DOI: 10.37856/bja.v97i2.4300

PERFORMANCE OF VEGETABLE CROPPING AND EFFECTS ON SOIL PROPERTIES UNDER CONSERVATION AGRICULTURE MANAGEMENT IN SOUTHEASTERN BRAZIL

Roberto Botelho Ferraz Branco[1], Jane Maria de Carvalho Silveira[1], Douglas Florian Maia[2], Fernando de Carvalho[2], Júlia Carvalho Gomes de Lima[2], Getúlio Coutinho Figueiredo[3]

[1]Researcher, Instituto Agronômico (IAC/APTA), Ribeirão Preto, São Paulo State, Brazil. E-mail: roberto.branco@sp.gov.br, jane.silveira@sp.gov.br
[2]Agronomist, Agronomy College, Centro Universitário Moura Lacerda, Ribeirão Preto, São Paulo State, Brazil. E-mail: florian.maia@hotmail.com, ferclavemusic@gmail.com, juuh_judd@hotmail.com
[3]Professor, Departament of Soil Science, Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre, Rio Grande do Sul State, Brazil. E-mail: getulio.figueiredo@ufrgs.br

ABSTRACT

Conservation Agriculture (CA) is based in principles of the minimum soil disturbance, preservation of organic mulch on soil surface and crop rotation. Therefore, this study aimed to compare the CA versus conventional tillage for tomato and broccoli cropping. The experimental treatments were two tillage method (no-tillage and conventional tillage) as the main plot and species of cover crops, legumes, grasses and a mix (legume + grass) as subplot. Soil properties and vegetable agronomic performance were assessment. No-tillage provided higher soil water content and increased soil fertility and higher soil mechanical resistance to penetration than conventional tillage. Broccoli growth and yield were impaired under no-tillage, while tomato had greater root length and similar yield compared to the conventional tillage. Regarding to the cover crops there was no difference on the experimental traits. Conservation Agriculture is recommended to increase soil fertility and soil water storage as well as for ensure sustainable vegetable production.

Keywords: *Solanum lycopersicum* L., *Brassica oleracea* var *italica*, no-tillage, crop rotation, soil conservation

INTRODUCTION

Conservation Agriculture (CA) is based on three agronomic principles: minimum soil disturbance, preservation of organic residues that provide permanent soil cover and diversification of crop rotation (FRIEDRICH et al. 2012). Together, these techniques aim to achieve the sustainability of the crop environment, mainly toward the conservation of soil and water. The erosive process in tropical regions causes soil loss from 6 to 20 Mg ha^{-1} year^{-1} when managed under conventional tillage; however, field management based on no-tillage, crop rotation and soil surface permanently covering by straw or living mulch reduces runoff by up to 99% (LABRIÈRE et al. 2015).

Using cover crops in crop rotation and straw production for no-tillage improves environmental conditions by increasing soil fertility through nutrient recycling and increase of organic matter (BENINCASA et al. 2017; HOYT et al. 1994). As a consequence, it increases soil water content (NOVELLI et al. 2017; MITCHELL et al. 2012; MAROUELLI et al. 2010), the stability of soil aggregates (WILLIAMS & WEIL, 2004; ROSOLEM et al. 2002), the organic matter and nutrients (NYAMBO et al., 2020; BRANCO et al. 2017), the microbiological activity (DUDA et al. 2003; HOLAND, 2004) and, finally, the crop yield (AHMADIANI et al. 2016; MELO et al. 2010; MAROUELLI et al. 2006).

Notwithstanding, conventional tillage is the most commonly used method for establishing horticultural crops in Brazil (FILGUEIRA, 2000), which aims to disrupt the soil in the arable layer (0.3 m soil depth). Such soil disturbance increases the vulnerability to the erosion process and, consequently, increases environmental impacts such as siltation and eutrophication of water resources (HOLLAND, 2004). In semi-arid conditions, Murillo et al. (2006) found improvement in soluble organic carbon, carbon of microbial biomass and protease activity under conservation tillage, which means enhancement of soil fertility and sustainability on production system. Researchers related crop performance comparing reduced tillage versus conventional tillage and verified great crop yield achieved under no tillage (DERPSCH, 1986; YAU et al. 2010; PITTELKOW et al. 2015). However, studies are necessary to ensure high yield of vegetables crops at the condition of Conservation Agriculture, with minimum soil disturbance and high straw quantity on soil surface. Therefore, the aim of this research was studied the impact of no-tillage integrated with cover crops on agronomic performance of tomato and broccolis as well as improvements in soil properties.

MATERIAL AND METHODS

Site description

On-farm trial was carried out in Ribeirão Preto, São Paulo state, Brazil, at geographic coordinates 21°12'20''S and 47°52'17''N and altitude of 631 m. The average annual rainfall is 1,427 mm, with 19.3 °C and 25 °C as minimum and maximum average temperatures, respectively. Soil in the experiment area is classified as Oxisol with clayey texture: 10.2% sand, 32.1% silt and

DOI: 10.37856/bja.v97i2.4300

57.7% clay; and soil chemical fertility: pH=5.7, organic matter (OM)=21 g kg^{-1}, phosphorus (P)=69 mg kg^{-1}, potassium (K)=2.8 mmolc kg^{-1}, calcium (Ca)=37 mmolc kg^{-1}, magnesium (Mg)=12 mmolc kg^{-1}, cationic exchange capacity (CEC)=77 mmolc kg^{-1} and base saturation (BS)=67%, at 0.0 to 0.2 m depth.

Experimental design and trial management

Treatments were no-tillage and conventional tillage as main plot, combined with three species of cover crops: legumes, grasses and mix of both species of cover crops as sub plot. Vetch (*Vicia sativa* L.), bristle oat (*Avena strigosa* Schreb) and the mix of both species were grown in the autumn/winter experiment. In spring/summer experiment, millet (*Pennisetum glaucum* L. R. Brown), sunn hemp (*Crotalaria junceae* L.) and the mix of both species were grown. The experimental design was a split-plot (2x3) in a randomized block with four replications, totalling 24 experimental plots. The area of the experimental plots was 60 m^2, with 4 m width per 15 m length.

Crops were grown in this chronological sequence: winter cover crops (May–August 2016)–broccoli (September–November 2016)–summer cover crops (December 2016–February 2017)–tomato (March–July 2017). Each plot was grown keeping respective cover crops species—legumes, grasses, or mix of both species—at the same plots during the two years of the experiment. Winter cover crops were sown with no-tillage seed-drill equipped with straw cutting coulters, at 0.25 m spacing between row, 133 kg ha^{-1} of vetch seeds, 100 kg ha^{-1} bristle oat seeds and a mix of 66 kg ha^{-1} vetch seeds and 50 kg ha^{-1} bristle oat seeds. There was no fertilisation or crop management of the cover crops, which were allowed to grow freely.

At the end of the cover crop cycle, 85 days after sowing, samples were taken from 1 m^2 at two points of each plot, to measure aboveground biomass. Afterwards, the cover crops were killed with a 2.0 m wide roller crimper (model Terras altas®—Agrimec company, Santa Maria, Rio Grande do Sul State, Brazil) and left as straw on the soil surface throughout the whole experimental area. Later, in the plots designated to conventional tillage, the soil was tillage at 0.3 m depth with disc harrows with 20 inch powered by 100 hp tractor, incorporating the cover crops residue into the soil. In order to raise the basic saturation to 80%, liming was performed with 1.2 Mg ha^{-1} of dolomitic limestone throughout the experimental area. In the case of conventional tillage, lime was incorporate into the soil by disc harrow at 0.30 m depth at time of tillage.

Broccoli, Avenger hybrid, was transplanted with a spacing of 0.8 m between rows and 0.6 m between plants, with seedlings having five established mature leaves. The transplanting was done using vegetable mechanical transplanters with a single row (Sathya company, Indaituba, São Paulo, Brazil), equipped with straw cutting coulters and powered by a 75 hp tractor. This planting method was done for both no-tillage and conventional tillage. The base fertilisation was performed with 60 kg ha^{-1} of N, 200 kg ha^{-1} of P_2O_5 and 180 kg ha^{-1} of K_2O, and topdressing fertilisation was performed with 150 kg $ha^{-1}$of N and 100 kg ha^{-1} of K_2O, sliced in two applications, 30 and 60 days after transplanting. The sources of fertiliser were ammonium sulphate, triple superphosphate and potassium chloride.

Water was supplied through drip irrigation with 0.2 m spacing between drippers, at a 2 litres $hour^{-1}$ per linear m. Irrigation management was done by tensiometry and the volume of water applied based on the recommendations by Marouelli et al. (1996) to broccoli by the data of daily evapotranspiration and kc indice of the crop. As the broccolis grew under good climatic conditions, there was little attack of pest and diseases and so there was no necessity for pest and disease control.

After broccoli harvest, the spring/summer cover crops were sown with a no-till seed-drill at 0.25 m spacing between rows, with 70 kg ha^{-1} of millet seeds, 100 kg ha^{-1} of sunn hemp seeds and the mix composed of 35 and 50 kg ha^{-1} of millet and sunn hemp, respectively. Crop management was not performed during the cover crop cycle, and the plants were left to grow freely. After 60 days of cover crops sowing, in the blooming, samples were taken from 1 m^2 at two points of each plot, to measure dry biomass yield of the cover crops. Afterwards, the plants were terminated with a 2.0 m wide roller crimper (model Terras altas®—Agrimec company) to provide straw on the soil's surface. In the plots intended for conventional tillage, the soil was harrowed with a 20 inch disc harrow powered by 100 hp tractor. Tillage was performed at the 0.30 m depth of soil profile, incorporating all residues into the soil.

Tomato, Candieiro hybrid, was transplanted when seedlings presented five leaves, at 40 days after sowing. The seedlings were transplanted with 1.5 m spacing between rows and 0.5 m between plants with single row vegetable mechanical transplanters (Sathya company), equipped with straw cutting coulters and powered by a 75 hp tractor.

Base fertilisation was performed with 60 kg ha^{-1} of N, 300 kg ha^{-1} of P_2O_5 and 200 kg ha^{-1} of K_2O, and topdressing was performed with 200 kg ha^{-1} of N and 240 kg ha^{-1} of K_2O, sliced in three applications 30, 45 and 60 days after transplanting. Water was supplied to the tomato plants through drip irrigation, applying water volume management as described by Marouelli et al. (1996) using data from evapotranspiration daily and kc indice of the crop. Pest control was done with preventive applications of entomopathogenic fungi, *Metarhizium anisopliae* and *Beauveria bassiana*, and the bacteria *Bacillus thuringiensis.*

Soil water content

Soil water content was measured by the gravimetric method, taking soil samples with an auger with rings of 98 cm^3, at 0 to 0.05 m, 0.05 to 0.10 m and 0.10 to 0.20 m soil depths, in three points per plot, at 15 days after transplanting (DAT) of broccoli and 26 DAT of the tomatoes. For those dates, there were 25 days with no rain on the broccoli crops and 17 days with no rain on the tomato crops, indicating a dry period (Ciiagro, 2017). Soil wet sample was measured with the aid of digital scale and after was sent to dry at 105 °C for 72 hours in drying oven, reaching constant mass. Then, the dry weight was measured, and the percentage of moisture (soil water content) was calculated as %U={(MF-MS)/MS}*100, where MF = fresh weight of the soil sample, and MS = dry weight of the soil sample.

Soil mechanical resistance to penetration

Soil mechanical resistance to penetration (RP) was measured at six points per plot, three points in the crop row and three in between the rows, at 15 and 26 days after transplanting of broccoli and tomato, respectively. Measurements were taken using the automatic penetrometer DLG PNT-2000 (DLG Automação Industrial, Sertãozinho, São Paulo State, Brazil) with a 0.60 m rod, with readings recorded every 0.05 m down until 0.60 m depth. These measurements were done when the soil presented about 21% and 19% of moisture for the broccoli and tomato crops, respectively.

Root and aboveground growth of the vegetables

Broccoli and tomato root length was measured by using the mini rhizotron method. For this, acrylic tubes, 400 mm long with 70 mm diameter, were inserted into the soil in the crop row, in between two plants and at one point of each experimental plot. Afterwards, the images were generated through the introduction of a root scanner, model CI-600 (CID-Bioscience, Camas, Washington, USA), into the acrylic tubes. Images were generated at 55 (DAT) of broccoli and at 60 DAT of tomato from the area of 0.42 m^2 of the visual field from the acrylic tube, at 0.0 to 0.40

m soil depth. Then, the images were processed using Winrhizotron® (Regent Instruments, Quebec, Qc, Canada) software to quantify the total root length (m).

Growth of broccoli and tomato plants was measured as the aboveground dry biomass. For this, two plants were randomly collected from each experimental plot and dried at 70 °C for 72 hours, reaching constant biomass. Afterwards, the aboveground dry biomass of the plants was measured with a digital scale with accuracy of 0.1 g. Harvesting of plant samples for this purpose was performed at 50 and 82 DAT for broccoli and tomato plants, respectively.

Crop yield

Broccoli yield was measured by the harvest of the commercial inflorescence from eight plants per experimental plot, measuring the biomass fresh weight (kg). For the tomato crop, the yield was measured by the harvest of marketable fruit and quantified the fruits (number plant^{-1}) and their fresh weight (kg plant^{-1}). The yield of both broccoli and tomato was estimated in Mg ha^{-1} of commercial production.

Soil fertility

Samples were taken from two subsamples in each experimental plot in order to analyse the chemical fertility of soil. Samples were collected at 0.0 to 0.05 m, at 0.05 0.1 m and at 0.1 to 0.2 m soil depth at the end of the experiment, in between the rows of tomatoes. Afterwards the samples were sent to the lab for analysis of organic matter (OM) by volumetric method, pH in CaCl, H+Al, calcium (Ca), magnesium (Mg) and potassium (K) content by NH_4Cl extractor (van Raij et al., 2001), base saturation (BS) calculated by sum of Ca+Mg+K and, cation exchange capacity (CEC) calculated by sum of H+Al +Ca+Mg+K (Ronquim, 2010).

Statistical analysis

The results were statistically analysed using the SAS 9.4 software, with PROC MIXED programming and analysis of variance and mean comparison by PDIFF. Previously, the data were subject to a normality and homoscedasticity test and detection of outlier values.

RESULTS AND DISCUSSION

Aboveground dry biomass of cover crops

In the winter, vetch was the cover crop that had greater aboveground dry biomass yield, compared to oats and to the mixture of both species (Table 1). During the cultivation of the cover crops (86 days), there were 16 days of rain, with 151 mm of total precipitation; and the average maximum and minimum air temperatures were 26.4 °C and 12.8 °C, respectively.

In the summer, aboveground dry biomass of both millet and the mix of millet and sunn hemp were significantly greater than sunn hemp sole (Table 1). During the 59-day period of cover crop growth, there were 36 days with precipitation, with 348 mm along the cover crops growth and the average maximum and minimum air temperatures were 30.2 °C and 19.7 °C, respectively.

Table 1. Aboveground dry biomass (ADB) of winter and summer cover crops.

Winter Cover Crops (CC)	ADB (Mg ha^{-1})	Summer Cover Crops (CC)	ADB (Mg ha^{-1})
Vetch	2.12 a^y	Sunn hemp	4.92 b
Oat	1.48 b	Millet	7.78 a
Vetch + Oat	1.50 b	Sunn hemp + Millet	7.54 a
P≤F	0.0068*	P≤F	0.0248*
Tillage (Till)		Tillage (Till)	
No Tillage	1.62	No Tillage	6.17
Tillage	1.76	Tillage	7.32
P≤F	0.3878	P≤F	0.1904
Interaction (CCxTill)		Interaction (CCxTill)	
P≤F	0.2133	P≤F	0.4928

*Significant differences by the analysis of variance (ANOVA) at 5% of probability.
^{y} Differences between the means in the column are shown by different letters, by PDIFF at 5% of probability.

Soil mechanical resistance to penetration

Tillage methods had significant difference when considering the soil mechanical resistance to penetration (RP) at 0.0 to 0.3 m depth at measured done at 15 days after transplanting (DAT) of broccoli crop, where RP was smaller in conventional tillage than in no-tillage. At 0.3 to 0.6 m soil depth, RP was similar between the tillage methods (Figure 1a).

At 26 DAT of tomato crop the RP was smaller in conventional tillage on the profile from 0.0 to 0.3 m soil depth, but below that one, in the range from 0.3 to 0.6 m depth, there was no significant difference between tillage methods (Figure 1b).

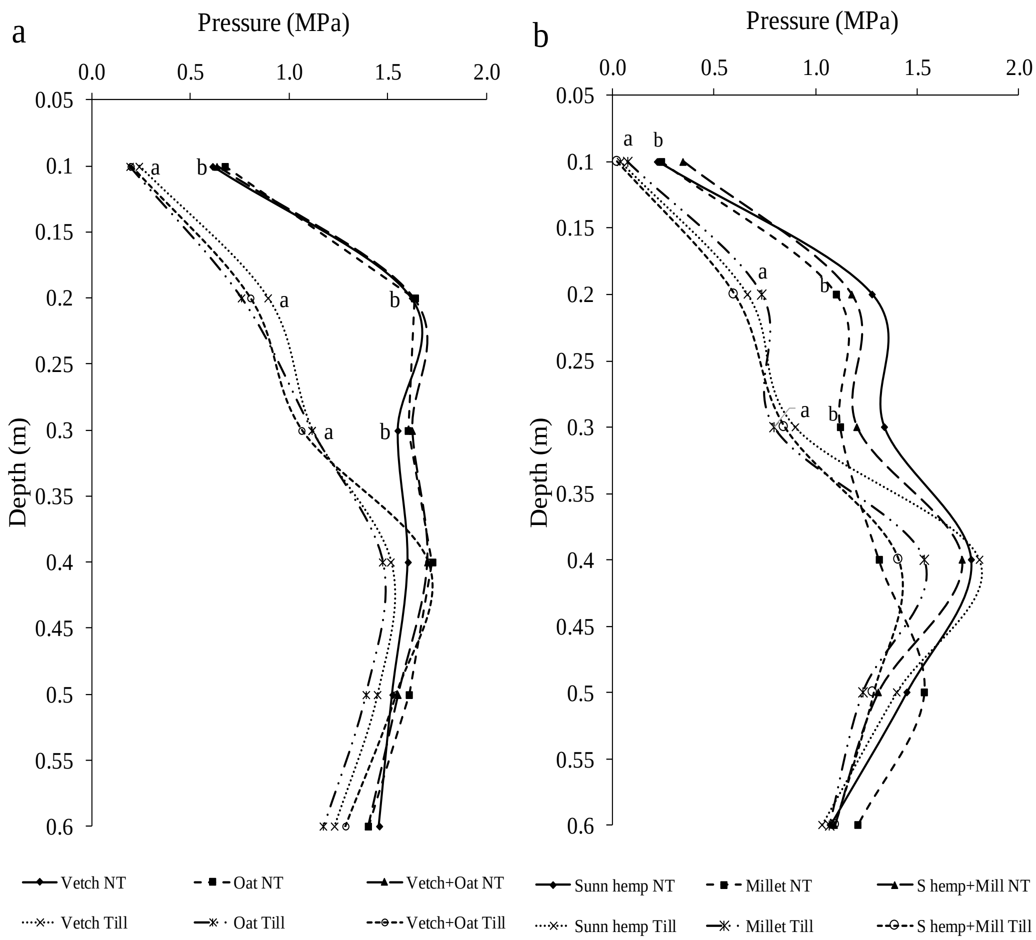

Figure 1. Soil mechanical resistance to penetration in the profile of 0 to 0.60m of depth in cultivation of broccoli (a) and tomato (b). Differences letters shown difference between the means by PDIFF at 5% of probability.
NT = no-tillage; Till = conventional tillage.

Soil water content

In the broccoli growing under no-tillage, soil had a greater water content compared to that found with conventional tillage, about 13% at 0.0 to 0.05 m depth, 9% at 0.05 to 0.1 m depth and

10% at 0.1 to 0.2 m depth (Table 2). In the tomato growing, the soil water content under the treatments of millet and the mix of millet and sunn hemp resulted in greater water storage when compared to sunn hemp at the depths from 0.1 to 0.2 m of the soil profile (Table 2). At the depth from 0.0 to 0.05 m and 0.05 to 0.1 m, cover crops had no significant difference. The soil under no-tillage in the tomato growing had better water content in the profile at 0.0 to 0.2 m depth, on average 24% above, when compared with conventional tillage.

Table 2. Water content (%) in soil profile (0.0 to 0.05, 0.05 to 0.10 and 0.10 to 0.20 m soil depth) under broccoli and tomato cultivation.

	0.0 to 0.05m		0.05 to 0.10m		0.10 to 0.20m	
Cover crops (CC)	Broccoli	Tomato	Broccoli	Tomato	Broccoli	Tomato
			%			
Legume[x]	20.1	18.0	21.5	16.9	21.6	18.6 b
Grass	20.8	19.6	21.9	18.6	21.4	20.4 a
Legume+Grass	20.7	19.0	21.2	18.1	21.1	20.2 a
P≤F	0.7173	0.2677	0.6363	0.2199	0.8289	0.0130*
Tillage methods (Till)						
No Till	21.8 a[y]	21.3 a	22.5 a	19.6 a	22.4 a	21.6 a
Tillage	19.2 b	16.4 b	20.6 b	16.2 b	20.4 b	17.9 b
P≤F	0.0026*	<.0001*	0.0080*	0.0003*	0.0122*	<.0001*
Interaction (CCxTill)						
P≤F	0.7573	0.5597	0.6908	0.2895	0.8906	0.0124*

* Significant differences by the variance analysis (ANOVA) at 5% of probability.
[y] Difference between the means in the column is shown by different letters, by PDIFF at 5% of probability.
[x]Legume = vetch and sunn hemp; Grass = oat and millet as cover crops for both broccoli and tomato crop respectively.

Root growth and the aboveground dry biomass of vegetable crops

During the broccoli growing (97 days), there were 45 days with rain, with 494 mm of precipitation, with an average maximum and minimum temperatures of 30.5 °C and 17.9 °C, respectively. The environmental conditions were favourable for good growth and yield of the broccoli, according physiological requirement of the crop (Filgueira, 2000). Aboveground dry biomass of broccoli at 50 days after transplanting (DAT) was greater in the plants grown in conventional tillage about 57% compared to no-tillage. Tillage methods also had a significant effect on root length of broccoli at 55 DAT, as for conventional tillage, this was significantly greater than for no-tillage at about 62%, (Figure 2).

Along 113 days of tomato growing there was 157 mm of precipitation in just 16 days, needing water supply by irrigation. Average maximum temperature was 27.9 °C and average minimum was 15.7 °C. The environmental conditions favoured the good physiological and agronomic performance of tomato plants (Filgueira, 2000). At 82 DAT, there was no significant difference between tillage methods to the aboveground dry biomass of tomato. However, tomato root length at 60 DAT was greater about 68% in no-tillage compared to the conventional tillage at the 0.0 to 0.40 m depth of the soil profile (Figure 2).

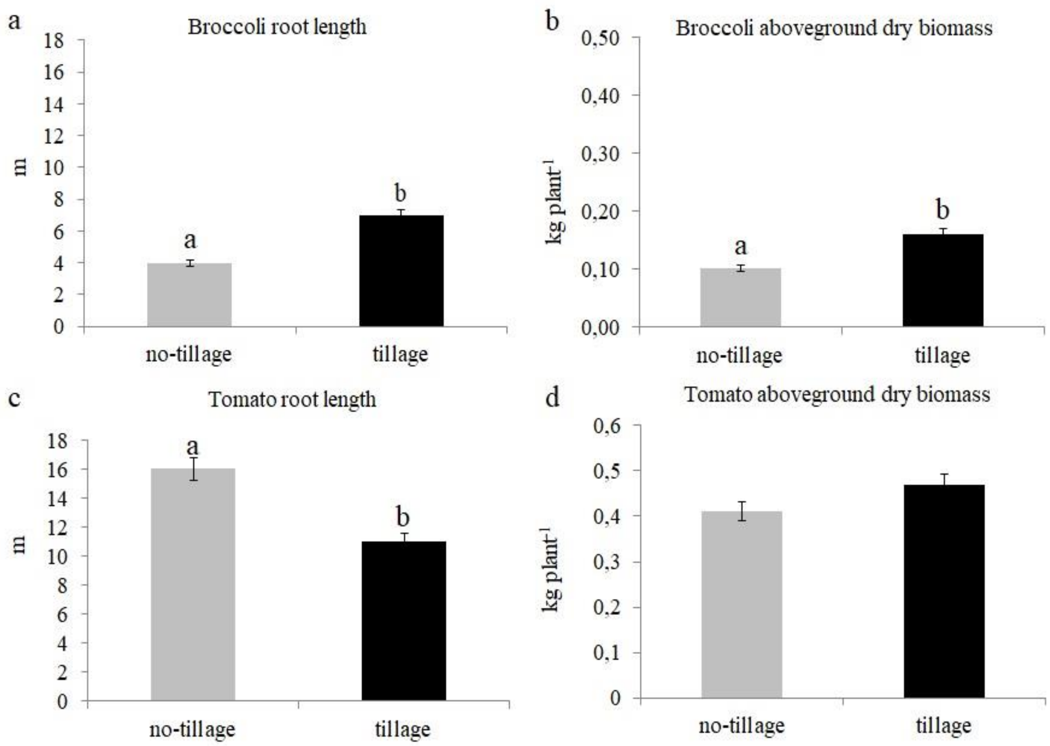

Figure 2. Root length (a) and aboveground dry biomass (b) of broccoli at 55 days after transplanting (DAT); root length (c) and aboveground dry biomass of tomato (d) at 60 DAT, in the different soil tillage. Differences letters shown difference between means by PDIFF at 5% of probability.

Soil fertility

Regarding the chemical fertility of the soil at 0.0 to 0.05 m depth, there was significant difference between tillage methods. Under no-tillage there was increasing in the contents for calcium (Ca), magnesium (Mg), sum of bases (SB), phosphorus (P), organic matter (OM), cation

DOI: 10.37856/bja.v97i2.4300

exchange capacity (CEC) and base saturation (BS) and decreasing in pH and hidrogen+aluminum (H+Al) compared to conventional tillage. At the 0.05 to 0.10 m of soil depth no tillage provided improvement in Ca, Mg, SB, CEC and BS and decreasing pH, H+Al (Table 3). However, there was no difference between tillage methods at 0.10 to 0.20 m depth. Also, there was no difference among cover crops on the soil chemical fertility.

Table 3. Chemical fertility, calcium (Ca), magnesium (Mg), potassium (K), sum of bases (SB), phosphorus (P), organic matter (OM), pH, hydrogen + aluminium (H+Al), cation exchange capacity (CEC) and base saturation (BS) at 0.0 to 0.05 m and 0.05 to 0.10 m soil depth.

Tillage Methods	Ca	Mg	K	SB	P	OM	pH	H+Al	CEC	BS%
	mmolc kg^{-1}				mg kg^{-1}	g kg^{-1}		mmolc kg^{-1}		
0.0 to 0.05m depth of soil profile										
No Tillage	69.5 a [y]	28.2 a	9.4	113.4 a	162.2 a	31.2 a	6.6 a	15.1 a	128.7 a	87.8 a
Conventional Tillage	50.5 b	22.2 b	9.2	81.9 b	123.4 b	27.7 b	5.9 b	22.8 b	104.7 b	78.0 b
P≤F	<.0001*	0.0010*	0.8435	<.0001*	0.0412*	0.0062*	0.0001*	<.0001*	0.0002*	<.0001*
0.05 to 0.10m depth of soil profile										
Tillage Methods (TM)										
No Tillage	64.3 a [y]	25.8 a	7.9	99.9 a	143.6	27.4	6.4 a	18.2 a	118.3 a	84.4 a
Conventional Tillage	50.6 b	22.1 b	8.5	81.1 b	123.3	28.1	5.9 b	23.7 b	105.0 b	76.8 b
P≤F	0.0014*	0.0163*	0.4581	0.0002*	0.2894	0.4222	0.0026*	0.0061*	0.0022*	0.0002*

* Significant differences by the variance analysis (ANOVA) at 5% of probability.

[y] Difference between the means in the column is shown by different letters, by PDIFF at 5% of probability.

Crop yield

Regarding the broccoli yield, there was significant difference between tillage methods, whereby the conventional tillage produced each inflorescence with 18% more fresh biomass and had yield of 37 Mg ha^{-1}, 43% greater than that of no-tillage (Table 4). Tomato yield was not affected by the treatments, so the number of commercial fruits per plant and the commercial yield were not affected by cover crops and tillage methods.

Table 4. Commercial fresh mass of inflorescence (FMI), broccoli yield, commercial number of tomato fruit (NCF) and tomato yield.

	Broccolis		Tomato	
Cover crops (CC)	FMI (g $plant^{-1}$)	Yield (Mg ha^{-1})	NCF number $plant^{-1}$	Yield (Mg ha^{-1})
Legume[x]	619.0	33.0	42	57.3
Grass	670.9	32.7	46	55.8
Legume+Grass	649.0	29.1	50	63.0
P≤F	0.214	0.4171	0.3858	0.3773
Tillage methods (Till)				
No Till	592.3 b[y]	26.0 b	45	57.5
Tillage	700.3 a	37.2 a	47	59.9
P≤F	0.0003*	0.0007*	0.6992	0.5865
Interaction (CCxTill)				
P≤F	0.6222	0.3077	0.0885	0.1077

* Significant differences by the analysis of variance (ANOVA) at 5% of probability.
[y] Difference between the means in the column is shown by different letters by PDIFF at 5% of probability.
[x]Legume = vetch and sunn hemp; Grass = oat and millet as cover crops for both broccoli and tomato crop, respectively.

Cover crops and vegetables performance

During the of winter cover crops growing, the low quantity and irregular distribution of rainfall hindered adequate growth and, consequently, the aboveground dry biomass yield of the winter cover crops. Even under low water availability, vetch produced a greater amount of aboveground dry biomass than oats or the mix of vetch+oats. In the summer cover crops cultivation, climate conditions were favourable to plant growth, with adequate distribution of rainfall and, consequently, a great aboveground dry biomass yield. Hence, millet and the mix of millet+sunn hemp had a better productive performance of aboveground dry biomass than sunn hemp sole. Although the effect of cover crops on the properties studied in the experiment was little evident, the biological action of roots on soil decompaction is very relevant, highlighting millet potential to be used in conditions of soil with high levels of penetration resistance (ROSOLEM et al., 2002).

Tosti et al. (2012) related that tomato had yield favoured when cultivated in succession with a mix of barley and vetch as cover crops, when compared to barley alone. The better yield was attributed to the improvement in the tomato nutritional status due to nitrogen fixed into the soil by vetch. However, our study showed no significant effect of cover crop on the yield of broccoli and tomato.

Broccoli aboveground growth was impaired when cultivated in no-tillage. The fact that determined the reduction in growth under no-tillage was the smaller root length compared to that under conventional tillage. The conditions of high soil mechanical resistance to penetration under no-tillage at the first 0.3 m (Figure 1a) caused the reduction of broccoli root length. Conditions of compacted soil reduce the foliar growth of broccoli by 54% due to the reduction of 70% of total root length (MONTAGU et al., 2001). When comparing the agronomic performance of vegetable species in high levels of penetration resistance of the soil, Wolfe et al. (1995) concluded that cabbage, a species in the same family as broccoli, was the most vulnerable to loss of productivity when compared to cucumber, beans or sweet maize.

On the other hand, even with the smaller yield of broccoli under no-tillage, techniques which can favour the increase of crop yield in Conservation Agriculture (CA) could be suggested, like the adoption of minimum tillage at crop row (‘strip tillage’), which promotes punctual reduction in the soil mechanical resistance to root penetration and benefits root length (AHMADIANI et al., 2016). Cultivation of cover crops with deep rooting in crop rotation associated with traffic controlled in the field will also improve and help avoid the high levels of penetration resistance (MCHUG et al., 2006). In a comparative experiment between no-tillage and conventional tillage, Melo et al. (2010) did not find a difference in broccoli yield, suggesting its adoption by growers for CA. Pittelkow et al. (2015) reported that no-tillage reduces crop productivity, although under certain environmental conditions it could produce similarly to or even more than conventional tillage. They also highlight that the adoption of CA by maintenance of the soil’s cover and crop rotation potentiates the crop yield under no-tillage besides significantly reducing the erosive process and improving fertility conditions of the soil.

Different to broccoli, the root length of tomato plants was greater in no-tillage. The capacity of root length of tomato plants stands out when it is confronted with the greater soil mechanic resistance to penetration of the roots under no-tillage.

Regarding penetration resistance, the biopores produced by the roots of cover crops may help alleviate soil compaction, especially under no-tillage, providing low resistance paths to successor crop roots, a process dubbed ‘biodrilling’. Connected pores only exist in no-tillage, since tillage destroys that structure (WILLIANS & WEIL, 2004). Plant species show different performance when comparing conventional tillage with no-tillage. Yau et al. (2010) did not find difference between conventional tillage and no-tillage on the dry biomass accumulation of barley, chick-peas and safflower.

In the case of tomatoes, the similarity of productivity between no-tillage and conventional tillage was assigned to the vigorous root length of tomato plants, even when under conditions of greater mechanic resistance of soil to penetration under no tillage. Marouelli et al. (2006) reported an increase of up to 17% in tomato productivity for no-tillage, compared to conventional tillage, which is a fact that increases the feasibility of CA in the preservation of soil and water for agricultural exploitation. Kuhwald et al. (2017) recommended on-time inversion tillage for overcoming of some the main disadvantages associated with long-term reduced tillage, as the high resistance of the soil to penetration, technique that preserving the positive effects of CA on soil physical properties. In Mediterranean environment, marketable yield of tomato plants was higher in no tillage legume mulched soil compared to conventional tillage and no tillage bare soil (CAMPIGLIA et al., 2011).

Soil water content

Soil water content was significantly greater in CA conditions than for conventional tillage. This is attributed to the fact that no-tillage preserves the soil structure, improving stability of aggregates and the relation of macro and micropores (NOVELLI et al., 2017), as well as the maintenance of straw on the soil surface that reduces the evaporation (MITCHELL et al., 2012). Despite the improvement in soil water content, there were not found any agronomic benefits for the vegetables, because the adequate water supply by irrigation suppressed the benefits that could happen in conditions of water restriction. In the light of the results, we could suggest a reduction of up to 15% in water supply when CA is adopted for vegetable cultivation.

Onion grown under CA reduced 30% of the irrigation water for the first 30 days of the cycle and 19% along the cultivation compared to conventional tillage (MAROUELLI et al., 2010). In study of tomato crop, Marouelli et al. (2006) reported an increase of 23% in water use efficiency under no-tillage, when compared to conventional tillage. Therefore, the increase in the water saving in crop irrigation under CA conditions is clear.

Soil fertility

Soil fertility increased in the superficial layers of the soil under no-tillage, with increases in the content of organic matter and nutrients at 0.0 to 0.1 m depth. Preserving soil structure and maintaining straw on the surface leads to increasing organic matter and nutrient content and, consequently, improvement in soil fertility (NYAMBO et al., 2020; DUDA et al., 2003). Notwithstanding, increase in soil fertility in the most superficial layer did not influence the improvement of vegetables yield. However, based on the results, reduction in fertiliser could be recommended for CA. Branco et al. (2017), while growing tomatoes under CA, reduced the application of nitrogen fertiliser compared to the current technical recommendation by 51%, which was attributed to the increase of organic matter in the soil. In semi-arid conditions also was reported improvement on soil fertility on the top soil profile with increasing in carbon soluble, carbon of microbial biomass and protease activity under conservation tillage (MURILLO et al., 2006). Kumar et al. (2016), also related that soil management under CA improved the soil quality by enhancing water-stable aggregates, labile and total organic carbon fractions and biological soil attributes mainly in the surface soil layer of 0-0.05m.

Increase in pH and base saturation is assigned to the accumulation of nutrients Ca and Mg in the top layer of the soil due to non-inversion by no-tillage. Therefore, below 0.20m depth under no-tillage conditions, it is hard to reach the adequate Ca and Mg content and pH because to the low mobility these nutrients in the soil profile. However, the results showed no difference between tillage methods on Ca and Mg distribution, pH, base saturation and cation exchange capacity at a depth of 0.2 m that contradict this low mobility of Ca and Mg. Caires et al. (2005) reported effect of liming on depths below 0.2 m after two years of the application, for no-tillage conditions. Therefore, the lime application on the soil surface, under no-tillage without incorporation, is enough for the correction of soil even at depths below 0.2 m. This mobility of Ca and Mg under CA should be attributed by the dynamic of nutrients recycling and root exudation from cover crops in rotation that drives to an increase in soil biology activity and soil fertility.

CONCLUSION

Under Conservation Agriculture (CA) the soil had greater water storage capacity and increasing in fertility, mainly at a depth of 0.0 to 0.1 m, but had greater soil mechanical resistance to penetration at 0.0 to 0.3 m compared to conventional tillage. Regarding the crop performance, broccoli was impaired to growth and yield under CA. Tomato plants had improved root growth under no-tillage and similar aboveground growth and yield between both tillage methods. The winter cover crops, vetch, bristle oat and the mix of both species as well as summer cover crops, millet, sunn hemp and the mix of both species despite be extremely important for the concept of CA they didn´t differ among them regarding the traits studied in this experiment.

Therefore, we propose the adoption of CA for vegetable cultivation under tropical condition but further studies, are necessaries for enhance this technique and achieve high yield of vegetable crops with improvement in ecosystem services.

ACKNOWLEDGEMENTS

This work was supported by Agrisus Foundation under greater number PA 1737-16.

REFERENCES

AHMADIANI, M.; LI, C.C.; LIU, Y.; FONSAH, E.G.; BLISS, C.M.; BRODBECK, B.V.; ANDERSEN, P.C. 2016. Profitability of organic vegetable production via sod based rotation and conventional versus strip tillage in the Southern Coastal Plain. **Sustainable Agriculture Research**, Ontário, v.5, p.46–55. DOI:10.5539/sar.v5n4p46

BENINCASA, P.; TOSTI, G.; GUIDUCCI, M.; FARNESELLI, M.; TEI, F. 2017. Advances in research on fertilization management of vegetable crops, In: **Advances in olericulture**, 115–148 (Eds F. Tei, S. Nicola, P. Benincasa). Gewerbestrasse, Switzerland: Springer International Publishing.

BRANCO, R.B.F.; BLAT, S.F.; GIMENES, T.G.S.; NOWAKI, R.H.D.; ARAÚJO, H.S.; SALLES, F.A. 2017. Nitrogen fertilization of vegetables cultivated under no-tillage after cover crops. **Horticultura Brasileira**, Brasília, v.35, p.103–110. DOI: http://dx.doi.org/10.1590/S0102-053620170116

CAIRES, E.F.; ALLEONI, L.R.F.; CAMBRI, M.A.; BARTH, G. 2005. Surface application of lime for crop grain production under a no-till system. **Agronomy Journal**, Madison, v.97, p.791–798. DOI: 10.2134/AGRONJ2004.0207

CIIAGRO - Centro Integrado de Informações Agrometeorológicas. 2017. Available at: <http://www.ciiagro.sp.gov.br/> Accessed on: 0ct. 10.

CAMPIGLIA, E.; MANCINELLI, R.; RADICETTI, E. 2011. Influence of no-tillage and organic mulching in tomato (*Solanum lycopersicum* L.) production and nitrogen use in the Mediterranean environment of central Italy. **Scientia Horticulturae**, Amsterdan, v.130, p.588–598. DOI: https://doi.org/10.1016/j.scienta.2011.08.012

DERPSCH, R.; SIDIRAS, N.; ROTH CH. 1986. Results of studies made from 1977 to 1984 to control erosion by cover crops and no tillage techniques in Paraná, Brazil. **Soil & Tillage Research**, Amsterdan, v.8, p.253–263. DOI:10.1016/0167-1987(86)90338-7

DUDA, G.P.; GUERRA, J.G.M.; MONTEIRO, M.T.; DE-POLLI, H.; TEIXEIRA, M.G. 2003. Perennial herbaceous legumes as live soil mulches and their effects on C, N and P of the microbial biomass. **Scientia Agricola**, Piracicaba, v.60, p.139–147. DOI: https://doi.org/10.1590/S0103-90162003000100021

FILGUEIRA, FAR. 2000. **Novo Manual de Olericultura: Agrotecnologia Moderna na Produção e Comercialização de Hortaliças**, 1 edn, Universidade Federal de Viçosa, Viçosa.

FRIEDRICH, T.; DERPSCH, R.; KASSAM, A. 2012. Overview of the global spread of conservation agriculture. **Field Actions Science Reports** [Online], Special Issue 6. Available at: <http://factsreports.revues.org/1941> Accessed on: 0ct. 10, 2017.

HOLLAND, J. 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. **Agriculture, Ecosystems and Environment**, Amsterdan, v.103, p.1–25. DOI:10.1016/j.agee.2003.12.018

HOYT, G.D.; MONKS, D.W.; MONACO, T.J. 1994. Conservation tillage for vegetable production. **HortTechnology**, Alexandria, v.4, p.129–35. DOI: https://doi.org/10.21273/HORTTECH.4.2.129

KUHWALD, M.; BLASCHEK, M.; BRUNOTTE, J.; DUTTMANN, R. 2017. Comparing soil physical properties from continuous conventional tillage with long-term reduced tillage affected by one-time inversion. **Soil Use Management**, Bedford v.33, p.611:619. DOI: https://doi.org/10.1111/sum.12372

KUMAR, S.; GARG, A.K.; AULAKH, M.S. 2016. Effect of Conservation Agriculture practices on physical, chemical and biological attributes of soil health under soybean-rapessed rotation. **Agricultural Research**, New Delhi, v.5, p.145-161. DOI:10.1007/s40003-016-0205-y

LABRIÈRE, N.; LOCATELLI, B.; LAUMONIER, Y.; FREYCON, V.; BERNOUX, M. 2015. Soil erosion in the humid tropics: A systematic quantitative review. **Agriculture, Ecosystems and Environment**, Amsterdan, v.203, p.127–139. DOI:10.1016/j.agee.2015.01.027

MAROUELLI, W.A.; ABDALLA, R.P.; MADEIRA, N.R.; SILVA, H.R.; OLIVEIRA, A.S. 2010. Water use and onion crop production in no-tillage and conventional cropping systems. **Horticultura Brasileira**, Brasília, v.28, p.19–22. https://doi.org/10.1590/S0100-204X2010000400004

MAROUELLI, W.A.; SILVA, H.R.; MADEIRA, N.R. 2006. Uso de água e produção do tomateiro para processamento em sistema de plantio direto com palha. **Horticultura Brasileira**, Brasília, v.41, p.1399–1404. DOI: https://doi.org/10.1590/S0100-204X2006000900008

MCHUGH AD, HONGWEN L, TULBERG JN (2006) Controlled Traffic Farming takes Conservation Agriculture into China. **Controlled Traffic Framing Conference,** 28–33, Ballarat, Australia. DOI: 10.1007/978-3-642-03681-1_8

MELO RAC, MADEIRA NR, PEIXOTO JR (2010) Cultivo de brócolis de inflorescência única no verão em plantio direto. **Horticultura Brasileira**, Brasília, v.28, p.23–28. DOI:10.1590/S0102-05362010000100005

MITCHELL, J.P.; SINGH, P.N.; WALLENDER, W.W.; MUNK, D.S.; WROBLE, J.F.; HORWATH, W.R.; HOGAN, P.; ROY, R. HANSON, B.R. 2012. No-tillage and high-residue practices reduce soil water evaporation. **California Agriculture**, Davis, v.66, p.55–61. DOI: https://doi.org/10.3733/ca.v066n02p55

MONTAGU, K.D.; CONROY, J.P.; ATWELL, B.J. 2001. The position of localized soil compaction determines root and subsequent shoot growth responses. **Journal of Experimental Botany**, Oxford, v.2, p.2127–2133. DOI:10.1093/JEXBOT/52.364.2127

MURILLO, J.M.; MORENO, F.; MADEJÓN, E.; GIRÓN, I.F.; PELEGRIN, F. 2006. Improving soil surface properties: a driving force for conservation tillage under semi-arid conditions. **Spanish Journal of Agricultural Research**, Madrid, v.4, p.97-104. DOI: 10.5424/sjar/2006041-180

NOVELLI, L.E.; CAVIGLIA, O.P.; PIÑEIRO, G. 2017. Increased cropping intensity improves crops residues inputs to the soil and aggregate-associated soil organic carbon stocks. **Soil and Tillage Research**, Amsterdan, v.165, p.128–136. DOI: https://doi.org/10.1016/j.still.2016.08.008

NYAMBO P, CHIDUZA C, ARAYA Y. 2020. Effect of conservation agriculture on selected soil physical properties on haplic cambisol in Alice, Eastern Cape, South Africa. **Archives of Agronomy and Soil Science**, London, v. 68, p.195-208. https://doi.org/10.1080/03650340.2020.1828578

PITTELKOW, C.M.; LINQUIST, B.A.; LUNDI, M.E.; LIANG, X.; VAN GROENIGEN, K.J.; LEE, J.; VAN GESTEL, N.; SIX, J.; VENTEREA, R.T.; VAN KESSEK, C. 2015. When does no-till yield more? A global meta-analysis. **Field Crops Research**, Amsterdan, v.183, p.156–168. DOI: 10.1016/j.fcr.2015.07.020

RONQUIM CC. 2010. Conceitos de fertilidade do solo e manejo adequado para as regiões tropicais. Embrapa Monitoramento por Satélites, **Boletim de Pesquisa e Desenvolvimento**, 8, 27p.

ROSOLEM, C.A.; FOLONI, J.S.S.; TIRITAN, C.S. 2002. Root growth and nutrient accumulation in covers crops as affected by soil compaction. **Soil and Tillage Research**, Amsterdan, v.65, p.109–115. DOI:10.1016/S0167-1987(01)00286-0

VAN RAIJ B.; ANDRADE, J.C.; CANTARELLA, H.; QUAGIO, J.A. 2001 Análise química para avaliação da fertilidade de solos tropicais. Instituto Agronômico, Campinas, 285p.

TOSTI, G.; BENINCASA, P.; FARNESELLI, M.; PACE, R.; TEI, F.; GUIDUCCI, M.; THORUP-KRISTENSEN, K. 2012. Green manuring effect of pure and mixed barley—hairy vetch winter cover crops on maize and processing tomato N nutrition. **European Journal of Agronomy**, Amsterdan, v.43, p.136–146. DOI: https://doi.org/10.1016/j.eja.2012.06.004

WILLIANS, S.M.; WEIL, R.R. 2004. Cover crops root channels may alleviate soil compaction effects on soybean crop. **Soil Science Society of America Journal**, Madison, v.68, p.1403–1409. DOI: https://doi.org/10.2136/sssaj2004.1403

WOLFE, D.W.; TOPOLESKI, D.T.; GUNDERSHEIM, N.A.; INGALL, B.A. 1995. Growth and yield sensitivity of four vegetable crops to soil compaction. **Journal of American Society for Horticultural Science**, Alexandria, v.120, p.956–963. DOI: https://doi.org/10.21273/JASHS.120.6.956

YAU, S.K.; SIDAHMED, M.; HAIDAR, M. 2010. Conservation versus conventional tillage on performance of three different crops. **Agronomy Journal**, Madison, v.102, p.269–276. DOI:10.2134/AGRONJ2009.0242

Received in: March, 15, 2022.
Accepted in: July, 1, 2022.