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FEASIBILITY OF WINTER COVER CROP PRODUCTION UNDER RAINFED CONDITIONS IN THE EASTERN CAPE PROVINCE OF SOUTH AFRICA

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ABSTRACT

Low winter rainfall poses a challenge to production of high biomass from cover crops, which is necessary for the success of conservation agriculture systems in the Eastern Cape Province of South Africa. An experiment was conducted to evaluate the adaptability of white oats (*Avena sativa*), grazing vetch (*Vicia dasycarpa*), rye grass (*Lolium multiflorum*), barley (*Hordeum vulgare*), radish (*Raphanus sativa*) and triticale (*Triticale secale*) production under low winter rainfall conditions in the Eastern Cape. The cover crop species were relayed into maturing maize (*Zea mays* L.) in February, March and April of 2010, exposing them to varying rainfall conditions. They were followed with summer maize. Growth rate and final biomass of cover crop species decreased with delayed planting, except for radish. February planted cover crops had the lowest residues remaining at maize planting, resulting in higher weed dry weights at 3 and 6 weeks after planting (WAP). April planted cover crops improved soil N by a greater margin compared to earlier plantings, which were comparable within their category. Grazing vetch and radish resulted in the greatest soil N improvement. Significantly higher ($P<0.05$) maize grain yield was recorded in grazing vetch, while all other species had comparable yields. It is, thus feasible to produce cover crops under winter rainfall conditions in the Eastern Cape and grazing vetch and radish can serve this purpose.

Key Words: Barley, oats, radish, vetch

RÉSUMÉ

Une faible pluviosité en temps d'hiver constitue une contrainte majeur à la production d'une biomasse suffisante des cultures de couverture nécessaires pour la réussite des systèmes d'une agriculture de conservation en province Est du Cape en Afrique du Sud. Une étude était conduite pour évaluer l'adaptabilité de l'avoine (*Avena sativa*), le vesce (*Vicia dasycarpa*), l'ivraie (*Lolium multiflorum*), l'orge (*Hordeum vulgare*), le radis (*Raphanus sativa*) et le triticale (*Triticale secale*) en conditions de basses pluviosité de l'Est de Cape. Les espèces de cultures de couverture étaient relayées sur le maïs (*Zea mays* L.) en pleine croissance en Fevrier, Mars et Avril 2010, les soumettant ainsi à des conditions de pluviométrie variées, suivi en suite de la culture de maïs en été. Le taux de croissance et la biomasse des cultures de couverture ont diminué avec le semis retardé excepté pour le radis. Les plantes de couverture plantées en Fevrier ont produit une plus petite quantité de résidues restantes à la plantation du maïs, résultant en un poids sec plus élevé des herbes envahissantes après 3 et 6 semaines de la plantation. Les plantes de couverture plantées en Avril ont considérablement amélioré l'azote du sol en comparaison aux cultures de couverture plantées plus tôt, ce qui était comparable à l'intérieur de sa catégorie. Le vesce et le radis ont induit une amélioration plus élevée de l'azote. Un rendement significativemet ($P<0.05$) plus élevé en grain de maïs était observé sous le vesce, pendant que toutes les autres espèces avaient des rendements comparables. Il est donc plus faisable de produire les cultures de couverture en conditions de pluviosité d'hiver à l' Est de Cape, le vesce et le radis étant pour ce faire les mieux indiqués.

Mots Clés: Orge, ivraie, radis, vesce

INTRODUCTION

Cover cropping is one principle of conservation agriculture (CA) currently promoted to arrest and reduce soil degradation processes in the rural communities of the Eastern Cape Province of South Africa. Scientific evidence has shown that cover cropping offers many benefits, which include improvement of soil fertility, conservation of soil moisture and weed suppression (Murungu *et al*., 2010). In the Eastern Cape, poor soil fertility and weed infestation are the major maize yield barriers (Fanadzo *et al.,* 2009). If cover cropping is able to address these problems, then it is more likely to be accepted by smallholder farmers.

The experience gained thus far has shown that winter cover cropping under irrigation can produce enough cover crop biomass, to ensure soil cover for the subsequent summer crop (Murungu *et al.,* 2010; Musunda, 2010). However, maintenance of permanent cover from one summer season to the next, under rain fed conditions, is a challenge, as ascertained by Ganyani (2010) in his study of conservation agriculture systems in the central Eastern Cape. In that study, most residues from the previous summer crop had degraded by the time of planting the next summer crop. Furthermore, soil fertility improvement by summer-grown cover crops was often not realised due to a lack of synchrony between nutrient release and uptake by the follow-on crop. Improved synchrony, as observed by Murungu *et al.* (2010), with irrigated winter cover crops suggests that the successful production of winter cover crops under dry land conditions could provide several advantages. It would lead to permanent soil cover, better weed suppression and the synchronisation of nutrient release and usage by a follow-on summer crop.

The central region of the Eastern Cape receives annual rainfall of about 575 mm, a quarter of which is received in winter, from May-August (Ganyani, 2010). It is not known whether producers could rely solely on winter rainfall for the production of cover crops given the low amounts of rain experienced. A successful strategy of winter cover crop production would, of necessity, attempt to utilise some of the summer rains, without unduly increasing competition for water with maize, the main summer crop. Analysis of the Alice station in the central Eastern Cape showed that cover crops planted in February, March and April could potentially receive about 221, 172 and 140 mm of rainfall, respectively. Planting during these late summer months also offers high frequencies of wet spells, ideal for successful cover crop establishment under rain fed conditions, in comparison to the winter months (Ganyani, 2010).

Several strategies can be used to introduce cover crops into smallholder maize-based cropping systems. Rotation would be difficult for many because of the small size of landholdings. Intercropping, in particular, relaying of two or more crops in the field at the same time during part of the season, would minimise investment in terms of labour allocation and the requirement for tillage for establishment of the cover crop and possibly fertilisers. Studies by Ganyani (2010) and Chimonyo (2012) showed that it is feasible to realise maize yields of 3-4 t ha^{-1} under rainfed conditions with good agronomic management, particularly timely planting and weed control. Relaying cover crops, particularly after late vegetative stage of maize, would reduce competition for the low amounts of rainfall received in the summer months.

Selection of cover crops tolerant to low rainfall conditions is the key to successful production of winter cover crops under rain fed conditions in the Eastern Cape. A number of cover crop species have been reported to grow in limiting moisture conditions. These include Italian rye grass (*Lolium multiflorum*) (Evans and Scoles, 1997), grazing vetch (*Vicia dasycarpa*) (Zulfiqur *et al*., 2006), white oats (*Avena sativa*), forage radish (*Raphanus sativa*) (Weil *et al*., 2007) and barley (*Hordeum vulgare*) (Pala *et al*., 2008).

The objective of this study was to investigate the feasibility of producing winter cover crops under rainfed conditions in the Eastern Cape in South Africa.

MATERIAL AND METHODS

Experimental site. The study was carried out at the University of Fort Hare Research Farm (32° 472 S and 27° 502 E). The farm is at an average altitude of 508 m above sea level and has an average annual rainfall of 575 mm, and annual mean temperature of 18 °C. The soil is an Eutric Cambisol (IUSS Working Group WRB, 2006), with pH 5.9, electrical conductivity of 0.14 d Sm^{-1}, total C and N of 0.81 and 0.08%, respectively; and Bray1 extractable P, 2.19 mg kg^{-1}. At initiation of the cover crop experiment, the field selected was planted to maize, cultivar DKC-61-25, short season and suited for the rainfall of the study area. Relay intercropping was used to introduce the cover crops into the maize from the late reproductive phase onwards.

Treatments and design. The experiment evaluated two factors; planting date and cover crop species laid in a split-plot design replicated three times. Planting date was the main plot factor and cover crop species the sub-plot factor. The main plot factor had three levels; early planting (maize at the late reproductive stage, which was on 25th February), mid-planting (maize at physiological maturity, which was on 25th March) and late planting which was 3 weeks after maize harvest on 23rd April 2010. The subplots consisted of cover crop species; white oats (*Avena sativa* var Pallinup), grazing vetch (*Vicia dasycarpa* var Max), Italian rye grass (*Lolium multiflorum* var PAN Dargle), barley (*Hordeum vulgare* var SVG 13), Japanese radish (*Raphanus sativa* var Star) and triticale (*Triticale secale* var PAN 248). A weedy fallow was included as a control at each planting and was left with the maize crop for the first two planting dates and with maize stover for the last planting date.

Cover crop management. Cover crops were drilled into small furrows 30 cm apart in 6 m x 3 m sub-plots at 100 kg ha^{-1} for white oats, barley and triticale, 50 kg ha^{-1} for grazing vetch, 30 kg ha^{-1} for Japanese radish and 40 kg ha^{-1} for Italian rye grass. Grazing vetch was inoculated with *Rhizobium leguminosarium* bio var *viciae* inoculant with 5 x 10^{8} rhizobial cells g^{-1} (Stimuplant CC, Zwavelpoort 0036, SA) just before planting. Only basal fertiliser was applied to the cover crops at planting as Compound 2:3:4 (30) + 0.5% Zn to supply 13.3 kg N ha^{-1}, 20 kg P ha^{-1} and 26.7 kg K ha^{-1}. No weed or pest control was done during the growth of the cover crop.

Cover crop sampling and weed evaluation. Destructive sampling of cover crops and weeds was done using two randomly thrown 0.35 m x 0.35 m quadrants. Sampling was done at 58, 68, 83, and 123 DAP (days after planting) for February planted cover crops, 33, 62, 93 and 126 DAP for March planted and 42, 67, 90 and 126 DAP for April planted. All cover crop and weed biomass present within the quadrant were cut at ground level in each plot excluding the protruding radish roots. Harvested biomass was separated into cover crop and weeds. All the samples were oven dried at 65 °C, to constant mass, and weighed. A weed species count was done at cover crop termination using 1 m x 1 m quadrant and weed species were identified following guidelines by Bromilow (1995). Cover crops were terminated by application of Glyphosate (360 g l^{-1}) at a rate of 3 L ha^{-1} (300 ml in 20 liters of water) and rolling with a tractor-drawn roller. The residues were left to degrade on the soil surface. February, March and April planted cover crops were terminated in June, July and August 2010, respectively.

Biomass decomposition. To measure the amount of biomass by the time of maize planting, a litter bag study was carried out a week after termination of cover crop. The biomass samples collected at each termination from the cover crop and weed fallow plots were used in this study. Three 0.20 m x 0.20 m nylon litterbags (1 mm pore size) were filled with 10 g of the oven-dried material from each plot as means of indexing cover crop decomposition in different plots (Devi and Singh, 2009). The litterbags were randomly placed on the soil surface of their corresponding treatment plots a week after termination and rolled-on.

The three litterbags were collected at maize planting, from each plot. Roots were removed from the non-decomposed material in the litterbags and oven-dried to constant mass at 65

°C for dry weight determination. The effects of soil adhering to plant materials were discounted by ashing the samples in a muffle furnace at 450 °C for 5 hours. Ash free dry weight representing the true weight was determined by subtracting the ash content from the sample dry weight before ashing. The amount of cover crop or weed residue remaining (R) in the field was calculated using Equation 1 below.

*R (kg/ha) = (AFDW (g))/IWL(10g) * ADWT (kg/ ha)* .... (Equation 1)

AFDW = ash free dry weight in grammes, IWL being the initial residue weight at initiation of the litterbag study (10 g); and ADWT = either cover crop or weed dry weight at termination in kg ha^{-1}.

Chemical composition of soil. Three random soil samples (0-20 cm depth) were taken, and mixed to make a composite sample for each plot, at follow-on maize planting. The samples were air-dried and ground (<1 mm). Total C and N content were determined using the LECO C/N analyser (LECO Cooperation, 2003). Soil pH was determined in water and soil inorganic P was measured using the Bray 1 method, as outlined by Okalebo *et al.* (2002).

Follow-on maize production. A short season maize cultivar, DKC 61-25, popular with the local rainfed farmers (Fanadzo *et al*., 2009), was planted in plots previously under cover crops and weed fallow. The crop was planted on 29 October 2010, at a spacing of 50 cm in-row and 90 cm inter-row targeting a population of 22,000 plants ha^{-1}. Hand-held jab planters, recommended for minimal soil disturbances were used for maize planting. The planters dropped 2-3 seeds, and the crop was later thinned to one plant per station at three weeks after planting (3 WAP). Fertiliser was applied at 60 kg N ha^{-1}, with a third of the N applied as a basal Compound fertiliser with an N: P: K ratio of 2:3:4 at planting. The remainder was applied as top-dressing of limestone-ammonium nitrate (LAN) with 28% N at 6 WAP.

Weed control in the maize crop was only done after 9 WAP to allow measurement of effect of cover crop residues on weeds during the critical phase of weed competition in maize. Thereafter, weeds were controlled using Basagran (a.i: thiadiazine 480 g l^{-1}) applied at 5 L ha^{-1}. No supplementary irrigation was applied to the maize crop. The sampling of weed biomass in the maize crop was done as described for cover crops above, at three week intervals up to 9 WAP. The weed species count and identification was done only at 9 WAP. Maize grain yield and stover estimates were taken from a net plot of 2 m x 1.5 m from the two central rows. Whole maize plants were sampled from the ground level and the stover dry weight was determined after oven drying for 72 hrs (to a constant weight) at 65 °C.

Data analyses. The data were subjected to two-way analysis of variance using GenStat Release 12.1 statistical software (Lawes Agricultural Trust, 2009). Treatment means were separated using the least significant difference (LSD) at P<0.05. 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 (Gomez and Gomez, 1984). The cover crop growth rate was analysed by comparing the slopes of the regression lines of plots of cover crop dry weights against time (Fageria *et al.,* 2006). This method was used because the limited number of sampling points made it difficult to plot a sigmoid curve to analyse growth. To determine differences in cover crop growth rates, homogeneity of the regression coefficients was tested as described by Gomez and Gomez (1984). Correlation analyses were performed to determine the relationship between cover crop biomass and weed abundance measures; and residue remaining and weed abundance measures.

RESULTS

Cover crop dry weight accumulation. There was a significant interaction (P<0.01) between planting time and cover crop species growth rates (CGRs). Both planting time and cover crop species main effects were highly significant (P<0.01 and P<0.001, respectively). For February and March planted cover crops, vetch had the highest CGR, while radish achieved the highest CGR for April plantings (Table 1). Radish CGR was higher in

March and April plantings compared with February planting. In contrast, grazing vetch CGR was higher with February and March plantings and lower with April planting. For oats, February planting had higher CGR than March and April. Rye exhibited similar trend to that of oats whilst there were no differences in CGR observed for the three planting scenarios with triticale.

There was a significant interaction (P<0.001) between planting time x cover crop species for cover crop dry weights at termination (Fig. 1). February planting gave the highest cover crop

TABLE 1. Regression analysis for cover crop species and planting time on cover crop growth rates (CGRs) at the University of Fort Hare Research Farm in South Africa

Cover crop	February planting		March planting		April planting	
	Slope	R^2	Slope	R^2	Slope	R^2
Barley	19.2	0.99	21.8	0.99	13.9	0.95
Oats	30.2	0.72	24.1	0.90	8.9	0.83
Radish	23.5	0.73	42.1	0.89	38.9	0.99
Rye	40.3	0.96	16.1	0.88	11.2	0.98
Triticale	14.6	0.93	5.9	0.98	20	0.81
Vetch	45.8	0.92	46.1	0.99	26	0.99
$LSD_{0.05}$ (Species)	5.20					
$LSD_{0.05}$ (Planting month)	9.94					
$LSD_{0.05}$ (Interaction)	16.12					

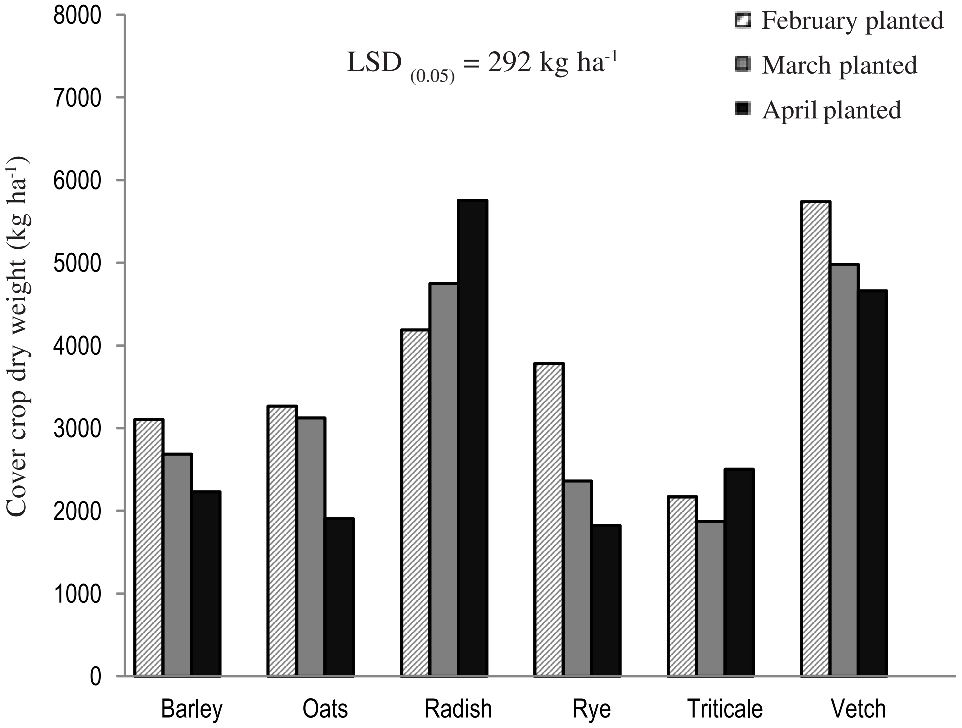

Figure 1. Interaction effects of planting date and cover crop species on cover crop dry weight at termination in Eastern Cape Province, South Africa.

dry weights, except for triticale and radish. In the case of radish, highest dry weight was achieved with April planting, while there were no differences observed for the three plantings with triticale.

Weed dry weights and species counts. There was a significant interaction between planting time x cover crop species ($P<0.001$) for weed dry weights. Barley, oat, triticale, vetch, rye and weedy fallow had significantly different weed dry weights at all the planting times. Weed dry weights decreased with delay in cover crop planting in all the cover crop treatments. Weed fallow gave the highest weed dry weights; the least dry weights were measured from radish, vetch and rye across the planting dates (Fig. 2).

There was no significant interaction between cover crop species and planting time with respect to weed species density (per m^2) at cover crop termination. However, main effects of cover crop species were significant ($P<0.001$), but planting date was not significant ($P>0.05$) (Table 2). Weedy fallow had the highest number of weed species; while rye, vetch and radish had the lowest and comparable to white oats. The weed species counts in the barley and triticale treatments were higher than in the radish, rye and vetch treatments, but lower than in the fallow. The major weed species observed were *Galinsoga parviflora, Lamium amplexicaule, Conyza canadensis, Lactuca serriola, Senecio vulgaris and Crepis runcinata.*

Residue persistence. A significant interaction ($P<0.001$) between cover crop species and planting time was observed with the amount of residues remaining at maize planting (Fig. 3).

TABLE 2. Weed species counts observed in cover crop species at cover crop termination

Cover crop species	Weed species (counts m^{-2})
Barley	3.4
Oats	2.7
Radish	2.1
Rye	2.1
Triticale	3.2
Vetch	2.1
Weedy fallow	5
$LSD_{0.05}$	0.7
CV (%)	15.30

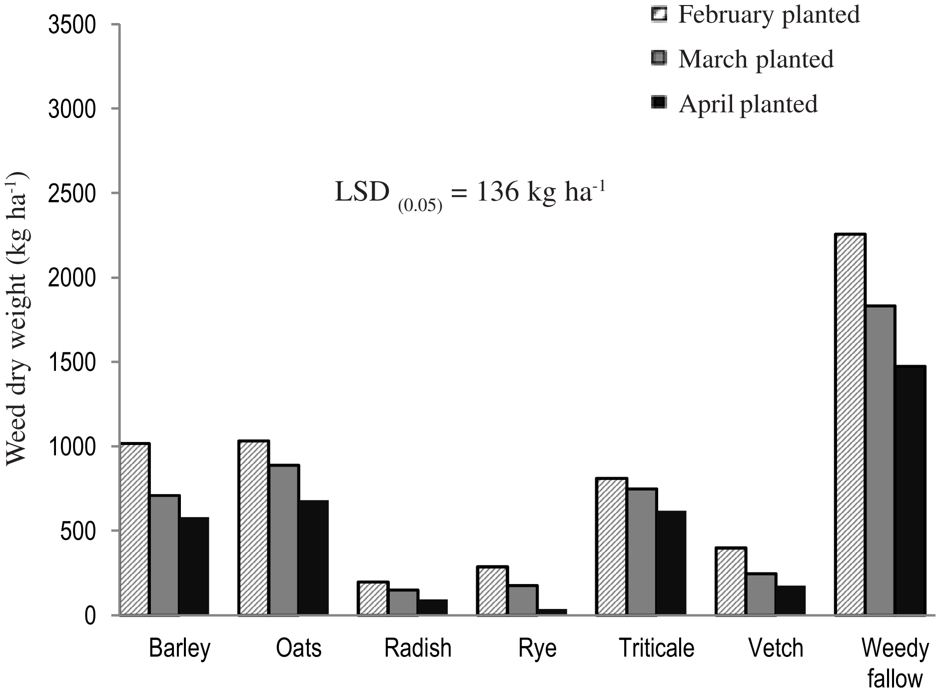

Figure 2. Weed dry weights at cover crop termination in Eastern Cape Province, South Africa.

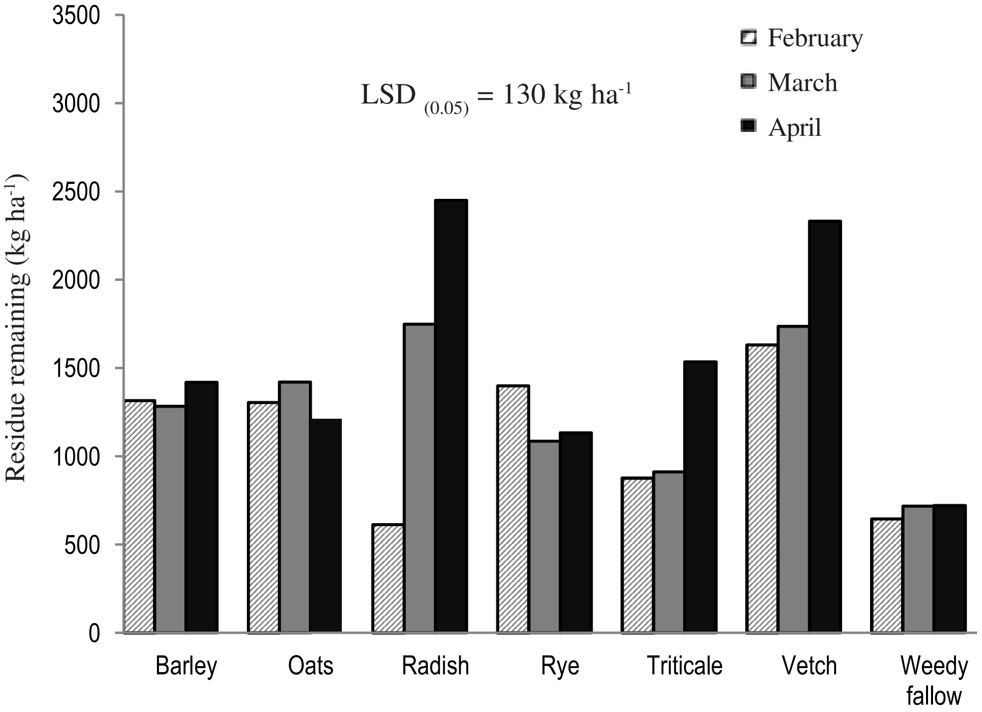

Figure 3. Amount of residues remaining at maize planting in Eastern Cape Province, South Africa.

Barley, oats and weedy fallow residues were similar for all three planting scenarios. Late planted radish, triticale and vetch had high residues remaining at maize planting compared with earlier plantings. Rye was the only species that achieved higher residues from February plantings compared with April planting. April plantings of radish and vetch had the highest amounts of residue remaining at maize planting. Weedy fallow consistently achieved the least amount of residues across all three planting scenarios except for February planting when it was similar to radish.

Total carbon and N, and extractable P. The interaction between cover crop species and planting date was not significant with respect to soil total C and N, and Bray 1 extractable P measured at maize planting. However, cover crop species and planting time main effects were significant ($P<0.05$) for total C and N, but not extractable P (Table 3). Plots where cover crops were planted in March had higher total C than those planted in April. Plots previously under cover crops planted in April had higher total N

TABLE 3. Residual effect of time of planting and cover crop species on selected soil properties measured at maize planting in Eastern Cape Province in South Africa

Planting date	Total N	Total C	P (Bray 1)
	...........%...........		... mg kg^{-1}...
February	0.081	0.82	2.43
March	0.083	0.85	2.46
April	0.089	0.79	2.40
LSD $_{0.05}$	0.005	0.42	Ns
Cover crop species			
Barley	0.079	0.85	2.34
Oats	0.085	0.82	2.46
Radish	0.091	0.88	2.25
Rye	0.084	0.83	2.44
Triticale	0.081	0.76	2.47
Vetch	0.09	0.80	2.59
Weedy fallow	0.078	0.78	2.48
LSD $_{0.05}$	0.008	0.06	Ns
CV (%)	9.59	8.13	10.45

CV = Coefficient of Variation; NS = no significant difference compared to the February and March planted cover crops. Vetch, radish and oats gave higher total N than the weedy fallow, which had the lowest. Only radish plots had greater total C than the weedy fallow.

Weed suppression in maize. The interaction of cover crop species x planting time was not significant with respect to weed dry weights sampled at 3, 6 and 9 WAP in the follow-on maize crop (Table 4). However, the main effect of planting time was highly significant ($P<0.001$) at all three samplings; while cover crop main effect was only significant ($P<0.05$) at 3 WAP. Plots previously planted to cover crops in February gave the highest weed dry weights, while those planted in April had the lowest. At 3 WAP, the weedy fallow treatment had higher weed dry weights than all the cover crop treatments, which were comparable in their category. High cover crop biomass remaining at maize planting resulted in low weed dry weights as observed in significant negative correlation values of -0.66 , -0.65 and -0.72, at 3, 6 and 9 WAP, respectively.

There was no significant interaction between planting time and cover crop species with respect to weed species count at 9 WAP. Cover crop species main effect was significant ($P<0.01$). The weedy fallow had higher species count (per m^2) but was similar to barley and oats. Vetch, rye, radish and triticale had lower species number, but did not differ with oats, while triticale did not differ from barley (Table 5). The common summer weeds that were found in the follow-on maize were *Galinsoga parviflora, Amaranthus hybridus, Chenopodium album, Portulaca oleracea, Cyperus esculentus* and *Nicandra physaloides.*

Maize yield. There was no significant interaction of cover crop species and their planting time for maize grain yield. However, main effects of both cover crop planting time ($P<0.001$) and cover crop species ($P<0.5$) were significant (Table 6). With regard to planting time, highest maize grain yield (3,888 kg ha^{-1}) was measured in plots previously under March planted cover crops. With regard to cover crop species, plots previously sown to vetch had higher maize grain yield than all other cover crop treatments, which did not differ from the weed fallow control. No significant differences ($P>0.05$) were noted with regard to maize stover dry weights which ranged from 8933 to 9800 kg ha^{-1} amongst all the treatments.

TABLE 4. Residual effect of time of planting and cover crops species on weed dry weights (kg ha^{-1}) at three sampling periods during growth of the follow–on maize

Planting date	3 WAP	6 WAP	9 WAP
February	183	553	883
March	154	494	872
April	114	456	771
$LSD_{0.05}$	29	49	45
Cover crop species			
Barley	155	494	820
Oats	147	523	850
Radish	139	514	843
Rye	133	472	837
Triticale	145	482	856
Vetch	128	464	797
Weedy fallow	206	560	894
$LSD_{0.05}$	44	NS	NS
CV (%)	30.45	14.98	8.49

CV = Coefficient of Variation; NS = no significant difference

TABLE 5. Residual effect of cover crop species on weed species counts in follow-on maize crop at 9 WAP in Eastern Cape Province, South Africa

Cover crop species	Weed species (counts m^{-2})
Barley	2.7
Oats	2.4
Radish	2
Rye	2
Triticale	2.2
Vetch	2
Weedy fallow	2.9
LSD (0.05)	0.6
CV (%)	14.76

CV = Coefficient of Variation

TABLE 6. Residual effect of time of planting and cover crop species on maize grain yield (kg ha^{-1}) in Eastern Cape Province, South Africa

Planting date	Grain yield (kg ha^{-1})
February	3514
March	3888
April	3508
LSD $_{0.05}$	195
Cover crop species	
Barley	3537
Oats	3578
Radish	3584
Rye	3665
Triticale	3570
Vetch	4005
Weedy	3516
LSD $_{0.05}$	299
CV (%)	8.64

CV = Coefficient of Variation

DISCUSSION

Based on the results of this study, it is clear that under the conditions of this study, it is feasible to grow winter cover crops in the Eastern Cape Province, improving the potential of successful establishment of CA systems under rain fed conditions. Planting at the tail end of summer produces sufficient biomass to provide cover during the normally long winter fallow period (Figs.1 and 3). February planted cover crops achieves the highest biomass, except for radish; but this did not translate into better services or higher yield for the follow-on maize crop. Better soil cover shown by the residues remaining at maize planting time, higher total soil N and better weed suppression were observed in April planted plots. March-planted cover crops provided relatively higher maize grain yield in comparison to the other planting times, regardless of the lower biomass achieved in these plots at termination of the cover crops. This suggests that mid-plantings favour persistence of cover crop residues and possibly better synchrony in terms of release of nutrients for the follow maize crop.

The results of the litterbag study could be explained by the amount of biomass input and residence time up to maize planting. The higher dry weights in radish and grazing vetch resulted in greater amounts of residues remaining than the other treatments at maize planting. Cover crops terminated in June, July and August had 4, 3 and two months, respectively, to degrade in the soil, which explains the similarity (barley, oat, and triticale) and lower quantity (radish and vetch) of residues remaining in the treatments planted in February than later dates. This effect of residence time was more pronounced with radish and grazing vetch because their C:N ratios are lower than threshold value of 30, beyond which degradation is limited (Schroth, 2003).

There was higher maize grain yield from March-planted cover crop plots compared to the rest of the planting times (Table 6). However, this was despite the fact that April-planted cover crop had relatively higher residue remaining at maize planting and soil total N than the rest of the planting times. The weed suppression from these March-planted cover crop plots was better compared to the February-planted cover crop plots and comparable to the April-planted cover crop plots. However, the data at hand do not readily explain this observation thus further work is required to assess synchrony in the release of nutrients and soil moisture status at maize planting and during maize growth to understand the advantage offered by March plantings of cover crops.

Though parameters measured, except for maize yield, favour April plantings, rainfall data (data not presented) showed that risk of failure of cover crop plantings is higher with April plantings compared to March and February. The rainfall received for each of the scenarios tested in this study was below the long-term average. February planting offered better reliability than either March or April plantings. However, data presented showed that acceptable levels of cover crop biomass were achieved with radish and vetch planted in April when total amount of rainfall achieved was 123 mm for this scenario.

The variation of cover crop biomass, with the planting date, was largely dependent on the CGRs. The improved growth of the cover crops, except radish, when planted in February (late summer) was in agreement with Odhiambo and Bomke (2001), who reported similar results for hairy vetch, under the Rego Humic gleysols of the British Columbia. This could be as a result of better soil moisture (higher rainfall), warmer temperatures and longer days before the onset of low temperatures and shorter day lengths. In contrast, radish CGR and biomass was higher with delayed planting because it is a cool season crop. Radish is also able to tolerate drier conditions and use its long tap root to draw moisture from depths (Weil *et al.,* 2010).

Grazing vetch, rye and radish offered best weed suppression in all the cover cropping scenarios, (Table 2) mainly as a result of the greater biomass accumulation which smothered the weeds (Teasdale *et al.,* 2007; Musunda 2010). Whereas rye did not accumulate as much dry matter, its high weed suppression effect could be attributed to its growth characteristic of spreading out to form a carpet on the ground, hence reducing light for understory growth (Teasdale *et al*., 2007). The consistently higher weed dry weights and species counts in the weedy fallow plots demonstrated the importance of cover cropping.

However, weed suppression in the follow-on maize was largely influenced by the residue remaining at maize planting (Tables 4 and 5, Fig. 2). Biomass loss was higher in early-planted cover crops than in the late-planted ones due to the longer period between killing date and maize planting. As a result, higher amounts of residue remained in the April planted cover crop plots at maize planting, suppressing weeds in the follow-on crop. However, the ability of radish to control weeds in maize despite accelerated decomposition could be due to the glucosinolates in radish residues, which are known to have allelopathic effects on weeds (Malik *et al.,* 2010).

Plots planted to cover crops in February and March had lower N levels compared to April plantings due to a longer period of decomposition and possibly more leaching of nutrients by the time of maize planting. Roy *et al.* (2010) reported that the mineralisation of wheat and rice crop residues surpass immobilisation at day 40 regardless of temperature. Moreover, the soils of the study area are high in sand (64.2%) and silt (16.0%); and low in clay (19.8%) (Mandiringana *et al.* (2005), a condition which favours high rates of mineralisation (Odhiambo, 2009). The higher soil N in radish and vetch was probably due to a high N uptake by the high biomass levels achieved. However, the higher total soil C in the radish plots requires further verification.

The significant differences observed among the three planting dates with respect to maize grain yield could be attributed to the residual effects of the time of planting cover crop species. Plots previously with March planted cover crops gave the highest grain yield, possibly due to an interaction of factors, including the synchronisation of nutrient release with peak demand by the maize crop and weed control as affected by residue decomposition in the maize crop. The difference in the maize grain yield between the vetch and weedy fallow treatments of 489 kg ha^{-1}, though significant, suggests the need for careful scrutiny of economics of use of vetch as a cover crop under rain fed conditions in the Eastern Cape. However, CA may not always result in reasonable returns during the early stages of adoption (Dube, 2012). Therefore, it is necessary to study the economics of using the identified best performing species over a long-term.

CONCLUSION

Greater cover crop biomass yield, residual soil N and follow-on maize yield can be achieved if grazing vetch is planted in February and March, to benefit from late summer rains and warm conditions. Although the yield advantage of vetch is agronomically significant, more work is required under more representative smallholder farmer conditions to confirm the economic advantages of vetch under rain fed conditions in the Eastern Cape. Radish could be used for delayed planting in April.

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