Continuous cropping - is it sustainable?

Lessons from the Condobolin long term tillage trial

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Overview

Many views exist as to whether continous cropping is sustainable. Results from a long term tillage trial at Condobolin indicate direct drilled crops are outperforming crops using tillage. Stubble retention compared to burning gives mixed results for yield, although more weed build up is evident with retained stubble. Wheat yields are higher when grown after peas than after wheat in succession.

Summary

Tillage

- Yields with direct drilling have been equal or better than with tillage in almost all years.
- The highest yields over the last 7 years have come from direct drilling after burning (2.63 t/ha compared to 2.38 t/ha).
- Aggregate stability and surface structure are better with direct drilling.

Stubble

Stubble retention gave slightly higher yields in the first five seasons.

Stubble retention and burning gave similar yields in the next four seasons.

- Stubble retention had almost no affect on yields in the cultivated treatments (1990-97).

From 1990-1997 in the direct drilled treatments, yields were higher with stubble retention (1.27 cf. 1.12t/ha) in the two dry years (1991 and 1995) and lower with stubble retention in the other five years (2.83 cf. 3.23 t/ha).

- The reason for the outstanding performance of the stubble burnt, direct drilled treatment is not clear.

Stubble treatment has had little effect on soil organic carbon, perhaps because of the lower yielding environment and rapid breakdown rates.

Less than 5% of the added stubble carbon is usually incorporated into the soil organic carbon pool [For a yield of 2.5 t/ha, with 5 t/ha of stubble which is 40% carbon, then 0.1 t/ha of carbon is added to the soil pool]. Average soil contains about 15 t/ha of carbon in the surface 10cm, so the rate of change will be slow.

- Measurements of organic carbon exclude surface and undecomposed stubble which may be beneficial for erosion control and moisture storage.

Rotations and fertiliser

- Yields of wheat are higher after peas than after wheat, particularly at lower N fertiliser rates. Protein is also higher

Ryegrass is becoming a problem in the stubble retained plots, particularly in combination with tillage.

Background

The chemical and physical fertility of Australian soils relies on the maintenance of soil organic matter. A legume-based pasture phase in rotation with cereal crops has been used in southern Australia to maintain soil fertility, with most of the nitrogen (N) requirement of the crops being met from the mineralisation of soil organic matter and plant residues. A move to more intensive cropping is likely to increase the loss of soil organic matter and contribute to a decline in fertility and structural stability. This decline may be slowed or halted by conservation farming methods.

Direct drilling should result in higher soil organic carbon than conventional cultivation although the measured differences have usually been small for continuous cereal production in other areas of Australia. Direct drilled soils often develop higher concentrations of organic matter near the surface compared to ploughed soils, where inversion mixes C and N more uniformly.

Retaining crop residues at the soil surface rather than burning or incorporating by tillage has also been shown in many studies to increase organic C and total N in the top layer of the soil. This results from slower residue decomposition, slower oxidation of soil C and reduced erosion. The concentration of soil organic C will therefore depend on the quantity of residue retained and its rate of decomposition. The soil temperature and rainfall pattern of western NSW results in low crop residue production and probably high decomposition rates, limiting the increase in soil organic matter.

To be acceptable to fanners, direct drilling and stubble retention must give economic returns similar to traditional methods, at least in the medium term. In the longer term, if these practices benefit soil physical and chemical fertility, they should result in significantly higher yields.

A field experiment to compare the productivity and sustainability of continuous crop production using a range of tillage, stubble and N fertiliser management practices was commenced in 1979 at Condobolin in the Central West of NSW. The site had been cleared for at least 50 years prior to the experiment and had a long history of ley farming using medic-based pastures and cereal cropping. Wheat crops were grown using conventional cultivation methods in 1977 and 1978 and the treatments were imposed following the 1978 harvest.

Five treatments used are:

(i) BDD, stubble burnt, direct drilled;

(ii) BC, stubble burnt, cultivated with a scarifier;

(iii) INC, stubble incorporated by an offset disc plough, cultivated with a scarifier;

(iv) RDD, stubble retained, direct drilled;

(v) RC, stubble retained, cultivated with a chisel plough fitted with sweeps.

Further details of the cultural treatments are at the end of the article.

Results and discussion

Grain yields

There were large year to year variations in grain yield reflecting the variation in growing season rainfall, but a pattern of responses to the tillage treatments emerged (Table 1). Over the first 5 years (1979-83) there was little response to nitrogen fertiliser, sufficient nitrogen being provided from the mineralisation of soil organic matter. Average yields were higher from the stubble retained than the burnt treatments (1.97 compared to 1.70 t/ha). There was little difference between cultivation and direct drilling although the highest yield came from the combination of direct drilling and stubble retention, RDD. During this period, there were a number of years with significant summer or autumn rainfall followed by drier winters and stubble retention apparently increased the availability of moisture to the wheat crop.

Table 1: Grain Yields for different tillage treatments

Stubble Treatment	Tillage method	Grain yield (t/ha)		
		1979-83	**1985-88**	**1990-93**
Burnt	Scarifier	1.69	1.76	2.27
Burnt	Direct drill	1.70	1.79	2.38
Incorporated	Offset disc	1.92	1.80	2.21
Retained	Chisel plough	1.94	1.82	2.17
Retained	Direct drill	2.06	1.86	2.10

Over the second period (1985-88), rainfall was a little below average and yields for the five treatments were generally similar; the combination of stubble retention and direct drilling again performing well. There were some responses to nitrogen fertiliser but no interaction with tillage treatment.

From 1990 onward, there were large responses to nitrogen fertiliser and so the yields shown in Tables 1 and 2 are for the highest N rate. There was a major change in treatment rankings during the period 1990 to 1993, the highest yield coming from BDD (2.38 t/ha), and the lowest from RDD (2.10 t/ha). Inspection of the yields from the individual years in this period is informative (Table 2). The BDD treatment significantly higher yields than all other treatments in two wetter years, 1990 and 1993. Yields for the other treatments were similar in 1990 whereas in 1993 the RC combination yielded less than both BD and RDD. In the driest year (1991), yield was highest from RDD. The only instance of a yield reduction resulting from direct drilling over the 19 years of the trial occurred in 1992. Grain yield in the DD plots was 0.3 t/ha lower in the absence of stubble and 0.9 t/ha lower in the presence of stubble. In that year, a prolonged dry period followed a small sowing rain and it is likely that high soil strength restricted early root elongation and hence plant growth during this period. Reduced early growth with DD has been reported in other parts of Australia but has not been a problem at Condobolin in other seasons.

Table 2: Condobolin tillage trial yield results (commenced 1979)

	1990	1991	1992	1993	1995	1996	1997
Cultivated							
Burnt	3.51	0.97	3.16	3.30	**1.16**	2.37	2.41
Retained	3.24	0.91	3.19	3.32	1.19	2.35	2.39
Direct Drilled							
Burnt	3.59	0.92	2.63	4.38	1.31	2.75	2.80
Retained	3.27	1.05	2.39	3.67	1.49	2.38	2.42

Notes:

N rate of 50kg/ha, or mean if no N response

Insufficient rainfall was received to sow the trial in 1994. In 1995 to 1997, the pattern established in 1990 to 1993 continued (Table 2). The RDD treatment gave the highest yield in the drier year (1995), whereas BDD performed best in the other two years and the other four treatments were similar.

The effects of nitrogen supply on grain yield and protein in 1997 are shown in Table 3. It should be noted that the nitrogen response might be to previous applications of fertiliser as well as to the 50 units of N added in 1997, as the same plots receive fertiliser each year. It is probably surprising that the nil N plots were able to achieve any yield after 19 years of cropping with only the annual addition of 8 kg/ha of N in the starter fertiliser. In the absence of N fertiliser, yield and protein were a little higher for the direct drilled than the cultivated treatments, suggesting a slightly faster loss of organic nitrogen with cultivation. The response to nitrogen was greatest for BDD (0.73 t/ha), least for RDD (0.11 t/ha) and intermediate for the other three treatments (0.3 t/ha). This suggests that some factor other than nitrogen was limiting yield in these treatments, a conclusion supported by the grain protein data. Protein was highest where yield was lowest (RDD), and the value (12.3%) was above that generally considered to indicate a yield restriction by nitrogen. In comparison, protein was lowest for BDD (10.5%) where N supply may have limited yield.

Table 3: Grain yields and protein 1997

Stubble treatment	Tillage method		Nitrogen rate (kgN/ha)	
			0	50
Burnt	Scarifier	Yield (t/ha) Protein (%)	1.43 8.9	1.79 11.5
Burnt	Direct drill	Yield (t/ha) Protein (%)	1.50 9.0	2.23 10.5
Incorporated	Offset disc	Yield (t/ha) Protein (%)	1.41 8.6	1.82 11.8
Retained	Chisel plough	Yield (t/ha) Protein (%)	1.44 8.5	1.77 10.8
Retained	Direct drill	Yield (t/ha) Protein (%)	1.54 9.0	1.65 12.3

The contribution that a pulse crop can make to the rotation is also evident in the 1997 results (Table 4). In the absence of nitrogen fertiliser, wheat yields were about 0.8 t/ha higher after peas than after wheat, and protein was almost one percentage point higher. The exception was the RC treatment where the yield response was only half as great, again suggesting some other yield restriction. There was no yield response to N fertiliser after peas but protein percentages were 2 to 3 units higher, suggesting that in years of close to average yield the pea-wheat rotation was supplying sufficient nitrogen. The relatively small difference between the yield after wheat and after pea of BDD plus N suggests that the benefit of peas was almost solely a result of better N nutrition in this treatment. In contrast, yields in RDD were much lower after wheat than after pea and even where nitrogen fertiliser was applied. This suggests some yield depression associated with the presence of wheat stubble during crop growth.

Table 4: Grain yields and protein, after wheat and after peas, 1997

Stubble treatment	Tillage method		Nitrogen rate (kgN/ha)	
			0	50
After wheat				
Burnt	Direct drill	Yield (t/ha) Protein (%)	1.50 9.0	2.23 10.5
Retained	Chisel plough	Yield (t/ha) Protein (%)	1.44 8.5	1.77 10.8
Retained	Direct drill	Yield (t/ha) Protein (%)	1.54 9.0	1.65 12.3
After peas				
Burnt	Direct drill	Yield (t/ha) Protein (%)	2.30 10.1	2.40 12.4
Retained	Chisel plough	Yield (t/ha) Protein (%)	1.83 8.5	2.02 10.8
Retained	Direct drill	Yield (t/ha) Protein (%)	2.29 9.7	2.29 12.8

Weed populations

The major weed species present at the site were Indian hedge mustard, wireweed and annual ryegrass. These were all controlled satisfactorily in the early years of the experiment by in-crop herbicides. However, by 1993 differences in ryegrass numbers between treatments were noted some time after the application of a grass herbicide (Table 5). Although densities were quite low, ryegrass numbers were significantly higher in the RC treatment. By 1995, ryegrass densities before spraying were very high under RC (190 plants/m2) and moderate in RDD (33 plants/m^2). By comparison, there was almost no ryegrass in the BDD and BC plots. Seed from the trial site is yet to be tested but it appears certain that a population of plants resistant to Group A herbicides has developed in the RC and RDD plots. Burning has helped control ryegrass, and this may have been helped by the absence of grazing. The higher ryegrass densities in RC than RDD suggests that cultivation creates better conditions for ryegrass to germinate and establish than does direct drilling.

Table 5: Ryegrass density

Treatment	Ryegrass density (plants/m2)	
	August 1993	June 1995
Burnt, cultivated	**1**	4
Burnt, direct drilled	**0**	1
Retained, cultivated	**10**	190
Retained, direct drilled	**2**	33

Soil properties

Soil organic carbon concentrations measured in February 1994 are shown in Table 6. There was no significant differences detected between the tillage treatments. However, the regular addition of nitrogen fertiliser helped maintain organic carbon compared to the nil treatment. This suggests that increasing dry matter production might be more important than stubble management in maintaining soil organic matter. The lack of differences in organic carbon due to stubble treatment is not unique to this experiment and is likely to result from the rapid breakdown of stubble in the soil in this environment, It is known that less than 5% of added stubble carbon is incorporated into the soil organic pool. If yield averages 2.5 t/ha, giving 5 t/ha of stubble which is 40% carbon, then 0.1 t/ha of carbon is added to the soil pool annually. As the soil contains about 15 t/ha of carbon in the top 10 cm, the rate of change is slow. Also, even in the burnt plots carbon is added from the roots and from the unburnt residues. However, it must be noted that measurements of organic carbon exclude surface and undecomposed stubble which may be beneficial for erosion control and moisture storage.

Table 6: Organic Carbon and Nitrogen, 0-10cm, 1994

Stubble treatment	Tillage method	Organic carbon (%)	Total Nitrogen (%)
Burnt	Scarifier	0.95	0.086
Burnt	Direct drill	0.94	0.087
Incorporated	Offset disc	0.96	0.088
Retained	Chisel plough	0.96	0.089
Retained	Direct drill	0.97	0.085
Other			
Nitrogen Fertiliser	0 kgN/ha/year	0.92	0.083
	50 kgN/ha/year	0.99	0.091

Soil total nitrogen levels followed a very similar pattern to that for organic carbon. There were no significant effects of tillage or stubble but nitrogen content was higher where nitrogen was applied annually.

Soil pH was also similar for all the tillage and stubble treatments when measured in 1994. However, the annual addition of fertiliser nitrogen as ammonium nitrate lowered the upper surface (0-2.5 cm) soil by 0.4-0.5 units compared to the nil, the values being 5.24 and 5.64 respectively. The effect on lower depths was also significant but of lesser magnitude. The pH of the adjoining area kept in pasture was 6.09, showing that cropping has acidified the surface more than has grass-based pasture.

The effects of stubble and tillage on water stable aggregation, a measure of soil structural stability, was measured in 1990 (Table 7). There was little response to stubble treatment but direct drilled plots were more stable than cultivated plots (22% compared to 22%). However, both were much lower than the adjoining pasture which measured 58%. Reducing cultivation would appear to be more important than retaining stubble as a means of maintaining soil stability. This finding is confirmed by observations of the plots during the wet 1998 winter. Surface ponding and aggregate breakdown has been observed to be greatest in the RC and INC plots; cultivation of these treatments at high moisture contents during late autumn, a result of the stubble present on the soil surface, may have contributed to this breakdown.

Table 7: Effects of stubble and tillage treatments on water stable aggregation, March 1990

Stubble treatment	Tillage method	Water stable aggregation (%)
Burnt	Scarifier	11.9
Burnt	Direct drill	21.9
Incorporated	Offset disc	13.4
Retained	Direct drill	**21.8**
Other Pasture		57.7

Conclusions

The results from this trial provide guidelines for more intensive cropping in western NSW. The importance of avoiding the development of herbicide resistant weeds is highlighted as is the value of cultural treatments such as stubble burning and direct drilling. Reliance on fertiliser nitrogen is likely to accelerate the acidification of the surface soil although some acidification is probably inevitable in agriculture. In the long term, lime application is likely to be required whatever the cropping system. The value of direct drilling for maintaining soil stability and achieving high yields has been demonstrated as has the contribution of pulse crops in the rotation. The value of stubble retention is equivocal. On sloping sites it may reduce soil erosion and in dry years it gave small yield increases. However, in many years the presence of surface stubble reduced wheat yields in the continuous wheat plots. It may be advantageous to retain stubble when crops are rotated but to late burn stubble when wheat follows wheat.

Experimental design

The experiment was a randomised block design with 8 treatments replicated 4 times in main plots measuring 50 by 8.5 m, each split into subplots for rates of N fertiliser. Five treatments using continuous wheat were used to compare the effects of cultivation and stubble management:

(vi) BDD, stubble burnt, direct drilled;

(vii) BC, stubble burnt, cultivated with a scarifier;

(viii) INC, stubble incorporated by an offset disc plough, cultivated with a scarifier;

(ix) RDD, stubble retained, direct drilled;

(x) RC, stubble retained, cultivated with a chisel plough fitted with sweeps.

A further three treatments had a pea-wheat rotation using BDD, RDD or RC; these were similar to the continuous wheat treatments except that pea residues were not burnt.

Plots were initially grazed after harvest but this practice was discontinued in 1990 when differences in weed numbers between treatments began to become apparent. From that time, any weed control required in December and January was by herbicide which was applied to all treatments. Crop residues in the BDD and BC treatments were burnt in February or March each year and the BC treatment was cultivated soon after. The INC and RC treatments were cultivated following the first significant rainfall event after the end of January, and differed in the degree of stubble incorporation and soil disturbance. The cultivated treatments were tilled 2-3 times prior to sowing each year to a depth of 8-10 cm. Weeds on the direct drilled treatments were controlled during the fallow period with non-residual herbicides, all plots were given one application of herbicide prior to sowing and post-emergent herbicides were applied as required. The crops were sown at 5 cm depth using a presswheel seeder equipped with edge-on tines and narrow seeding points designed to minimise soil disturbance. All treatments were sown on the same day with wheat at 45 kg/ha and mono-ammonium phosphate at a rate equivalent to 15 kg P/ha and 8 kg N/ha.

There were 3 nitrogen subplot treatments in each main plot:

(i) nil, given only the basal N rate;

(ii) medium, given an additional 20 kg N/ha (until 1988) or 25 kg N/ha (1989 onwards)

(iii) high, given an additional 40 kg N/ha (until 1988) or 50 kg N/ha (1989 onwards).

The additional N was applied as ammonium nitrate dropped onto the soil surface in front of the seeding tines and mixed with the soil during the sowing operation.

Grain yields were determined using a plot harvester, and grain protein by Kjeldahl analysis. Soil samples were taken in February or March each year prior to stubble burning and tillage so that the soil was in a settled condition and likely to reflect long-term changes. Soil pH, organic carbon and total nitrogen were measured.

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