically similar yield.

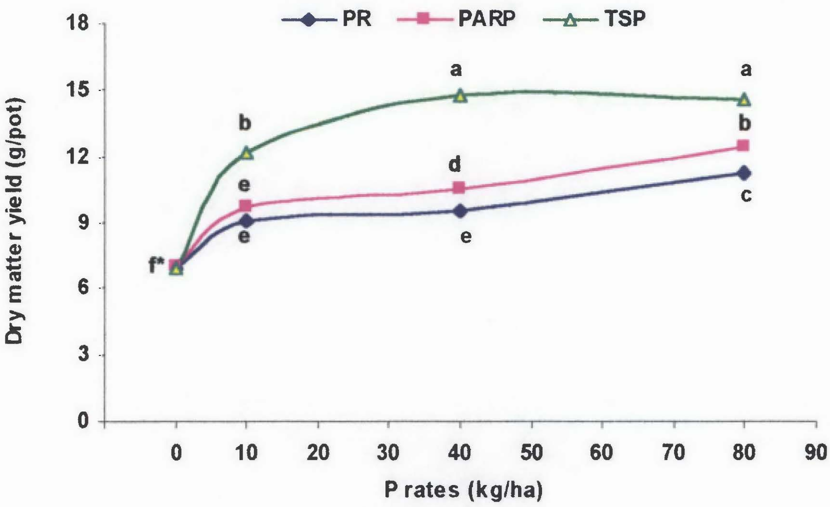

Figure 9.12. Dry matter yield at maturity as affected by P-sources and rates for Kirby soil.

Data points labelled with the same letters within a figure are not significantly different according to DMRT $P \leq 0.05$. * = Letter applies to all 0 kg P/ha data points

2) P-uptake

The P uptake data (Figure 9.13) showed a similar trend as in the first harvest. Triple super phosphate showed significantly higher P-uptake when compared with PARP and PR at the level of 80 kg P/ha and at 40 kg P/ha was statistically similar to PARP and higher than PR, whereas at 0 and 10 kg P/ha all the three sources showed a non-significant effect on P uptake. The P uptake increased significantly with the level of P application in the case of TSP and PR at all the levels of application whereas in the case of PARP, 40 and 80 kg P/ha showed statistically similar behaviour towards P uptake but were significantly higher than 10 kg P/ha which in turn was significantly higher than the control (0 kg P/ha).

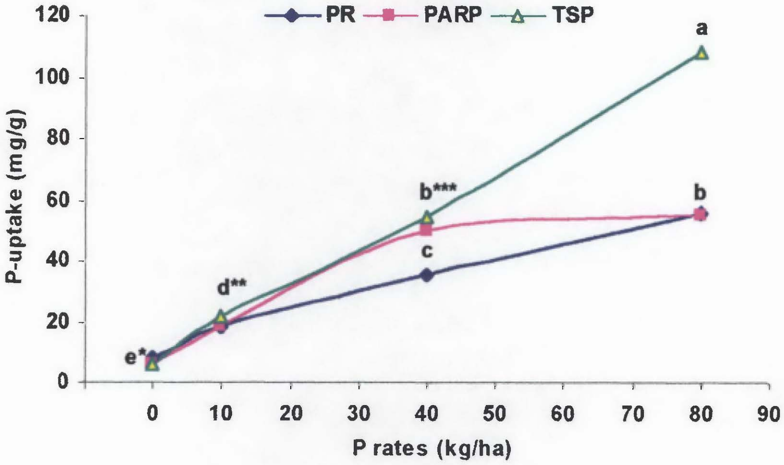

Figure 9.13. P-uptake at maturity as affected by the P-sources and rates for Kirby soil.

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

* Letter applies to all 0 kg P/ha data points ** = Letter applies to all 10 kg P/ha data points

*** = Letter applies to two 40 kg P/ha data points

3) Specific activity ratio

In the Kirby soil, 1-SAR data at maturity (Figure 9.14) showed that TSP gave significantly higher proportion of P when compared with PARP and PR which were non-significant among themselves, whereas the levels of application showed a non-significant effect towards P contribution from different sources.

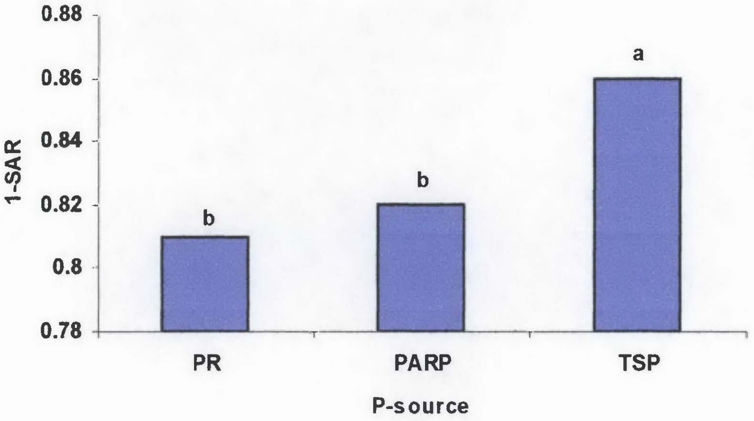

Figure 9.14. Specific activity ratio at maturity as affected by P sources for Kirby soil.

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

9.4. DISCUSSION

Dry matter yield (first harvest) was higher with TSP when compared with PARP and PR in the case of Coventry soil which means that the difference in yield is due to difference in the solubility of these sources. Partially acidulated rock phosphate and PR behaved similarly in the case of Coventry soil whereas in the case of Kirby soil at higher levels of application the differences between three sources were more prominent and were in the order of TSP > PARP > PR. The reason for this trend is the solubility of these sources as TSP is the most soluble source, which allows better growth and larger dry matter production.

In the final harvest at maturity for both the soils, TSP failed to improve the dry matter yield after 40 kg P/ha which means the requirement of the crop was fulfilled at 40 kg P/ha but PARP and PR continued to show response towards dry matter yield even after 40 kg P/ha due to the lower solubility of these sources when compared with TSP. These results are supported by Van Ray and van Diest (1979) who used super phosphate, calcined aluminum phosphate and four rock phosphates and observed that buckwheat showed an exceptional behaviour in utilising all phosphate sources compared with other crops. They also observed higher dry matter yield with super phosphate when compared with other sources. McLachlan (1976) used four different crops including buckwheat against a gradient of phosphorus availability in four soil situations and found that buckwheat obtained more phosphorus and used it more efficiently in dry matter production than the other species. Efficiency of rock phosphate was improved when mixed with different proportions of TSP for different crops e.g. bean and rice (Menon *et al.*, 1991), maize (Menon and Chien, 1990), corn (Chien, *et al.*, 1987). The availability of P from PR increased with increasing the proportion of TSP. The dry matter yields of all these crops were significantly higher with TSP and decreased with decrease in TSP proportion mixed with PR.

The uptake of P in the Coventry soil in the first harvest showed the same trend as observed in the case of yield, which means uptake, increased significantly up to 40 kg P/ha with all the three sources. The reason for this behaviour could be associated with the growth and requirement of the plants, which were at this stage small and their requirements were fulfilled at 40 kg P/ha. However in the case of Kirby soil the uptake of P increased significantly with increasing level of application. In both the soils PARP and PR behaved similarly at all levels. Similar results with buckwheat were observed by Van Ray and van Diest (1979). They used super phosphate, calcined aluminium phosphate (CAP) and hyper phosphate (RP-H) and the uptake from super phosphate- P was higher than the others were. P uptake was related to the final pH of the soil and buckwheat is a crop showing an alkaline uptake, which is defined as the property to absorb more cations than anions (Van Ray and van Diest, 1979). It absorbs more Ca and Mg resulting in more anions in the soil which in turn makes the soil acidic and thus releasing more P from phosphorus sources especially rock phosphates. Similar behaviour of buckwheat was observed by McLachlan (1976) who used four soils and four plant species and observed a correlation between the ability of the plant to acidify the soil environment and solubility of P sources. Due to its highly alkaline uptake, buckwheat exerts a strongly acidifying effect (decreased pH by 0.9) on the soil environment. This effect in turn, promotes the dissolution of the phosphate source, leading to a high degree of availability of P to buckwheat and promotes growth (Van Ray and van Diest, 1979).

The uptake of P increased with increasing rates of P fertiliser the rooting zone was increased, resulting in more acidity in the rooting zone and thus releasing more P from P sources. A similar effect of buckwheat on the rhizosphere was observed by Strong and Soper (1973), who suggested that high utilisation of applied P was aided by the high efficiency of its root in absorbing P from high concentrations of phosphorus. Similarly, Soper and Kalra (1969) suggested that both the quantity of the roots in the fertiliser zone and the efficiency of roots in absorbing phosphorus are important factors in the ability of the plant to absorb fertiliser P.

In final harvests for both soils TSP gave maximum uptake of P and it increased with increasing the rates of P application. In the case of Coventry soil at 80 kg P/ha, TSP and PARP behaved similarly, whereas in Kirby soil, at the same level, PARP and PR were similar, which means solubility of different P sources is affected differently due to these soil conditions. These results are consistent with the findings reported by Van Ray and van Diest (1979) and McLachlan (1976).

Specific activity data was calculated as 1-SAR, which gave the percentage of P coming from different sources. 1-SAR data at maturity confirmed the P uptake data for both soils. In the case of the Coventry soil the P contribution from sources was in the order of TSP > PARP > PR and the P from different sources increased significantly with the increase in the level of application. Similar behaviour of levels was observed in the case of P uptake at maturity. In the case of the Kirby soil the ranking of sources towards P contribution was TSP > PARP = PR and levels of application had non-significant effect on this soil. These results are again confirmation of P uptake in the case of Kirby soil.

From these findings it is suggested that a soluble form of P may be used. This could be triple-super phosphate or where a sulfur deficiency exists single super phosphate should be used. The rate of application should be used as 40 kg P/ha for the soil types used in this study.

CHAPTER 10

GENERAL DISCUSSION

10.1. Buckwheat in the New England Tablelands

Buckwheat (*Fagopyrum esculentum* Moench), an old crop with a new market value is emerging as a full season multipurpose grain crop. It is generally considered in conjunction with cereals though it is not a true cereal. Due to its new market and its multiuses as a food grain, interest in its cultivation is gaining popularity. This applies to the New England Tablelands where the study was undertaken. Thus, research on various aspects including its adaptability, sensitivity to climatic conditions and most importantly "its nutrition" are urgently required. The literature review (Campbell and Gubble 1986; Ruszkowski, 1986; Guan and Adachi, 1992; and Bjorkman 1998) indicated that if the comparisons are made with other regions of the world buckwheat growing areas particularly Japan and North America, then buckwheat should be well adopted to several cool climate highland and coastal districts of mainland Australia stretching from Northern South Wales to Southwest Victoria. New England Tableland around Armidale is the potential buckwheat growing area (Clarke *et al.*, 1998). This crop is more successful in cooler tableland areas as it is very sensitive to high summer temperature, particularly during flowering and seed formation (Hennessy, 1992). Frosts that can seriously affect buckwheat are very rare in the New England Tablelands (Bureau of Meteorology Australia, 1999).

A diversity of soil types including podsolic, solodics, euchrozems, red earths, krasnozems, chocolates, black earths and prairie soils are found in the New England Tableland (Stace *et al.*, 1972 and McGarity, 1977). These soils have comparatively low pH and most of them are suitable for buckwheat cultivation (Clarke *et al.*, 1998). The potential for buckwheat cultivation and the one, which has limitation due to shallow depth and steep slopes, are delineated on the Map-3.7.

In view of the favourable environmental conditions of the New England Tablelands (Bureau of Meteorology Australia, 1999; Clarke *et al.*, 1998; Hennessy, 1992) and renewed market interest in buckwheat production, it is imperative to investigate the nutritional aspects of this crop. This study was undertaken to investigate the mineral nutrition and to establish the deficiency symptoms of buckwheat for the essential nutrients. To achieve these objectives, various experiments were designed including nutrient solution using sand culture (Chapter-4), and diverse type of soils (Chapter 5). The response of buckwheat to 2 levels of N, P, K, and S and their sources was investigated in pot using two diverse type of soils, chocolate and grey brown podsolic (Chapter-6). The effect of N, P, K, and S was also investigated on the yield of buckwheat in the field using chocolate and yellow podsolic soils (Chapter-7).

The effect of micronutrients (Zn, Cu, B, and Mo) at 2 levels (0 and 5 kg/ha) of each alone and in different combinations was studied on the yield of buckwheat using soil pot in the glasshouse (Chapter-8). The influence of P sources on the yield of buckwheat and P uptake was investigated under P deficient soils (Chapter-9).

The details of the results are presented and discussed in the relevant chapters while the major findings are summarised and highlighted in this section.

10.2. Visual deficiency symptoms of buckwheat and soils nutrient evaluation

The nutrient visual deficiencies symptoms of N, P, K, and S were established in this experiment as shown in the pictures given in Section 4.3. Nitrogen deficiency symptoms were characterised by pale yellowish coloured leaves and stunted growth and were similar to those illustrated for various crops (Chapman, 1966; Baule, 1970; Bergmann, 1976; Bergmann, 1983 and Tisdale *et al.*, 1985). The bluish green coloured leaves, slow and stunted growth associated with reduced number of flowers and thin stems with a delay in reaching maturity were similar to P deficiency symptoms as indicated by the reviews of Tisdale *et al.* (1985) and Mengal and Kirkby (1987).

The chlorosis of leaf margins and small brown necrotic spots suggested the typical deficiency symptoms of K (Tisdale *et al.*, 1985 and Pissarek, 1973). The deficiency of S caused uniform yellowish green coloured leaves (Tisdale *et al.*, 1985 and Ulrich, 1967) which started on the younger leaves first. Plants had spindly stems while on some plants pinkish coloured leaves were formed. The deficiency symptoms of K and S on buckwheat were similar to those reported for cereal crops (Tisdale *et al.* 1985, and Robson and Snowball, 1988).

The omission of Ca, Mg, and trace elements did not cause any visual deficiency symptoms on the plant leaves although plant size was reduced as compared to +All treatment. Reduction in plant size suggests that the visual deficiency of the micronutrients might have been exhibited by the plants if the micronutrients were omitted individually. It is possible that the simultaneous omission of all micronutrients might have masked the development of visual deficiency symptoms of a given micronutrient. The shortage of two or more nutrients simultaneously can complicate the situation whereby the visual symptoms do not appear (Tisdale *et al.*, 1985). Micronutrients are required by the plants in a very small amount and before the visual deficiency symptoms appear, their amount in plant must reach to a level whereby the plants can no longer function properly (Mortvedt, 1982; Tisdale *et al.*, 1985, Kabata-Pendias and Pendias, 1986).

In conclusion the visual deficiency symptoms observed for N, P, K, and S in these studies, were established so clearly in buckwheat that it could be considered a classical example of success when compared to those reported in the literature for other crops as quoted earlier and by many more.

Five diverse type of soils (chocolate, black earth, and 3 grey brown podsolic soils, Kirby-17, Clark's and Uralla) were used to evaluate their nutrient levels and their supply to buckwheat. To achieve this objective, triple-pot experiment was designed whereby the given major nutrient was omitted individually and the micronutrients collectively from the nutrient solution (Table 4.1).

The results indicated that the response of buckwheat to the omission of nutrients was mainly determined by the amount of dry matter produced and the initial level of the given nutrient in these soils. For example, the omission of N, P, and S from the system caused significant decrease in dry matter yield in all the soils with the exception of grey brown podsolic (Clark's) soil whereby no reduction in yield was observed with the omission of P. This soil contained 38 mg/kg P, which is several fold higher than all the other grey brown podsolic and black earth soils which was sufficient to support about 2 g dry matter (root + shoot). All the other 3 soils containing low levels of P (Table 5.1) responded positively to the omission of P.

The response of chocolate soil to the omission of N and P despite of the fact that this soil contained initial levels of 65 and 61 mg/kg N and P, respectively may apparently seems intriguing but the closer analysis of the yield data in relation to the total mass of this soil provides plausible explanation for this observation. This soil has invariably produced the dry matter yield (root + shoot) higher by a magnitude of 5-10 times than all the other soils when all the nutrients were applied. The total amount of N and P present in 0.5 kg soil comes to 32.5 and 30.5 mg/kg, respectively. Even if it is assumed that all the N and P were bio-available, the given concentrations and mass of soil would hardly produce the tissue concentrations of 0.16 and 0.34%, respectively. Given the high yield of the soil and the overall requirement of the plant for N and P (Tisdale *et al.*, 1985), this amount seemed inadequate to maintain the required plant tissue concentration (Mengal, 1987) as a result, plant responded to the omission of N and P in terms of yield reduction. This observation suggested that the initial nutrient level of the soil alone is not enough to determine the adequacy of a nutrient. It is important that the plant yield and the total amount of nutrient supplied by the given mass of soil must be taken into account while interpreting the data (Jarrell and Beverly, 1981).

The omission of K caused significant yield reduction only in case of grey brown podsolic (Uralla) soil which contained the lowest initial level of K (0.1 meq/100g). All the soils were found deficient in S, as indicated by the increase in yield when it was added and reduction in yield when omitted. The levels of Ca and Mg in these soils could be considered adequate, as no reduction in yield was associated with the omission of these nutrients.

Omission of micronutrients caused significant yield reduction only in chocolate soil. This observation is supported by the amount of dry matter produced per small amount of soil, which generated an increased requirement of the buckwheat for micronutrients.

10.3. Micronutrients

Effect of B, Zn, Cu, and Mo on the yield of buckwheat was also evaluated in pot experiments using chocolate and grey brown podsolic (Kirby-17) soils. The results indicated that the straw and grain yields in the absence of any micronutrients, and presence of other three were lower than the control while addition of 5 kg/ha B caused further reduction (14-21%) in yield in both the soils indicating that it may have caused toxicity (Bubicz and Szklarz, 1986). Mortvedt (1982) while reviewing literature about B toxicity reported that yield of soybean was decreased by the application of 2.5 kg/ha of B in a glasshouse experiment. Band application of 5 kg/ha of B resulted in decreased yield and toxicity symptoms. It was further noted that the application of 1.12 kg/ha of B on corn significantly reduced the dry matter yield and increased B concentration in tissue. Adriano (1986), also reported B toxicity in many field crops. Addition of Cu tended to stimulate the yield significantly in low Cu (<0.5 mg/kg) grey brown podsolic soil and non-significantly in higher Cu (3.2 mg/kg) chocolate soil.

The beneficial effect of Cu was exhibited also in the Zn x Cu and B x Cu interaction while the depressing effect of Zn and B were seen in the Zn x B and Cu x B x Mo interactions.

From these studies it can be concluded that, micronutrients required in small amounts by the plant, present complex interactive effects and their application in proper and balance amounts is difficult if not impossible. This complexity is evident by the inconsistency in their mutual additive or antagonistic behaviour found in the earlier literature (Warcholowa, *et al.*, 1991; Bubicz and Szklarz, 1986).

10.4. Buckwheat yield as affected by sources of fertilisers

The response of buckwheat to the rate and sources of N, P, K, and S was evaluated in pot experiments using 5 kg of two diverse very dark greyish brown chocolate and grey brown podsolic soils (Chapter-6). The effect of P sources was also evaluated in a separate experiment using ^{32}P (Chapter-9). The major findings of these experiments are highlighted in the preceding sections.

As compared to control, the application of N, P, K, and S had no significant impact on plant height but the straw and grain yield significantly increased with P and K but no significant difference was observed with the addition of N and S in case of chocolate soil (Table 6.2). However, in case of grey brown podsolic soil, addition of these nutrients significantly increased all the yield parameters over control (Table 6.3). With the exception of few instances, the differences and the effect of various sources of N, P, K, and S on the yield parameters were statistically non-significant in both soils.

It is important to note that yield parameters (plant height, straw yield and grain yield) were not significantly affected by addition of N in case of chocolate soil but were significantly increased in the grey brown podsolic soil (Table 6.2 and 6.3). This difference in response to N by the two soils was based on their initial level of NO_3-N. The chocolate soil contained 65 mg/kg NO_3-N while grey brown podsolic soil contained 11 mg/kg NO_3-N. The chocolate soil being a nutrient rich soil produced straw yield of 13.91 g/pot for control, which is 2.8 times greater than the straw yield (4.88 g/pot) obtained at grey brown podsolic soil. Addition of N to grey brown podsolic soil generated net significant increases of 15.22, 12.35, and 12.09 g/pot in straw yield with urea, $(NH_4)_2SO_4$, and NH_4NO_3, respectively, but in case of chocolate soil these increases were only 6.16, 5.99, and 8.99 g/pot. These results showed that application of N fertilisers is more beneficial to the low N soils such as grey brown podsolic soil.

Variations in the effect of various sources of fertilisers in general and those of P sources in particular are commonly reported (Bolland and Bowden, 1984; Boswell, 1987; Robert *et al.*, 1994; Dinev, 1995; Jacobsen *et al.*, 1997) but in the present study, these variations in yield parameters due to various sources of N, P, K, and S were non-significant. Although, grain yield was significantly increased by TSP in the chocolate soil and SSP in the grey brown podsolic soil.

The reason for non-significant effect of N and P sources could be the acidic pH of the soils. The differences in the effect of sources of fertilisers, particularly P sources, are mostly determined by the degree of their solubility, nature of crop, and the type of soil (Mengal and Kirkby, 1987). For example Bjorkman (1998) and Berglund (1995) have emphasised that buckwheat is a heavy user of rock phosphate as it has the ability to acidify the soil and thereby increase the solubility of rockphoshpate (Van Ray and van Diest, 1979). This beneficial effect of rockphosphate is applicable to slightly acidic and neutral to alkaline soils where most of the native P is in insoluble forms and the crop has to depend mostly on the acidifying effect of the buckwheat.

In the present studies where the pH of the soils was already strongly acidic (less 5.0) and the solubility of fertilisers applied in the limited mass of soils was not a limiting factor, therefore, the yield of the plant was less dependent on the sources of fertilisers. That's why the performance of slowly soluble sources of P (PARP and RP) was comparable to soluble sources of P (SSP and TSP).

The superiority of TSP over PR and PARP in terms of P-uptake and yield of buckwheat was demonstrated by the studies whereby reverse dilution technique was used (Chapter-9). These findings based on the use of ^{32}P are in agreement with the trends observed in the previous studies (Chapter-6).

These studies suggested that the soluble forms of P (SSP and TSP) may be more useful as a source of P fertiliser. Triple-super phosphate or single superphosphate in case of S deficiency, is recommended. However, the cost and availability of the fertiliser may be given due consideration.

10.5. Buckwheat (Mancan cv.) production in soils of New England Tablelands as influenced by N, P, K, and S.

Effect of N_{50}, P_{40}, K_{50}, and S_{50} application was evaluated by conducting field trials at Coventry (yellow podsolic soil) and at Laureldale (chocolate soil) sites as per experimental plan provided in Chapter-7. The selection of the two soils having diverse physico-chemical properties (Table 7.2) provided an opportunity to compare the buckwheat production potential on different soils.

The dry matter (3.40 t/ha) and grain production (1.65 t/ha) at Laureldale (chocolate soil) sites was several fold higher than the Coventry sites, grey brown podsolic soil (0.6 and 0.5 t/ha) without addition of any fertilizers. This observation is consistent with the results of the pot experiments where the chocolate soil produced 4 to 10 time greater yields than grey brown podsolic soil. The higher yield potential of this soil is associated with its favourable soil texture (light clay) and adequate initial level of NO_3-N, P, K, S and the micronutrients (Cu, Zn, Mn, Fe, and B). This observation is substantiated by the fact that compared to control, the addition of N_{50} alone produced 122 and 136% significant increase in straw and grains yields in low N Coventry sites (yellow podsolic) and only 26 and 21% increases, respectively were observed in nutrient rich chocolate soil.

Addition of P_{40}, K_{50}, and S_{50} did not produce any significant increases in either of the two soils, but addition of SN, SKN, NP, KNP, and SNP together showed additional yield increases suggesting that N was the major yield limiting nutrient and its beneficial effect were promoted by S and P in Coventry sites.

The additive effect of K was invariably missing with any of the nutrient except when added as NPK which produced highest straw yield of 1.78 and 4.65 t/ha in Coventry and Laureldale sites, respectively. Most of the interactions in the Coventry sites were significant when N_{50} was added to S_0 x P_0, S_{50} x P_{50} or S_0 x K_0 and S_{50} x K_{50}, confirming the major beneficial role of N in the buckwheat production in the Coventry sites. The crop response to K depends to great extent on N nutrition. When the crop is supplied with adequate N, the yield increases due to K are more (Gartner, 1969 and Heathcote, 1972). In future, the response to higher applications of K needs to be assessed at higher level of N and P. For example, Burkart (1975) reported that rates as high as 300 kg K_2O/ha give only slight response and as much as 900 kg/ha K_2O were needed for to obtain maximum grain yields of spring wheat. The rates may be too high but the one used in these studies were relatively low.

In Laureldale sites which contained several times higher initial NO_3-N, the above interactive effect with the addition of N_{50} was not significant which suggested that N was not a limiting factor in this soil.

It can be safely concluded from the field trials that chocolate soil is the most suitable for buckwheat production. It may be able to produce high yield on sustainable basis for some time but for continuous buckwheat production, nutrient status must be monitored periodically. As for as Coventry sites is concerned, the results have amply demonstrated that N is the yield limiting nutrient. However, the response of buckwheat to higher N, P, K, and S levels may be tested to establish proper fertiliser levels and yield potential of this soil.

10.6. Achievements

The research conducted herein is one of the few and extensive studies on buckwheat in Australia, yet reported. These findings should have useful and practical implications for the cultivation of buckwheat in this country in general and in New England Tablelands in particular. The areas potentially suitable, marginal, or unsuitable were mapped for the New England Tablelands. This information will help growers and researchers in their planning for buckwheat cultivation in this region.

The deficiency symptoms of N, P, K and S for buckwheat were recorded and were clearly established for the first time under this research project.

At present, the general recommendation for buckwheat is that the application of P only is needed in this country. However, in the current research, the soils are found to be generally deficient in N, P, and S. These findings should be used as a guideline rather recommendation for N, P, and S requirements of buckwheat on the major types of soils in this region.

The findings on the sources of N, P, K, and S indicated that any source of N and K could be used on the chocolate and grey brown podsolic soils for satisfactory yields of buckwheat. Among the P source for the chocolate soil, TSP followed by PARP and RP, while for the grey brown podsolic soil, SSP is preferred.

The research showed that the major soil types used in this study are adequate in micronutrients for satisfactory yields of buckwheat, therefore, it is concluded that there is no need for micronutrient application on these soils at present.

The results of the field experiments have proven that buckwheat not only required P but also N and S. As compared to control, application of 50 kg/ha N increased straw and grain yield by 121 and 136% in yellow podsolic, Coventry sites and 26 and 21% in chocolate, Laureldale sites, respectively. Phosphorus and S application alone were not associated with any improvement in yield where N was a limiting factor. The combined application of N and P further improved the yield over N alone and gave the highest benefit in the Coventry sites.

On the basis of yield obtained, chocolate soil is undoubtedly a high yielding soil and can be considered suitable for buckwheat cultivation.

10.7. Limitations and difficulties

The original research program was compromised by most uncharacteristic weather conditions. Firstly, it had been planned to hold preliminary field trials on the effects of various major nutrients on the yield of buckwheat on different farmer's fields. These were to have been followed by in-depth systematic glasshouse and field experiments. However, unusually heavy, untimely rain washed out several of the field sites at critical phases. This meant that the data, in practice, could only be collected from two field sites. Furthermore, a freakish, hailstorm which caused millions of dollars of damage in the town of Armidale in 1996 wrecked the glasshouses and the experiments as well. This occurred just before data were to be collected. The repair of the glasshouses took time, which further delayed the research program. So due to the limited time and sponsorship it was not possible to pursue the total field trials which were planned. Data from different years would have been valuable.

10.8. Future research

It is recommended that studies on the nutrition of buckwheat be continued so that the findings of these efforts are built upon and refined. Experimentation in the field on additional soil types would be helpful for recommending fertiliser applications on them for buckwheat production. In the current studies only one rate of each major and micronutrients was used. Further studies on the different rates (lower and higher than the current rates) of macronutrients on various soils should be carried out. The superiority of chocolate soil in terms of higher yield be further investigated in relation to its unique physical and chemical conditions. Studies are required on the omission type experiments using other soil types of New England Tablelands (that is, ones not used in this study) to investigate the potential of these soils for the yield of buckwheat. The deficiency symptoms of micronutrients on buckwheat are required to be confirmed.

In conclusion this research will not only lead to further research into buckwheat production, but will also have useful implications in production of this nutritious crop both in Australia and overseas.