EFFECT OF LEGUME OR GRASS COVER CROPS AND NITROGEN APPLICATION RATE ON SOIL PROPERTIES AND CORN PRODUCTIVITY

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Abstract

Winter Cover Crops (WCC) into continuous agriculture in Uruguay could improve water erosion control, soil organic carbon, and crop productivity. On the other hand, could reduced soil water and nutrients interfering with cash crops. We conducted a four years field study on a clay loam (Typic Argiudol) in Uruguay to evaluate the effects of WCC on soil chemical properties, water content, soil N-nitrate with nitrogen variable rate at V_6 on corn productivity. The six treatments consisted of Common Oat (Avena sativa L.), Annual Ryegrass (Lolium mutiflorum L.), Triticale (× Triticosecale wittmack), Egyptian clover (Trifolium alexandrinum L.), Pea (Pisum sativum L.), and no WCC. The highest corn yields were observed with no WCC (6.47 Mg ha^{-1}), followed by legumes WCC (5.97 Mg ha^{-1}) and grasses WCC (4.52 Mg ha^{-1}). These differences were probably due to more soil water content at corn planting (35%) and soil NO_3-N at corn planting and V_6 (44 and 36%, respectively) in no WCC than overall WCC. The N yield response in V_6 corn was highest in grass WCC (31%), followed by legume WCC (23%) and no WCC (7%). No soil organic carbon different were detected among treatments after four years with low risk of soil erosion. This result could be explained by similar carbon inputs (shoot and roots residue adding corn + cover crops) since the beginning of the experiment (averaged over treatments: 46.5 Mg ha^{-1}). Farmers, who adopt use of WCC, could take disadvantage on low corn yield, therefore could increase cost by adding more N in corn.

Keywords: Cover crop; Corn; N fertilization

Introduction

Winter cover crops (WCC) have an important role in N management and soil erosion control especially in regions that have high levels of winter precipitation (1). Winter CC can positively or negatively affect the following crop by their influence on nitrogen and water dynamics (2). Positive effects of WCC on yield have been attributed to an increase in soil N availability through a build up of soil organic carbon and N mineralization during decomposition of WCC residues (3,4,5). Legume cover crop can increase inorganic soil N availability through symbiotic N fixation (6). Moreover, legume residues usually decompose faster than grasses, releasing inorganic N into the soil that becomes available for the following crop (7,8). On the other hand, grass WCC following corn in a no-till system reduced spring NO_3–N accumulation in soil due to N uptake by the cover crops generated by short-term N immobilization because of their high C/N ratio that affect the growth and yield of the following crop (6,9,10). Additionally, N recovery is directly related with biomass production but the tissue N concentration is commonly 10 to 15 g kg^{-1} or less, so the total N accumulation may be low for these cover crops. As example, biomass production of annual ryegrass (Loliunm multiflorum) for Uruguayan conditions has shown a high variation (2-8 Mg ha^{-1}) depending on the winter and spring weather condition (11, 12). Then, depending on biomass production produced by the cover crops, these could affect N dynamics and then cash crops response.

Winter cover crop residues can affect soil water dynamics by reducing runoff, increasing infiltration, and reducing evaporation, all of which may ultimately benefit crop yield (13). Conversely, WCC can also compete with the crop by using soil water during active growth. The effects of cover crops on soil moisture and cash crop production are depending on amount and distributions of precipitations, cover crops species and kill date, and soil type. Studies have shown that during dry spring, WCC depleted soil moisture content increasing the risk of cropping systems (14). Studies realized by (12) concluded that with two months from WCC killing date to corn planting WCC did not deplete soil moisture at planting corn. However, there was evidenced by visible signs of greater corn water stress on the WCC plots that affected corn yields compared to without WCC. Studies have shown corn following grass WCC yielded the same as following winter fallow but corn following legume WCC yielded 24% more than following WCC (15). According to these authors, corn grown had marginal benefits from the use of WCC when growing seasons were shorter and WCC are planted late in the fall. Late fall WCC growth is limited and spring growth is generally interrupted by corn planting. This narrow window for plant growth restricts WCC biomass production and the associated benefits of WCC.

Our objective was to compare winter cover crops before corn to increase soil fertility under no-till systems with different N application rates for corn productivity and soil properties.

Materials and Methods

Site description

The experiment is located approximately 10 km from Paysandú (32° 21' S and 58° 02' W; 61-m elevation) in the northwest of Uruguay, South America. The soil was a clay loam (Typic Argiudol) with an available water holding capacity of 100 mm in the top 0.6 m of soil profile. The region is mesothermal sub-humid climate with annual precipitation of 1200 mm, with a moderately uniform throughout months, but very unpredictable among years. In fall 2007, we started a corn-cover crops rotation in an no till systems. We evaluated six cover crops, Common Oat (Avena sativa L.), Annual Ryegrass (Lolium mutiflorum L.), Triticale (× Triticosecale wittmack), Egyptian clover (Trifolium alexandrinum L.), Pea (Pisum sativum L.), and no WCC. Cover crops and N rate at Corn V_6 were evaluated in a split-plot design with three replications. The cover crops served as whole plot in the design and two N applications rates at V6 Corn (0 and 50 Kg N ha^{-1}) served as subplots.

Site management

All winter cover crops were planted in fall (middle of April), after corn harvest. The plant density used for the cover crops were: Oat (80 kg ha^{-1}), Triticale (80 kg ha^{-1}), Ryegrass (15 kg ha^{-1}), Epyptian Clover (15 kg ha^{-1}), and Pea (80 kg ha^{-1}). In the Pea plots, the first two years of the experiment was planted with Trifolium balansae instead. Winter cover crops were not fertilized in entire cycle. Grasses WCC were terminated prior summer with applications of glyphosate at rate of 1.7 kg a.i. ha^{-1} 8 wk before corn planting. Egyptian clover and Pea were killed with glyphosate at 1.7 kg a.i. ha^{-1} with 2,4-D ester at 0.532 kg a.i ha^{-1} at the same time as we did in grass WCC. A five-row Semeato® planter (Semeato, Brazil) was used to plant corn at 72.000 seed ha^{-1} in a no-till system at beginning of November. Cultural practices for cover crops and corn productions were recommended by the Faculty of de Agronomy best management practices. Phosphorous to corn was applied according to Faculty of Agronomy soil test recommendations. Solid urea was used for nitrogen application rate at corn V_6, where plots within these areas were 15 m long and 5.0 m wide with ten, 0.50 m rows.

Data collection

Immediately after WCC herbicide applications biomass dry matter were collected in all cover crops treatments evaluated. Three sub-samples (0.10 m^2 each) were taken from each plot, dried at 60°C until all moisture was removed, and weighed to determined dry matter. Soil moisture was measured at corn planting (end of October) gravimetrically by taking three cores (2.54 cm diameter) by plot. We evaluated one depth (0-60 cm). The samples were weighing, drying them for 48 h at 105ºC, and reweighing. Volumetric soil water was calculated using gravimetric soil water and bulk density for each depth under study. Soil water content for this loamy clay soil ranges between 0.325 m^3 m^{-3} at field capacity to 0.197 m^3 m^{-3} at the permanent wilting point. The concentration of soil NO_3–N was determined at 0-20 cm depth. Soil samples were taken at corn planting and V_6 as the soil moisture samples. Soil samples were collected using a standard 25 mm diameter soil probe. A minimum of eight cores were taken per plot. Soil samples were dried at 60º C and sieved to 2mm. Concentration of NO3–N was determined with anion electrode Orion model 93-07 using $CaS0_4$ as flocculent. Soil samples for SOC content were collected in April 2011. Ten samples were taken at 0-20 cm composited for each plot. Soil was lightly crushed and sieved through a 2 mm mesh.

Soil organic carbon was determined using the Walkey and Black technique (16). Grain yield on each plot was measured by harvesting the central 8 m^2 by hand and crop stubble produced was estimate from the average harvest index for each plot. Crop below growth biomass was estimated using shoot/ root ratio of 5.6 for corn, 7.4 for Oat, Triticale, and Ryegrass, and 2.2 for Pea and Egyptian Clover reported by (17).

Statistical analysis

Winter Cover crops and N application rate at V_6 (N) were evaluated using an appropriate Split Plot Designs with the PROC MIXED procedure of the Statistical Analysis Systems (SAS) (18). Replications and its interactions were considered random effects and treatments (WCC and N) fixed effects. Due to interactions (year × winter cover crops) cover crops biomass production, soil NO_3-N at planting and V_6, soil water available at corn planting data are presented separately by year. Besides due to interactions (year × winter cover crops× nitrogen) corn yield data are presented separately by year. Least square means comparisons were made using Fisher's protected least significant differences (LSD). A significance level of $P \leq 0.10$ was established a priori.

Results and Discussion

Rainfall quantity and distribution were different among years (Fig. 1). No water deficit or excess were recorded in winter period for cover crops growing. Between June to August, mean monthly temperatures were similar compared to historical average (data no presented). For corn productivity, early spring and summer were drier in 2007-2008, 2008-2009, and 2010-2011 than average (-66, -270, and -176 mm less rainfall, respectively). On the other hand, summer 2009-2010 was extremely wet (600 mm more than averaged). Between Nov. to Mar. mean monthly temperatures were similar between 60-yr average and the period under study (data no presented). Due to interaction among WCC and years, the biomass production and soil water available data is presented by year (Table 1). Among WCC treatments, Pea presented the highest biomass production among years considering only the last two years that was in the experiment (6.04 Mg ha^{-1}). In the last year (2010), Pea obtained an unexpected high biomass production (7.38 Mg ha^{-1}) compared to the overall WCC (2.23 Mg ha^{-1}). On the other hand, EC presented the lowest biomass production (2.44 Mg ha^{-1}). The grasses WCC presented differences among years; however Oat had the highest biomass production among years (4.41 Mg ha^{-1}).

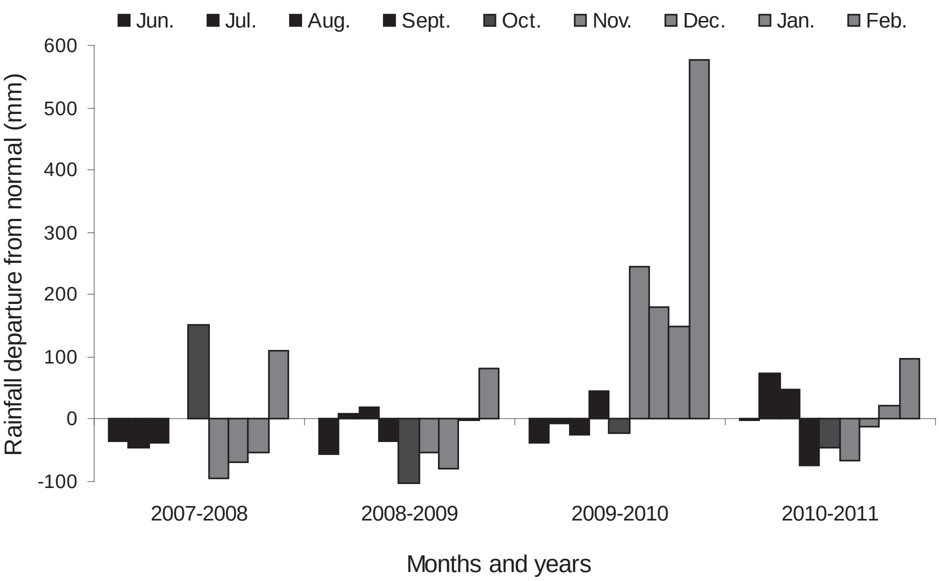

Figure 1. Monthly departure from long-term average rainfall (1935-2011) for the four years under study (2007-2011).

Winter cover crops × year interaction existed for available soil water (Table 1) and it's reflects the net effect between rainfall additions and water losses to drainage, evaporation, and runoff (likely to be minimal on the nearly level soil of the site). Available soil water content at corn planting on 2007, which was the highest among years, was around 64% of available soil water capacity. Analyzed by year, the lowest soil water content was in 2008 and 2009.

Table 1. Cover crops dry matter biomass and available soil water at corn planting for each WCC treatments by year (2007-2010).

Treatments	2007	2008	2009	2010	*Averaged*
			Biomass Production (Mg ha^{-1})		
No winter CC	0.12	0.17	0.16	0.09	0.15
Oat	3.86	6.98	4.62	2.18	4.41
Triticale	3.30	4.57	4.94	2.09	3.72
Ryegrass	3.06	3.85	1.92	1.81	2.66
Egyptian clover	2.66	2.79	1.49	2.82	2.44
Pea	--[a]	--	4.70	7.38	6.04
Averaged	2.60	3.67	2.97	2.73	
$LSD_{0.10}$ (WCC)					0.65
$LSD_{0.10}$ (WCC × year)	0.53	0.83	0.98	0.76	
			Available water (mm)		
No winter CC	70	57	13	59	50
Oat	66	33	19	38	39
Triticale	51	27	25	41	36
Ryegrass	74	20	14	39	37
Egyptian clover	58	29	10	20	29
Pea	--	--	8	42	25
Averaged	64	33	15	40	
$LSD_{0.10}$ (WCC)					14
$LSD_{0.10}$ (WCC × year)	ns	11	ns	13	

As we discuss in Figure 1, the rainfall in late spring were the lowest for these two years. Averaged over years, available soil water was affected by WCC treatments (35% more available water in no WCC compared to overall WCC) indicating that herbicide application to kill WCC to corn planting date (8 wk) was not enough for soil water restoration in either WCC evaluated. These results were different as presented by (12) where with two months from WCC killing date to corn planting, cover crops as Ryegrass or Egyptian clover did not deplete available soil water.

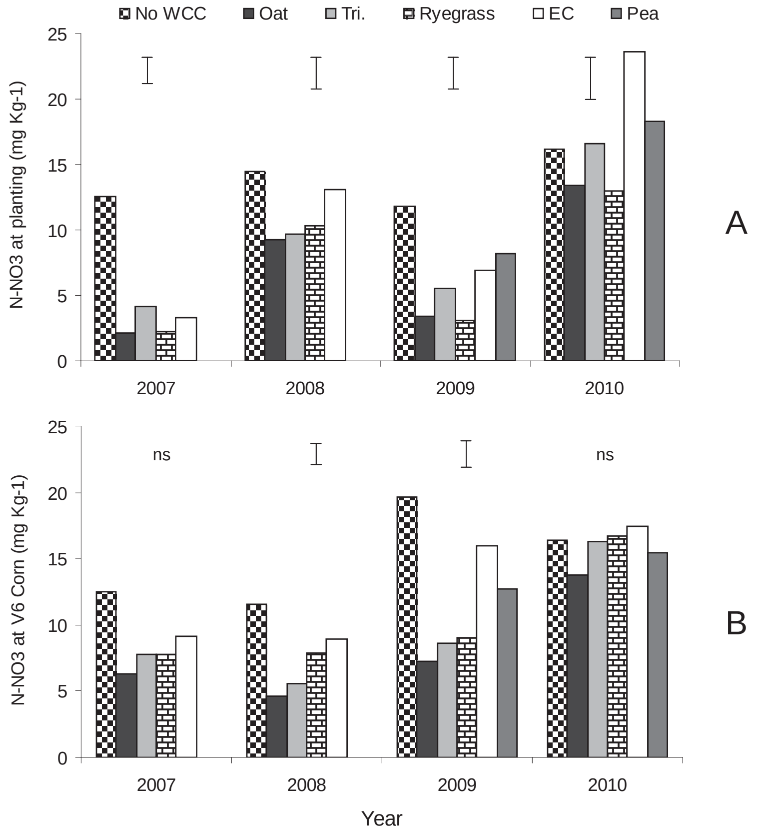

Figure 2. Soil NO_3-N in 0-20 cm depth at corn planting (A) and at corn V_6 (B) as affected by winter cover crops treatments in four years (2007-2010).

Due to interactions (winter cover crops × year), soil NO_3-N at corn planting and V_6 corn data are presented separately by year (Fig. 2). No WCC treatment presented the highest soil NO_3-N in all years, especially in corn planting, but the magnitude of this difference among type of WCC varied among years. Averaged over years, no WCC presented the highest soil NO_3-N at corn planting and V_6 (44 and 36% more than the overall WCC, respectively). On the other hand, grasses WCC (Oat, Triticale and Ryegrass) presented the lowest value for soil available N determined at corn planting and V_6. These results were similar obtained by (6), where residue cover crops has been shown to affect N availability to the following crop, causing a risk of short-term N immobilization due to high C/N ratio. There was no difference between no WCC and legumes WCC in two years (2008 and 2010), but there was a consistent trend toward increased soil NO_3-N at corn planting in 2010 in legumes WCC compared to no WCC (30% greater soil NO_3-N). Legume cover crop can increase inorganic soil N availability through symbiotic N fixation (6). Therefore, due to narrow C/N ratio, legume residues usually decompose faster than grasses, releasing inorganic N into the soil that becomes available for the following crop (8).

Table 2. Corn yields as affected by winter cover crops and nitrogen fertilization at Corn V_6 in four years (2007-2011).

	2007-2008			2008-2009			2009-2010			2010-2011		
	0 N	50 N	AVG	0 N	50 N	AVG	0 N	50 N	AVG	0 N	50 N	AVG
	Mg ha^{-1}											
No winter CC	4,74	5,01	*4,88*	8,34	7,52	*7,93*	7,31	8,24	*7,77*	4,92	6,28	*5,60*
Oat	4,33	5,87	*5,10*	6,12	6 ,67	*6,39*	1,94	2,68	*2,31*	4,16	5,75	*4,95*
Triticale	3,30	6,57	*4,93*	4,76	5,91	*5,34*	2,28	3,62	*2,95*	4,67	5,34	*5,01*
Ryegrass	4,11	4,86	*4,49*	5,02	6,15	*5,59*	1,32	2,00	*1,66*	4,38	5,46	*4,92*
Egyptian clover	5,34	5,32	*5,33*	5,13	5,11	*5,12*	4,90	7,73	*6,31*	4,74	5,43	*5,08*
Pea	--[a]	--	--	--	--	--	5,50	7,09	*6,29*	5,21	6,77	*5,99*
Averaged	4,36	5,53		5,87	6,27		3,87	5,23		4,68	5,84	
$LSD_{0.10}$ (WCC)			0.57			0.79			0.84			ns
$LSD_{0.10}$ (N)	0.26			ns			0.45			0.29		
$LSD_{0.10}$ (WCC × N)	0.67			ns			ns			ns		

Averaged over years, the highest corn yields were observed with no WCC (6.47 Mg ha^{-1}), followed by legumes WCC (5.97 Mg ha^{-1}) and grasses WCC (4.52 Mg ha^{-1}) (Table 2). Similar results have been found by (12) where no WCC resulted 12% in higher corn yields compared to WCC averaged over 3 years, indicating that grasses or legume cover crops could deplete corn yields. As we discuss before, available soil water and NO_3-N at corn planting and V6 were higher in no WCC compared to legumes and grasses WCC and could be the explanation about corn productivity. Further, interactions among WCC × N at V_6 × year occurred for corn yields. In 2009-2010, where the weather conditions were excellent for corn productivity (more rainfall), the N applications impact were maximized (29 kg grain by Kg N) averaged over all WCC. Additionally, for this year, despite of the good rainfall, the grasses WCC without N at V_6 was the worst scenario (1.94, 2.28 and 1.32 Mg ha^{-1} for Oat, Triticale, and Ryegrass, respectively). However, this extra N to corn was not enough to equal the no WCC or legume WCC. We speculated that several factors are acting in concert: N immobilization during residue decomposition, N leaching by rainfall excess and allelopathic effects that consequently hinder corn growth (19). The others three years under study with normal o low rainfall for corn productivity; with just only 50 kg N ha^{-1} applied to V_6 corn, was sufficient to reach the best corn productivity treatment (no WCC). Legume CC could serve as a tool in order to reduce the N introduced to the environment from intensive corn production systems. However our results suggest that corn need higher N inputs after legume CC than in no WCC management. Similar results have been obtained by other authors. A meta-analysis over 36 experiment involved corn and sorghum as cash crop conclude that yields were reduced by an average of 10% under legume cover crop management (20). This average reduction was explained by inadequate legume growth. It would be necessary a minimal CC dry matter production established as those that provided at least 110 kg N ha^{-1}. If this minimal dry matter production is not provided, additional N will be required to a cash crop yield equivalent to yields in conventional fertilizer-driven systems. In Argentina corn yield after legume WCC has been negatively affected in dry seasons only (21). In normal and wet seasons corn yields were similar after N fertilized no WCC than no N fertilized legume WCC. Only one of the five years legumes WCC introduced less than 100 kg N ha^{-1}.

Table 3. Soil Organic carbon at 2011 and estimate residue input above and below ground for corn and winter cover crops adding the four years evaluated (2007-2011).

Variable	No WCC	Oat	Triticale	Ryegrass	Egyptian C.	Pea
Soil Organic Carbon (g kg^{-1})	*18,2*	*18,2*	*17,7*	*17,9*	*18,5*	*17,5*
Residue above ground Corn (Mg ha^{-1})	39,7	27,3	27,2	24,6	32,4	36,5
Residue below ground Corn (Mg ha^{-1})	4,7	3,2	3,2	2,9	3,9	4,3
Residue above ground cover crops (Mg ha^{-1})	--	17,6	14,9	10,6	9,8	12,1
Residue below ground Corn (Mg ha^{-1})	--	2,4	2,0	1,4	4,483	5,5
Total residue (Mg ha^{-1})	*44.5*	*50.6*	*47,3*	*39,6*	*50,5*	*58,4*

No soil organic carbon significantly differences were detected among WCC treatments after four years with low risk of soil erosion (Table 3). This result could be explained by the carbon inputs for corn plus cover crops estimated through dry matter production (Table 3). We estimate dry matter input in no WCC of 44.5 Mg ha^{-1} (only corn) adding the four years. Despite of the total dry matter inputs for the other WCC treatments were similar, were composite completely different. Averaged grasses WCC the total residue input were 45.8 Mg ha^{-1} (29.5 corn + 16.3 cover crops) and for legumes WCC the total residue input was 54.8 Mg ha^{-1} (38.6 corn + 15.9 cover crops). However, Pea cover crop that was evaluated just only the last two years, presented the highest residue above and below input. On the other hand, Pea cover crop residues usually decompose faster than grasses (7,8). As resulted, soil organic carbon measured after four years did not present significant differences among WCC evaluated. According to (22), winter cover crops modifies soil organic fraction quickly, but its effect on total soil organic carbon depend on CC production and its C/N ratio.

Corn monoculture in tropical conditions under no-tillage system provided higher soil organic content and water-stability of soil aggregates than corn combined with different winter crops (23). Rihzodeposit and greater physical protection by crop residues are possible mechanisms determining of water stability aggregation and soil organic protection.

Conclusions

Our results indicated that the WCC depleted available soil water at corn planting (-35%) compared to without WCC. Moreover, soil NO_3-N at corn planting and V_6 was 41 and 29%, higher in no WCC than overall WCC, respectively, being stronger the difference compared to grasses WCC. These better soil conditions at corn planting in no WCC resulted in highest corn yields (6.47 Mg ha^{-1}), followed by legumes WCC (5.97 Mg ha^{-1}) and grass WCC (4.52 Mg ha^{-1}). Averaged over years, the N yield response in V6 corn was highest in grass WCC (31%), followed by legume WCC (23%) and no WCC (7%). Nitrogen fertilization at corn V6 stage could reduce the corn yield difference among use of WCC compared to no WCC in wet summer, but it was uncertain in a normal o dry weather conditions.

After four years of integrated winter cover crops in a corn monoculture, no soil organic carbon different were detected among treatments. These results could be explained by similar residue inputs in all treatments evaluated (shoot and roots residue adding corn + cover crops) since the beginning of the experiment (averaged over treatments: 46.5 Mg ha^{-1}). Farmers, who adopt use of WCC to reduce erosion potential and consequently improve soil fertility in the middle-long term in western Uruguay, could take disadvantage on low corn yield in the short term, therefore could increase cost by adding more extra N in the systems.

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