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Full Length Research

Biomass accumulation, weed dynamics and nitrogen uptake by winter cover crops in a warm-temperate region of South Africa

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Production of large biomass yields and weed suppression from cover crops have been major constraints affecting success and uptake of conservation agriculture technologies by smallholder irrigation farmers. A field study was undertaken to evaluate biomass accumulation and N uptake by oats (*Avena sativa),* grazing vetch (*Vicia dasycarpa*), faba bean (*Vicia faba*), forage peas (*Pisum sativum*) and Lupin (*Lupinus angustifolius*) and their winter weed suppression efficacy in the 2007 and 2008 winter seasons. Cover crops were grown at two fertiliser levels: no fertiliser and fertilized. Control plots were included where no cover crop was grown. At the end of each winter season, glyphosate was applied to kill the cover crops and maize planted. Oats, grazing vetch and forage pea's cover crops produced mean dry weights of 13873, 8945.5 and 11073 kg ha^{-1} respectively while lupin had the lowest dry weight of 1226 kg ha^{-1}. Oats responded to fertilisation while, there was little or no response from the other cover crops. Oats and grazing vetch also reduced weed density by 90 and 80% respectively while lupin only reduced weed density by 23% compared with the control plots. Grazing vetch fixed a mean of 112 kg N ha^{-1}. The results suggest that legumes such as grazing vetch and forage peas may be grown to maximise biomass yields with minimal fertilizer inputs. Amount of biomass produced was a major factor in controlling winter weeds, while there was a progressive decline in the winter weed burden from the first to the second season. The low C: N ratio of grazing vetch (<15) and its high N content may make it attractive for resource-limited farmers in warm-temperate climates.

Key words: Biomass yield, conservation agriculture, cover crops, weeds dynamics.

INTRODUCTION

Most smallholder irrigation schemes in South Africa (SA) face various production challenges which include: heavy weed infestations, low soil fertility especially N and P, and lack of tillage services (Mandiringana et al., 2005; Fanadzo, 2007). Burning crop residues has reduced soil organic matter resulting in extreme soil erosion (Laker, 2004; Mills and Fey, 2004). Soil losses above 60 t ha^{-1} yr^{-1} have been reported on a maize crop in SA (Laker, 2004). The need to address these challenges has prompted the search for sustainable solutions, such as conservation agriculture (CA). Different views on what constitutes CA exist and it is often thought to be synonymous with conservation tillage (CT).

Conservation tillage consists of minimum-tillage practices and maintenance of at least 30% soil cover by plant residues (Fowler and Rockstrom, 2001; Baker et al., 2002). Conservation agriculture, on the other hand, combines minimal soil disturbance, a permanent soil cover through use of cover crops with crop rotations (Derpsch, 2005; Hobbs, 2007). Hobbs (2007) argued that CT uses some of the principles of CA, but has more soil disturbance. Opinions also vary on whether CA benefits can be realized on smallholder farms in Sub-Saharan Africa (Giller et al., 2009). It is however agreed that before a wholesale promotion of CA, it needs to be adapted to

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agro-ecological and socio-economic conditions on smallholder farms.

Research in Latin America and South Asia has demonstrated that CA can result in improved weed control and soil N, reduced production costs and timely planting (Balota et al., 2004; Hobbs and Gupta, 2004). Conservation agriculture is a relatively new technology being actively promoted on smallholder irrigation farms in SA. Prioritisation of production challenges in the smallholder irrigation sector is critical when selecting an appropriate entry point for introducing CA, in particular cover crops. Ongoing work in one of the 317 irrigation schemes in SA, at Zanyokwe has shown that heavy weed pressure is a major constraint to high crop yields (Bembridge, 2000; Fanadzo, 2007). Use of winter cover crops has been identified as an avenue of introducing cover crops as land is usually not planted in winter on most smallholder irrigation farms. Reasons for not planting winter crops included lack of tillage services, lack of technical knowledge and labour shortages (Fanadzo et al., 2010). High biomass producing cover crops requiring little attention during their growth provide an opportunity to introduce CA without a major disruption of the farming system. High biomass yields are necessary to ensure success of no-till systems (Steiner, 1998).

Winter cover crops are planted in autumn, grown in winter and killed in spring prior to planting a summer crop, usually maize, the staple crop. Failure of CA in preliminary trials in a warm temperate region of SA has been blamed on low cover crop biomass yields resulting in an increased weed burden on the succeeding crop. The low cover crop biomass has been explained by inappropriate cover crop species selection and low soil fertility (Derpsch, 2003). While it is necessary to have cover crop species adapted to warm-temperate climates, it has been suggested that fertilising the cover crops may also be necessary to ensure high biomass yields (Derpsch, 2003). Weed control depends upon the ability of a cover crop to suppress weeds while actively growing and upon the residual effect of cover crop mulch after senescence (Bàrberi and Mazzoncini, 2001). While actively growing, cover crops suppress weeds by competing for the use of growth resources, such as light and nutrients. Weed suppression efficacy is also a function of rate of cover crop growth and canopy production (Liebman and Davis, 2000). Control of winter weeds by growing cover crops may reduce the impact of perennial weeds and reduce the winter weed seed bank, benefiting farmers who may plant winter cash crops in future. The effect of different cover crop species on the winter weed spectrum has not been quantified. Changes in tillage have a significant effect on weed populations. A switch from conventional to conservation agriculture systems may alter the species composition, total amount and temporal pattern of emergence of weeds (Wruckle and Arnold, 1985; Bilalis et al., 2003).

While production of sufficient biomass is necessary for weed suppression, the quality of biomass is an important factor that affects soil fertility. The use of nitrogen-fixing legume cover crops in improving soil nitrogen status is widely acknowledged (Burity et al., 1989; Jeranyama et al., 2000; Gitari et al., 2000; Kaizzi et al., 2006). However, N-fixation may differ among species, with some cover crops being more efficient than others in different agro-ecologies. Plant litter that is high in nutrients especially nitrogen and decomposes rapidly, is considered to be of high quality. Indices such as the C: N ratios have been used to describe biomass quality, where a C: N ratio above 25:1 increases potential for N immobilisation in the soil (Nair, 1993; Sainju et al., 2005). The C: N ratio of a particular species is important as it may be used to predict nutrient contributions to a succeeding crop. The objectives of this study included; 1) determining biomass yields, C and N uptake by winter cover crop species, 2) to determine effect of fertilisation on cover crop biomass production, and 3) to evaluate the effect of actively growing cover crop species on winter weeds in a warm temperate region of SA.

MATERIALS AND METHOD

The study was done at the University of Fort Hare Research Farm (32°46'S, 26°50'E) which has a warm-temperate climate. It is at a mean altitude of about 535 m.a.s.l; mean monthly temperature range from 13 to 17°C during the winter (May to October) and a 28-year mean rainfall of about 127.6 mm in the same period (Table 1). The coefficients of variation (CV) of the temperatures during the winter months when cover crops are grown are very low, less than 10%, while monthly rainfall CVs show great variation (Table 1). The soil is classified as a Luvisol in the FAO system with 64.2% sand, 16.0% silt and 19.8% clay. The soil has a pH of 6.1 (2.5:1 water to soil), 0.35 g P kg^{-1}, 4.04 g K kg^{-1}, 4.25 g Ca kg^{-1} determined through atomic emission spectrometry (Mandiringana et al., 2005). The climate and soil type at the research farm closely relate those on smallholder irrigation farms in the study area.

Treatments and experimental design

In the winter of 2007, four cover crops, oats (*Avena sativa* cv. Sederbrg), grazing vetch (*Vicia dasycarpa* cv. Max), faba bean (*Vicia faba* cv. Icarus) and Lupin (*Lupinus angustifolius* cv. Tanjil), were planted on the 20^{th} of May at two fertiliser levels, with and without fertiliser. Control plots with no cover crops but weeds were left to grow were included. This gave a 4 $\times$ 2 factorial plus control plots laid in a randomised complete block design with three replications. All legume cover crop seed, including the no fertiliser treatments, were inoculated with *Rhizobium legunominosarium biovar viciae* having 5 x 10^8 rhizobial cells g-1 (Stimuplant CC, Zwavelpoort 0036, SA) at planting. Seeds were coated by mixing with slurry containing the inoculants, water and a sticker (methyl cellulose). Seeds were sown immediately in the field. In all fertilised cover crop plots, 10 kg P ha^{-1} was applied as a compound (2:3:4 (30)) at planting. The 2:3:4 in the compound fertiliser represents a ratio of N: P: K in the elementary form and 30 refers to the total concentration (%) of nutrients in the compound fertiliser. This fertilizer also provided starter N to the young seedlings. For oats, extra N

Table 1. Mean monthly temperatures, rainfall and irrigation at the UFH Research Farm from May to September in the 2007 and 2008 seasons.

	Temperature (°C)				Rainfall (mm)				Irrigation (mm)	
	2007	2008	28 year mean	C.V%	2007	2008	28 year mean	C.V%	2007	2008
May	16.4	16.9	16.7	6.2	45	8.8	21.4	84	40	-
June	13.5	13	13.0	6.5	43.6	14.9	20.7	72	30	30
July	12.2	13.8	12.9	8.1	16	2.5	17.2	65	20	40
Aug	14.3	14.2	14.2	7.1	20.6	68.1	32.9	125	50	20
Sep	17	15.5	16	5.6	5.1	5	35.4	109	40	50
Oct	17.7	17.9	17.7	3.5	105.9	25.2	60.3	130	-	20

Table 2. Summary of the fertilizer applications on the plots during the course of the experiment (fertilized, +; not fertilized, -).

Fertilizer regime	Winter 2007 fertilization	Summer 2007/2008 fertilization	Winter 2008 fertilization	Summer 2008/2009 fertilization
R1	+	+	+	+
R2	+	-	+	-
R3	-	+	-	+
R4	-	-	-	-

was applied as lime ammonium nitrate (LAN - 28% N) at 42 days after sowing (DAS) to make a total of 45 kg N ha^{-1} applied to oats.

In the first winter of growing the cover crops, all the plots were ploughed and disked and the cover crops planted in small trenches, 25 cm apart and 2 - 3 cm deep, dug using hand hoes. It has generally been recommended to start no-till practices after growing a cover crop that covers the soil when converting to CA (IIRR and ACT, 2005). In the subsequent season, no tillage was done. All cover crops were grown at recommended seed rates of; 90 kg ha^{-1} for oats, 35 kg ha^{-1} for grazing vetch, 90 kg ha^{-1} for faba bean, 80 kg ha^{-1} for lupin and 90 kg ha^{-1} for forage peas in 2008. The gross plot size was 17 × 7.2 m in the first season. No weed or pest control was done during the growth of the cover crops. Similar amounts of water were applied to all treatments, through overhead irrigation based on Class A evaporation pan readings (Table 1). On the 8th October 2007, all cover crops were killed by rolling them and applying glyphosate (1.8 kg ha^{-1}) immediately, this was done to allow glyphosate to reach any weeds growing in the understory. At this stage cover crops had reached the flowering stage or just starting the grain filling period and no grain yield was harvested from the cover crops. All plots, including control plots, were then split (gross plot size: 8 × 7.2 m) and maize planted at two fertiliser levels (0 and 60 N kg ha^{-1}) on the 14th December 2007. For fertilized maize, a third of the N was supplied using the same NPK compound fertilizer used in winter, while the remainder was applied as LAN. Maize was planted at 37.000 plants ha^{-1} using jab planters (Farmarama, East London, SA) and no tillage was done.

Subsequent to maize harvesting, maize stalks were rolled, glyphosate applied and cover crops were planted as in the first season, without ploughing on the 20th of June in 2008. Hand hoes were used to cut through mulch and open shallow trenches on the soil. After planting, the soil and then mulch were used to cover the seed. In 2008, faba bean were replaced with forage peas (Pisum sativum cv. Maple) because of seed unavailability. Fertilizer was applied as in the first season and, this gave four fertilizer regimes; R1, R2, R3 and R4 as summarized in Table 2. The R1 treatments where fertilized in both winter and summer seasons, while the R2 treatments were only fertilized for winter cover crops with no fertilization in the subsequent maize. The R3 treatment, where only the summer maize crop was fertilized, investigated whether summer maize fertilization had any residual fertility effects on winter cover crop growth. The R4 regime had no fertilizer applications in both the winter and summer seasons. There were thus, two factors in the second winter experiment; cover crop species and fertilizer regime giving a 4 × 4 factorial plus control plots lay out as a randomised complete block design with three replications. The second winter experiment was terminated on the 21st October 2008. A total of about 160 mm water was applied as irrigation in the second season to all plots as summarized in Table 1.

Measurements

Two quadrats, measuring 35 × 35 cm, were randomly placed in each plot and plants were destructively sampled by cutting them at the soil surface for determination of shoot cover crop dry weights and weed dry weights. Samples were randomly taken from plots on 9 July, 11 August, and 22 September 2007 in the first season and on 22 August, 26 September and 21 October in the second season. Weeds and cover crops were separated and oven dried to a constant weight at 65^{o}C and dry weight determined. On the last sampling date in both seasons, weeds were identified and grouped into their species. At each sampling period in 2007, cover crop subsamples were ground to pass through a 1 mm sieve and C and N concentration (%) were determined using the C:N LECO analyser. Weed C and N concentration was determined using the same procedure for the last sampling date only. Percentage of symbiotically fixed N was estimated for grazing vetch by the total N-difference method with N uptake from oat plots being used as reference biomass (Giller, 2001; Anthofer, 2005):

$$NdA (\%) = (TNfix - TNref)/TNfix * 100$$

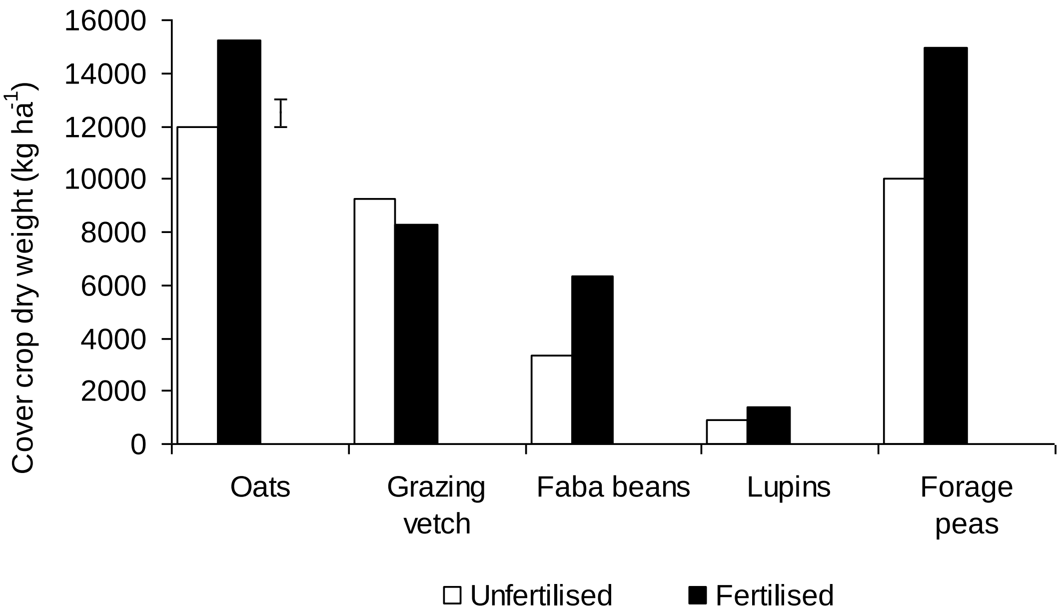

Figure 1. Final dry weights from different cover crop species, means averaged for the 2007 and 2008 winter seasons. Error bar represent LSD.

Where NdA is N derived from atmosphere; TNfix and TNref are total N accumulation by N2 fixing and reference plants, respectively. Atmospheric N2 fixation was determined at termination of the cover crops. The N-difference method assumes that the N-fixing species takes up the same amount of soil N as the reference crop. This may underestimate N fixation because the legumes often utilize less soil N than the reference crop (Carranca et al., 1999). When the reference crop takes up much more N from the soil than a poorly growing legume, this may result in negative estimates (Carranca et al., 1999).

Data analyses

Measurements were analysed as a factorial design using analysis of variance (ANOVA). Common treatments between seasons were used to allow an across season analysis. Were appropriate, an extra factor (cover cropping) was included while cover crop species*fertilisation were nested within cover cropping to include analysis of controls in the ANOVA (Cochran and Cox, 1957). Genstat Statistical package release 7.1 was used for the analysis. Weed species counts, C and N concentration (%) as well as the C: N ratios were square-root transformed before being subjected to ANOVA. Regression analyses were done to determine the relationship between cover crop dry weights with time or weed dry weights.

To determine differences in cover crop growth rates, methods described by Gomez and Gomez (1984) were used to test homogeneity of the regression coefficients for plots of dry weight accumulation against time. Where transformation was not required, means and least significant differences (LSD) are presented. Where transformation was required, back-transformed means are shown, without presentation of the LSD as it is not appropriate. Unless otherwise stated, differences referred to in the text are significant at $P < 0.05$. This paper reports on growth and nutrient uptake by cover crops as well as the weed dynamics during the winter seasons only.

RESULTS

Temperature and rainfall

The temperature during cover crop growth between the two seasons was similar with very little variation (Table 1). These temperatures are comparable to the long-term 28-year mean temperatures. In 2007 cover crops received a total of 310 mm from rain and irrigation during their growth while in 2008 they received 260 mm (Table 1).

Cover crop dry weight

Seasonal effects were not significant with respect to final dry weight, while cover crop species effects were significant ($P < 0.01$). The cover crop species × fertiliser interaction was significant ($P < 0.01$) (Figure 1). Fertilising oats and forage peas increased dry weights but not that of grazing vetch, faba beans and lupins (Figure 1).

There were significant ($P < 0.01$) differences in the slopes for the plots of dry weight of cover crops against time (Figure 2). The slopes, as shown by the regression coefficients, represent the mean crop growth rate (CGR) (Fageria et al., 2006). These slopes are an estimate based on approximately the linear portion of the sigmoid curve. Oats and grazing vetch had higher CGR compared to faba bean, and lupin. Data was combined for fertilised and unfertilised cover crops as there were no differences in the regression coefficients due to fertilisation for the respective cover crops. Summer maize fertilization had

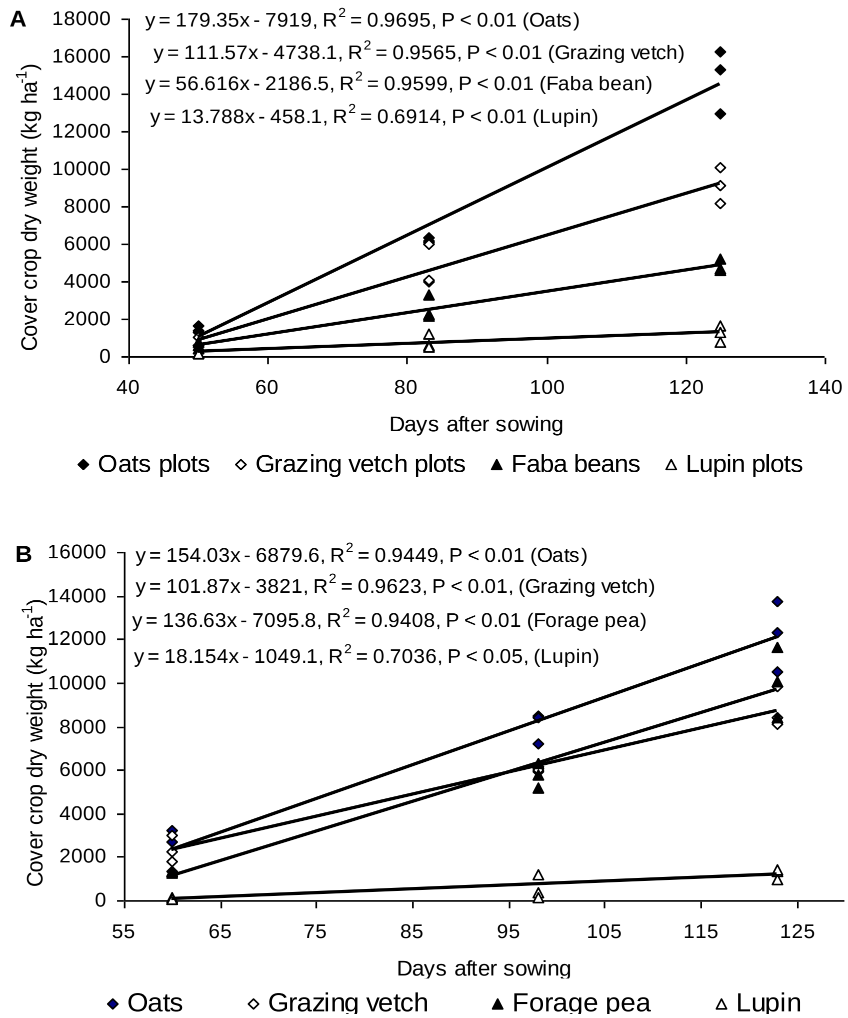

Figure 2. Dry weight accumulation over time by different cover crops in the 2007 (A) and 2008 (B) winter seasons.

no significant residual fertility effects on cover crop growth in 2008 (data not shown).

C and N uptake by cover crops

Grazing vetch had significantly lower C concentration (30.8%) than oats, faba bean and lupin which had C concentrations of 39.2, 40.9 and 40.8% respectively at 50 DAS. However, at the other sampling dates, cover crops species had no significant effects on C concentration which averaged 38.9% and 40.6% at 83 and 125 DAS, respectively, across cover crops. Fertilisation did not significantly affect C and N concentration at all the sampling periods. While oats initially had significantly greater N concentration at 50 DAS, it had the lowest N concentration at 125 DAS (Figure 3).

Cover crop species significantly affected the C: N ratio at 50, 83 and 125 days ($P < 0.01$) after planting (Figure 4). Fertilisation had no effect on C: N ratio at all the sampling times and, the interaction between cover crop species and fertilization was not significant. At 50 DAS, oats and grazing vetch had the lowest C: N ratio. However, the C: N ratios of oats increased significantly as the plants grew older while the C: N ratio of grazing vetch only increased marginally (Figure 4).

Carbon uptake closely resembled biomass uptake as shown in Figure 2. Cover crop species significantly ($P < 0.01$) affected total N uptake at all the sampling times. Grazing vetch had the highest N uptake despite having lower biomass than oats, while lupin accumulated the least N compared with other cover crops (Figure 5). Grazing vetch symbiotically fixed a mean of 111.5 kg N ha^{-1}. On average, 29.8% of the assimilated N was derived

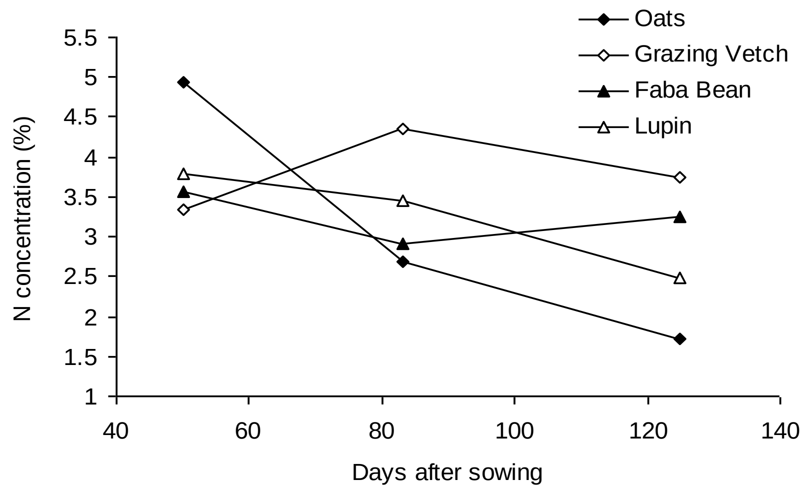

Figure 3. Percent nitrogen over time in cover crops in the 2007 winter season. Back-transformed means are presented.

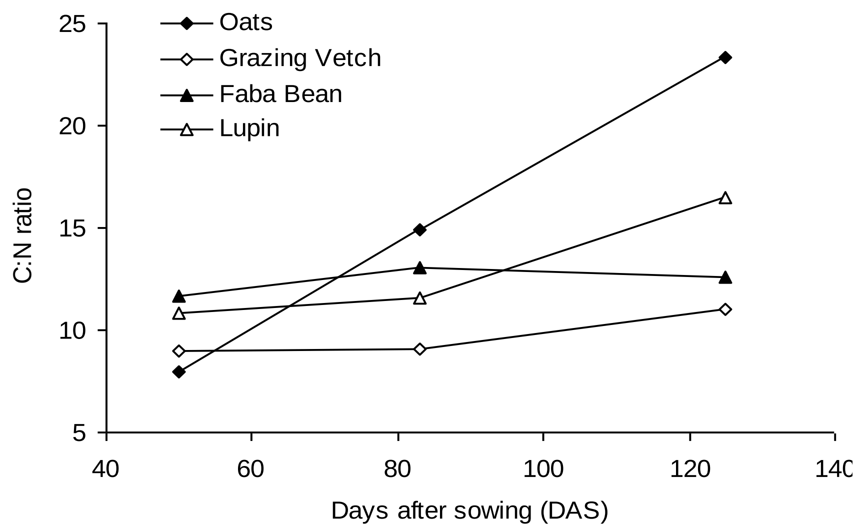

Figure 4. Changes in C: N ratio over time for the different cover crop species in the 2007 winter season. Back-transformed means are presented.

from the atmosphere (Table 3). Fertilization did not significantly affect N fixation in grazing vetch. It was not possible to estimate N fixed from faba bean and lupin because of their much lower biomass and N uptake compared to the reference crop, resulting in negative estimates.

Weed dry weight, C and N uptake

Season and cover crop species significantly ($P < 0.01$) affected final weed dry weights. Lower weed dry weights were recorded on oat and grazing vetch plots, than in faba bean, lupin and control plots (Table 4). This trend was the same with earlier sampling dates (data not shown). In 2008, a similar trend as in 2007 was observed. However, the second winter season had lower weed dry weights compared to the first season (Table 4). Fertilization had no effect on weed dry weights. There was a significant ($P < 0.01$; $R^2 = 0.69$) inverse relationship between cover crop dry weight and weed dry weight for the two seasons.

A decline in weed dry weight as cover crop dry weights increased, irrespective of cover crop species was observed. Weeds growing under the different cover crop species and fertiliser regimes had similar C and N

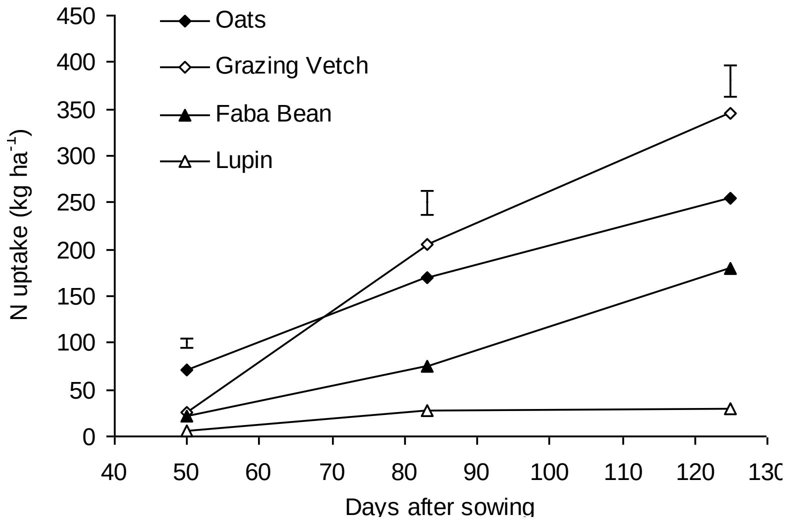

Figure 5. Changes in N content over time for the different cover crop species in the 2007 winter season. Error bars represent LSD.

Table 3. Estimates of N fixed by grazing vetch in the 2007 winter season.

	Fertilised	Unfertilized
Mean N fixed (kg N ha-1)	125.1	97.9
Percent N fixed in biomass (NdA)	32.5	27.1

Table 4. Effect of different cover crop species on final weed dry weights (kg ha^{-1}) in the 2007 and 2008 winter seasons.

Season	Oats	Grazing vetch	Broad beans/ forage peas	Lupin	Control
2007	955	1404	4848	5432	7401
2008	376	1010	2588	3309	5013
LSD a (0.05)			1976		
LSD b (0.05)			1711		
LSD c (0.05)			1397		

LSDa = for control to control comparisons only, minimum replications,
LSDb = for comparisons of controls with other treatments, minimum replication and maximum replications
LSDc = for treatment comparisons only, with controls excluded, maximum replications.

concentration (%) as well as the C: N ratio (Table 5). However, oats and grazing vetch significantly ($P < 0.001$) restricted total C and N uptake by weeds compared to faba beans and lupins (Table 5).

Weed species diversity

Season and cover crop species reduced the number of weed species occurring in the plots. Oat and grazing vetch plots had significantly fewer weed species than the broad bean, forage pea and lupin plots, while the second winter season also had fewer weed species compared to the first season (Table 6). The major weeds species in the plots were *Bromus carthraticus* and Capsella *bursa-pastoris.* Some of the more prevalent broadleaf weed species included: *Chenopodium album*, *Malva parviflora* and *Stellaria media.*

Table 5. C and N concentration, C: N ratio and nutrient uptake by weeds in plots with different cover crop species in the 2007 winter season. Back-transformed means for %C, %N and the C: N ratios are presented.

	Oats	Grazing vetch	Faba bean	Lupin	Control
%C	39.4	39.8	40.2	39.3	39.8
%N	2.63	2.64	2.63	2.59	2.30
C:N ratio	15.4	15.4	15.3	15.3	17.4
Total C kg ha^{-1}	18.6	48.5	208	226	348
LSD (0.05)			71.1		
Total N kg ha^{-1}	1.29	3.77	13.5	14.7	20.9
LSD (0.05)			5.9		

Table 6. Effect of different cover crops on number of weed species in the 2007 and 2008 winter seasons. Back-transformed means are presented.

Season	Oats	G. vetch	Broad beans/ forage peas	Lupin	Control
2007	2.8	2.9	4.6	4.1	5.6
2008	1.0	1.0	2.1	3.0	3.3

DISCUSSION

Only oat and forage pea cover crops responded to fertilization (Figure 1). An application of 60 N kg ha^{-1} to summer maize without fertilizing the follow-up oat cover crop did not improve oat biomass, when biomass yields from the R3 and R4 treatments were compared. The practice of applying 60 kg N ha^{-1} is common in small-holder irrigation schemes but, it may not leave enough residual fertility for improved oat growth, necessitating the supply of fertilizer. This may make it unsuitable for resource poor farmers who are unable to buy fertilizers. On the other hand, grazing vetch may require less fertiliser, presumably because it is able to fix nitrogen. Grazing vetch symbiotically fixed an average of 111.5 kg N ha^{-1} or 29.8% NdA with oats as the reference crop (Table 3). Other studies estimated N fixation rates in grazing vetch, with oats as reference crop, ranging from 42 - 95% NdA (Monsen et al., 2005), 70 to 98% NdA (Monsen and Shennan, 2006) and 78 - 82% NdA or 131 - 163 kg N ha-1 (Haque and Lupwayi, 2000). Site specific factors such as soil fertility, differences in growth rates and N uptake of reference crops across sites may explain the differences. This may also be compounded by methodological factors as accurate estimations using this method require the legume and reference crops to absorb similar amounts of nitrogen from the soil (Hardarson and Danso, 1993).

Steiner (1998) reported that a permanent soil cover is critical for the success of no-tillage systems. Farmers in Brazil aim for biomass yields between 6 – 10 t ha^{-1} to ensure success of CA systems (Derpsch, 2005). Winter biomass yields of at least 5 t ha^{-1} are necessary for control of summer growing weeds in the south-western parts of SA (Fourie et al., 2001). The high biomass yields (> 9 t ha^{-1}) obtained from oats, grazing vetch and forage peas may be high enough for CA to be practiced successfully. Lupin yields may be too low to sustain any meaningful CA technology. The rhizobium strain used may not have been suitable for lupin resulting in its poor growth. Lack of adaptation to the agro-ecology by the lupin may also be a factor. Fourie et al. (2001) reported that climatic conditions, temperature and rainfall, play an important role in the amount of dry matter produced by cover crops. Effective weed suppression is one of the major requirements of a cover crop in smallholder farms. Actively growing cover crops can control weeds by out competing weeds for resources through fast growth rates or allelopathy. The allelopathic effects of oats are widely acknowledged (Fujii, 2001; Sanchez-Moreiras et al., 2004). Oats and grazing vetch were in reducing weeds biomass probably because of their superior CGR (Figure 2). This agrees with work done in the USA that recommends oats and grazing vetch for weed control (SAN, 2007). About 69% of the variation in weed dry weight was explained by amount of cover crop dry weight, irrespective of cover crop species (Figure 6). This suggests that amount of cover crop dry weight was more important than other factors in determining weed suppression. Teasdale (1996) also reported that weed control increased with increased cover crop biomass production. Cover crop growth habit may also explain variations in weed dry-weights. For example, in the second season, despite the higher forage pea dry weights than grazing vetch, it had higher weed biomass. This may be the result of slow initial growth of forage peas than grazing vetch (Figure 2b), and its upright growth habit allowing more light to reach the soil surface, leading to greater initial weed growth. However, the greater weed set from the previous year also have been factor. Grazing vetch has a creeping growth habit, which ensures a quick ground cover thereby cutting off light supply to weeds that may grow (Lu et al., 2000).

One practical implication of the superiority of oats and grazing vetch with respect to weed control is that they may be more suitable when introducing CA systems where weeds are a major problem, while forages peas may also be an option in the later cycles of growing cover crops. This is because weed dry weights drop from the initiation of CA onwards, as observed in this study and elsewhere (Bàrberi and Mazzoncini, 2001). It has also been observed that to restrict the build-up of pests and soil-borne diseases cover crops must be rotated (Fourie et al., 2001). It is therefore important to have a variety of species for cover cropping. While oats and grazing vetch maybe used in the initial stages of introducing CA, as weed densities decrease because of CA, forage peas may be a viable alternative in the rotation of cover crops because of its high biomass production. The major weeds species in the plots were *Bromus cartharticus* and *Capsella bursa-pastoris*. Other broadleaf weed species were also observed. However, species diversity was reduced in oats and grazing vetch, implying species-specific weed control by these cover crops. Oats and grazing vetch effectively out-competed most of the minor broadleaf weeds such as *Ciclospermum leptophyllum*, *Sonchus oleraceus*, *Lepudium bonariense*, *Taraxacum officinale*, *Lepudium bonariense*, *Oxalis latifolia*, *Galinsoga parviflora*, *Lepudium bonariense* and *Sisymbrium capense*. That cover crop species are able to selectively suppress some weed species more than others has also been reported elsewhere (Carson and Peterson, 1990; Teasdale, 1996). Oats were able to effectively out-compete weeds but complete control was not possible. In the second season, fewer weed species were observed compared with the first season, probably because of the maize residues averaging 8 t/ha which were left on the ground.

The N concentration of cover crops generally decreased as they matured. This is explained by increases in the observed C concentration, resulting in a general increase of the C: N ratio as cover crops matured (Figure 4). This may suggest that cover crop kill dates are critical as they affect the C: N ratio especially in oats were C: N ratios are known to exceed 35 (Baggs et al., 2000). Plant residues with a C: N ratio exceeding 25:1 are not easily broken down by soil microbes and may result in immobilisation (Clark et al., 1994). At 125 days after sowing, oats had a C: N ratio of about 23.5 while grazing vetch had a C: N ratio of only 11.1. The C:N ratio results suggest that oats may persist as mulch and smother weeds for a longer period in a succeeding crop, while grazing vetch may contribute N through faster decomposition (Clark et al., 1994). Total N uptake was highest in grazing vetch (345 kg ha^{-1}) followed by oats (253 kg ha^{-1}). The superiority of grazing vetch over oats with respect to N uptake, despite lower biomass yields may be explained by the ability of the former to fix nitrogen from the atmosphere. Grazing vetch fixed about 111.5 kg N ha^{-1} which may translate to about 400 kg AN (28% N) with a current market value of about US$ 220.00. According to the Department of Agriculture, (2008) maize yields of 10 t/ha is achievable with LAN application of 650 kg ha^{-1} under irrigation. This may mean that grazing vetch can potentially supply over 60% of the N required by a maize crop, substantially reducing fertilizer costs. This may make grazing vetch particularly more attractive than oats since oats require a significant investment in fertilisers while grazing vetch require less fertilization for its growth. Cereal cover crops such as oats do not add N to the system, but reduce N losses from leaching by immobilising it (Clark et al., 1994).

Conclusions

Legumes such as grazing vetch and forage peas may be grown to maximise biomass yields with minimal fertilizer inputs, while oats may need fertilisation. Maize fertilization, in the summer season, does not leave enough residual fertility to optimize oat growth. Amount of cover crop biomass produced was a major factor in controlling winter weeds. Oats and grazing vetch are more superior to faba bean, forage peas and lupin in smothering weeds while there was a progressive decline in the winter weed burden from the first to the second season. The low C: N ratio of grazing vetch (<15) and its high N content make it attractive for resource-limited farmers in warm-temperate climates.

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