Comparing cover crops in organic farming for weed suppression and soil fertility

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Abstract

The study compared several plant species, and their mixes, as autumn sown cover crops in an organic farming system. Cover crops were assessed for their suitability in crop rotation including effects on the following crop. Their weed suppression effects were also examined. Some cover crops tested showed between 72% and 90% reductions in total weed dry weight in the spring. The best weed suppression was observed in plots of ryecorn, oat and peas and oat and tares. The results identified several cover crops which can be sown as late as May in Canterbury. Forage brassica, oats and, oat and peas were especially successful. Growth and vigour of the succeeding wheat was correlated with soil nitrogen (N) content after cover crops e.g. higher leaf chlorophyll content and greater biomass of wheat after oat and peas correlated well with higher soil N following this mixture. In contrast, oat plots had the lowest soil N and poor growth of following wheat. Potential benefits of cover crops in terms of soil fertility are analysed.

Additional keywords: Integrated weed management, organic weed control, crop residue, soil nitrogen, crop rotation

Introduction

Cover crops, as grown after a pasture phase or in the period between two cash crops, offer a range of benefits including soil and water conservation, adding organic matter, improving soil structure and weed suppression. They can be especially valuable in organic systems as a source of readily available N and other nutrients for the following crop. Weed suppression from cover crops is also of particular interest for organic growers. It has been shown in a conventional low-input cropping system that previous field pea (*Pisum sativum* L.), or ryegrass (*Lolium perenne* L.), cover crops significantly reduced weed biomass in a following wheat crop (*Triticum aestivum* L.) (Dastgheib *et al*., 1999). These benefits vary between species, timing and duration of the growing season. Cover crops are commonly used in both conventional and organic systems in New Zealand but quantifying their value in organic systems requires further work. The potential weed suppression effects from certain cover crops has been demonstrated overseas (Moonen and Barberi, 2004; Teasdale *et al*., 2007) but has not been studied much in New Zealand. Especially, late autumn-early winter planting presents particular challenges of establishment prior to winter and biomass gain prior to a desired spring sowing of cash crops.

This study was therefore undertaken to

compare a number of autumn-sown cover crops for their potential in a typical rotation with particular interest in their weed suppressing effects. The study consisted of three years of field experiments conducted on an organic farm. The trial in the second year also examined weed suppression effects in a short fallow after the harvest of cover crops. The third year experiment studied the effects of cover crops on a following spring wheat crop in relation to soil organic matter and N.

Materials and Methods

General

A series of field trials at the Biological Husbandry Unit (BHU), Lincoln University, Canterbury compared several cover crops and their mixtures during the 2003, 2004 and 2005 growing seasons. A control treatment with no cover crop was included in all experiments. This was left undisturbed and had natural weed populations so it is referred to as quasi-fallow. All the experiments were laid out in randomised complete blocks with four replicates. All data were analysed by ANOVA and where the F test was significant, $LSD_{0.05}$ values were calculated for mean comparison.

First year

In the first year, cover crops, namely ryecorn (*Secale cereale* L.), triticale (*Triticum* x *Secale* Wittm. ex A. Camus), oats (*Avena sativa* L.), oat and tares (*Vicia sativa* L.), hairy vetch (*Vicia hirsuta* L. (Gray.)), oat and vetch and subclover (*Trifolium subterraneum* L.) were sown in plots 3.7 m wide and 30 m long on 24 April 2003. In addition, a fallow plot was included with no crop. Sowing was with a Duncan drill except for subclover which was sown by hand. Table 1 shows sowing details.

Crop establishment and weed growth were monitored during the season. The number of plants was measured in two 0.25 m^2 quadrats randomly placed in each plot on 4 September 2003 and crop dry matter (DM) and weed DM were measured on 30 September 2003.

Second year

The second year trial compared five cover crops namely ryecorn, oat and tares, oat and vetch, and forage radish (*Raphanus sativus* L.). These were sown in 5 × 15 m plots with a precision cone seeder on 15 March 2004. Details of these crops are shown in Table 1. Data were collected on crop and weed density on 10 May 2004, and crop and weed biomass on 23 August as described above. Crops were mow-chopped on 23 September and all plots were scraped with a rotary hoe close to soil surface to cut the roots and plant residue was left to dry until 14 October. Land was grubbed, followed by a rotary hoe and roller. This produced a fine and firm seed bed with plant residues incorporated into the top soil. Plots were marked but not sown to examine weed growth. Data were collected during spring and summer on weed density by sampling as described above. Moreover, a visual assessment of % weed cover was made on 8 November.

Third year

Cover crops, namely triticale, barley (*Hordeum vulgare* L.), oats, oat and tares, oat and peas (*Pisum sativum* L.), forage brassica (*Brassica napus* L.) and narrow leafed lupin (*Lupinus angustifolius* L.) were sown in 5 × 15 m plots on 2 May 2005 and harvested at two dates, six weeks apart, on 1 September (first harvest) and 17 October (second harvest). Crop fresh weights and dry weights were measured by taking 2 quadrat samples (0.25 m^2) from each plot. Dried samples were ground and a 100 g composite subsample of each treatment was sent to Hill Laboratories (Christchurch, New Zealand) for N analysis. After each harvest, crop residue was mulched and the soil was prepared as described in the second year experiment. A spring wheat crop (*Triticum aestivum*, cv. Torlesse) was then sown on 3 October (first crop) and 31 October (second crop). Soil samples, three 15 cm deep cores from each plot, were taken on 8 December 2005 and a composite subsample from each treatment was sent to Hill Laboratories for determination of total and available N contents. This time corresponded to GS 31 (pseudo stem erect) of the spring wheat crop. Chlorophyll content of the wheat flag leaf was assessed by SPAD meter (Minolta Corporation) on 21 December. Chlorophyll content is commonly related to N status in wheat and other crops (Lopez-Bellido *et al*., 2004).

Table 1: Sowing rate (kg ha^{-1}), crop and weed densities (plants m^{-2}) on 4 September 2003 and 10 May 2004.

Cover crop	First year			Second year		
	Sowing rate	Crop density	Weed density	Sowing rate	Crop density	Weed density
Ryecorn (Rahu)	128	218	398	100	144	289
Triticale (Monster)	130	197	467	--	--	--
Oat and tares (local)	--[1]	--	--	90	140	256
Oats (Charisma)	150	242	468	--	--	--
Oat and vetch (local)	180	318	205	45+45	166	405
Hairy vetch (K551)	23	41	330	--	--	--
Subclover (Denmark)	27	19	383	--	--	--
Radish (Diabolo)	--	--	--	30	114	331
Quasi-fallow	--	--	392	--	--	592
$LSD_{(0.05)}$	--	50.4	189.5	--	30.6	87.9

[1] -- indicates the cover crop type was not tested that year.

Results

First and second year

In the first year, hairy vetch and subclover had low population densitiesand left a lot of space for weeds to grow (Table 1). This was despite the relatively high sowing rates used for these crops and was very likely due to land preparation. Populations of ryecorn, triticale and oat were similar and all produced a full canopy in a short period. The mixture of oat and vetch had the highest crop density. Weed density also differed among treatments but the density alone can not show differences in weed control. Plant size (e.g. dry matter in Table 2) needs to be considered in conjunction with weed density. On average, there were more than 330 large weeds m^{-2} (dry matter of over 135 g m^{-2}) in hairy vetch, subclover or fallow plots. Ryecorn, triticale, oat and oat and vetch had between 205 and 468 weeds m^{-2} but these were very small plants as indicated by their total dry matter of less than 39 g m^{-2} (Table 2).

In the second year, ANOVA results showed that weed density, measured eight weeks after sowing, was significantly different ($P<0.05$) among treatments. Fallow plots had 592 weeds m^{-2}, while weed density was reduced by as much as 57% in oat and tares plots (Table 1).

In the first year, triticale and ryecorn produced the highest dry matter followed by oats approximately five months after sowing on 30 September 2003 (Table 2). Dry matter yields of hairy vetch and subclover were very low as they had only sparse plant populations. Weed dry matter was very low in plots of ryecorn, triticale, oat and, oat and vetch, with no significant difference among them. On the other hand, weed dry matter was significantly higher in hairy vetch, subclover and the fallow treatment.

In the second year, crop dry matter, measured approximately five months after sowing, was not significantly different among the tested cover crops and aall of the crops produced a dense canopy. In both years, high crop dry matter resulted in low weed dry matter. For example, with the exception of hairy vetch and subclover in the first year, all of the cover crops tested gave more than a 72% reduction in weed biomass compared to the fallow treatment (Table 2).

Weed growth in spring after cover crops

In the second year, weed density values, measured approximately six weeks after harvesting cover crops, were similar irrespective of the previous cover crops. However, visual scores for the percentage weed cover showed significant reductions after ryecorn and radish (Table 3) indicating there were smaller weeds in these plots.

Third year

Growth of cover crops and weed suppression

The first harvest on 1 September occurred four months after sowing cover crops. At this time, lupins had the lowest dry weight due to their low germination and all other crops produced similar dry weights (Figure 1). Forage brassica had the highest fresh weight (data not presented) followed by oat and tares. Fast growth in spring resulted in remarkable increases in biomass in all crops. At the second harvest on 17 October, approximately 5.5 months after sowing, lupins had the lowest dry weight of 2.1 t ha^{-1} followed by brassica with just over 3 t ha^{-1}. There was no significant difference between cereals in the amount of dry matter in the second harvest. The mixture of oat and peas produced significantly higher dry matter than oat and tares.

Table 2: Crop and weeds dry matter (g m^{-2}) measured on 30 September 2003 and 23 August 2004.

Cover crop	First year			Second year		
	Crop DM	Weed DM	% Weed suppression[1]	Crop DM	Weed DM	% Weed suppression[1]
Ryecorn (Rahu)	483.6	13.7	90	631.5	42.8	87
Triticale (Monster)	557.5	22.6	84	--	--	--
Oat and tares (local)	--	--	--	883.3	82.6	76
Oats (Charisma)	388.6	23.6	83	--	--	--
Oat and vetch (Local)	236.2	39.2	72	904.7	61.2	82
Hairy vetch (K551)	16.8	142.6	0	--	--	--
Subclover (Denmark)	26.2	135.1	4	--	--	--
Radish (Diabolo)	--	--	--	964.3	90.9	73
Quasi-fallow	--	140.5	--	--	339.0	--
$LSD_{(0.05)}$	101.36	34.79		360.6	188.50	

[1]as a percentage of weed dry matter in the fallow treatment.

Table 3: Weed density (plants m^{-2}) and visual assessment of % weed cover in the fallow following different cover crops on 8 November 2004**.**

Cover crop	Weed density	Weed cover %
Ryecorn	301	48
Oat and tares	381	63
Oat and vetch	353	61
Radish	332	47
Quasi-fallow	371	75
$LSD_{(0.05)}$	ns	20.1

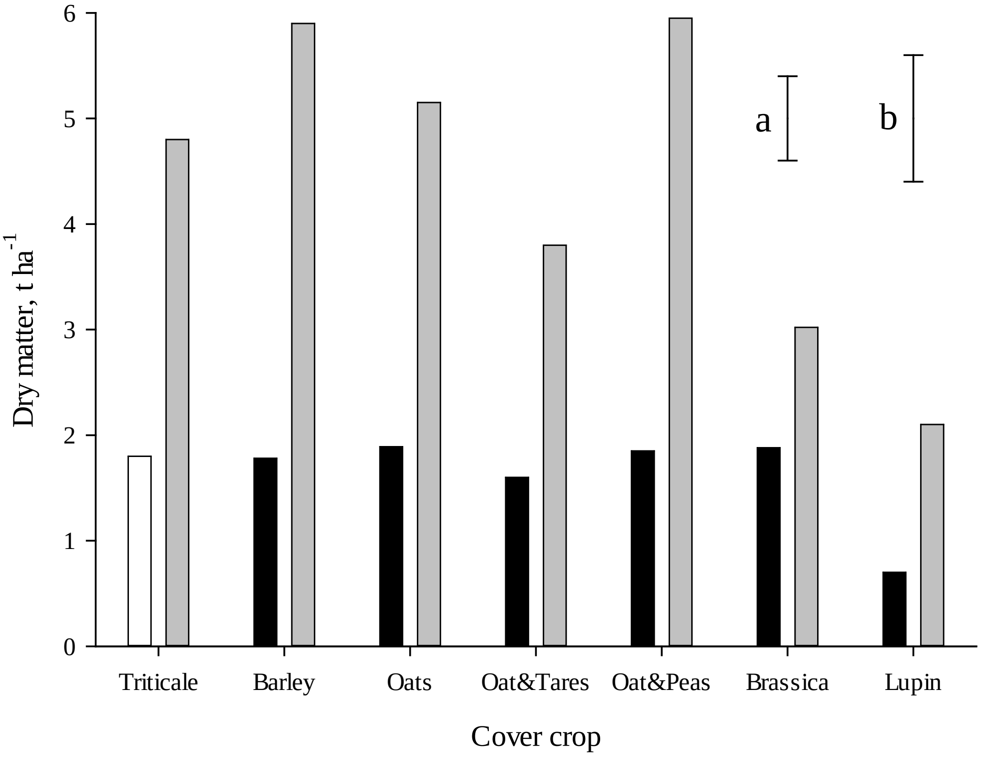

Figure 1: Dry matter of cover crops in the first (black bars) and second (grey bars) harvests. Error bars represent $LSD_{0.05}$ for first (a) or second (b) harvests.

ANOVA results showed that weed density and dry matter as well as % weed cover were significantly different among cover crops at the first harvest (Table 4). Weed density was highest in the quasi-fallow plots followed by lupins. These plots had 94 and 87.5% weed cover, respectively. The lowest weed density and weed cover were observed in oat and tares and oat and peas. Dry weight measurement at the same time showed the lowest values in oat and peas followed by triticale and oat and tares resulting in weed suppression percentages of approximately 82, 78 and 73 compared to the fallow (Table 4).

Table 4: Weed density (plants m^{-2}) and other parameters measured in different cover crops on 1 September 2005.

Cover crop	Weed density	% weed cover	Weed dry matter g m^{-2}	Weed suppression[1]
Triticale	262	18.5	44.6	78.2
Barley	297	20.5	61.2	70.1
Oats	385	32.0	63.8	68.9
Oat and tares	170	8.5	55.9	72.7
Oat and peas	187	12.5	37.2	81.9
Forage brassica	305	33.8	77.6	62.1
Lupin	400	87.5	171.1	16.5
Quasi-fallow	512	94.0	205.0	0.0
$LSD_{(0.05)}$	120.3	18.28	64.92	--

[1]as a percentage of weed dry matter in the fallow treatment.

Growth of spring wheat

The SPAD readings of the wheat flag leaf were no different among treatments for the first wheat crop (data not presented). In the second wheat crop SPAD readings ranged from 41.2 after oats to 47.2 and 47.5 after oat and peas and after lupins, respectively, both significant increases ($P<0.05$). Visual assessment showed the highest vigour was in wheat following oat and peas, while wheat following cereals, especially after oats, had poor vigour. The dry weight of the first wheat crop ranged from 3.84 to 6.11 t ha^{-1}, and was highest after forage brassica, lupins, quasi-fallow and oat and peas. The lowest biomass was in plots previously sown to triticale and barley (Figure 2). The second wheat crop showed a similar pattern. Plots after cereals, especially triticale, had low biomass production (2.22 t ha^{-1}), while wheat after oat and peas gave the highest dry weight (3.89 t ha^{-1}). Averaged over the two sowing dates, wheat biomass was greater in plots after oat and peas, forage brassica and lupins and less after cereal crops. The differences in grain yield were not statistically significant.

Nitrogen content of foliage and soil

At both harvests, tares recorded the highest foliage N% followed by peas and lupins (Table 5). Cereal crops had a low N%, especially at the second harvest. At the first harvest on 1 September, forage brassica, oat and peas, oats and barley had the highest amounts of N per ha. At the second harvest on 17 October, the highest amounts of N ha^{-1} was found in oat and peas, oat and tares, barley and lupins.

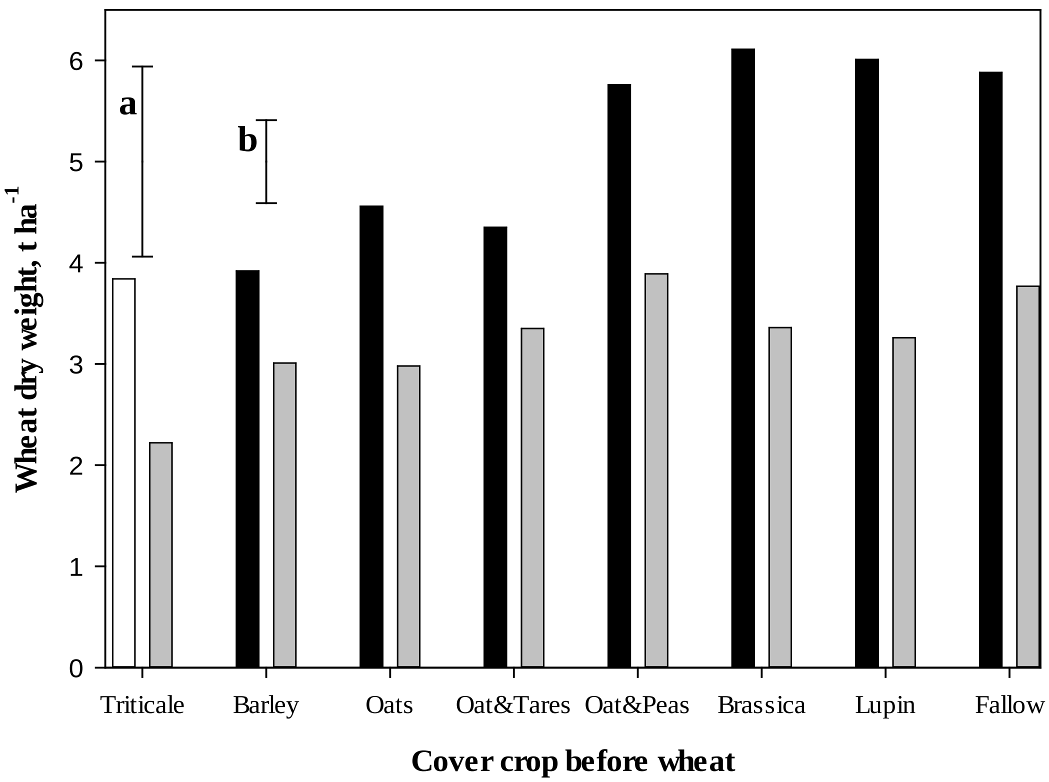

Figure 2: Biomass dry weight of both wheat crops measured on 30 December 2005, sown on 3 October (black bars) and 31 October (grey bars) after the first and second harvest of different cover crops. Error bars represent $LSD_{0.05}$ for first (a) or second (b) wheat crop.

Table 5: Cover crop foliage N% and their total nitrogen content based on their dry matter production at each harvest[1].

Cover crop	First harvest		Second harvest	
	N %	kg N ha^{-1}	N %	kg N ha^{-1}
Triticale	2.1	35.1	1.2	57.4
Barley	2.5	42.4	1.2	71.3
Oats	2.2	38.3	1.1	56.6
Oat and tares (oat only)	2.1	26.4	1.3	36.8
Oat and tares (tares only)	5.0	10.6	4.1	40.1
Oat and peas (oat only)	2.2	21.9	1.4	43.8
Oat and peas (peas only)	3.5	27.0	2.1	59.5
Brassica	2.9	50.7	1.6	48.8
Lupin	3.1	19.8	3.3	70.2

[1]No statistical analysis is presented as values are based on a composite sample from all replicates.

Soil test at GS 31 of spring wheat showed a narrow range of 0.16-0.18% for total N. On the other hand, available N showed more variation among treatments (Table 6). The highest values for soil available N were measured after oat and peas and oat and tares, while oat plots had the lowest (Table 6). Good growth, higher chlorophyll and greater biomass of wheat after oat and peas correlates well with higher available soil N values at GS 31, which is the period of fast growth and greater demand for N. In contrast, oat plots had the lowest available soil N, low chlorophyll readings and poor growth of the following wheat.

Table 6: Soil analysis[1] of second sowing of wheat at GS 31, 8 December 2005.

Cover crop	N %	Available N, kg ha^{-1}	O.M. %
Triticale	0.18	89	3.9
Barley	0.16	86	3.8
Oats	0.17	78	3.8
Oat and tares	0.17	95	3.8
Oat and peas	0.17	100	4.1
Brassica	0.16	84	3.7
Lupin	0.17	89	3.7

[1]No statistical analysis is presented as values are based on a composite sample from all replicates.

Discussion

It was evident from the results that some cover crops reduced weed population and growth during the winter. Ryecorn, triticale and oats either alone or mixed with a legume were especially effective and gave significant (72 and 90%) reductions in weed dry weight (Table 2). The weed suppressing effect was also noticeable six weeks after harvest of ryecorn and forage radish in the spring (Table 3). This may suggest a mild allelopathic effect but the study was not designed to investigate the mechanism. Among the cover crops studies, ryecorn gave the highest weed suppression in both years (Table 2). It is especially noteworthy that in the second year, ryecorn biomass was the lowest but its weed suppression ability was the highest suggesting effects other than weed smothering caused solely by its mass. Living ryecorn, as well as a few other plants or their residues have been reported to reduce germination or growth in a number of weeds (Przepiorkowski and Gorski, 1994; Weston and Inderjit, 2007). In the third year, other than lupins, that had a poor establishment and biomass, excellent weed suppression was obtained with all of the cover crops tested. Consistent with the results from previous years oat and peas and triticale showed the highest weed suppression of 82 and 78%, respectively, and other cereals like barley and oats were also very effective (Table 4). The weed suppressive ability of these crops ties in with their high biomass at the second harvest (Figure 1).

Wheat was sown after harvest of the cover crops as a model crop to indicate soil fertility differences, and to suggest an optimum harvest time for cover crops. Wheat biomass of the first crop was greater than in the second crop as it had, approximately, an extra four weeks of growth (Figure 2). In general, wheat growth was minimal after a cereal cover crop and was much higher after crops with a legume in the mix or after forage brassica. Wheat growth after quasi-fallow was also high in both crops. In this study the quasi-fallow treatment was left undisturbed and many weeds including legumes such as clover species grew in these plots. This apparently raised the fertility and organic matter content of the soil after their residue was turned into the soil. Farmers usually disc or grub their fallow paddocks several times to control weeds. Under such conditions, much lower growth of a successive crop, after fallow, is expected in the spring. For example, Ganeshan (1998) reported a significant reduction in dry matter production of ryegrass after fallow compared to plots previously planted in lentil, lupin or peas. No particular problem in terms of residue management was noticed for the two harvest times of the cover crops. As such, optimum harvest time depends on the suitable planting date for the spring crop intended. The results demonstrated that even with sowing dates as late as May, good growth of the cover crops can be expected and sowing of a spring crop can be managed in time. Comparing the dry weight of cover crops between the two harvest dates of 1 September and 17 October also shows that forage brassica made most of its final growth in winter while the other crops relied on the warmer temperatures in spring to build up their dry matter (Figure 1). In situations where early sowing in spring is planned, forage brassica may be a suitable crop to consider.

The integration of cover crops into cropping systems brings costs and benefits. Benefits include weed and pest suppression, improvements in soil and water quality, nutrient cycling efficiency, and cash crop productivity. Costs of adopting cover crops include increased direct costs and production expenses and potentially reduced income if cover crops interfere with cash crop planting or slow soil warming in spring. Indicative operational costs for both fallow and cover crop options for a typical farm are given in Table 7. Although the values can vary widely among regions and management systems, the analysis indicates an approximate additional cost of \$460 ha^{-1} associated with cover crops. At the same time Table 6 shows the amount of available N in the soil following the harvest of different cover crops ranging from 78 to 100 kg ha^{-1}. The soil analysis was conducted at GS31 of wheat, approximately five weeks after sowing. It can be suggested that wheat had used some of the N left from the cover crops by this time and the original values may be somewhat higher. Nevertheless, taking the current cost of urea (46% N) at \$630 t^{-1}, 100 kg N ha^{-1} translates into \$136.70 which will pay for > 30% of the cost of growing a cover crop of oat and peas. It must be emphasised that an analysis solely based on soil N will underestimate the value of cover crops as other benefits, both financial and environmental, are not considered.

Table 7: Indicative cost per ha of operations[1] for winter fallow and cover crop options

Operation	Winter fallow	Cover crop
Land management after pasture	Plough, roller = $200	Plough, roller, disc = $280
Sowing cost	Nil	$240
Land management during winter	3 cultivation (grub and tine) = $260	Nil
Land management after cover crop	Nil	Chopping mower, rotary, roller = $400
Total	$460	$920
Difference		$460

[1] Cultivation costs for Canterbury as quoted in Financial Budget Manual (Burtt, 2010).

Conclusion

In conclusion, oat and peas, oat and tares, and forage brassica produced excellent growth and weed suppression during the winter and were financially viable options as cover crops. Mixtures of cereals and legumes increased available soil N and are probably more beneficial than cereals alone in most situations.

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