MINIMUM TILLAGE AND VEGETABLE CROP ROTATION

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Abstract

Soil quality improvement by reducing soil tillage is one tool of sustainable agriculture. Covers crops left on soil surface prevent soil erosion, reduces evapotranspiration and weeds, and improves soil infiltration; key factors for a successful vegetable production on heavy clay soils. The objective of this research was to evaluate the effect of cover crops plus ridge tillage on soil water content, soil, physico-chemical and biological properties and on vegetable yield. In 2005 at INIA Las Brujas Research Station was established a field experiment on a Typic Argiudoll soil, of silty clay loam texture with a 3% slope. Conventional treatment with fallow periods was compared with sustainable treatment included cover crops and minimum tillage. Onion (*Allium cepa* L.), cabagge (*Brassica oleracea,* Capitata group), carrot (*Daucus carota*), sweet potato (*Ipomoea batata*) and squash (*Cucurbita moschata* x *C. maxima*) crops were included in the study. Black oat (*Avena strigosa*), foxtail millet (*Setaria italica*) and forage sorghum (*Sorghum sudanense* x *S. bicolor*) were the cover crops. Soil water content was measured by time domain reflectometry on soil surface and by neutron probe in depth. Weed population was evaluated by number and dry weight. Soil biological activity was determined by soil respiration. Weed population and weight of weeds were reduced with minimum tillage as compared to conventional treatment. Soil water content was higher at certain periods on minimum tillage and biological activity was better on minimum tillage. Vegetable crop yields were similar on both treatments.

Key words: vegetable crops, conservation tillage, crop rotation.

Introduction

Worldwide vegetable production is supported by an intensive use of the soil. Conventional tillage (CT) involves the uses of rototiller, disc plow and moldboard plow, deteriorating soil physical properties, infiltration and excessive crusting among other properties. Also, all erosive processes are aggravated when the landscape has high slope gradient. These problems are conducive to a poor vegetable crop performance, increasing agrochemical dependence and production costs. Besides that, in the last decades societies are much worried about environmental issues, among them, soil quality. Soil quality was defined as ”the capacity of the soil to function within ecosystem to sustain biological productivity, maintain environmental quality, and promote plant and animal health” (1). In this statement, concepts of environment, productivity and ecosystem concerns are involved. Soil Organic Matter (OM) is a key factor for a good soil quality because reduces soil crusting, increase infiltration rate and is a major nutrient source for the soil microorganism and plant growth. Soil OM could be increased by the addition of animal manure or plant residues (cover crops, composts). Cover crops mainly brings to the production system: organic matter, soil erosion protection, better infiltration, water savings, weeds and soil diseases control.

Also reduced tillage is defined by the amount of residues left on soil surface (>30%) (2).

Tillage reduction also contributes to increase soil organic matter, reduce erosion risks, save costs and makes more sustainable the production system. In Uruguay the majority of vegetable crops are grown on beds or in ridges, then “no tillage” practices are not able for these crops. Based on previous studies the uses of

cover crops and ridge tillage (minimum tillage) are the key factors for a successful sustainable vegetable crop production on heavy clay soils in Uruguay (3, 4, 5).
On farm study was established with the objective of evaluate the effect of cover crops plus ridge tillage on soil water content, soil chemical, physical and biological properties and on vegetable yield.

Materials and methods

In 2005 at INIA Las Brujas Research Station was established a field experiment on a Typic Argiudoll soil, of silty clay loam texture with a 3% slope. Conventional treatment with fallow periods was compared with minimum tillage and cover crop treatment.

Onion (*Allium cepa* L.), cabagge (*Brassica oleracea,* Capitata group), carrot (*Daucus carota*), sweet potato (*Ipomoea batata*) and squash (*Cucurbita moschata* x *C. maxima*) crops were included in the study (Table 1). Black oat (*Avena strigosa*), foxtail millet (*Setaria italica*) and forage sorghum (*Sorghum sudanense* x *S. bicolor*) were the cover crops. (Table 2). Onion were transplanted on raised beds 1.65 m apart (the same beds for carrots, cabbage and squash) with four rows per bed and plants 10 cm apart. Cabbage was transplanted at 45 cm apart in 2007, and 35 cm apart in 2009. Carrot was sowed at the rate of 4 kg/ha; sweet potato was transplanted on ridged 0.8m apart and plants 30 cm apart, and squash was sowed 1 m apart in one row per bed.

Table 1. Description of vegetable crops in the rotation schedule.

Year	Crop - cultivar	Sowing/transplanting	Harvest
2006	Onion - INIA Casera	June	November
2007	Carrot - Flam	May	November
2007	Cabbage - Gloria	June	**
2007-2008	Sweet Potato - Arapey	October	April
2008-2009	Squash - Maravilla del Mercado	October	April
2009	Cabbage - Gloria	August	December
2010	Onion - INIA Casera	June	November

** Due to cold weather cabbage plants bolting so sample plants were taking on 20 mt long beds to determine total dry matter produced.

Table 2. Description of cover crops in the rotation schedule.

Year	Cover crop	Rate (kg/ha)	Cover crop g.p[1]	Dry matter (kg/ha)	C/N[2] ratio
2005/2006	Forage Sorghum	30	Dec.-April	14,950	26:1
2007	Foxtail millet	30	January-March	7,684	23:1
2008	Black oat	120	April-Sep.	18,947	32:1
2009	Black oat	100	June-Aug.	1,366	17:1
2010	Forage sorghum	30	Jan.-May	6,824	45:1
	+ foxtail millet	30			

[1]g.p: growth period. [2] C/N: Carbon/Nitrogen.

Seasonally soil samples were taken from the first 10 cm soil profile for chemical and physical analysis and were analyzed at INIA- La Estanzuela soil laboratory. For microbiological activity soil samples from the first 10 cm soil profile were collected in 2006, 2008, 2009 and 2011. Soil water content was measured weekly during squash in 2008, cabbage in 2009 and onion in 2010. Weed population number and weight of weeds were evaluated in cabbage in 2007 and 2009 and in squash in 2009.
Soil carbon was determined by 900 ºC combustion and CO_2 infrared detection technique. In order to obtain soil carbon stock, laboratory data was adjusted with soil bulk density. Soil total nitrogen was determined by 900 ºC combustion and N_2 thermal conductivity detection. Nitrogen data was adjusted with soil bulk density and total nitrogen stock was determined. Soil microbiological activity (soil respiration) was estimated by titration of the released CO_2 from fresh soil samples (0-10 cm depth) (6). Physical parameters were determined from a sample of an intact soil core volume and its dry weight (7). Soil microbial populations were determined by plating soil dilutions on semi-selective media: dilutions 10^{-3} y 10^{-4} for Fluorescent Pseudomonads on King B + antibiotics (8), dilutions 10^{-2} y 10^{-3} for *Trichoderma* spp on THSM media (9), and dilutions 10^{-4} y 10^{-5} for *Actinomycets* on corn starch media (10). Volumetric water content to 20 cm was measured by time domain reflectometry (TDR) in the raised beds. Soil moisture from 20 to 90 cm was measured by neutron probe calibrated with gravimetric samples. Measurements were taken from four different positions across a slope (block effect). Weeds were evaluated in a quadrant of 0.5 by 0.5 m.

Results and Discussion

Effects on Chemical properties

Effects on the dynamics of Soil Organic Carbon Stock.

Soil OM is one of the most important soil parameter because it is related to soil structure, water retention, soil biological activity among other properties. This parameter was quantified along the study and the dynamics of soil organic carbon stock expressed in ton/ha is presented in Figure 1.

No statistical differences among treatments were found. Minimum tillage (MT) treatment performed a trend of a better carbon stock. The organic carbon added by cover crops was in average 4.5 tons/ha/year. Minimum tillage accumulated a difference of 2.2 ton/ha of organic carbon more than CT after the five study years. Minimum tillage treatment was not enough to increase soil carbon differences respect to the conventional tillage due to the inclusion of the fallow period.

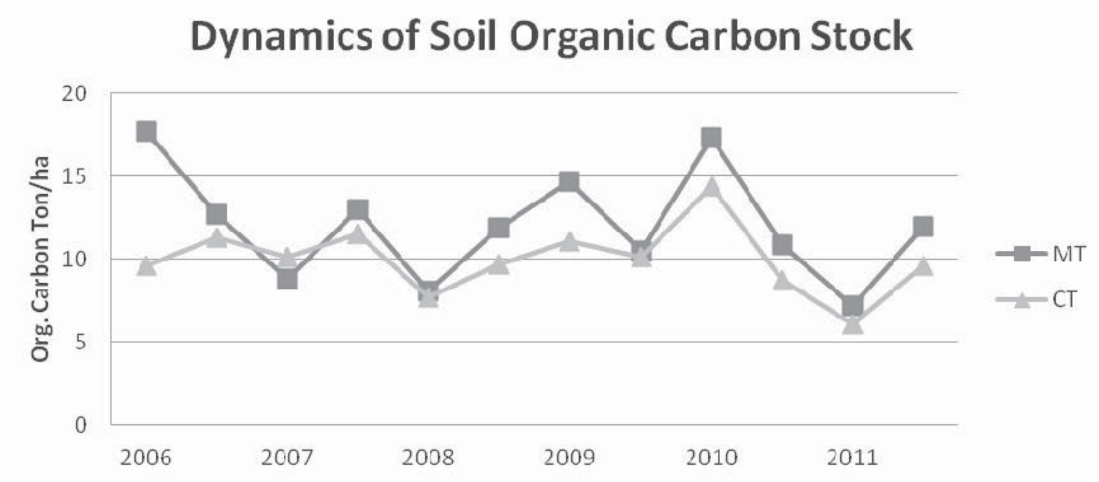

Figure 1. Dynamics of Soil Organic Carbon Stock (Ton/ha) from 0 to 10 cm depth2006-2011.

Effects on the dynamics of Soil Total Nitrogen**.**
No statistical differences among treatments were found. Minimum tillage performed a trend of a better N content during the five study years. Conventional tillage was fertilized with 382 kg/N/ha during the study period. Due to the cover crop species used belonged to the Gramineae family, extra nitrogen was needed to overcome nitrogen sequestering processes at the commercial crop phase. Minimum tillage treatment received the same amount during the study plus 100 kg/ha in 2008. MT treatment accumulated a difference of 1.1 ton/ha of total nitrogen more than CT at the end of the experiment (Figure 2).

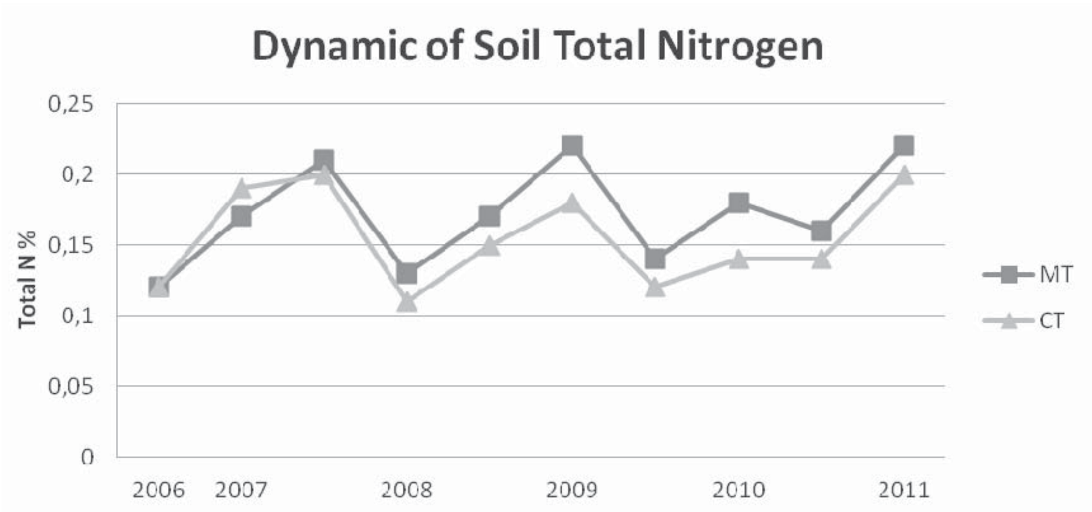

Figure 2. Dynamics of Soil Total Nitrogen (%) from 0 to 10 cm depth, 2006-2011

Effects on Phosphorus, Potassium and pH
During the study only 80 kg /ha of phosphorus were added to CT and MT in 2007. Phosphorus (P) content was higher in CT (31.5 to 36.0 ppm) than MT (34 to 30.0 ppm). This fact could be explained partially by the double cropping phase, cover crops and cash crops, which promoted a major extraction of P in the MT treatment. Soil potassium increments in MT (0.43 meq/100gr to 0.91 meq/100gr) than conventional treatment (0.56 meq/100gr to 0.50 meq/100gr), could be related with major soil carbon content and its ability to hold and supply essential nutrients over time on this treatment. Soil pH remained stable: 6.4-6.7 for MT and 6.3 -6.5 for CT, along the study without differences among treatments.

Effects on Soil Physic Parameters
Bulk density, total porosity and gravimetric water content were determined during the five year study (Table 3). Bulk density was not different among treatments, with values between 0.89-1.27 g/cm^3, which are suitable for plant root growth (11). Total porosity (F) values ranged from 52%-64%, with an average of 59.6% for MT and 59.2% for CT. Air porosity levels are close related with soil water content. No statistically significant differences among treatments were detected for air porosity and gravimetric water content.

Table 3. Bulk density, Total Porosity and Gravimetric Water Content Dynamics 2006-2011.

	Minimum Tillage				Conventional			
Date	B. Density g/cm³	F* %	FA** %	G.W.C*** %	B. Density g/cm³	F %	FA %	G.W.C %
May 06	1.15	56	28	28	1.05	60	30	30
Dec.06	1.08	59	48	11.3	1.15	56	4 9	
11.1								
April 07	1.03	61	36	25	1.12	57	34	23
Oct. 07	1.07	60	31	28	1.13	57	26	31
March 08	0.89	66	48	21	0.93	65	48	19
Dec. 08	1.13	62	38	26.3	0.99	62	46	16
April 09	1.17	56	39	18.5	0.99	61	50	13.2
Nov.09	1.05	60	32	32	1.09	59	32	31
Sep. 09	1.24	52	28	26	1.27	52	31	23.6
Nov. 10	1.03	61	44	18.2	1.06	61	43	19.1
July 11	0.95	64	40	26	1.02	61	39	25
Nov. 11	1.1	59	45	15	1.07	60	45	14.5

*_ Total Porosity **_ Air Porosity *** G.W.C._ Gravimetric Water Content

Effects on microbial activity

The minimum tillage always expressed a higher soil respiration except for the Spring 2009, even though not always statistically significant (Tables 4 and 5). Soil respiration is an estimator of soil microbial activity and reflects microbial heterotrophic activity, thus is used as an indicator of the carbon cycle (12). The respiration trends obtained here are in accordance with the results of the carbon stock under MT (Figure 1).

Also no significant differences were found among the two managements for the microbial communities measured (Figure 3)Tillage intensity impacts on soil communities, and is generally assumed that intensive tillage systems have less microbiological activity and are bacteria dominated whereas and no-till and MT systems have more activity and are fungal dominated, trends that can be observed in our data (13).

Table 4. Soil microbial activity (soil respiration in mg CO_2 / g dry soil / day) for the two tillage managements, measured at sowing and transplant of the cash crop.

	Squash		Carrot	
	Sowing Oct. 2008	Harvest April 2009	Sowing May 2011	Harvest Oct. 2011
Fallow + Conventional tillage	0.014[1]	0.013	0.013	0.011
Green Manure + Minimum tillage	0.018	0.031	0.024	0.019
Pr(>F)	*ns*	*0.078*	*ns*	*0.007*
C.V (%)	*59.4*	*83.4*	*65.2*	*66.7*
LSD (α=0.05)	*0.016*	*0.020*	*0.016*	*0.013*

[1] Average of four repetitions, [2] Crop sequence: Black oat - Squash, [3] Crop sequence: Foxtail millet - Carrot.

Table 5. Soil microbial activity (soil respiration in mg CO_2 / g dry soil / day) for the two tillage managements, measured at the end of the summer green manure (SGM) or winter green manure (WGM).

	SGM		WGM	
	Sorghum Fall 2006	Foxtail Millet Fall 2011	Black Oat Spring 2008	Black oat Spring 2009
Fallow + Conventional tillage	0.013[1]	0.013	0.014	0.021
Green Manure + Minimum tillage	0.040	0.024	0.018	0.017
Pr(>F)	----	*ns*	*ns*	*ns*
C.V (%)	----	*65.2*	*59.4*	*53.2*
LSD (α=0.05)	----	*0.016*	*0.016*	*0.021*

[1] Average of four repetitions, except for Fall 2006 (one measurement for each management).

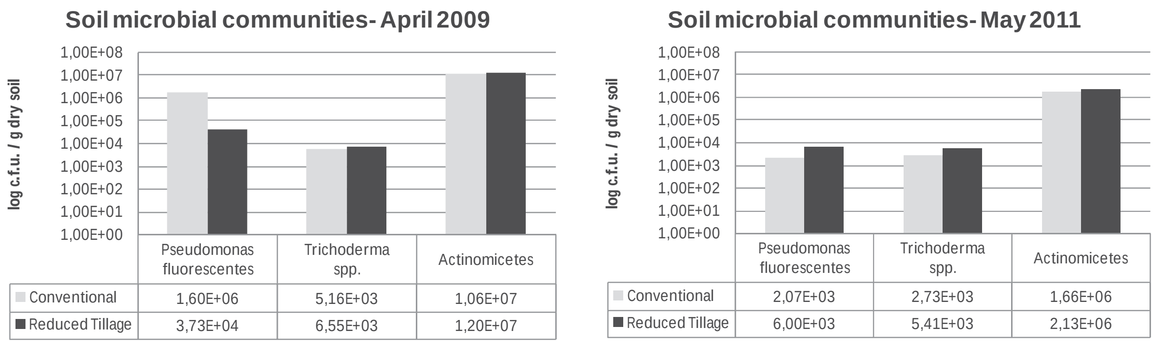

Figure 3. Soil microbial communities

Effects on soil water content

Topsoil moisture content was higher at certain periods under MT (Figure 4). The difference of soil water between systems in the first 20 cm of soil, was up to 12 mm during the squash crop, up to 5 mm during the cabbage crop, and up to 7 mm during the onion crop.

Comparing soil moisture at different positions in the landscape and different dates, the higher values were detected in general at the foot slope and the lower values at the upper slope or shoulder position, being intermediate the values at the top and at the lower slope.

After rainfalls, water infiltrates more in the MT, which was inferred due to the higher values of soil moisture at 20 cm depth in that treatment (Figure 4). This was valid during the three crops, from summer 2008 till spring 2010. During the pumpkin crop (summer 2008 and autumn 2009), the difference in soil moisture between treatments was at water content below field capacity. During the cabbage and onion crops, differences in soil moisture between treatments were detected also at field capacity (7th and 15th October (spring 2009), and 21st July, 6th august, and 18th August 2010 (winter 2010). This result indicates that MT resulted in an increase of the soils capacity to retain water. These data was partially corroborated by the porosity results shown in Table 3, since a trend of higher porosity for MT was found.

During fall 2009 (end of squash crop) and spring 2010 (end of onion crop), water content was higher on MT as compared to CT on sunny weeks. This is explained due to less evaporation from the soil surface due to the mulch effect.

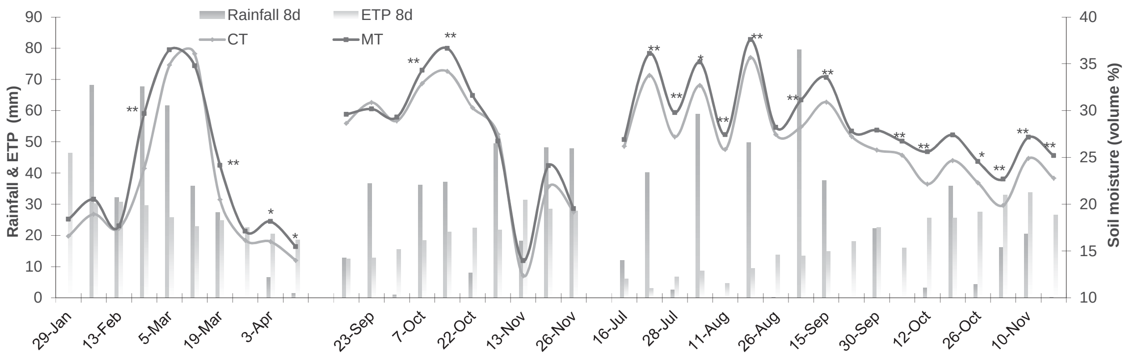

Figure 4. Soil moisture evolution to 20 cm depth under MT and CT measured by TDR from summer 2008 to spring 2010 during the pumpkin, cabbage and onion crops; and 8 days accumulated precipitation and evapotranspiration before each measurement. *, **, Significant at the 0.1 and 0.05 probability levels respectively.

No significant difference in the soil moisture in the soil subsurface was detected during the squash or the cabbage crops. Differences in soil moisture in the soil subsurface (till 55cm depth) were detected during the onion crop (Figure 5). During the spring 2010 at the end of the onion crop, similarly to what happen at the soil surface, soil water content to 55cm depth decreased due to higher atmospheric demands. Significant differences between treatments were also found. Three to five more mm of water each 10 cm of soil was measured under MT than under CT.

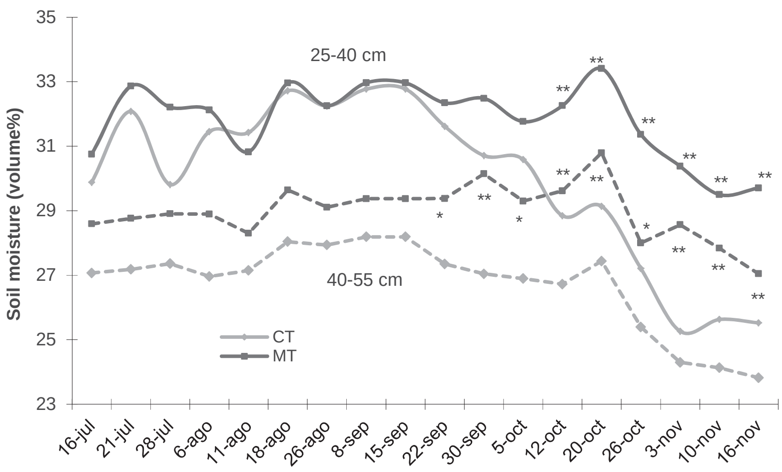

Figure 5 Soil moisture evolution at 25-40 and 40-55 cm depth under MT and CT measured by neutron probe during the onion crop. *, **, Significant at the 0.1 and 0.05 probability levels respectively, when comparing within each depth.

Higher capacity for water infiltration (14) and less evaporation from the soil under minimum tillage and cover crops (15) can explain the difference on water content in favor to this treatment.

Effects on yield

Vegetable crops yield were similar between CT and MT in the rotation and there were not significant differences in marketable yield (Table 6).

Table 6. Marketable yield of vegetable crops (t/ha).

Year	2006	2007	2007	2007/2008	2008/2009	2009
Vegetable	onion	carrot	cabbage[1]	sweet potato	squash	cabbage
Treatments						
Conventional	26	34	3.6	11	49	55
Minimum tillage	22	37	3.6	10	47	53
LSD	NS	NS	NS	NS	NS	NS
Cv (%)	12	22	18	0.97	6.9	14

[1]:total dry matter produced.

Effects on weed population.
Weed population, evaluated by the number and weight of weeds per square meter showed a trend to decrease with MT as compared to CT (Table 7).

Table 7. Weed number and dry weight on carrot, cabbage (2007), squash (2008) and cabbage (2009).

Year	N° of weeds/m^2				N° of weed/m^2 in bed	betw. beds	Weed dry weight/ m^2	N° of weed/ m^2	Weed dry weight/m^2
	Carrot (2007)	%	Cabbage (2007)	%	Squash (2008/2009)			Cabbage (2009)	
Conventional	346	100	532	100	18	31	219	123	6.2
Minimum tillage	200	58	356	70	13	33	22	99	3.8
LSD (P<0.05)	NS		NS		NS	NS	188	NS	NS
Cv (%)	56		15		44	44	69	34	78

Conclusion

Cover crops and minimum tillage produced changes in soil organic carbon and nitrogen, but were not significant, in order to enhance content differences, the inclusion of other organic sources and a mix with legumes as cover crops would be required. Soil respiration was higher on MT as compared with CT, as with soil organic carbon content. Soil physics parameters only detect seasonal differences, due to the yearly tillage in MT and CT treatment. Higher soil water content detected in minimum tillage in this study could help to withstand drought or safe water for irrigation.

Weed population was reduced between 20 to 40% in carrot and cabbage. Even though weed number per square meter was not significantly different between treatments on squash, weeds dry weight was significant reduced with MT as compared to CT.

Yield was not significantly different between treatments for all the vegetable crops included in the five year rotation.

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