On-farm Assessment of Cover Crop Management Effects on Plant Tissue Nutrients and Soil pH in the Western Cape Province

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***Abstract*—** The choice of cover crop (CC) species and their growth termination stage is crucial to optimize their benefits. Field experiments were carried out at two sites (Nietvoorbij and Bien donne) in the Western Cape, from 2017 to 2018. This study examined the: (i) Effect of two termination stages (vegetative and flowering) on the chemical composition (C, N and C:N) of four CCs (oats, rye, pea, vetch) and (ii) Short-term impacts of living CCs and residues on soil pH. The experiment was conducted in a randomized block design with three replicates. Plants were sampled at kill while soil was sampled at kill and one year after. Delaying termination from vegetative till flowering increased the total C and C:N ratios of vetch, pea, oats and rye, respectively, while their tissue N decreased, at both sites. CC presence also decreased soil pH at both sites. Results of this study showed that CC tissue and soil C, N, C:N ratios may be manipulated through appropriate species selection and termination stage. However, longer-term studies are needed to evaluate the long-term effects of CC species on soil pH which have the potential to affect microbial activities and nutrient release.

***Keywords*—** Carbon, cover crop, nitrogen, pH

I. Introduction

Conventional farming practices are among the key factors increasing soil degradation and seriously impairing global agricultural production [1]. The cultivation and proper management of cover crops (CCs) can serve as a viable approach to maintain and improve soil fertility [2]. CCs may be legumes and non-legumes/grass. They improve soil organic matter, aggregate stability, nutrient supply, water retention capacity and reduce soil erosion, thereby enhancing soil physical, chemical and biological properties [3].

The chemical composition of CC residues, such as C:N ratio and lignin are important features influencing the breakdown process and N release in the soil [4]. CC chemical composition, however, varies with species and growth stage [5]. Grass residues usually have high C:N ratio, are more effective at increasing soil C concentrations and persist longer on the soil surface than legume CCs owing to slower putrefaction of grass CC residues [6]. Legumes, on the other hand, have higher N contents and therefore lower C:N ratios that permit rapid decomposition and N release for the following crop [7]. However, it is crucial to consider and manipulate C:N ratio of CC residue to preserve soil cover when preferred but allow optimum decomposition, nutrient recycling and release rates. Several studies have reported that CCs including vetch, pea, rye, oats and crimson clover grown during fallow periods or rotation systems, considerably increased soil organic carbon (SOC), N and concentrations in contrast to plots without CCs [8, 9]. However, very little is known about the impact of the CCs on soil pH, which is one of the important soil chemical properties that control nutrient availability, organic acids, root growth and enzyme activities.

Therefore, the objectives of this study were to determine the (i) effect of two growth termination stages on the chemical composition (C, N and C:N) of CCs and (ii) short-term impacts of CCs on soil pH.

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II. Materials And Methods

A. Experimental description

The study was conducted from 2017 to 2018 at two fallow sites, 42 km apart; at the Agricultural Research Council (ARC) Nietvoorbij Research Farm (33°55'10''S, 18°51'57''E) and ARC Bien Donne Research Farm (33°50'30''S, 18°58'59''E), in the Western Cape Province, South Africa. The sites are under a Mediterranean climate, with a mean annual temperature of about 18°C, a January mean of about 24°C and a July mean of about 13°C. A randomized block design was used and each treatment was replicated three times, at both sites. The experiment consisted of five CCs namely; oats (*Avena sativa L.*), rye (*Secale cereal L.*), pea (*Pisum sativum*), vetch (*Vicia dasycarpa Ten.*) and a control (no CC), which were terminated at two growth stages (vegetative and flowering). Details of the baseline soil characteristics, plot sizes, CC seeding and fertilizer rates and termination dates have been reported by [10].

B. Plant/Soil sampling and analysis

Before CC termination (hereafter referred to as kill), a 0.25

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m^2 quadrat was used to collect aboveground biomass per treatment plot with a cordless grass shear at the ground level, at both sites. Biomass samples were oven-dried at 60°C for 48 hours and were ground through a 1 mm screen using a Polymix Kinematica (PX-MFC 90 D). The total N concentration was measured in the plant samples (0.1 g) using a TruSpec N Nitrogen Analyzer (LECO, St. Joseph, MI, USA). The total C concentration in the plant was measured by wet-combustion analysis (Dalal 1979; Shaw 2006). The C:N ratio was then determined from these two values. Soil samples were randomly collected from 3 points per treatment plot (0 - 15 cm depths) just before CC kill and at one year after. The composite soil samples were passed through a 2 mm mesh. Soil pH was analysed in a 1:2.5 Soil: KCl mixture (1 M KCl solution) using a glass electrode pH meter (PHS-3BW Benchtop pH/mV Meter).

C. Statistical analysis

The trials were conducted at two sites. Levene’s test for homogeneity of experimental variances was verified for comparable variances [11]. The data were then subjected to a combined analysis of variance (ANOVA) using General Linear Models Procedure (PROC GLM) of Statistical Analysis Software (SAS) (Version 9.4; SAS Institute Inc, Cary, USA). Observations over sampling time (kill and one year) were combined in a split-plot analysis of variance with sampling time as a sub-plot factor [12] for soil variables. The Shapiro-Wilk test was performed on the standardized residuals from the model to verify normality [13]. Fisher’s least significant difference was calculated at the 5% level to compare treatment means [14]. A probability level of 5% was considered significant for all significance tests.

III. Results And Discussion

A. Effect of termination stage on cover crop total C, total N and C:N ratio

Termination stage significantly affected CC total C, total N and C:N ratio, at both sites. At both sites, total C concentration of all CCs significantly increased from vegetative stage to flowering, except vetch and rye which marginally increased at Nietvoorbij (Table I). Total C concentrations were highest at the flowering stage in rye (55.5%) and oats (55.5%) at the Nietvoorbij site and in rye (56.2%) and pea (55.8%) at the Bien Donne site. However, tissue N concentration significantly decreased in all CCs from vegetative to flowering with vetch being the highest followed by pea, rye and oats, at both sites (Table I). At both sites, the C:N ratio significantly increased from vegetative to flowering across all CCs with the highest concentration observed in oats followed by rye, pea and vetch. The C:N ratios of vetch and pea were lower than that of rye and oats at vegetative and flowering stages, at both sites (Table I).

This study confirmed that CC termination stage is a crucial management approach as it affected CC total C, total N and C:N ratio concentration, at Nietvoorbij and Bien Donne sites. Also, the general increase in tissue total C and C:N ratio from vegetative to flowering and the differing relationship between legumes and non-legumes detected at both sites, is in agreement with the previous greenhouse pot experiment with similar treatments [15] and the trends reported in other studies [4, 16, 17]. Findings from this study also support previous studies [4, 17] that termination of vetch and pea and most importantly oats and rye at the vegetative stage will improve soil N levels. Thus, early or late termination of rye, oats, pea and vetch can serve as management methods to improve C input, surface cover, microbial activity, N mineralization and reduce N immobilization in cropping systems [6, 18].

B. Effect of cover crop species on soil pH at different sampling times

Living CCs and their residues affected soil pH at both sites. At kill, the soil pH in the control (5.12) plot was significantly higher than the living vetch (4.99) plot and marginally higher than the pea (5.05), oats (5.02) and rye (5.02) plots, respectively, at the Nietvoorbij site (Table II). Similarly, at the Bien Donne site, the soil pH in the control (6.23) plot was significantly higher than the living pea (6.01), rye (6.04) and vetch (6.0) plots, respectively. At one year, soil pH at both sites was reduced across all treatments with the control still being higher than the CC residue plots, except vetch plot which was similar at Nietvoobij (Table II).

The acidity and alkalinity of the soil have been shown to affect nutrient availability, organic acids, root growth and enzyme activities to some extent, hence, making soil pH a determining factor for soil fertility [19]. The results from this study showed that living CCs and their residues reduced soil pH at both sites in the short term, which is consistent with previous studies [9, 19, 20]. This may be due to the acidic root exudates by CCs which may alter nutrient availability at the root surface [20]. Furthermore, when the organic matter is mineralized there is a production of organic acids that could increase the soil acidity [20]. Mukherjee and Lal [9] reported that in one year the presence of pea and turnip decreased soil pH from about 6.7 to 5.7 compared to the control. Additionally, Maltais-Landry [19] indicated that legumes such as faba bean, vetch and pea had lower soil pH compared to no CC and cereal treated soils. This was also noticed in this study with living vetch having the lowest soil pH at both sites including its (vetch) residue at Bien Donne plots. However, under greenhouse conditions, CCs had no impact on soil pH [21]. Although the reduction in soil pH at both sites was observed to be associated with CC presence in the present study, further/future sampling is needed to investigate if the effect is temporary or permanent.

IV. Conclusion

This study suggests that delaying termination till the flowering stage will increase total C and C:N ratio and reduce total N of plant tissue, irrespective of CC species. Thus, early termination of CCs may be targeted to reduce soil C:N ratio for optimum nutrient mineralisation and increase soil N. At both sites, CC presence decreased the soil pH in the short term. CC cultivation may therefore be used to control soil pH in highly alkaline soils as extremely high or low soil pH may cause nutrient deficiency or toxicity to plants. However, the results of this field study suggest that longer periods may be needed to explore the impact of CCs on soil pH in this Mediterranean environment.

TABLE I
INTERACTION EFFECTS OF COVER CROP SPECIES (OATS, PEA, RYE AND VETCH) AND TERMINATION STAGE (VEGETATIVE AND FLOWERING) ON COVER CROP TOTAL C, TOTAL N AND C:N RATIO AT NIETVOORBIJ AND BIEN DONNE STUDY SITES

Site	CC	Termination stage	C (%)	N (%)	C:N
Nietvoorbij	Oats	Vegetative	53.1c	1.9d	30.3d
	Pea		53.2c	2.5b	21.9ef
	Rye		54.3abc	2.3bc	24.1e
	Vetch		53.8abc	3.1a	17.8f
	Oats	Flowering	55.5a	0.8f	65.8a
	Pea		55.1ab	1.4e	40.5c
	Rye		55.5a	1.0f	52.4b
	Vetch		53.6bc	2.2cd	24.4e
Bien Donne	Oats	Vegetative	51.8e	2.0de	25.2d
	Pea		53.7dc	2.7b	19.9e
	Rye		53.1d	2.2c	23.8de
	Vetch		51.5e	4.1a	12.9f
	Oats	Flowering	55.2b	0.6f	86.8a
	Pea		55.8a	1.9e	30.1c
	Rye		56.2a	0.7f	81.2b
	Vetch		54.6bc	2.1cd	25.9cd

CC = cover crop. Each value represents the mean (n = 3). Values within the same column (separated by site) followed by the same letter are not significantly different at $P<0.05$ according to Fisher's least significant difference test (LSD).

TABLE II
COVER CROP SPECIES AND SAMPLING TIME EFFECTS ON SOIL PH AT NIETVOORBIJ AND BIEN DONNE STUDY SITES

Sampling time	CC	Soil pH	
		Nietvoorbij	Bien Donne
Kill	Oats	5.02abc	6.11ab
	Pea	5.05ab	6.01bc
	Rye	5.02abc	6.04bc
	Vetch	4.99bc	6.00bcd
	Control	5.12a	6.23a
One year	Oats	4.92cd	5.96cde
	Pea	4.95bcd	5.88def
	Rye	4.84d	5.86ef
	Vetch	4.89cd	5.83f
	Control	4.95bcd	6.06bc

CC = cover crop. Each value represents the mean (n = 3). Values within the same column followed by the same letter are not significantly different at $P<0.05$ according to Fisher's least significant difference test (LSD).

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