The effect of crop rotations and residue level on wheat yield and gross margins

K. C. Flower[1,2], N. Cordingley[2], C. Weeks[3], S Micin[4] and P.R. Ward[4]
[1]School of Plant Biology and Institute of Agriculture, The University of Western Australia
[2]Western Australian No-Tillage Farmers Association
[3]Planfarm Pty. Ltd., Geraldton
[4]CSIRO Plant Industry

KEY MESSAGES

- Crop rotation had no consistent effect on wheat yield.
- Continuous wheat had maintained a similar yield to the other rotations after five years at Cunderdin.
- Yield differences between full residue retention and windrow burning were not consistent across years and rotations; although for some situations in 2011, windrow burning reduced yield.
- Seasonal rainfall, grain prices, input costs and rotation order had a major effect on annual and total gross margins.
- Continuous wheat and wheat/lupin were the most profitable at Cunderdin and Mingenew respectively.
- The diverse rotation at Mingenew (P2) was overall the most profitable with good returns from all crops and only one negative cover crop in each of the first three years.

AIMS

The aim of this GRDC funded trial was to determine the long term benefits of the key components of conservation agriculture (CA) (crop residue retention, diverse rotations, minimal soil disturbance and controlled traffic) in Western Australian cropping systems. Aspects that are considered include soil carbon sequestration, diseases, insects, weeds, the water balance as well as crop yield and profitability. The effect of rotation and residue level on wheat yield is discussed in this paper as well as the annual and mean gross margins.

METHOD

Two long-term conservation agriculture cropping system experiments were started in 2007, one on a farm near Mingenew (115°17´E, 28°56´S) and the other at the Cunderdin College of Agriculture (117°14´E, 31°38´S) in Western Australia. The soil at Mingenew was deep yellow sand with a soil pH (0.01M $CaCl_2$) ranging from 5.4 to 5.0. The Cunderdin soil was red sandy clay loam with pH of 6.6, increasing with depth to 7.9.
The treatments were based on four different cropping philosophies titled “P1–maximum carbon input”, “P2– maximum diversity”, “P3–controls” and “P4–maximum profit” (Table 1). There were a total of 11 crop sequences (S1-S11) each replicated three times in a randomised complete block design: the P1, P2 and P4 philosophies had a three-year rotation with each phase presented every year, giving nine crop sequences, while P3 had two sequences, being continuous crop and pasture. The crop types grown at the two sites were selected according to the particular philosophies/treatments (Table 1), but differed in some instances because of soil type and local experience (Table 2). Crops were only changed after three years (still within the ‘philosophy’), when all phases of the rotation were complete.
In 2010 (start of the second three year rotation cycle) all of the “P1–maximum carbon input” and “P2– maximum diversity” sequences (S1-S3 and S4-S6, respectively) were split for full stubble retention (original treatment) and windrow burning (low residue level).
Plots of 36 m x 80 m were sown with 4.5 m disc or tine seeders (Table 1). All crops were sown at 300 mm row spacing and normal agronomic practices were followed. Cover crops were knife-rolled using a steel drum with blunt knives before spraying with glyphosate at anthesis - to control weeds and prevent use of soil water.

Table 1. Treatment philosophies[a] used at Mingenew and Cunderdin

Philosophy	Description
P1	Name: 'maximum carbon input'. Three year rotation with cereals only and every phase presented every year. Crops seeded with a minimum disturbance disc opener. No burning or tillage. Sequences P1/S1, P1/S2 and P1/S3. Philosophy: Low crop diversity with maximum residue retention.
P2	Name: 'maximum diversity'. Diverse three year rotation (cereal – legume – *Brassica*) with every phase presented every year. Crops seeded with a minimum disturbance disc opener. No burning or tillage. Sequences P2/S4, P2/S5 and P2/S6. Philosophy: high crop diversity with maximum residue retention.
P3	Name: 'controls'. Continuous wheat and continuous pasture. Crops seeded with a minimum disturbance disc opener. No burning or tillage. The continuous wheat at Mingenew was only started in 2010. Sequences P3/S7 (wheat) and P3/S8 (pasture). Philosophy continuous wheat with maximum residue retention.
P4	Name: "maximum profit". Three year rotation (cereal – cereal – legume) with every phase presented every year. Crops sown with a higher disturbance tine and knife-point no-till seeder. Burning and tillage allowed. Sequences P4/S9, P4/S10 and P4 S11. Philosophy current farmer practice with low residue retention.

[a] see Table 2 for details of crop types and cultivars

Table 2. Crop sequences for the different philosophies showing crop types and cultivars at Mingenew and Cunderdin from 2007 to 2011 (bold indicates wheat crops for yield comparisons)

Crop sequence	2007 Crop (cultivar)	2008 Crop (cultivar)	2009 Crop (cultivar)	2010 Crop (cultivar)	2011 Crop (cultivar)
Mingenew					
P1/S1	Oat CC (Black oat)[a]	**Wheat (Calingiri)**	Barley (Yagan)	Oat CC (Palinup)[b]	**Wheat (Mace)**
P1/S2	**Wheat (Calingiri)**	Barley (Yagan)	Oat CC (Black oat)	**Wheat (Mace)**	Wheat (Mace)[c]
P1/S3	Barley (Yagan)	Oat CC (Black oat)	**Wheat (Calingiri)**	Wheat (Mace)[c]	Oat CC (Palinup)
P2/S4	**Wheat (Calingiri)**	Lupin (Mandelup)	I Mustard CC (21)[d]	**Wheat (Mace)**	Lupin (Coromup)
P2/S5	Lupin (Mandelup)	I Mustard CC (21)	**Wheat (Calingiri)**	Lupin (Mandelup)	Canola (Eclipse RR)
P2/S6	Canola CC (Bravo)	**Wheat (Calingiri)**	Lupin (Mandelup)	Canola (Eclipse RR)	**Wheat (Mace)**
P3/S7	Pasture (grass)[e]	**Wheat (Calingiri)**	Lupin (Mandelup)	**Wheat (Mace)**	**Wheat (Mace)**
P3/S8	Pasture (grass)	Pasture (grass)	Pasture (grass)	Pasture (grass)	Pasture (grass)
P4/S9	Pasture (barley)[f]	**Wheat (Calingiri)**	Lupin (Mandelup)	**Wheat (Mace)**	Pasture (vol. grass)
P4/S10	**Wheat (Calingiri)**	Lupin (Mandelup)	Pasture (barley)	Pasture (vol. grass)	Lupin (Coromup)
P4/S11	Lupin (Mandelup)	Pasture (barley)	**Wheat (Calingiri)**	Lupin (Coromup)	**Wheat (Mace)**
Cunderdin					
P1/S1	Oat CC (Black oat)[a]	Barley (Baudin)	Barley (Baudin)	**Wheat (Magenta)**	**Wheat (Magenta)**
P1/S2	Barley (Baudin)	Barley (Baudin)	Oat CC (Black oat)	**Wheat (Magenta)**	**Wheat (Magenta)**
P1/S3	Barley (Baudin)	Oat CC (Black oat)	Barley (Baudin)	**Wheat (Magenta)**	**Wheat (Magenta)**
P2/S4	**Wheat (B. Rock)[g]**	Vetch/oat CC[h]	Canola (Tanami)	**Wheat (Magenta)**	Field pea (Kaspa)
P2/S5	Vetch/oat CC	Canola (Stubby)	**Wheat (B. Rock)**	Field pea (Kaspa)	Canola (Eclipse RR)
P2/S6	Canola (Stubby)	**Wheat (B. Rock)**	Vetch/oat CC	Canola (Eclipse RR)	**Wheat (Magenta)**
P3/S7	**Wheat (B. Rock)**	**Wheat (B. Rock)**	**Wheat (B. Rock)**	**Wheat (Magenta)**	**Wheat (Magenta)**
P3/S8	Pasture (legume)[i]	Pasture (legume)	Pasture (legume)	Pasture (legume)	Pasture (legume)
P4/S9	**Wheat (B. Rock)**	Barley (Baudin)	Lupin (Mandelup)	**Wheat (Magenta)**	Barley (Buloke)
P4/S10	Barley (Baudin)	Lupin (Mandelup)	**Wheat (B. Rock)**	Barley (Buloke)	Field pea (Kaspa)
P4/S11	Lupin (Mandelup)	**Wheat (B. Rock)**	Barley (Baudin)	Field pea (Kaspa)	**Wheat (Magenta)**

[a] Black (Saia) oat cover crop (CC) *Avena strigosa* Schreb. Brackets indicate common name or cultivar
[b] *Avena sativa*
[c] Wheat crop treated as a cover crop i.e. low input and sprayed with glyphosate to control weeds and conserve soil water
[d] Indian mustard (*Brassica juncea*, selection 21)
[e] Cadiz French serradella sown in 2007, 2010 and 2011, Dalkeith subterranean clover sown in 2008 and 2008. A large number of volunteer grasses (mainly annual ryegrass) were also present in all years
[f] Sown barley that was mown and then sprayed with glyphosate for weed control
[g] Wheat cultivar Bonnie Rock
[h] Popany vetch (*Vicia benghalensis*) (40kg ha^{-1}) and Swan oats (30 kg ha^{-1}) mix
[i] Dalkeith subterranean clover sown in 2007 and Angel medic sown in 2010

Rainfall varied considerably from 2007 to 2011, with 2010 being particularly dry at Cunderdin (Table 3).

Table 3. Annual and growing season (GSR) rainfall (mm) at Cunderdin and Mingenew from 2007 to 2011.

Site	Rainfall	2007	2008	2009	2010	2011
Mingenew	Annual	172	359	336	185	436
	GSR	136	266	320	184	337
Cunderdin	Annual	235	338	280	140	356
	GSR	186	285	213	101	268

Wheat yields

Crop yields were assessed by taking 12 harvest cuts of 1 m x 0.9 m (3 rows). The remainder of the plots were then harvested by a commercial harvester

RESULTS

Wheat Yield

Seasonal rainfall had a major effect on average wheat yields at both sites, with Cunderdin in 2010 being the lowest rainfall and yield.

Mingenew

Crop rotation (Philosophy) only had a significant effect on wheat yield in 2009, where wheat following an oat cover crop (CC) (P1/S3) had a lower yield than wheat following an early knife-rolled Indian mustard CC (P2/S5) or early sprayed out barley pasture (P4/S11) (Figure 1). In 2011, wheat yield following lupin (P4/S11) appeared to be higher than the other treatments, but this was not significant at $P \leq 0.05$. The low yield of wheat in 2009 in P1/S3 (following the oat CC in 2008) was probably because of weed competition in this treatment, as the spraying of the cover crop was delayed until 7 October, allowing the ryegrass to set seed. Windrow burning had no effect on yield in 2010, but significantly reduced yield in 2011 (Figure 1).

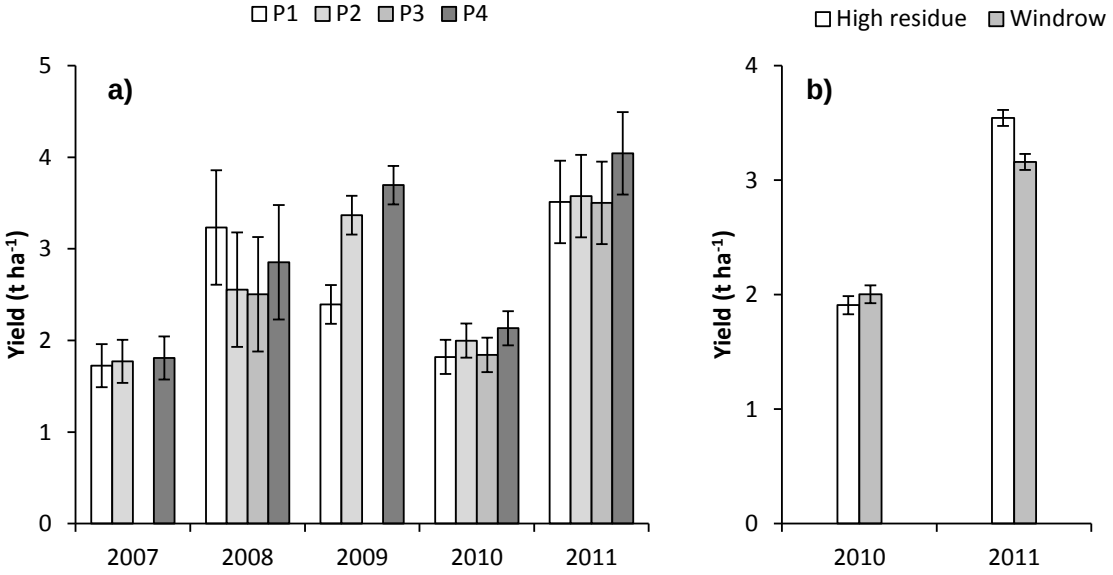

Figure 1. Wheat yields at Mingenew from 2007 to 2011: a) effect of treatment ('philosophy') (P1-P4) and associated crop rotations, shown in Tables 1 and 2 (comparisons within years only); and b) effect of high and low residue (windrow burning) (mean of philosophies 1 and 2). Error bars are ± Lsd $P \leq 0.05$.

Cunderdin

Crop rotation had a significant effect on crop yield in 2010, which was a very low yielding year (Figure 2). The P3/S7 (continuous wheat) and P4/S9 (wheat following lupins) rotations had yields of about 300 kg ha^{-1} which were higher than the other treatments. The differences are difficult to explain, although continuous wheat (P3/S7) had the lowest crop establishment, possibly resulting in less early growth and water use. In 2011, the highest yield occurred with wheat following wheat, with oat CC in 2009 (P1/S2), and the lowest was wheat following canola (P2/S6). Continuous wheat (P3/S7) had similar yields to the other 'cereal only' rotations (barley and oat CC for the first three years). The effect of windrow burning was not consistent across years or sequences (Figure 2). There was no significant effect in 2010. In 2011, only one sequence (P1/S2) in the 'cereal only' rotation had significantly higher yield with full residue retention compared with windrow burning. There were no differences in crop establishment, and the reason for this windrow burning effect could not be established.

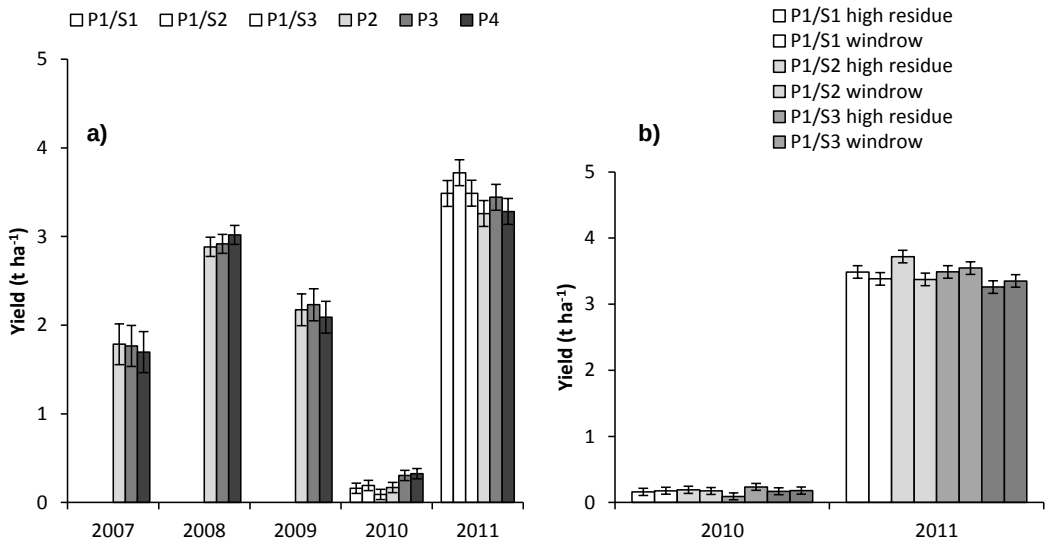

Figure 2. Wheat yields at Cunderdin 2007-2011: a) effect of treatment ('philosophy') and associated crop rotations, shown in Tables 1 and 2; and b) effect of high and low residue (windrow burning) on wheat yield for main plot philosophies 1 and 2 only. Error bars are ± Lsd $P \leq 0.05$ (comparisons within years only and for b) comparison between high residue and windrow within the same sequence). Note all three sequences for P1 are shown because all had wheat.

Economics

There were large differences between gross margins due to annual fluctuations in grain prices, input costs and seasonal rainfall. The total gross margin is the sum of five years, with the final year of the second three year rotation still to be completed the final total gross margins may change.

Mingenew

Wheat and lupins were the most profitable crops at the Mingenew site with canola also providing a positive gross margin in 2010 and 2011. The number and timing of the cover crops and pastures within each philosophy had a major impact on the total gross margin with a negative gross margin for that year.

Philosophy 4 (P4) had consistently high total gross margins driven by good wheat and lupin yields and the negative pasture crops having lower input costs than the cover crops in P1 and P2 providing less of an impact on the total gross margin. P2/S4, P2/S6 and P3/S7 had the highest total gross margins due good wheat and lupin crops and only one negative cover crop in P2 and a pasture crop in P3.

Philosophy 1 (P1) had the lowest mean gross margins due a high number of cover crops and feed barley only being profitable in 2007 due to high prices and demand for livestock feed. Low grain prices and high input costs in 2008 and 2009 gave the feed barley a negative gross margin.

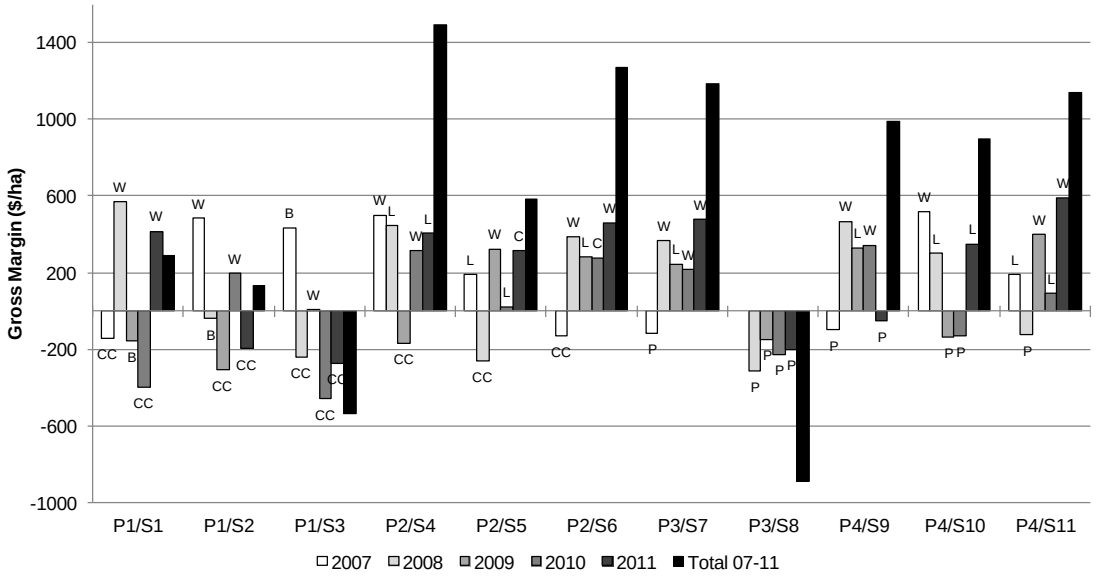

Figure 3. Annual and total gross margins at Mingenew from 2007 to 2011.
The letters above the bars show crop type grown each year: CC = cover crop (oat, wheat or brassica), B = barley, W = wheat, C = canola (2010 to 2011 Roundup Ready™), P = pasture (legume/grass pasture or barley crop sprayed out) and L = lupin.

Cunderdin

Seasonal variability, grain prices and input costs had an influence on the gross margins at Cunderdin with very low rainfall and yields in 2010 giving negative gross margins for all crops. Above average rainfall in 2011 provided good yields and positive gross margins in all crops with wheat and canola providing the highest gross margins. High input costs and low grain prices in 2009 gave low or negative gross margins. The cover crops in philosophies P1 and P2 from 2007 to 2009 had a negative effect on the total gross margins in these philosophies.
Wheat was the most profitable crop at the Cunderdin site with continuous wheat in P3/S7 providing the highest total gross margin. Philosophy 4 (P4) had high gross margins in P4/S9 and P4/S11 although P4/S10 was lower due low lupin yield in 2008, high input and low wheat prices in 2009 and low rainfall and yield in 2010. The total gross margins in philosophies P1 and P2 were improved by good wheat yields in 2011 and good canola yield at a high price in P2/S5.

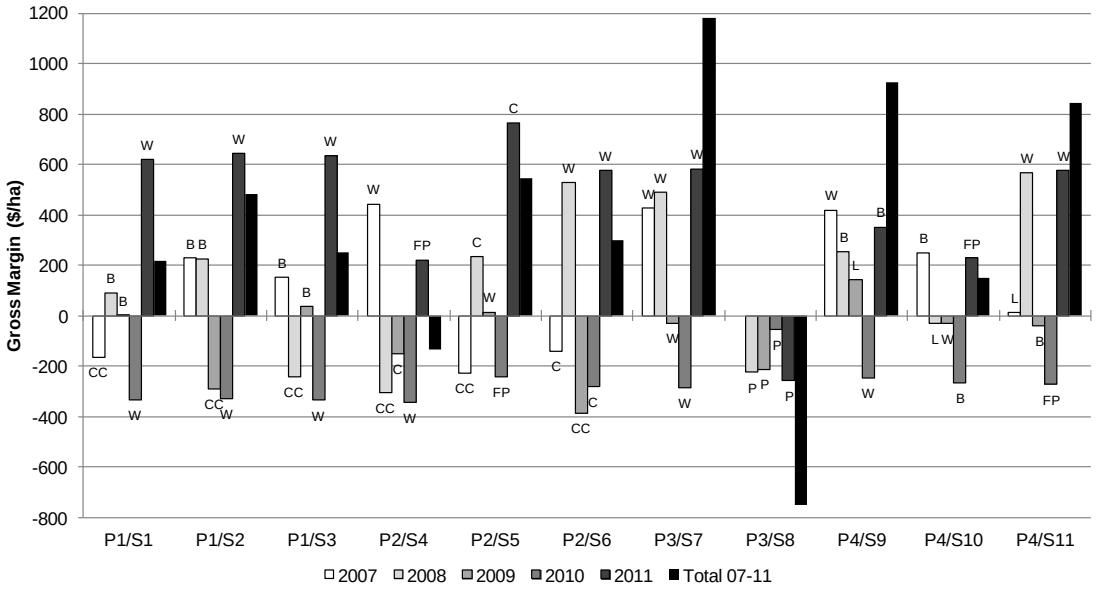

Figure 4. Annual and total gross margins from 2007 to 2011 at Cunderdin.
The letters above the bars show crop type grown each year: CC = cover crop (oat or brassica), B = barley, W = wheat, FP = field pea, C = canola (2010 to 2011 Roundup Ready™), P = pasture (legume) and L = lupin.

CONCLUSION

Crop rotation had no consistent effect on wheat yield, although at Mingenew yield appeared to be higher after lupins in some years. Continuous wheat had maintained a similar yield to the other rotations after five years at Cunderdin. Delaying knife-rolling or spraying out of cover crops appeared detrimental to wheat yield in the following year, especially where weed pressure was high. Alternatively, early spray or knife-rolling appeared to contribute to higher yields. Windrow burning had no effect in 2010, the first year when these treatments were imposed. However, some differences occurred in the following year, where full residue retention out-yielded windrow burning. In other international research, benefits from increased residue retention became apparent after 5-8 years, and the Cunderdin trial will be continued to determine the long-term impacts of changes to the farming system on crop yields.

Wheat and lupins were the most profitable at Mingenew with P2/S4 providing the highest total gross margin. The cover crops and pasture crops had an overall negative effect on the total gross margins. The pasture crops in P4 with lower input costs had slightly less of negative impact compared to the cover crops in P1.

At Cunderdin wheat was the most profitable crop with continuous wheat in P3/S7 providing the highest total gross margin. The use of cover crops in P1 and P2, the high input costs with low grain prices in 2009 and the low yields in 2010 had a negative impact on the total gross margins. Overall the Mingenew site had more consistent total gross margins in P2 and P4 due less seasonal variation and more reliable break crop options such as lupins and canola compared to Cunderdin which had inconsistent yields and gross margins for lupins, canola and field peas.

KEY WORDS

Rotations Residues Stubble Wheat yield Gross margin Economics

ACKNOWLEDGMENTS

The Authors would like to thank the GRDC for their support and RSU Geraldton for their technical assistance. Ian Broad (Mingenew) and Cunderdin Agricultural College (Cunderdin) generously allowed trials on their land.

GRDC Project No.: WAN00012 (2007-09), UWA00136 (2010-2012)

Paper reviewed by: Matthew McNee