CHAPTER 5

THE EFFECT OF CROP DURATION AND SOIL TYPE ON EXTRACTABLE S

5.1 Introduction

In Chapters 3 and 4, it was found that the KCl-40 extraction removed the soil solution and some portion of the adsorbed sulfate fraction and labile HI reducible S pools while the KCl-100 extraction removed a larger portion of HI-reducible S pool. By contrast MCP removed a greater amount of soil soluble and adsorbed sulfate but a lower amount of HI-reducible S. In Chapter 3, the KCl-40 extract was found to have the highest correlation with % maximum pasture yield. This higher correlation was probably because of the extraction of an appropriate amount of HI-reducible S by KCl-40 which is readily mineralised. Specific radioactivity data confirmed the ability of the KCl-40 extract to remove S from similar S pools as the rice plant. Similarly, the KCl-40 extract was found to remove S from the similar S pool as ryegrass in Chapter 4.

Some crops such as vegetables (e.g. radish) have a relatively short growth period and absorb sulfur at a rapid rate, hence, a supply of readily available sulfate is especially important (Jordan and Ensminger, 1958). Legumes, cotton, tobacco and corn are grouped as intermediate in their growth period and S requirement, whereas, crops having a prolonged growth period such as grasses and forage have a low sulfur demand rate.

Because of the differing rates of S supply required by this range of crops, it is hypothesised that the relative importance of the soil sulfate and organic S pools will vary between crops. The experiment reported in this chapter aims to test this hypothesis.

5.2 Materials and Methods

5.2.1 Experimental procedures

A factorial experiment, consisting of three replicates and two rates of S fertiliser (0 and 17.7 mg kg^{-1} soil, equivalent to 0 and 30 kg S ha^{-1}), three crop species (radish, corn and ryegrass), and two soils (granite and basalt) was arranged in a randomised block design. The experiment

was conducted at the same time as that reported in Chapter 4, and the ryegrass treatment was common to both experiments. All operations and measurements were the same as reported for that experiment.

^{35}S obtained from Amersham Australia Pty. Ltd. was added as K_2SO_4 solution (2.091 g K_2SO_4 L^{-1}) to give a solution containing 0.325 MBq mL^{-1}. Aliquots of 7 mL, 24 mL and 60 mL were added to the soil which was to grow radish, corn and ryegrass so that 2.275, 7.800 and 19.5 MBq was added to the respective crops. The soil was incubated for three weeks as in the ryegrass experiment.

Radish (*Raphanus sativus* L.), corn (*Zea may* L.) and ryegrass (*Lolium perenne* L.) seeds were sown into the pots, and thinned to 3, 1 and 10 plants per pot respectively after emergence. The radish, corn and ryegrass were harvested at 23, 50 and 50 days respectively. The four test extractants (Section 4.2.5a) were evaluated.

5.2.2 Statistical Analysis

Dry matter yield (g pot^{-1}), plant uptake (mg S pot^{-1} or KBq pot^{-1}), specific activity (KBq mg S^{-1}), S concentration in plant (%) and soil S status (µg S g^{-1} soil, mg S pot^{-1} or KBq pot^{-1}) as determined by the range of extractants, the recovery of ^{35}S, and the specific activity ratio (SAR) data were analysed using the analysis of variance statistical package NEVA (Burr, 1982).

The relationship between the amount of S removed from the extract (S before planting - S after cropping) by the four test extractants in the -S treatment in the two soils and three crop species (radish corn and ryegrass) and plant S uptake was calculated by using a linear regression of the form

$$Y = a + bX$$

where Y is the S uptake (mg pot^{-1}), X is the calculated amount of S lost from the soil pool (S before planting - S after cropping) (mg S pot^{-1}), a is the intercept and b is the slope.

The confidence belt at the 5% level of significance around the regression line was plotted by using the confidence limit of Little and Hills (1978).

5.3 Results

5.3.1 Yield

The data for the ryegrass has been presented in Chapter 4 so will not be repeated here.

a) Radish

There was a significant dry matter yield response to S in tops, roots and total plants (top+root) in both the Uralla and Walcha soils (Table 5.1).

Table 5.1 *Dry matter yield (g pot^{-1}), S concentration (%S), S content (mg S pot^{-1}), and specific activity (SA) (KBq mg S^{-1}) of radish grown in the Uralla granite and Walcha basalt soils.*

	Top		Root		Total (top+root)	
	-S	+S	-S	+S	-S	+S
Uralla Granite						
Yield	1.76 b[A]	2.16 a	0.38 b	0.46 a	2.14 b	2.62 a
%S	0.46 b	1.42 a	0.70 b	1.62 a	1.16 b	3.04 a
S content	4.08 b	16.80 a	1.53 b	4.74 a	5.61 b	21.54a
SA	137.5 a	24.2 b	100.0 a	20.9 b	127.2 a	23.5 b
Walcha Basalt						
Yield	1.94 b	2.37 a	0.39 b	0.54 a	2.33 b	2.91 a
%S	0.46 b	1.23 a	0.73 b	1.45 a	1.19 b	2.68 a
S content	4.65 b	15.51 a	1.44 b	4.80 a	6.09 b	20.31a
SA	106.04 a	20.87 b	84.8 a	18.00 b	101.02 a	20.22 b

[A] *Numbers followed by the same letter within the same plant part and component are not significantly different according to DMRT at P <0.05.*

b) Corn

The highest yield of the tops, roots and total plant was recorded in the +S treatment in both soils (Table 5.2).

Table 5.2 *Dry matter yield (g pot^{-1}), S concentration (%S), S content (mg S pot^{-1}) and the specific activity (SA) (KBq mg S^{-1}) of corn grown in the Uralla granite and Walcha basalt soils.*

	Top		Root		Total (top+root)	
	-S	+S	-S	+S	-S	+S
Uralla Granite						
Yield	12.57 b[A]	14.98 a	3.25 a	3.67 a	15.82 b	18.65 a
%S	0.05 a	0.08 a	0.06 b	0.17 a	0.11 b	0.25 a
S content	6.90 b	12.31 a	2.70 b	6.33 a	9.60 b	18.64 a
SA	312.8 a	97.1 b	253.7 a	115.4 b	296.2 a	104.0 b
Walcha basalt						
Yield	13.37 b	16.34 a	3.38 a	4.50 a	16.75 b	20.84 a
%S	0.05 a	0.08 a	0.05 b	0.11 a	0.10 b	0.19 b
S content	7.00 b	11.53 a	1.85 b	4.76 a	8.85 b	16.29 a
SA	321.6 a	129.6 b	222.4 a	96.3 b	300.9 a	119.8 b

[A] *Numbers followed by the same letter within the same plant part and component are not significantly different according to DMRT at P < 0.05.*

5.3.2 Total S content and S concentration (%S) in plant

a) Radish

The highest S content and S concentration in the tops, roots and the total plant was recorded in the +S treatment in both soils (Table 5.1). The S concentration of the roots was higher than that of the tops.

b) Corn

As for radish there was a significant S response in both S concentration and S content in all plant parts of corn in both soils (Table 5.2).

5.3.3 Specific radioactivity (SA) of the plants

a) Radish

There were significant differences in the SA of the tops, roots, and the total plants between the -S and +S treatments in both soils with the highest recorded in the -S treatment (Table 5.1).

b) Corn

The SA of the tops, roots and total plant was significantly higher in the -S than the +S treatment in both soils (Table 5.2).

5.3.4 Soil S: Uralla granite soil, -S treatment

a) S concentration in the extractants and fractions in the Uralla granite -S treatment

There were significant differences in the S concentration, % of the ^{35}S recovered and in the SA of the various components in both crops and cropping.

Before planting radish

The S concentration in the extractants as measured by ICP increased in the order MCP<Bray<KCl-40<KCl-100 (Table 5.3). The S concentration in the components of ICP-S (SO_4-S and Organic S) fraction was also found to be highest in the KCl-100 extract and lowest with MCP. The KCl-100 extract had the lowest and the Bray extract the highest S concentration in the second extraction fraction. The KCl-100 also had the lowest concentration of HI-S remaining in the soil after the first extraction while the highest concentration in this fraction was in the MCP extract. There were no significant differences between extractants in the concentration of S in the remainder fraction.

After cropping with radish

There were significant differences in the concentration of ICP-S with the highest S concentration in the KCl-100 extract and the lowest in the MCP extract (Table 5.3). The KCl-100 extract also had the highest S concentration in the Organic S fraction with the lowest also found in MCP extract. The S concentration in the 2nd MCP fraction was highest in the KCl-40 and KCl-100 extracts. The concentration of HI-S remaining was lowest in the KCl-100 extract. The KCl-40 and KCl-100 had the higher S concentration in the remainder fraction.

Table 5.3 *S concentration (μg S g^{-1}) in a range of extractants in the -S treatment, radish and corn, before planting and after cropping, Uralla soil.*

	Radish				Corn			
	MCP	KCl-40	KCl-100	Bray	MCP	KCl-40	KCl-100	Bray
Before								
ICP-S	1.9 c[A]	3.7 b	9.2 a	2.9 b	2.3 c	5.1 b	10.5 a	2.6 c
SO_4-S	1.4 b	1.8 b	4.5 a	1.6 b	1.7 c	3.3. b	6.7 a	1.6 c
Organic S	0.5 b	1.9 b	4.7 a	1.3 b	0.6 c	1.8 b	3.8 a	1.0 c
2nd MCP	0.5 ab	0.6 ab	0.4 b	0.7 a	0.9 a	1.2 a	1.2 a	0.8 a
HI-S remain.	51.5a	48.5 c	43.6 d	49.8 b	43.9 a	40.4 a	34.5 b	43.1 a
Remainder	36.4 a	37.6 a	37.0a	37.1 a	43.1 a	43.8 a	44.3 a	43.5 a
After								
ICP-S	1.6 c	2.3 b	6.0 a	2.0 b	1.4 b	1.4 b	4.6 a	1.8 b
SO_4-S	1.2 b	1.0 b	3.5 a	1.1 b	0.9 bc	0.6 c	2.1 a	1.2 ab
Organic S	0.4 d	1.3 b	2.5 a	0.9 c	0.5 c	0.8 b	2.5 a	0.6 bc
2nd MCP	0.8 b	2.2 a	1.9 a	0.6 b	0.5 ab	0.8 a	0.4 bc	0.2 c
HI-S remain.	29.8 a	29.4 a	26.3 b	30.8 a	34.2 a	33.7 a	31.3 b	33.9 a
Remainder	44.9 a	44.7 a	44.1 a	43.6 a	32.6 a	33.0 a	32.4 a	32.4 a

[A] *Numbers followed by the same letter within the same crop and fraction are not significantly different according to DMRT at P <0.05.*

Before planting corn

Significant differences were recorded in the concentration of S in the ICP-S fraction with the order being MCP=Bray<KCl-40<KCl-100 (Table 5.3). The KCl-100 and KCl-40 extracts also had a significantly higher S concentration in the Organic S fraction than the Bray and MCP extracts. There was no difference between extractants in the S concentration in the 2nd MCP fraction. The concentration of S in the HI-S remaining fraction following the KCl-100 extraction was lower than that where MCP, Bray and KCl-40 was used. The S concentration in the remainder fraction did not differ significantly among the four test extractants (Table 5.3). The higher ICP-S and SO_4-S values of the corn soil before planting, compared to the radish soil, is due to the small amount of sulfate (K_2SO_4) that was added with the ^{35}S. Since more ^{35}S was added to the soils in which corn was to be grown, these pots also received slightly more sulfate.

After cropping with corn

The KCl-100 extract had the highest concentration of ICP-S, with the differences between the Bray, KCl-40 and MCP extracts not significant (Table 5.3). The highest S concentration in the

SO_4-S and Organic S fractions was also recorded in the KCl-100 extract. The MCP extract had the lowest S concentration in the Organic S fraction. There were significant differences between the extractants in the S concentration of the 2nd MCP fraction with the highest concentration in the KCl-40 and the lowest in the KCl-100 and Bray extract. The lowest concentration of HI-S remaining was found where KCl-100 extraction was used. There were no significant differences between extractants in the S concentration of the remainder fraction.

b) The recovery of ^{35}S in the extractants and fractions

Before planting radish

A significantly higher amount of ^{35}S was recovered in the ICP-S fraction in the KCl-100 and KCl-40 extracts than in MCP and Bray extracts (Table 5.4).

Table 5.4 *The percentage of ^{35}S recovered in a range of extractants in the -S treatment Uralla soil, radish and corn, before planting and after cropping.*

	Radish				Corn			
	MCP	KCl-40	KCl-100	Bray	MCP	KCl-40	KCl-100	Bray
Before .								
ICP-S	27.1 b[A]	62.0 a	70.1 a	24.4 b	18.6 b	67.1 a	75.1 a	12.5 c
SO_4-S	24.5 b	57.0 a	69.3 a	21.8 b	17.1 b	62.6 a	73.5 a	11.9 c
Organic S	2.6 b	5.0 a	0.8 c	2.6 b	1.5 b	4.5 a	1.6 b	0.6 b
2nd MCP	5.4 a	3.1 ab	1.0 b	6.1 a	1.2 b	2.4 a	1.6 ab	1.3 b
HI-S remain.	50.6 a	19.3 b	8.5 b	33.9 ab	47.9 a	18.1 b	7.2 c	58.2 a
Remainder	22.3 a	18.7 a	21.4 a	41.7 a	33.5 a	14.7 b	17.6 ab	29.3 ab
After								
ICP-S	12.7 b	27.6 a	39.3 a	9.7 b	5.1 b	10.8 b	24.3 a	5.4 b
SO_4-S	8.9 b	25.3 a	28.5 a	9.2 b	2.6 b	6.9 b	14.8 a	2.9 b
Organic S	3.8 ab	2.3 ab	10.8 a	0.5 b	2.5 b	3.9 b	9.5 a	2.5 b
2nd MCP	1.3 a	1.1 a	1.4 a	2.1 a	1.7 a	2.3 a	1.9 a	1.8 a
HI-S remain.	26.5 a	23.9 a	25.0 a	29.8 a	29.0 a	22.2 a	39.6 a	33.8 a
Remainder	60.9 a	48.5 a	35.6 a	60.4 a	65.8 a	67.0 a	36.1 b	60.8 a

[A] *Numbers followed by the same letter within the same crop and fraction are not significantly different according to DMRT at P <0.05.*

Most of ^{35}S recovered was in SO_4-S fraction compared to the Organic S fraction. The % of ^{35}S recovered in the 2nd MCP fraction was considerably less than that recovered in the SO_4-S fraction in all extractants. The MCP and Bray extracts had the highest amount of ^{35}S recovered in both the HI-S remaining and the remainder fractions (Table 5.4).

After cropping with radish

The amount of ^{35}S recovered in the ICP-S fraction was lower in all extracts after cropping than before planting (Table 5.4). A higher percentage of the ^{35}S was recovered in the SO_4-S fraction compared to the Organic S and 2nd MCP fractions. The 2nd MCP fraction also had a low recovery of ^{35}S. The recovery of ^{35}S did not differ significantly between extracts in the 2nd MCP, HI-S remaining, and the remainder fractions.

Before planting corn

The KCl-100 and KCl-40 had the higher amount of ^{35}S recovered in the ICP-S fraction than the MCP and Bray extracts (Table 5.4). There was a higher recovery of ^{35}S in the SO_4-S fraction than in the Organic S fraction. The amount of ^{35}S recovered in the 2nd MCP fraction was low with all extractants. In the HI-S and remainder fractions the highest recovery of ^{35}S was recorded in the Bray and MCP extractants.

After cropping with corn

In the ICP-S fraction the highest recovery of ^{35}S was recorded in the KCl-100 extract. There was a marked reduction in the percentage of ^{35}S recovered in the SO_4-S fraction between sampling times and the SO_4-S fraction was larger than the Organic S fraction in all extracts. There were no significant differences between the extractants in the recovery of ^{35}S in the 2nd MCP and HI-S remaining fraction. The lowest amount of ^{35}S recovered in the remainder fraction was in the KCl-100 extract (Table 5.4).

c) The specific activity (SA) of the extractants and fractions.

Before planting radish

The SA of ICP-S fraction was highest in the KCl-40 and MCP extracts. The SA of the SO_4-S fraction was higher than the S-org fraction in all extractants. The SA in the second extraction fraction was high where MCP and Bray extractants had been used. The SA was low in the HI-S and remainder fractions (Table 5.5).

Table 5.5 *The specific activities (KBq mg S^{-1}) in a range of extractants in the -S treatment Uralla soil, radish and corn, before planting and after cropping.*

	Radish				Corn			
	MCP	KCl-40	KCl-100	Bray	MCP	KCl-40	KCl-100	Bray
Before								
ICP-S	111.6 a[A]	139.8 a	62.6 b	67.4 b	249.3 b	378.6 a	207.1 bc	137.7 c
SO_4-S	141.9 ab	279.1 a	127.7 b	139.5 ab	319.5 b	557.2 a	321.1 b	215.3 b
Organic S	38.8 a	21.4 b	1.3 c	19.6 b	75.8 ab	81.6 a	12.2 c	18.5 bc
2nd MCP	100.8 a	38.1 bc	20.4 c	71.9 ab	41.9 a	56.5 a	37.5 a	44.0 a
HI-S remain.	8.2 a	3.3 ab	1.6 b	5.8 ab	32.1 a	13.4 b	6.1 b	39.4 a
Remainder	4.7 a	3.9 a	4.5 a	10.0 a	23.5 a	10.4 b	12.3 ab	19.6 ab
After								
ICP-S	36.3 ab	55.9 a	31.2 b	22.7 b	35.9 c	76.8 a	53.5 b	29.7 c
SO_4-S	36.4 b	109.6 a	38.3 b	38.6 b	31.6 c	110.9 a	73.1 b	28.8 c
Organic S	43.1 a	9.8 bc	21.7 b	2.6 c	49.6 a	51.9 a	39.0 a	40.8 a
2nd MCP	9.1 a	2.3 a	3.7 a	18.2 a	53.7 b	30.2 b	43.6 b	229.2 a
HI-S remain.	4.1 a	3.7 a	4.4 a	4.5 a	8.6 ab	6.7 b	12.8 a	10.1 ab
Remainder	6.4 ab	5.0 ab	3.8 b	6.6 a	22.2 a	22.7 a	11.9 b	21.4 ab

A numbers followed by the same letter within the same crop and fraction are not significantly different according to DMRT at $P<0.05$

After cropping with radish

As in the before planting sampling the KCl-40 and MCP extracts had the highest SA in the ICP-S fraction (Table 5.5). The SA of the SO_4-S fraction was highest in the KCl-40 extract. There were no significant differences between extractants in the SA of the 2nd MCP and the HI-S remaining fractions. The SA of the 2nd MCP, the HI-S remaining and the remainder fractions in all extractants was low.

Before planting corn

The highest SA in the ICP-S fraction was found in the KCl-40 and the lowest in the Bray extract (Table 5.5). The SO_4-S fraction had a higher SA than the Organic S fraction with the highest SA in the KCl-40 extract. The SA of the 2nd MCP fraction was not significantly different between the extractants. The SA of HI-S fraction was higher following the MCP and Bray extractions. The SA of the remainder fraction was of the similar magnitude to that of the HI-S remaining fraction.

After cropping with corn

The KCl-40 extract had the highest SA in the ICP-S fraction. The SA in the SO_4-S fraction was of a similar magnitude to that in the ICP-S fraction. In the 2nd MCP fraction, the Bray extract had the highest SA. The SA of HI-S remaining fraction was lowest following the KCl-40 extraction (Table 5.5).

5.3.5 Soil S: Uralla granite soil, +S treatment

a) S concentration in the extractants and fractions in the Uralla granite +S treatment.

Significant differences were recorded in the S concentration, the recovery of ^{35}S, and the SA of the various extractants and fractions in both crops as a result of cropping (Tables 5.6, 5.7, 5.8).

Before planting radish

The S concentration in the extractants as measured by ICP increased in the order Bray<MCP<KCl-40<KCl-100 (Table 5.6). The SO_4-S concentration measured in the SO_4-S fraction was of a similar magnitude to that in the ICP-S fraction. The KCl-100 extract had the highest S concentration in the Organic S fraction and the lowest was in the MCP extract. The lowest S concentration in the 2nd MCP fraction was in the KCl-100 extract. In the HI-S remaining fraction the lowest S concentration was also in the KCl-100 extract and highest in the Bray extract. There were no significant differences between the extractants in the S concentration in the remainder fraction.

After cropping with radish

The concentration of ICP-S and the compcnents of ICP-S (SO_4-S and Organic S fractions) in the extractants was generally reduced as a result of cropping but the KCl-100 extract continued to extract more ICP-S and SO_4-S than the other extractants. The concentration of S in the 2nd MCP fraction was lowest in the MCP extract. The lowest S concentration in the HI-S remaining fraction was recorded in the KCl-100 extract and the highest in the Bray extract. There was no significant differences between the extractants in the S concentration in the remainder fraction (Table 5.6).

Before planting corn

The KCl-100 extract had the highest S concentration in the ICP-S fraction and the lowest concentration was in the Bray extract (Table 5.6). The highest S concentration in the SO_4-S and Organic S fractions was also recorded in the KCl-100 extract. The MCP extract had the lowest concentration in the Organic S fraction. The KCl-100 extract had the lowest S concentration in the 2nd MCP and the HI-S remaining fractions. The concentration of HI-S remaining and in the remainder fraction was high in all extractants with no significant differences between the extractants in the S concentration in the remainder fraction.

Table 5.6 *S concentration (μg S g^{-1}) in a range of extractants in the +S treatment, radish and corn, before planting and after cropping, Uralla soil.*

	Radish				Corn			
	MCP	KCl-40	KCl-100	Bray	MCP	KCl-40	KCl-100	Bray
Before								
ICP-S	32.4 c[A]	38.7 b	48.0 a	30.3 c	32.8 b	34.4 b	44.0 a	26.6 c
SO_4-S	31.6 bc	36.8. b	43.3 a	28.5 c	30.4 a	30.8 a	35.5 a	23.6 b
Organic S	0.8 b	1.9 b	4.7 a	1.8 b	2.4 c	3.6 b	8.5 a	3.0 c
2nd MCP	1.2 ab	1.7 a	0.5 b	2.0 a	2.0 b	2.1 b	1.5 b	6.7 a
HI-S	60.8 ab	54.3 b	44.4 c	62.7 a	48.8 a	44.6 ab	37.0 b	51.5 a
Remainder	39.3 a	39.5 a	40.1 a	39.5 a	45.6 a	48.2 a	46.1 a	49.1 a
After								
ICP-S	6.5 c	11.4 b	16.1 a	5.5 c	8.7 c	11.1 b	16.6 a	7.3 c
SO_4-S	5.6 c	10.0 b	13.3 a	4.2 c	7.5 bc	9.4 b	12.2 a	5.3 c
Organic S	0.9 b	1.4 ab	3.0 a	1.3 ab	1.2 a	1.7 b	4.4 c	2.0 b
2nd MCP	1.1 b	2.6 a	2.6 a	2.3 ab	1.2 b	1.2 b	0.7 b	2.0 a
HI-S	40.8 b	35.8 c	31.6 d	43.9 a	47.4 a	45.1 b	34.8 c	48.9 a
Remainder	38.9 a	38.9 a	38.5 a	36.7 a	28.6 b	28.4 b	33.2 a	28.4 b

[A] *Numbers followed by the same letter within the same crop and fraction are not significantly different according to DMRT at P <0.05.*

After cropping corn

The highest S concentration in the ICP-S fraction was recorded in the KCl-100 extract and the lowest in the Bray extract (Table 5.6). The KCl-100 extract also had the highest S concentration in both SO_4-S and Organic S fractions. By contrast, the KCl-100 had the lowest S

concentration in the 2nd MCP and HI-S remaining fractions and highest amount in the remainder fraction.

b) The recovery of ^{35}S in the extractants and fractions in the Uralla +S treatment.

Before planting radish

The highest recovery of ^{35}S in the ICP-S, SO_4-S and Organic S fractions was in the KCl-100 extract and the lowest in the MCP and Bray extracts (Table 5.7). Most of the ^{35}S recovered was in the SO_4-S fraction. The % of ^{35}S recovered in the 2nd MCP fraction was less than that recovered in the SO_4-S fraction. The lowest recovery of ^{35}S in the HI-S remaining fraction was found following the KCl-100 extract. The Bray extract had the highest recovery of ^{35}S in the remainder fraction.

Table 5.7 *The percentage of ^{35}S recovered in a range of extractants in the +S treatment, radish and corn, before planting and after cropping, Uralla soil.*

	Radish				Corn			
	MCP	KCl-40	KCl-100	Bray	MCP	KCl-40	KCl-100	Bray
Before								
ICP-S	37.0 c[A]	56.1 b	75.0 a	34.8 c	41.1 c	60.7 b	75.7 a	33.8 c
SO_4-S	35.6 c	54.3 b	70.9 a	33.3 c	39.6 c	58.3 b	73.4 a	32.2 d
Organic S	1.4 b	1.8 b	4.1 a	1.5 b	1.5 a	2.4 a	2.3 a	1.6 a
2nd MCP	2.4 b	8.1 a	1.3 b	2.9 b	2.2 b	1.5 b	2.0 b	6.3 a
HI-S	34.8 a	16.9 ab	6.0 b	15.7 ab	33.4 a	16.0 ab	9.8 b	34.0 a
Remainder	28.2 b	26.9 b	19.0 b	49.5 a	25.5 ab	23.2 ab	14.4 b	32.2 a
After								
ICP-S	18.0 c	52.1 b	65.2 a	14.4 c	34.3 b	54.2 b	65.9 a	29.9 c
SO_4-S	11.7 c	48.7 b	57.9 a	13.5 c	29.2 c	52.9 b	59.6 a	29.4 c
Organic S	6.3 a	3.4 ab	7.3 a	0.9 b	5.1 a	1.3 b	6.3 a	0.5 b
2nd MCP	1.6 a	4.1 a	5.1 a	6.3 a	1.5 b	4.7 a	0.5 c	5.7 a
HI-S	23.9 ab	31.6 a	12.5 b	49.1 a	21.1 a	12.1 a	11.1 a	15.2 a
Remainder	58.1 a	16.3 b	22.3 b	36.4 ab	44.5 ab	33.6 b	22.9 c	54.8 a

[A] *Numbers followed by the same letter within the same crop and fraction are not significantly different according to DMRT at P <0.05.*

After cropping with radish

The recovery of ^{35}S in the ICP-S fraction was highest in the KCl-100 and lowest in the Bray extracts. In the components of ICP-S, most of ^{35}S was recovered in the SO_4-S fraction compared to the Organic S fraction. There was a low recovery of ^{35}S in the 2nd MCP fraction. The lowest recovery of ^{35}S in the HI-S remaining fraction was in the KCl-100 extract and the highest in the Bray extract. The Bray and MCP extracts had the highest recovery of ^{35}S in the remainder fraction (Table 5.7).

Before planting corn

The recovery of ^{35}S in the ICP-S fraction increased in the order Bray<MCP<KCl-40<KCl-100 (Table 5.7). In the components of ICP-S fraction, the highest recovery of ^{35}S was in the SO_4-S fraction and the highest recovery was in the KCl-100 extract. The recovery of ^{35}S in the 2nd MCP fraction was low in all extracts. The lowest recovery of ^{35}S in the HI-S remaining was in the KCl-100 extract. The lowest recovery of ^{35}S in both the HI-S remaining and the remainder fractions was where the KCl-100 had been used.

After cropping with corn

The recovery of ^{35}S in the ICP-S fraction was of a similar magnitude to that of the before planting for all extractants (Table 5.7). The SO_4-S fraction was again found to contain a higher amount of the ^{35}S recovered than the Organic S fraction. There was a low recovery of ^{35}S in the 2nd MCP fraction in all extracts. There was no significant difference in the ^{35}S recovery in the HI-S fraction between extracts. The MCP and Bray extracts had the highest recovery of ^{35}S in the remainder fraction.

c) The specific activity (SA) in the extractants and fractions.

Before planting radish

The highest SA in the ICP-S fraction was found in the KCl-100 and KCl-40 extracts (Table 5.8). In the components of the ICP-S, the SO_4-S fraction had a higher SA than the Organic S fraction in all extracts. The SA in the HI-S remaining fraction was lower than in the KCl-100 extract than in the other extracts. The highest SA in the remainder fraction was recorded in the Bray and MCP extracts. A substantially lower SA was found in both the HI-S remaining and the remainder fractions than in the ICP-S fraction.

Table 5.8 *The specific activity (KBq mg S^{-1}) in a range of extractants in the +S treatment, radish and corn, before planting and after cropping, Uralla soil.*

	Radish				Corn			
	MCP	KCl-40	KCl-100	Bray	MCP	KCl-40	KCl-100	Bray
Before								
ICP-S	11.6 b[A]	13.3 a	14.8 a	11.1 b	40.3 b	56.3 a	54.1 a	41.3 b
SO_4-S	11.5 b	13.7 ab	16.2 a	11.5 b	42.8 b	61.2 a	67.7 a	45.0 b
Organic S	10.7 a	8.2 a	7.5 a	7.1 a	18.5 a	20.3 a	8.2 a	16.6 a
2nd MCP	17.1 ab	39.7 a	20.3 ab	11.8 b	31.6 ab	20.3 c	39.1 a	28.6 bc
HI-S	5.2 a	2.8 ab	1.4 b	2.1 ab	20.1 a	10.6 a	7.7 a	20.3 a
Remainder	7.7 ab	6.5 b	4.6 b	11.7 a	16.4 a	14.3 a	8.7 a	19.9 a
After								
ICP-S	16.4 b	27.6 a	23.8 a	15.4 b	79.2 c	98.1 a	79.7 c	82.1 b
SO_4-S	12.3 c	29.0 a	25.6 ab	20.2 bc	77.5 b	113.7 a	99.3 a	111.2 a
Organic S	63.6 a	16.2 ab	18.4 ab	3.4 b	89.8 a	15.6 b	31.6 b	5.7 b
2nd MCP	8.7 a	9.2 a	11.8 a	16.5 a	25.9 b	77.5 a	14.8 b	57.7 a
HI-S	3.4 ab	5.2 ab	2.3 b	6.5 a	8.9 a	5.4 a	6.5 a	6.3 a
Remainder	8.8 a	2.5 b	3.6 b	6.2 ab	30.9 ab	23.8 b	13.9 c	38.8 a

[A] *Numbers followed by the same letter within the same crop and fraction are not significantly different according to DMRT at P <0.05.*

After cropping with radish

In both the ICP-S and SO_4-S fractions, the SA after cropping was higher than the before planting. The KCl-40 and KCl-100 extracts had the highest SA in the ICP-S and SO_4-S fractions (Table 5.8). The SA of the SO_4-S fraction was similar to that in the ICP-S fraction in all extractants. The SA in the Organic S fraction was lower than in the SO_4-S fraction except in the MCP extract. There were no significant differences between the extractants in the SA in the 2nd MCP fraction. The SA in the HI-S remaining and the remainder fractions were also lower than the ICP-S and the components of ICP-S (SO_4-S and Organic S).

Before planting corn

The KCl-40 and KCl-100 extracts had a higher SA in the ICP-S and SO_4-S fractions than the Bray and MCP (Table 5.8). The SO_4-S fraction had the higher SA than the other fractions. A lower SA was found in both the HI-S remaining and remainder fractions than in the ICP-S and SO_4-S fractions.

After cropping with corn

The SA of the ICP-S and SO_4-S fractions after cropping was higher than that of before planting (Table 5.8). The highest SA in these fractions was in the KCl-40 extracts. The Organic S fraction had a lower SA than the SO_4-S fraction except in the MCP extract. A low SA were found in the HI-S remaining fraction with no difference between extractants. The KCl-100 extract had the lowest SA in the remainder fractions.

5.3.6. Soil S: Walcha basalt soil, -S treatment

a) S concentration in the extractants and fractions in the Walcha basalt -S treatment

Before planting radish

The S concentration as measured by ICP increased in the order KCl-40<MCP<Bray<KCl-100 (Table 5.9). In the components of ICP-S the KCl-100 extract also had the highest S concentration in both the SO_4-S and Organic S fractions. There was no significant differences between extractants in the concentration of S in the 2nd MCP fraction. A substantially higher S concentration was found in the HI-S remaining and remainder fractions than in the other fractions. The lowest S concentration in both the HI-S remaining and the remainder fractions was found in the KCl-100 extract.

After cropping with radish

There was a similar pattern in the S concentration in the various extractants and S fractions after cropping as before planting (Table 5.9).

Before cropping corn

The concentration of ICP-S increased in the order Bray<KCl-40<MCP<KCl-100 (Table 5.9). The KCl-100 extract had the highest S concentration in both the SO_4-S and Organic S fractions. The MCP extract had the lowest S concentration in the 2nd MCP fraction . The concentration of the HI-S remaining was lowest following KCl-100 extraction and the highest following the Bray extract. Conversely, the S concentration in the remainder fraction was found to be lowest in Bray and highest in KCl-100.

Table 5.9 *S concentration (μg S g^{-1}) in a range of extractants in the -S treatment, radish and corn, before planting and after cropping, Walcha soil.*

	Radish				Corn			
	MCP	KCl-40	KCl-100	Bray	MCP	KCl-40	KCl-100	Bray
Before								
ICP-S	4.7 c[A]	2.5 d	10.7 a	5.3 b	6.3 b	4.1 c	10.7 a	4.0 c
SO_4-S	2.3 c	1.2 d	6.4 a	3.1 b	4.8 a	1.5 b	6.2 a	2.3 b
Organic S	2.4 ab	1.3 b	4.3 a	2.2 ab	1.5 b	2.6 ab	4.5 a	1.7 b
2nd MCP	3.6 a	3.9 a	4.5 a	2.5 a	2.1 b	6.4 a	6.4 a	7.3 a
HI-S remain.	154.4 a	155.9 a	149.7 b	153.9 a	142.7 b	147.1 a	134.4 c	149.7 a
Remainder	107.6 a	108.3 a	106.2 a	107.5 a	140.7 b	138.4 bc	144.6 a	135.9 c
After								
ICP-S	3.6 b	2.4 b	8.5 a	3.5 b	4.2 b	1.4 d	6.4 a	3.1 c
SO_4-S	2.3 b	1.1 c	5.3 a	2.0 b	3.0 a	0.5 c	3.0 a	1.8 b
Organic S	1.3 b	1.3 b	3.2 a	1.5 b	1.2 bc	0.9 c	3.4 a	1.3 b
2nd MCP	2.4 c	10.6 a	10.8 a	4.8 b	3.6 bc	3.8 b	7.2 a	2.9 c
HI-S remain.	124.8 a	124.9 a	122.9 a	125.3 a	127.9 b	130.4 a	125.4 c	128.7 b
Remainder	64.3 a	65.4 a	61.3 a	63.9 a	96.2 a	96.5 a	96.6 a	96.5 a

[A] *Numbers followed by the same letter within the same crop and fraction are not significantly different according to DMRT at P <0.05.*

After cropping with corn

The highest concentration of the ICP-S was in the KCl-100 and the lowest in the KCl-40 extract (Table 5.9). The highest concentration of S in the SO_4-S, Organic S and 2nd MCP fraction was also found in the KCl-100 extract By contrast, the KCl-100 extract had the lowest S concentration in the HI-S remaining fraction. There were no significant differences between the extractants in the S concentration in the remainder fraction.

In -S treatment Walcha soil the highest concentration of ICP-S was found in the KCl-100 and the lowest in the KCl-40 extract in both crops and before planting and after cropping (Tables 5.9). A similar pattern was recorded in the SO_4-S fraction. The KCl-100 extract also had the highest concentration of S in the SO_4-S, Organic S and 2nd MCP fractions, and the lowest in the HI-S remaining fraction. In all extractants the concentration of S in the HI-S remaining and remainder fractions was higher than that the other fractions.

b) The recovery of ^{35}S in the extractants and fractions

Before planting radish

The highest recovery of ^{35}S in the ICP-S fraction was in the KCl-100 extract and the lowest in the KCl-40 extract (Table 5.10). Most of ^{35}S was recovered in the SO_4-S fraction. There was a lower recovery of ^{35}S in the Organic S and 2nd MCP fractions than in the other fractions. The lowest recovery of ^{35}S in the 2nd MCP fraction was in the MCP extract and the highest in the KCl-40 extract. The highest recovery of ^{35}S in both the HI-S remaining and the remainder fractions was following the KCl-40 extract.

Table 5.10 *The percentage of ^{35}S recovered in a range of extractants in the -S treatment, radish and corn, before planting and after cropping, Walcha soil.*

	Radish				Corn			
	MCP	KCl-40	KCl-100	Bray	MCP	KCl-40	KCl-100	Bray
Before								
ICP-S	61.8 a[A]	36.3 b	65.5 a	55.5 a	71.4 a	45.9 b	72.1 a	43.3 b
SO_4-S	59.6 a	32.0 b	56.9 a	52.6 a	68.3 a	41.2 b	69.7 a	41.9 b
Organic S	2.2 b	4.3 b	8.6 a	2.9 b	3.1 ab	4.7 a	2.4 ab	1.4 b
2nd MCP	8.1 c	24.9 a	18.3 ab	15.4 bc	8.6 c	28.0 a	15.4 b	25.3 a
HI-S remain.	20.5 a	25.7 a	22.9 a	22.3 a	17.3 c	28.9 a	21.3 b	26.4 ab
Remainder	17.7 b	38.0 a	11.6 b	22.2 ab	11.3 b	25.2 a	6.7 b	30.2 a
After								
ICP-S	27.4 bc	31.5 b	45.0 a	21.5 c	5.9 b	4.8 b	11.5 a	4.3 b
SO_4-S	18.5 bc	27.3 b	40.3 a	15.5 c	2.8 b	4.4 b	9.5 a	4.1 b
Organic S	8.9 a	4.2 a	4.7 a	6.0 a	3.2 a	0.4 b	2.0 a	0.2 b
2nd MCP	0.7 b	9.7 a	8.7 a	9.5 a	1.4 c	5.4 a	2.6 bc	4.2 b
HI-S remain.	41.8 a	39.1 a	31.7 ab	26.2 b	30.1 ab	21.6 b	31.4 a	23.3 ab
Remainder	30.8 b	29.4 b	23.2 b	52.3 a	63.9 ab	73.5 a	57.1 b	72.4 a

[A] *Numbers followed by the same letter within the same crop and fraction are not significantly different according to DMRT at P <0.05.*

After cropping with radish

The highest recovery of ^{35}S was found in the KCl-100 and the lowest in the Bray extract (Table 5.10). A greater proportion of ^{35}S recovered was in the SO_4-S fraction compared to the Organic S and 2nd MCP fractions. The MCP and KCl-40 extracts had a higher recovery of ^{35}S in

the HI-S remaining fraction than the KCl-100 and Bray extracts. Conversely, the highest ^{35}S recovery was found in the Bray extract in the remainder fraction.

Before planting corn

The KCl-100 and MCP extracts had the highest recovery of ^{35}S in the ICP-S fraction (Table 5.10). In the components of ICP-S, most of the ^{35}S was recovered in the SO_4-S fraction in all extractants. The other fractions contained a low amount of ^{35}S. The lowest recovery of ^{35}S in the 2nd MCP fraction was in the MCP extract. The KCl-40 and Bray extracts had the highest recovery of ^{35}S in the 2nd MCP, HI-S remaining and remainder fractions.

After cropping with corn

The recovery of ^{35}S in the ICP-S and the components of ICP-S and 2nd MCP fractions after cropping was reduced substantially from that measured before planting (Table 5.10). The highest recovery was recorded in the KCl-100 extract. The amount of ^{35}S recovered in the 2nd MCP and remainder fraction was of a similar magnitude to that recorded before planting but there was a substantial recovery of ^{35}S in the HI-S remaining fraction after cropping with the highest amount recorded in the KCl-100 and MCP extracts.

In the -S treatment Walcha soil the highest recovery of ^{35}S in the ICP-S fraction was recorded in the KCl-100 and MCP extracts and the lowest in the KCl-40 and Bray in both crops and before planting and after cropping (Table 5.10). A higher amount of ^{35}S was recovered in the SO_4-S fraction than in the Organic S fraction. A low recovery of ^{35}S was also recorded in the 2nd MCP fraction with the lowest amount in the MCP extract. The recovery of ^{35}S in the HI-S remaining and the remainder fractions was higher than that in the Organic S and the 2nd MCP fractions.

c) The specific activity (SA) in the extractants and fractions

Before planting radish

A significantly higher SA was found in the ICP-S fraction in the KCl-40, MCP and Bray extracts than in the KCl-100 extract (Table 5.11). The highest SA in all extractants was in the SO_4-S fraction, which had the similar pattern to that of the ICP-S. The other fractions had a lower SA in all extractants. However the SA remained high in the 2nd MCP with the highest SA recorded in the KCl-40 extract.

Table 5.11 *The specific activity (KBq mg S^{-1}) in a range of extractants in the -S treatment radish and corn, before planting and after cropping, Walcha soil.*

	Radish				Corn			
	MCP	KCl-40	KCl-100	Bray	MCP	KCl-40	KCl-100	Bray
Before								
ICP-S	94.5 a[A]	108.5 a	43.6 b	74.5 ab	309.8 a	322.0 a	182.9 b	290.9 a
SO_4-S	191.4 a	199.5 a	66.2 b	136.1 ab	389.1 c	768.8 a	318.1 c	489.7 b
Organic S	6.8 b	35.4 a	15.3 ab	13.2 ab	61.0 a	51.2 a	15.0 a	24.6 a
2nd MCP	21.1 b	47.7 a	30.1 ab	42.9 ab	113.5 ab	122.9 a	65.9 b	93.3 ab
HI-S remain.	0.9 a	1.2 a	1.1 a	1.0 a	3.3 a	5.3 a	4.3 ab	4.8 a
Remainder	1.1 b	2.6 a	0.8 b	1.5 ab	2.3 b	5.0 a	1.3 b	6.2 a
After								
ICP-S	31.6 b	60.8 a	22.3 b	25.9 b	20.3 b	51.9 a	25.9 b	19.9 b
SO_4-S	34.5 b	104.5 a	31.9 b	33.1 b	13.6 b	147.4 a	46.7 b	33.1 b
Organic S	32.4 a	47.2 a	7.0 a	16.9 a	39.1 a	7.1 b	7.9 b	2.6 c
2nd MCP	1.2 b	3.8 ab	3.5 b	9.1 a	5.7 b	20.0 a	5.0 b	20.1 a
HI-S remain.	1.4 a	1.3 a	1.1 ab	0.9 b	3.4 ab	2.4 b	3.6 a	2.6 b
Remainder	1.9 b	1.9 b	1.6 b	3.5 a	9.6 a	10.9 a	8.5 a	10.8 a

[A] *Numbers followed by the same letter within the same crop and fraction are not significantly different according to DMRT at P <0.05.*

After cropping with radish

The SA in all extractants and fractions after cropping exhibited a similar pattern to that before planting (Table 5.11). The SA of the SO_4-S fraction of the KCl-40 extract remained high after cropping.

Before cropping corn

A significantly higher SA in the ICP-S fraction was recorded in the KCl-40, MCP and Bray extracts than in the KCl-100 extract (Table 5.11). The SO_4-S fraction had a higher SA than the other fractions and the SA was lowest in the KCl-100 extract. The SA remained high in the 2nd MCP fraction with the highest SA recorded in the KCl-40 extract.

After cropping with corn

The KCl-40 extract had the highes SA in the ICP-S and SO_4-S fractions (Table 5.11). The SO_4-S fraction had a higher SA than the ICP-S fraction in all extracts except for the MCP. The other fractions had a low SA.

In the -S treatment Walcha soil the KCl-40 extract had the highest SA of ICP-S and SO_4-S fractions in both crops before planting and after cropping (Tables 5.11). The SO_4-S fractions had a higher SA than the Organic S fraction. The SA of other fractions was lower in all extractants.

5.3.7 Soil S: Walcha basalt soil, +S treatment.

a) The S concentration of the extractants and fractions in Walcha basalt +S treatment

Before planting radish

The S concentration as measured by ICP increased in the order KCl-40<Bray<MCP<KCl-100 (Table 5.12).

Table 5.12 *S concentration (μg S g^{-1}) in a range of extractants in the +S treatment, radish and corn, before planting and after cropping, Walcha soil.*

	Radish				Corn			
	MCP	KCl-40	KCl-100	Bray	MCP	KCl-40	KCl-100	Bray
Before								
ICP-S	29.0 b[A]	20.4 b	36.9 a	26.6 b	44.4 b	33.9 c	65.7 a	36.9 c
SO_4-S	26.3 b	18.8 c	32.3 a	22.3 c	40.3 b	28.7 c	53.4 a	29.6 c
Organic S	2.7 a	1.6 a	4.6 a	4.3 a	4.1 c	5.2 c	12.3 a	7.3 b
2nd MCP	4.6 c	14.0 a	10.4 b	5.6 c	9.8 d	24.8 b	20.3 c	31.1 a
HI-S remain.	194.3 b	205.4 a	187.1 c	199.4 b	154.9 b	167.3 a	151.8 b	171.8 a
Remainder	75.9 a	73.4 a	75.1 a	73.1 a	164.5 a	162.6 a	146.4 b	155.2 ab
After								
ICP-S	13.6 b	8.9 c	17.7 a	8.6 c	14.0 a	6.8 c	14.2 a	9.3 b
SO_4-S	12.2 b	7.4 c	14.2 a	6.7 c	11.9 a	4.3 c	8.7 b	5.4 c
Organic S	1.4 b	1.5 b	3.5 a	1.9 b	2.1 c	2.5 c	5.5 a	3.9 b
2nd MCP	3.8 d	16.0 a	12.5 b	5.8 c	4.1 b	8.4 a	10.2 a	3.7 b
HI-S remain.	136.7 b	140.1 b	139.4 b	147.2 a	152.6 c	159.9 a	149.9 c	156.2 b
Remainder	87.3 a	88.6 a	80.5 b	81.8 b	73.3 a	73.3 a	75.8 a	74.4 a

[A] *Numbers followed by the same letter within the crop and fraction are not significantly different according to DMRT at P <0.05.*

A similar pattern of S concentration was found in the SO_4-S and Organic S fractions. The MCP and Bray extracts had a lowest S concentration in the 2nd MCP fraction and the highest value was recorded in the KCl-40 extract. The highest S concentration was recorded in the HI-S fraction in all extractants with the concentration highest in the KCl-40 extract. There were no significant differences between the extractants in the S concentration in the remainder fraction.

After cropping with radish

The highest S concentration, as measured by ICP, was found in the KCl-100 and the lowest in the KCl-40 and Bray extracts (Table 5.12). The concentration of S in the SO_4-S fraction had the similar pattern to that in the ICP-S fraction. In the 2nd MCP fraction, the MCP extract had a lower S concentration and the KCl-40 a higher S concentration than in the other extractants. The S concentration of the HI-S remaining fraction following the Bray extraction was significantly higher than that in the other extractants. The concentration of S in the remainder fraction was highest in the MCP and KCl-40 extracts.

Before cropping corn

The concentration of ICP-S and SO_4-S fractions increased in the order KCl-40<Bray<MCP<KCl-100 (Table 5.12). The KCl-100 extract had the highest S concentration in the Organic S fraction. In the 2nd MCP fraction the highest S concentration was found in the Bray and the lowest in the MCP extract. The highest S concentration was found in the HI-S remaining and remainder fractions in all extractants. The KCl-100 extract had the lowest S concentration in both the HI-S remaining and the remainder fractions.

After cropping with corn

The concentration of ICP-S after cropping was higher in the KCl-100 and MCP extracts than in the Bray and KCl-40 extracts (Table 5.12). The MCP and KCl-40 extracts had the lowest S concentration in the Organic S fraction. The Bray and MCP extracts had the lowest S concentration in the 2nd MCP fraction. The concentration of the HI-S remaining fraction remained high and was lowest following the KCl-100 extract. There were no significant differences between the extractants in the S concentration in the remainder fraction but the concentration was reduced to approximately half that before planting.

In the +S treatment Walcha soil the KCl-100 extract had the highest and the KCl-40 the lowest concentration of ICP-S in both crops before planting and after cropping (Table 5.12). A similar pattern was recorded in the SO_4-S fraction. The KCl-100 extract also had the highest S

concentration in the Organic S fraction. The lowest S concentration in the 2nd MCP fraction was found in the MCP extract. By contrast, the KCl-100 extract had the lowest concentration in the HI-S remaining fraction. The highest S concentration was recorded in both the HI-S remaining and remainder fractions than in the other fractions.

b) The recovery of ^{35}S in the extractants and fractions.

Before planting radish

The lowest recovery of ^{35}S in the ICP-S and SO_4-S fractions was found in the KCl-40 extract (Table 5.13).

Table 5.13 *The percentage of ^{35}S recovered in a range of extractants in the +S treatment, radish and corn, before planting and after cropping, Walcha soil.*

	Radish				Corn			
	MCP	KCl-40	KCl-100	Bray	MCP	KCl-40	KCl-100	Bray
Before								
ICP-S	55.2 a[A]	41.9 b	56.8 a	51.4 ab	57.1 b	47.0 c	63.5 a	37.6 d
SO_4-S	52.9 a	39.2 b	53.5 a	48.9 ab	54.9 b	44.5 c	60.6 a	34.9 d
Organic S	2.3 a	2.7 a	3.3 a	2.5 a	2.2 a	2.5 a	2.9 a	2.7 a
2nd MCP	4.3 d	19.8 c	14.7 a	10.8 b	6.1 d	16.3 b	12.1 c	21.1 a
HI-S remain.	11.9 b	22.0 a	15.9 ab	19.7 ab	23.1 a	23.5 a	23.9 a	25.8 a
Remainder	32.9 a	36.0 a	27.2 a	28.9 a	19.7 b	29.4 a	12.5 c	36.6 a
After								
ICP-S	39.9 b	36.7 b	49.4 a	28.2 c	45.5 a	27.9 c	38.8 b	36.3 b
SO_4-S	31.0 b	32.2 b	46.4 a	18.8 c	39.2 a	26.9 c	36.5 ab	35.4 b
Organic S	8.9 a	4.5 a	3.0 a	9.4 a	6.3 a	1.0 b	2.3 b	0.9 b
2nd MCP	3.8 c	17.4 a	11.4 b	6.7 c	3.2 c	23.4 a	13.8 b	7.5 c
HI-S remain.	20.9 a	32.4 a	31.3 a	22.2 a	19.9 a	26.8 a	25.4 a	16.9 a
Remainder	39.1 ab	30.9 ab	19.2 b	49.6 a	34.5 b	45.3 ab	35.7 ab	46.8 a

[A] *Numbers followed by the same letter within the same crop and fraction are not significantly different according to DMRT at P <.05.*

In the components of ICP-S, there was a higher recovery in the SO_4-S than in the Organic S fraction. The lowest recovery of ^{35}S in the 2nd MCP fraction was in the MCP extractant. There was in excess of 40% of the ^{35}S recovered in the combined HI-S remaining and remainder fractions in all extractants with the recovery lowest following the KCl-100 extract.

After cropping with radish

The recovery of ^{35}S in the ICP-S fraction followed a similar pattern to that before planting (Table 5.13). More of the ^{35}S was recovered in the SO_4-S compared to the Organic S fraction in all extractants. The amount of ^{35}S recovered in the 2nd MCP fraction was low. There were no significant differences between extractants in the recovery of ^{35}S in the HI-S remaining fraction. The Bray extract had the highest recovery of ^{35}S in the remainder fraction. In excess of 50% of the applied ^{35}S was recovered in the HI-S remaining + remainder fractions.

Before planting corn

The highest recovery of ^{35}S in the ICP-S and SO_4-S fractions was recorded in the KCl-100 and the lowest in the Bray extract (Table 5.13). More of the ^{35}S was recovered in the SO_4-S than in the Organic S fraction. The lowest recovery of ^{35}S in the 2nd MCP fraction was found following the MCP extract. There were no significant differences between extractants in the recovery of ^{35}S in the HI-S remaining fraction and all exceeded 23%. ^{35}S recovery was lowest in the remainder fraction following the KCl-100 extract.

After cropping with corn

The highest amount of ^{35}S recovered in the ICP-S and SO_4-S fractions was recorded in the MCP extract and the lowest in the KCl-40 extract (Table 5.13). There was a higher recovery of ^{35}S in the SO_4-S than in the Organic S fraction. A total of 23.4% of the added ^{35}S was recovered in the 2nd MCP fraction in the KCl-40 extractant. There was no significant difference between extractants in the recovery in the HI-S fraction and only small differences in the remainder fraction.

In the +S treatment Walcha soil a higher recovery of ^{35}S in the ICP-S fraction was found in the KCl-100 and MCP extracts than that the KCl-40 and Bray extracts (Table 5.13). A higher amount of ^{35}S was recovered in the SO_4-S than in the Organic S fraction. There was low recovery of ^{35}S in the 2nd MCP fraction. In all extractants there was a high recovery of ^{35}S in the HI-S and remainder fractions and this increased after cropping.

c) The specific activity (SA) in the extractants and fractions

Before planting radish

A significantly higher SA was recorded in the ICP-S fraction in the KCl-40, MCP and Bray extracts than in the KCl-100 extract (Table 5.14). The SA in the SO_4-S fraction was similar to that

of ICP-S in all extractants. The MCP extract had the lowest SA in the 2nd MCP fraction. The SA was low in the HI-S remaining and remainder fractions of all extracts.

After cropping with radish

In the ICP-S fraction, the SA after cropping was higher than that before planting. The highest SA in the ICP-S fraction was recorded in the KCl-40 extract and the lowest in the KCl-100 extract (Table 5.14). The SA in the Organic S fraction was lower than in the SO_4-S fraction except in the MCP and Bray extracts. The other fractions had a low SA in all extractants.

Table 5.14 *The specific activity (KBq mg S^{-1}) in a range of extractants in the +S treatment, radish and corn, before planting and after cropping, Walcha soil.*

	Radish				Corn			
	MCP	KCl-40	KCl-100	Bray	MCP	KCl-40	KCl-100	Bray
Before								
ICP-S	13.8 a[A]	14.7 a	11.1 b	13.8 a	33.8 a	36.7 a	25.3 b	26.7 b
SO_4-S	15.0 a	14.8 ab	11.8 b	15.5 a	35.8 ab	41.1 a	29.7 b	31.0 b
Organic S	6.7 ab	17.8 a	13.7 ab	6.1 b	13.7 a	13.0 a	6.3 a	9.5 a
2nd MCP	6.6 b	10.2 a	9.9 a	13.2 a	16.9 a	17.5 a	15.8 a	18.1 a
HI-S remain.	0.4 b	0.7 a	0.6 ab	0.7 a	3.9 a	3.7 a	4.1 a	3.9 a
Remainder	3.0 a	3.5 a	2.5 a	2.8 a	3.1 c	4.8 b	2.2 c	6.2 a
After								
ICP-S	16.3 b	22.9 a	15.4 c	18.2 ab	56.6 b	72.4 a	47.7 c	68.3 a
SO_4-S	14.1 b	24.2 a	18.1 b	15.4 b	57.6 b	113.7 a	73.7 b	115.4 a
Organic S	37.3 a	17.6 a	4.9 a	33.6 a	53.3 a	6.8 b	7.2 b	4.1 b
2nd MCP	5.5 a	6.0 a	5.0 a	6.9 a	13.3 d	48.7 a	23.6 c	35.2 b
HI-S remain.	0.8 a	1.3 a	1.2 a	0.8 a	2.3 a	2.9 a	2.9 a	1.9 a
Remainder	2.8 ab	1.9 ab	1.6 b	3.6 a	8.3 a	10.9 a	8.2 a	11.2 a

[A] *Numbers followed by the same letter within the same crop and fraction are not significantly different according to DMRT at P <0.05.*

Before planting corn

The highest SA in the ICP-S, SO_4-S and Organic S fractions was recorded in the KCl-40 and MCP extracts (Table 5.14). There was no significant different between extractants in the SA of the 2nd MCP fraction. The SA was low in the HI-S and remainder fractions.

After cropping with corn

The SA of the ICP-S fraction after cropping was higher than that before planting. The KCl-40 extract had the highest SA in the ICP-S and SO_4-S fractions (Table 5.14). The SO_4-S fraction had a higher SA than the other fractions. The SA tended to increase during cropping in the 2nd MCP and remainder fractions and decrease in the HI-S remaining fraction.

In the +S treatment Walcha soil a higher SA of ICP-S fraction was found in the KCl-40, MCP and Bray extracts than in the KCl-100 extract (Table. 5.14). The SO_4-S fraction had a higher SA except in the MCP and Bray extracts in radish after cropping. The other fractions had a low SA in all extracts.

5.3.8 The relationship between the estimated amount of S lost from the soil pools and S uptake

A linear relationships of the form of Y = a + bX, where Y = S uptake by the crop and X = estimated S lost from the soil pool (extracted S before planting - extracted S after cropping) was established for the two soils, -S treatment and three crops established for the ICP-S fraction of each extractant.

The coefficient of determination (r^2) was highest for the KCl-40 and KCl-100 extract with r^2 values of 0.83 and 0.96 respectively. These were higher than those for the Bray and MCP extractants which were non significant (Table 5.15).

Table 5.15 *Coefficient of determination (r^2) for the relationship between S uptake (Y) and the estimated amount of S lost from the soil pool (S before planting - S after cropping) (X).*

Extraction method	Intercept (a)	Slope (b)	Coefficient of determination (r^2)
MCP	6.78	0.46	0.72
KCl-40	5.02	0.53	0.83 *
KCl-100	2.49	0.46	0.96 **
Bray	5.20	0.84*	0.73

* $P < 0.05$, ** $P < 0.01$

The slope of the regression line (b) was significantly higher with the Bray extractant than the other three extractants (Table 5.15). The data points for the four test extractants are presented in Figures 5.1a, b, c, and d. The loss of S, as estimated by the MCP extractant, was lower than plant

uptake in all treatments except ryegrass in the Walcha soil, and the 95% confidence interval of the fitted regression line was outside the 1:1 line for most of the data points (Figure 5.1a).

The KCl-40 extract tended to underestimate S supply at low uptake and over estimate at higher uptake (Figure 5.1b) although the 1:1 line fell within the 95% confidence interval. By contrast the KCl-100 extractant generally over estimated S uptake with the 1:1 line outside the 95% confidence interval for most data points (Figure 5.1c).

The Bray-S extract underestimated S uptake for all data points and the 1:1 line was only within the 95% confidence interval for the ryegrass in both the Uralla and Walcha soils (Figure 5.1d).

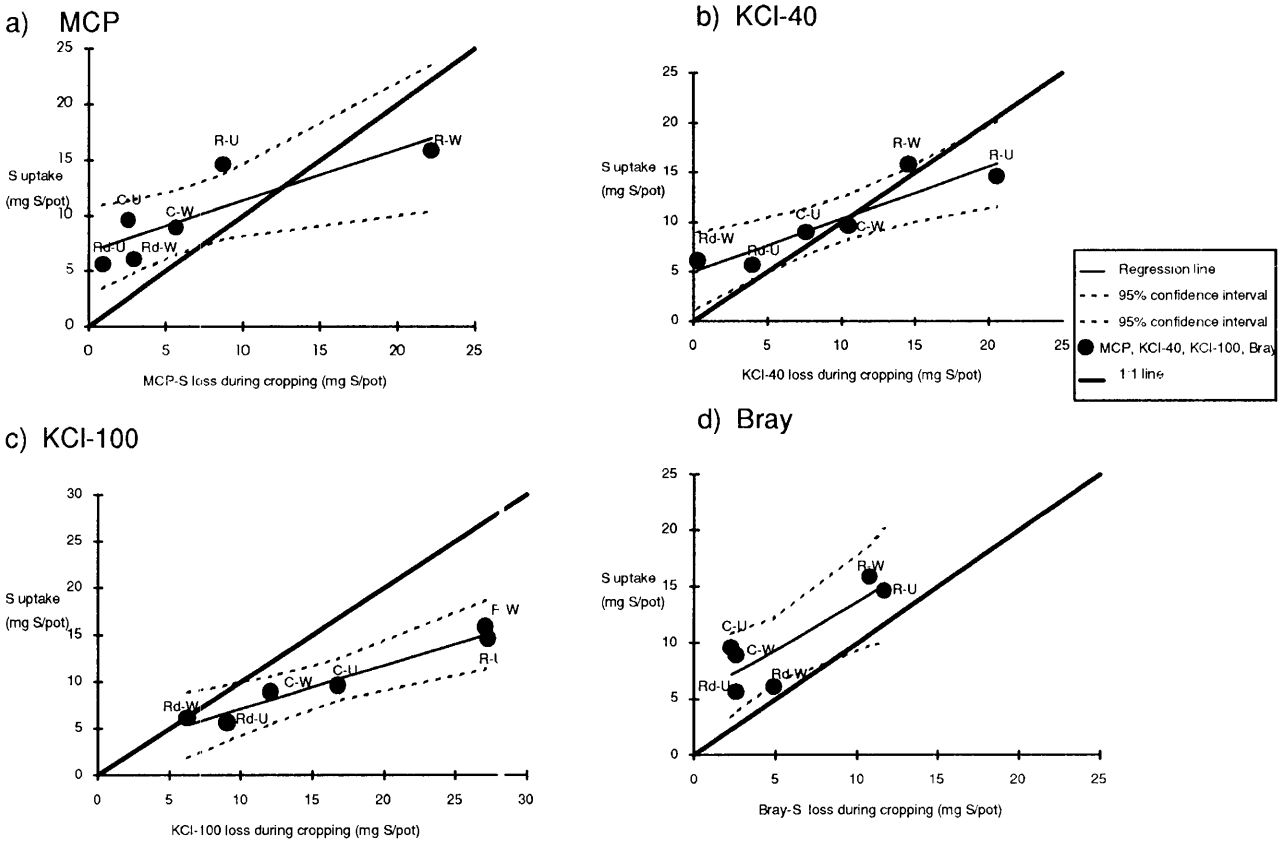

Figure 5.1 *Relationship between S uptake and a) the MCP-S loss during cropping b) the KCl-40 loss during cropping c) KCl-100 loss during cropping and d) Bray-S loss during cropping.*

5.3.9 The relationship between S pools sampled by the extractants and plant uptake.

The relationship between S removed by the four test extractants and plant uptake is shown by the SAR data.

The SAR calculated using the KCl-40 data determined before planting and after cropping was closest to 1 in all crops in the -S treatment and generally the closest to 1 in the +S treatments (Table 5.16). In these +S treatments where the KCl-40 treatment was not closest to 1, it was generally not significantly different from the KCl-100 extract in the Uralla soil. The SAR data for the MCP and Bray extracts was generally higher than 1 and greater than for the KCl-40 extract confirming the data presented in Figures 5.1a) and d). As in the Uralla soil the SAR was generally closest to 1 when the KCl-40 data was used in the calculation.

Table 5.16 *The specific activity ratios (SAR) (SA in the plant/SA in the extractant) by the four test extractants in the -S and +S treatment, before planting and after cropping, Uralla soil and Walcha soil.*

	Uralla				Walcha			
	MCP	KCl-40	KCl-100	Bray	MCP	KCl-40	KCl-100	Bray
Before -S								
Radish	1.26 b[A]	0.99 b	2.21 a	2.16 a	1.15 b	1.05 b	2.54 a	1.48 b
Corn	1.34 b	0.83 b	1.51 ab	2.39 a	1.04 b	1.07 b	1.77 a	1.11 b
Ryegrass	1.44 a	1.12 a	1.56 a	1.63 a	1.23 b	1.05 c	1.70 a	1.72 a
Before +S								
Radish	2.49 a	1.99 b	1.86 b	2.44 a	1.57 ab	1.41 b	1.90 a	1.52 b
Corn	2.62 a	1.90 b	1.94 b	2.61 a	3.89 b	3.60 b	5.14 a	4.85 a
Ryegrass	3.12 a	2.30 b	2.15 b	3.22 a	2.63 b	2.61 b	3.09 a	3.57 a
After -S								
Radish	3.82 a	2.58 a	4.71 a	3.09 a	3.75 a	2.07 b	4.89 a	4.39 a
Corn	9.15 a	4.07 b	5.94 b	10.98 a	16.30 a	6.79 b	12.73 a	17.32 a
Ryegrass	5.97 a	2.49 b	5.62 a	1.93 b	4.11 b	2.99 c	5.09 a	3.09 c
After +S								
Radish	1.47 a	0.87 bc	1.01 b	0.66 c	1.26 a	0.89 b.	1.33 a	0.89 b
Corn	1.23 a	0.99 b	1.21 a	1.18 a	2.25 a	1.07 c	1.76 b	1.13 c
Ryegrass	1.11 a	0.94 b	1.17 a	0.82 b	1.84 a	1.52 b	2.24 a	1.07 b

[A] *Numbers followed by the same letter within a same plant and soil are not significantly different according to DMRT at P <0.05.*

5.4 Discussion

5.4.1 Yield

The results in this experiment showed that the application of S fertiliser increased the yield of radish (Table 5.1) and corn (Table 5.2) in both the Uralla and Walcha soils which was similar to the result in the ryegrass experiment (Chapter 4, Section 4.3.1). Samosir (1989) reported a S response in flooded rice in the Uralla granite soil used in the present study. Similarly, Chaitep (1990) found that the application of S fertiliser to the Uralla granite soil resulted in an increased in grain yield and S uptake of rice grown under flooded and non flooded conditions. Recent research (Dana, 1992) showed that the highest total yield and S uptake of perennial ryegrass and white clover was recorded in the gypsum treatment and lowest in the unfertilised treatment on this same soil. Anderson (1992) reported that application S in both field and pot experiments increased the dry matter yield and S content of pasture on both the Uralla granite and Walcha basalt soils.

5.4.2 Total S uptake, S concentration and specific activity (SA) of the plant

The applied S increased the S concentration and S uptake in radish (Table 5.1) and corn (Table 5.2) in both soils. This was similar to the ryegrass experiment, which has been discussed in Chapter 4 (Section 4.4.1).

When the S concentration in the total plants of radish (Table 5.1), corn (Table 5.2) and ryegrass (Chapter 4, Tables 4.3 and 4.4) are compared, radish had the highest S concentration in the total plants and corn the lowest. Ryegrass was intermediate between these two. Duke and Reisenauer (1986) reported that most species of the Cruciferae family contain large amounts of S whereas the maize contains the least. This report agrees with this result.

The S concentration (%S) in the radish roots was higher than that of the tops (Table 5.1) because radish produced a thickened storage root (Langer and Hill, 1982) which accumulated a greater amount of S, compared to the tops. The S concentration in the tops of corn in the -S treatment was 0.05% in both soils (Table 5.2). This concentration was below the critical tissue concentration of 0.08 % for corn (6-8 weeks) reported by Terman *et al.* (1973) or the critical value of 0.08% reported by Reuter and Robinson (1986).

Sulfur application increased the S uptake similar to that reported by several workers. Tsuji and Goh (1979) grew ryegrass in two S responsive soils and found that both yield and S uptake of tops and roots was increased when S was applied. Chainwanakupt *et. al.* (1987) reported that S

fertiliser increased S concentration in the ear leaf of sweet corn. Ismunadji *et al.* (1983) reported that the ammonium sulfate application resulted in significant increases S uptake by rice grown in a grumusol soil.

Clarkson *et al.* (1983) found that there was a rapid increase in the capacity of the root to take up sulfate and transport S to the plant tops when S was applied. The results in this study support these findings.

The highest plant SA was recorded in the -S treatment in radish (Table 5.1) and corn (Table 5.2) in both soils, due to no dilution from applied fertiliser. This result was similar to the ryegrass experiment (Chapter 4, Section 4.3.3).

5.4.3 Sulfur removed by the extractants.

The higher total soil S concentration recorded in the Walcha than the Uralla soil most likely results from the higher clay and organic carbon content in that soil (Table 4.1). Kurmarohita (1973) found that there was a strong positive correlation between total S, total N, organic C and clay content in Thai soils. Freney (1986a) reported that there was a close relationship between organic C, total N and the total S in surface soils. Bailey (1985) also found that the total S content of 17 soils was significantly correlated with organic C and organic N. Thus the Walcha soil would be expected to have the high total S content, due to the high organic C. The difference in the amount of total S between the soils appears to be related to the stabilisation soil organic matter by the high clay content of the soil (Tiessen and Stewart, 1983, Ladd, et al., 1985, Dalal and Mayer, 1986) and indicated that the total S digestion method extracted a pool of organic S which has been stabilised by the clay.

The HI-S and total S concentration was higher in the Walcha than in the Uralla soil (Appendix 5.1) yet the extractants removed similar amounts of S from both soils (Tables 4.7, 4.13, 5.3, 5.9). This indicates that much of the sulfate and HI-S present in the Walcha soil is adsorbed at a strength in excess of that which can be removed by the extractants, or is inaccessible to the extractants, either in peds or incorporated into the structure of sorbing surfaces or organic matter. If adsorption of HI-S was one of the mechanisms responsible for this then this Walcha soil would be similar to the Welsh soils of Houghton and Rose (1976). In the Uralla soil all extractants removed most of the adsorbed S as indicated by the low S concentration in the second extraction (Table 4.7, Appendix 4.2, Tables 5.3, 5.6). Higher amounts of S were recovered in this extract in the Walcha soil (Table 4.13, Appendix 4.8, Tables 5.9, 5.12) indicating that the S is too strongly adsorbed in this soil to be removed even by MCP. This could be due to the adsorption capacity of P being higher than that supplied in the 500 ppm solution or that the strength of bonding of the

resident S was in excess of that of the added P. This result was supported by the finding of Santoso (1989) who found that the P adsorption occurred in excess of 1000 μg P g^{-1} soil in the high P sorbing soil. Therefore it is possible that most of the P added in MCP was adsorbed onto the P sorption complex without displacing sulfate.

The low recovery of added ^{35}S in the second extraction in the Uralla soil (Table 4.8, Appendix 4.3, Tables 5.4, 5.7) supports the contention that the adsorbed S in this soil is easily exchangeable and readily labile. The low recovery (8.1%) of added ^{35}S found in the second extraction following MCP (Table 5.10) indicates that this extract removes most of the readily exchangeable adsorbed S. By contrast in excess of 15% of the added ^{35}S was recovered in the second extraction following the KCl-40, KCl-100 and Bray extracts (Table 5.10). This indicates that these extractants do not removed all the readily exchangeable S from the adsorption complex.

In both soils a large proportion of the HI-S remained in the soil after the primary extraction. Where KCl-40 was used there was a low recovery of ^{35}S in this pool in the Uralla soil (Tables 5.4, 5.7) but in excess of 20% of the applied ^{35}S was recovered in this pool in the Walcha soil (Tables 5.10, 5.13) indicating incorporation into a form of ester sulfate which is more resistant to degradation or the HI-S was adsorbed to the soil particles. Freney *et al.* (1971, 1975) found that the ^{35}S was incorporated into both the HI-reducible S and C bonded S fractions, with the HI-reducible S fractions exhibiting greater specific activity. Most of the HI-reducible S was associated with fulvic acid (Freney, 1961). Freney *et al.* (1971) showed that the fulvic acid fraction contained about 78% of immobilized S of which approximately 90% was in the HI-reducible forms. There is evidence that HI-reducible S may also be adsorbed to soil particles. Houghton and Rose (1976) found that a variety of different ^{35}S labelled sulfate esters were adsorbed to Welsh soils to the extent of 67% of the total concentration of the ester sulfate that was initially added to these soils.

The MCP extractant failed to extract the labile S from the HI-S pool in the Uralla soil as in excess of 47% of the added ^{35}S was recovered in the HI-S fraction following the primary extraction with MCP (Table 5.4).

In the Walcha soil some of the extractants were not capable of recovering a high proportion of the added ^{35}S from the HI-S pool. This indicates that in this soil that there was a greater transformation of S into a more resistant HI-S pool than in the Uralla soil.

5.4.4 Relationship between S extracted by the extractants and plant uptake.

Data on the specific activity ratio (SAR) showed that all extractants before planting had a greater SAR in the +S treatment than in the -S treatment in all crops and soils (Table 5.16). None of the extractants could assess the S available pool used by plant in the +S treatment due to the dilution of ^{35}S in this pool by sulfate from the S fertiliser. All extractants underestimated the contribution from the S pool/s in this treatment. The SAR was higher for all extractants in the -S than in the +S treatment after cropping. The data of SA in the ICP-S fraction (Tables 4.9, 4.15, Appendices 4.4, 4.10, Tables 5.5, 5.8, 5.11, 5.14) and the SA of the plant (Tables 4.3, 4.4, 5.1, 5.2) supported this result. All the extracts had a lower SA than the SA of the plant. The SA in all extracts and SA in the plant was lower in the +S than in the -S treatment in each crop.

The SAR for the KCl-40 extract determined before planting was closest to 1 in all crops in the -S treatment in both soils and generally closest to 1 in the +S treatment after cropping (Table 5.16). This means that the specific activity (SA) of each crop was closer to the specific activity of the KCl-40 extract than the specific activity of the other extractants, indicating that the KCl-40 method extracted S from the same or similar pool/s to the plant. This result is supported by the data presented in Table 5.15 and Figure 5.1b. Although the KCl-40 method was found to have a lower correlation between the estimated amount of S lost from the soil pools and S uptake by all crops than the KCl 100 extract (Table 5.15) the data in Figure 5.1b suggests that the relationship was closer to the 1:1 line between uptake and S loss from the extracted pool. However the KCl-40 extraction was observed to underestimate the size of the available S pool taken up by radish in the Walcha soil (Figure 5.1b). In contrast, it tended to overestimate the S pool taken up by ryegrass in the Uralla soil. Radish and ryegrass have the different growth periods (Jordan and Ensminger, 1958) and radish needs a rapid supply of readily available sulfate which could not be removed by the KCl-40 extract in the Walcha soil. The amount of S removed by KCl-40 extract was less in the Walcha than that in the Uralla soil despite the higher adsorbed S and HI-S concentration in this soil which has been discussed in Chapter 4 (Section 4.4.2.C). On the other hand, ryegrass has a lower S demand rate and the KCl-40 extract appears to remove a greater pool of S than that taken up by the ryegrass in the Uralla soil. Data on the concentration of S (Tables 4.7, 4.13, Appendices 4.2, 4.8, Tables 5.3, 5.9, 5.6 and 5.12) and the recovery of ^{35}S (Tables 4.8, 4.14, Appendices 4.3, 4.9, Tables 5.4, 5.10, 5.7, 5.13) support this result.

The data on SA in all extracts showed that a higher SA was recorded in the ICP-S and SO_4-S fraction than in the other fractions in all crops and soils before planting and after cropping and the SO_4-S fraction had the highest SA (Tables 4.9, 4.15, Appendices 4.4, 4.10, 4.15, 4.18, 4.21, 4.24, Tables 5.5, 5.8, 5.11, 5.14). This indicates that the ^{35}S in these fractions was more highly labile than the other fractions. The recovery of ^{35}S confirmed this result. Before planting all

the extractants had a higher recovery of ^{35}S in the ICP-S and SO_4-S fractions than the other fractions in all crops and soils (Tables 4.8, 4.14, Appendices 4.3, 4.9, Tables 5.4, 5.7, 5.10, 5.13), indicating that a large amount of the ^{35}S added entered this pool. After cropping all extractants had a low recovery of ^{35}S in this pool (Appendices 4.14, 4.17, 4.20 4.23, Tables 5.4, 5.7, 5.10, 5.13) because of ^{35}S uptake by the plant. This result is similar to the results in Chapter 4.

Generally, the KCl-40 extract had a higher SA in the ICP-S and SO_4-S fractions than the other extracts in both S treatments and soils in all crops before planting and after cropping (Tables 4.9, 4.15, Appendices 4.4, 4.10, 4.15, 4.18, 4.21, 4.24, Tables 5.5, 5.8, 5.11, 5.14.), indicating that KCl-40 extract removed the more highly labelled of ^{35}S in the ICP-S and SO_4-S fraction than the other extracts. It was found that the KCl-40 extraction removed the soil solution and some portion of the adsorbed sulfate and labile HI-S pools in Chapters 3 and 4. These results confirmed this finding. Data on the S concentration (Tables 5.3, 5.6, 5.9, 5.12) and the recovery of ^{35}S (Tables 5.4, 5.7, 5.10, 4.13) also confirmed these results. The KCl-40 extract had a high S concentration in the ICP-S and SO_4-S fractions and a low concentration in the HI-S remaining fraction in the Uralla soil in both S treatments before planting and after cropping (Tables 5.3, 5.6). By contrast, the KCl-40 extract had a low S concentration in the ICP-S fraction and SO_4-S fractions and a high concentration in the HI-S remaining fraction in the Walcha soil (Tables 5.9, 5.12). A similar result was found in the recovery of ^{35}S. The difference in the S concentration and recovery of ^{35}S in the KCl-40 extract between two soils has been discussed above.

In the +S treatment before planting, where the SAR of the KCl-40 extract was not closest to 1, it was generally not significantly different from the KCl-100 extract in the Uralla soil (Table 5.16). The KCl-100 extract also had the high correlation between the estimated amount of S lost from the soil pools and S uptake by all crops (Table 5.15) However, the KCl-100 extract had a high SAR (higher than 1) in all crops and soils confirming the data presented in the Figure 5.1c. The KCl-100 extractant generally overestimated S uptake by all crops. This was because KCl-100 removed the soil solution and adsorbed sulfate and a large portion of HI reducible S. The portion of HI reducible S removed by the KCl-100 extract was more than that which became available to the crops. The data of the recovery of ^{35}S and the S concentration data supported this result. The KCl-100 extract removed the highest amount of S in the ICP-S and the components of ICP-S (SO_4-S and soluble organic S fractions) in both S treatments and soils before planting and after cropping (Tables 4.7, 4.13, Appendices 4.2, 4.8, 4.13, 4.16, 4.19, 4.22, Tables 5.3, 5.6, 5.9, 5.12). The lowest amount of S in the HI-S remaining in the soil after the first extraction was recorded in the KCl-100 extract. This confirms that the KCl-100 removed a higher amount of HI-S than the other extractants. The recovery of ^{35}S also supported this result. The KCl-100 had the highest recovery of ^{35}S in the ICP-S and SO_4-S fractions and the lowest recovery in the HI-S remaining fraction (Tables 4.8, 4.14, Appendices 4.3, 4.9, 4.14, 4.17, 4.20, 4.23, Tables 5.4, 5.7, 5.10, 5.13).

The SAR data for MCP and Bray extracts was generally higher than 1 and greater than for the KCl-40 extract in all crops in both S treatments and soils before planting (Table 5.16). A similar pattern was recorded in all extracts after cropping. The MCP and Bray extractants had a low correlation between the estimated amount of S lost from the soil S pools and S uptake by all crops, as shown by the data presented in Figures 5.1 a and c. It was observed that the MCP and Bray extractants tended to underestimate S supply because the loss of S as estimated by the MCP and Bray extractants was lower than plant uptake. The MCP extractant removed a greater amount of sulfate and a lower amount of HI reducible S than the KCl-40 extract. The MCP extractant had a lower S concentration in the ICP-S and SO_4-S fractions and higher amount in the HI-S remaining fraction in the Uralla soil and higher amount of S in these fractions in the Walcha soil than the KCl-40 extract. The Bray extractant also removed a lower amount of S in the ICP-S and SO_4-S fractions and left a higher concentration in the HI-S remaining fraction in both soils before planting and after cropping than the KCl-40 extract (Tables 4.7, 4.13, Appendices 4.2, 4.8, 4.13, 4.16, 4.19, 4.22, Tables 5.3, 5.6, 5.9, 5.12). The data of ^{35}S recovery supported this result. The MCP extract had a lower recovery of ^{35}S in the ICP-S and SO_4-S fractions and a higher recovery in the HI-S remaining fractions than the KCl-40 extract in the Uralla soil before planting. A reverse result was found in the Walcha soil. The Bray extract also had a low recovery of ^{35}S in the ICP-S and SO_4-S fraction and high recovery in the HI-S remaining fraction (Table 4.8, 4.14, Appendices 4.3, 4.9, Tables 5.4, 5.7, 5.10, 5.13). After cropping there was a lower recovery of ^{35}S in the SO_4-S pool in the MCP and Bray extracts than the KCl-100 and KCl-40 extracts in both S treatments and soils (Appendices 4.14, 4.17, 4.20, 4.23, Tables 5.4, 5.7, 5.10, 5.13).

The result reported in this experiment showed that the KCl-40 extract generally performed well for all crops and soils. It appeared that the KCl-40 extract removed S from the same pool/s as did the crops. The S pools taken up by radish, corn and ryegrass were the soil solution, some portion of adsorbed sulfate fraction and some of the HI reducible S fraction. This portion of HI-reducible S is most likely the highly labile ester sulfate (Freney, 1961, 1986a) which serves as a temporary storage of soil sulfate (Lou and Warman, 1992b) potentially available to plants (Freney et al., 1971, 1975; Schnitzer, 1991). This result supported the direct evidence found by Shedley (1982) that the ester sulfates can contribute S readily to plant uptake.

The data collected in this series of experiments have shown that by gaining an understanding of both the pool sizes and turnover rates of S that an appropriate chemical extractant can be developed. The series of experiments have confirmed the value of using ^{35}S as a tracer to estimate pool turnover rates.

It is suggested that this approach to soil testing should be extended to other nutrients such as N, P and K. The KCl-40 sulfur soil test was introduced into a commercial soil testing laboratory (Incitec Pty. Ltd.) in 1993 and is being evaluated in laboratories in other states of Australia.