MANAGING RESIDUES AND FERTILISERS TO ENHANCE THE SUSTAINABILITY OF WHEAT CROPPING SYSTEMS

A.M. Whitbread[1], G.J. Blair[1] and R.D.B. Lefroy[2].

[1] Division of Agronomy and Soil Science, University of New England, Armidale 2351.
[2] International Board for Soil Research and Management, Bangkhen, Bangkok, 10900 Thailand.

Abstract

The continuous cultivation and cropping of many Australian soils, which previously supported native vegetation, has resulted in substantial losses in soil organic matter (SOM). Field trials consisting of legume/wheat rotations were established at Warialda to investigate the effect of crop residue and fertiliser management on wheat yield, nutrient balances, carbon and soil structure. Wheat yields were significantly lowered in the first year following a lucerne or soybean legume phase. Wheat grain production was increased from 6 to 19 % with fertiliser application and from 3-9 % with the retention of wheat stubble. Nutrient balances showed negative N balances of -96 and -76 kg/ha on the wheat stubble residue removed and retained treatments, respectively. The balance of nutrients such as K, which are contained in larger proportions in stubble, were found to be -102 kg/ha on the wheat residue removed treatments and +8 kg/ha on the residue retained treatments. The greatest improvements in SOM were associated with 2 lucerne rotations which increased total carbon (C_T) by 16 % compared to the 2 fallow phases which decreased C_T by 8 % mg/g from the 1992 concentrations. Three seasons of a wheat phase, in which stubble was retained, resulted in labile carbon (C_L) significantly increasing and the Carbon Management Index (CMI) improving from 19 to 27.

Key words: stubble management, soil carbon, labile carbon, nutrient balances, wheat yield

Many Australian soils used for cropping are fragile and highly degraded. Farming practices such as the removal of crop residues, poor management of leys and excessive tillage, are common and unsustainable. The cultivation of soil which has previously supported native vegetation and/or pastures, generally leads to a decline in SOM and C levels (3), lower biological activity (6) and deteriorating soil structure (2).

A field trial was conducted at the University of New England's Douglas McMaster research station in north-west NSW to examine the effects of legume ley crops, management of the legume residue, management of wheat residue and fertiliser on wheat yields. The aim of this experiment was to investigate the effects of management systems on the level and nature of SOM, the changes in soil chemistry and soil physical properties that result from changes in organic matter and the nutrient dynamics of these systems and the subsequent effect on production.

Materials and methods

The University of New England's McMaster Research Station crop residue and nutrient management trial was established in 1992 on a moderately degraded Red Earth soil (Paleustaf) which had previously been cropped in a cereal-legume rotation. Briefly, 3 legume systems (chickpea, medic, lucerne) and a fallow were established with no fertiliser during the 1992 winter cropping season. The residue from these systems was either removed, returned or grazed. On these same sites, wheat (cv. Janz) was grown during 1993, 1994 and 1995 with 2 fertiliser treatments [0 (-F) or 25:7:27 kg N:P:S/ha(+F)] and 2 wheat residue management treatments [removed (-R), returned (+R)]. The legume (soybean, medic, lucerne) or fallow treatments were replanted during the winter of 1996 (8 and 8.8 kg P and S/ha, respectively) with the residue from these systems being removed, returned or burnt. Wheat was again grown during 1997 with 2 fertiliser treatments [Low (12.5:11.4:10 kg N:P:S/ha) and High (25:23:20 kg N:P:S/ha)] and wheat straw removed or returned. The yield of the legume crops and wheat crops were measured at harvest and straw and grain samples were collected for nutrient analysis. Soil samples (0-10 cm) were collected from all plots prior to sowing. C_T was measured in an automatic nitrogen and carbon analyser mass spectrometer system (ANCA-MS), consisting of a Dumas-type dynamic flash catalytic combustion sample preparation system (Carlo Erba NA1500), with the evolved gases separated and analysed by mass spectrometry (Europa Scientific Tracermass Stable Isotope Analyser). The more labile soil organic carbon (C_L) was measured by oxidation with 333 mM $KMnO_4$ (1). Reference soil samples were collected from a nearby uncultivated and uncleared site.

Results

Wheat yields

The impact of the initial 1992 pre-wheat legume/fallow phase on grain yields was limited to a decrease in wheat grain yield following the lucerne phase and was restricted to the first season of wheat. The main impacts on grain production during the first wheat phase were due to fertiliser which increased grain yields by 6.4, 7.8 and 19.4 % in 1993, 1994 and 1995 and wheat stubble retention which increased grain yields by 8.0 and 9.4? % in 1994 and 1995 (Table 1). The second legume phase resulted in grain yields of 3488 and 3454 kg/ha following the medic and fallow phases and significantly lower yields of 2376 and 2754 kg/ha following the lucerne and soybean phases, respectively. There was no effect of previous stubble management on grain yields in 1997, however the high application of fertiliser significantly increased yields.

Table 1. Fertiliser (1993-95 -F, +F: 1997 Low, High) and wheat stubble effects on wheat grain yield (t/ha).

?	Wheat Grain Yield (t/ha)			
?	1993	1994	1995	1997
- F/Low	3.3 b	2.0 b	2.2 b	2.9 b
+ F/High	3.5 a	2.2 a	2.6 a	3.1 a
- Wheat Stubble	-	2.0 b	2.3 b	2.9 a
+ Wheat Stubble	-	2.1 a	2.5 a	3.0 a

Means followed by the same letter within columns are not significantly different according to DMRT at $P \leq 0.05$.

Nutrient balances

Nutrient balances, determined by the difference between the inputs (fertiliser and legume residues) and outputs (grain and stubble), were calculated up until after harvest in 1995 and are presented in Table 2 for the lucerne and fallow treatments. The nutrient balance does not take account of the amount of N that may have been fixed during the crop growth, of nutrients contained in decomposing root material or of soil nutrient changes. Fertiliser and residue management were the primary determinants of the nutrient balance. Since approximately 80 % of N is contained in the grain, export of N in grain is high resulting in negative N balances (Table 2). Since approximately 80 % of the potassium (K) is contained in the stubble, the management of crop residue largely influences the K balance. The removal or burning of wheat stubble results in large amounts of K being exported and possible K deficiencies.

Table 2. The nitrogen and potassium balance (kg/ha) following a lucerne or fallow phase and three wheat crops.

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?	?	Nitrogen Balance (kg/ha)		Potassium Balance (kg/ha)	
?	?	Wheat Stubble Removed	Wheat Stubble Returned	Wheat Stubble Removed	Wheat Stubble Returned
Lucerne	- Fertiliser	-91	-86	-52	+45
?	+ Fertiliser	-43	-33	-79	+40
Fallow	- Fertiliser	-158	-143	-120	-27
?	+ Fertiliser	-116	-87	-133	-30

Soil carbon

The legume phases during 1992 and 1996 resulted in an overall increase in C_L, C_T and the CMI (Table 3). The greatest improvement occurred where lucerne was planted which resulted in a C_T of 8.61 mg/g compared to a C_T of 5.85 mg/g in the fallow treatment. There was a continued loss of C from the fallow treatments, where there were no organic matter inputs during the ley phase.

Table 3. The change in carbon (mg/g) and in the Carbon Management Index (CMI) from the 1992 legume/fallow phase until after the 1997 legume /fallow phase.

?	C_L	C_T	CMI
?	------ mg/g ------		?
Lucerne	0.11 a	1.20 a	2 a
Soybean	0.15 a	0.10 b	3 a
Medic	0.04 a	0.04 b	1 a
Fallow	-0.01 a	-0.51 b	0 a

Means followed by the same letter within columns are not significantly different according to DMRT at $P \leq 0.05$.

In 1996 after the 2 seasons of wheat stubble incorporation and surface retention of the 1995 wheat residues, C_L was significantly higher on the returned than the removed stubble treatments and both had increased from the 1995 C_L levels. C_T tended to be lower on both treatments than in the previous season but this was not significant. The higher C_L in the residue retained treatments resulted in an increase in the CMI to 27 (Table 4).

The C parameters in 1997 were statistically analysed separately from 1995 and 1996 data. C_T at sowing in 1997 increased from the pre-sowing 1996 levels due to the legume phase, however C_L decreased in the residue returned treatments. There were no longer any differences in C_L between the stubble removed and returned treatments, however, C_T was significantly higher on the stubble returned treatments. The CMI also deceased slightly in the stubble returned treatments due to the lower C_L concentrations in 1997.

Table 4. The effect of residue on total (C_T), labile (C_L) , non-labile (C_{NL}) carbon and the carbon management index (CMI) prior to cultivation and sowing in 1995 and 1996.

?	?	C_L	C_{NL}	C_T	CMI
?	?	________ mg/g _______			?
Uncropped	reference	5.31	19.91	25.22	100
1995	Removed	0.89c[A]	5.52 a	6.41 a	16 c
?	Returned	1.01 b	5.86 a	6.87 a	18 b
1996	Removed	1.04 b	4.89 a	5.93 a	19 b
?	Returned	1.38 a	5.13 a	6.51 a	27 a
1997	Removed	1.31 a[B]	5.16 b	6.47 b	25 a
?	Returned	1.34 a	5.63 a	6.97 a	25 a

AMeans followed by the same letter within columns in 1995 and 1996 are not significantly different according to DMRT at $P \leq 0.05$. [B]Means followed by the same letter within columns in 1997 are not significantly different according to DMRT at $P \leq 0.05$.

Discussion

As a result of farming activities, soil carbon declined by more than 70 % from the pre-clearing levels. Associated with the loss of SOM is poor structural properties (7), declining nutrient supply (4) and often decreasing yields (5, 8). The use of lucerne as a traditional ley phase resulted in the greatest improvement in C_T. The improvement in C_L was somewhat smaller than that in C_T. It is hypothesised that at the time of sampling, legume residues had been ploughed in and good soil moisture resulted in high rates of microbial decomposition, especially of the labile carbon compounds.

The retention of wheat stubble has resulted in significantly higher C_L and improvements in the CMI following the wheat phase in 1996. During the 1996 legume/fallow phases, the differences in C_L disappeared, however the improvement in soil carbon became apparent through an increase in C_T. Although longer term data is required, it appears that an improvement in soil carbon can be achieved through the retention of wheat stubble. This has longer term environmental consequences than the alternative of using it as a substrate for ethanol production or its loss through burning.

The benefits of wheat stubble retention are apparent through the 8 and 9.4 % increases in grain yields in 1994 and 1995. This benefit was not apparent in the 1997 grain yields following the 1996 fallow phase. Although carbon was somewhat higher following the lucerne phase, grain yield was significantly reduced due to lower pre-cropped stored moisture and difficulties in killing the lucerne plants during the wheat cropping season. The reduced yield in the lucerne and soybean treatments may have been partly associated with the reduced stored water in these treatments (lucerne-259 mm water, fallow- 267 mm water 0-70 cm).

Residue retention has the potential to influence the amount of nutrients being returned to the soil. This is especially important for K in which approximately 80 % is located in the stubble but less important for N being mostly contained and exported in grain. Other nutrients such as P and S are also significantly influenced by stubble management. The magnitude of K export in residue removed systems is up to 133 kg/ha and soil K deficiency would occur under this form of management. In the long term, nutrient balances can be used to predict likely fertiliser requirements.

One of the most significant impacts of stubble retention was found to be on soil physical properties. Stubble retention increased hydraulic conductivity by more than 65 %, increased water stable aggregates and lead to lower soil strength (9).

Conclusions

Adequate SOM levels are the key to sustainable agro-ecosystems. Management practices that optimise the use of crop residues and rotations to increase SOM are likely to be sustainable farming practices, but are however, costly to implement especially in the short term. Management decisions are largely market driven so the financial returns of improving SOM need to be quantified. Although legume species are widely used as a rotation phase, the use of grass species, either alone or in combination with legumes, is more likely to improve ground cover and organic matter additions.

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