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Growth and Development Responses of Tobacco (*Nicotiana tabacum* L.) to Changes in Physical and Hydrological Soil Properties Due to Minimum Tillage

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ABSTRACT

Minimum tillage is a soil conservation practice involving a reduction in soil disturbance and topsoil compaction, which could minimize environmental impact of the tobacco cultivation system. The objectives of this study were to evaluate the development and growth responses of Nicotiana tabacum and the changes in the physical and hydrological soil properties after the application of two different treatments: minimum tillage (MT) and conventional tillage (CT). MT did not cause any pronounced differences in the crop yield compared to CT, instead it positively affected the physical and hydrological soil properties and the plants' vegetative growth. Under MT, the soil showed a higher structural stability than CT with significantly lower compaction values. With MT the soil showed a higher capacity to maintain and store water during the drought periods, evidenced by soil moisture values significantly higher than CT. Tobacco on MT showed a good response, significantly prolonging the vegetative growth stage which at harvest determined a higher stem height, greater number of leaves and longer internodes.

Keywords: *Minimum Tillage, Phenology, Yield, Soil Moisture, Soil Compaction*

1. Introduction

Soil management is a decisive factor for crop development and growth, affecting the physical, biological and chemical properties of the root environment. Compared to conventional tillage (CT), minimum tillage (MT) is a soil conservation practice capable of reducing soil disturbance, wheel traffic compaction and soil erosion [1-3]; moreover conservative tillage can reduce the environmental and economic costs of the cultivation systems [4-6]. Studies on MT highlighted, since its first year of application, changes in soil physical and hydraulic properties with an increase in soil moisture [7-14] and water content at saturation [15], as well as an improvement in water use efficiency for many crops [7,13].

Studies of MT on many seed crops showed good yields that do not differ significantly from those obtained with CT [8,11-13,16-23]. Moreover, authors reported that already during the first year with MT it is possible to reach the same yields as CT [7,12,20,23]. Some of them explained these results as a consequence of the higher available water, and consequently greater nitrogen availability, induced by MT especially during the driest seasons [7] or in semi-arid condition [12].

Tobacco (*Nicotiana tabacum* L.) is particularly susceptible to water stress, a condition that severely affects the yield with reductions in plant height, total dry matter, number of leaves, leaf initiation rate and leaf area development [24-26].

Previous research on tobacco showed that MT, compared to CT, significantly reduces the erosion and total run-off with less loss of suspended solids and nutrients (*i.e.* nitrogen and phosphate compounds), and less pollutant dispersion (pesticides, etc.) in water run-off [27-30], playing a role in the development of a sustainable agricultural system for this intensive crop cultivation.

However, there are few scientific works advocating the use of MT on tobacco, and the primary factors limiting the diffusion of this conservation tillage practice include the mistrust of the growers, who traditionally use an intensive tillage system for this cash crop, and the uncertainty surrounding crop growth and yield responses [31].

The aim of this study was to analyze the effects of MT, compared to CT, on physical and hydrological soil properties, with particular attention to soil surface compaction and soil water availability, with an analysis of the responses of tobacco in terms of phenological development, biomass growth and yield.

2. Materials and Methods

2.1. Experimental Design and Tillage Treatments

The experimental design was set up in four randomized blocks, with a total of eight replications for treatment (**Figure 1**), in a level and pedologically homogeneous land. The plots, measuring 140 m^2 (20 m × 7 m) each, were treated with two different soil tillage methods: MT and CT.

Thanks to the uniformity of the chemical, physical and morphological properties of the soil in the experimental land, the extensive survey design, including large plots and many replications for treatment, and the meteorological analysis of the growing season, it was possible to monitor the consequences on the soil and their effect on the plants due to the tillage treatments, minimizing the influence of the spatial and temporal variability and evaluating the interaction between environmental variables and crop growth and development.

The MT plots were left until transplanting with standing stubble from the previous wheat crop (*Triticum aestivum* L.). They were tilled on the same day as the transplant with a rotating harrow (0.10 m deep) used to create the transplanting bed. The CT plots were tilled according to the traditional tillage management adopted by the farm: with deep ploughing (0.40 m) in the winter of 2007-2008, followed by a surface-disking tillage (0.10 m deep) in March and a rotating harrow (0.10 m deep) on the same day as the transplant. After the transplant the conventional operation of hoeing (0.05 m deep) and propping up were carried out for both treatments.

2.2. Experimental Site and General Conditions

The study was conducted on a farm near Montepulciano Abbadia (Tuscany, Italy) (43˚08'37"N, 11˚49'58"E). The area is predominantly characterized by alluvial and colluvial soils with a mild Mediterranean climate.

Meteorological data concerning precipitation (P), mean (Tm) maximum (Tmax) and minimum (Tmin) air temperatures, maximum (U%max) and mean (U%m) relative air humidity, were monitored at standard weather stations situated near the experimental fields and acquired daily from the "A.R.S.I.A. Agrometeorological Information System" database.

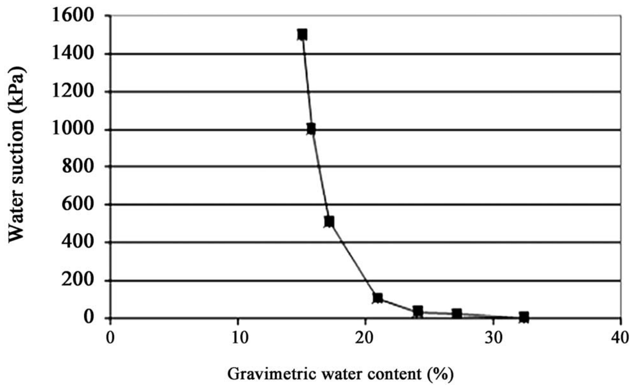

Figure 1. Soil retention curve.

The monthly averages of each meteorological variable, potential evapotraspiration (ETp) and crop evapotraspiration (ETc), were calculated from May to August 2008 and for a climatological base period of 12 years (from 1996 to 2007). The 2008 monthly averages were compared with the 12 years monthly averages to verify the climatic trend of the growth season and highlight any anomalies with respect to the climatological base period. ETp and ETc were calculated with the Priestley-Taylor method [32] and taking into account the FAO recommendations [33] for tobacco that consider a crop cycle length of 110 days and the following crop coefficients (Kc): during the initial stage 0.3 - 0.4 (20 days), 0.7 - 0.8 during the development stage (30 days), 1 - 1.2 during the mid-season stage (30 days), 0.8 during the late season stage (30 days). The ETc values were used to define the irrigation scheduling.

Before the tillage, the soil of the experimental field was characterized via physical and chemical analyses according to the official methods [34,35].

Soil samples were collected using an auger: according to an X-shaped pattern, five soil sub-samples were collected in each plot at 0 - 0.10 m, 0.10 - 0.20 m and 0.20 - 0.30 m for physical characterization, and at 0 - 0.10 m, 0.20 - 0.30 m for chemical characterization.

Soil pH was measured potentiometrically using an electronic pH meter (Intelligent pH Meter YK-2001PH, Lutron Electronic Enterprise Co., Taiwan) with a glass electrode in a 1:2.5 (mass fraction) suspension of air-dry soil (10 g, <2 mm) in deionised water (pH in H_2O). Electrical conductivity (EC) was measured in a 1:5 air-dry soil in deionised water extracted with a conductivity probe (YK-200PCT, Lutron Electronic Enterprise Co., Taiwan). The calcium carbonate content ($CaCO_3$) was determined using a Bernard calcimeter, quantifying the CO_2 released when the sample was treated with hydro chloric acid under a constant pressure and temperature [36,37]. Total carbon and total nitrogen content was determined by dry combustion at 1000˚C and gas-chromatographic determination in an elementary Thermo Finnigan Flash EA 1112 CHNS analyzer, from 5.0 ± 0.1 mg soil samples. The available phosphorus (P_2O_5) was extracted using the $NaHCO_3$ method [38], after which the P_2O_5 concentration in the extracts was determined colorimetrically by the phospho-molybdate [39]. The exchangeable potassium (K_2O) was extracted using the NH_4Ac method, and the K_2O concentration was determined by spectrophotometric analysis. The cation exchange capacity (CEC) was determined using the triethanolamine-buffered BaC_{12} solution (c = 0.1 M) followed by a re-exchange with aqueous MgC_{12} solution (c = 0.1 M) [40,41].

The bulk density was determined by pouring the oven-dried soil (105˚C) into a 250 ml cylinder containing 100 ml of deionised water, and the texture was determined using the pipette method [42]. The soil water retention curve was derived with the Richard pressure plate extractor [43] measuring the gravimetric water contents (w in $kg \cdot ha^{-1}$) at –1, –20, –33, –100, –500, –1000 and –1500 kPa water potential values. The soil mass was measured after oven drying the samples (105˚C; 24 h) at all water potential values. The field capacity (FC), the wilting point (WP) and the Available Water Capacity (AWC) were determined with the Richard plate. FC is the drained upper limit and WP is the lower limit, both are equivalent to the amount of water retained by the soil respectively at a suction pressure of –33 kPa and –1500 kPa. The AWC is the difference between the water contents at WP and at FC.

2.3. Agricultural Practices

The Virginia Bright tobacco was transplanted on 14 May 2008. The harvest was carried out at two different times according to maturation grade, evidenced by a yellow colouring and curved bearing of the leaves, on the 85th and 106th days after transplant (DAT) for the basal leaves and median-apical leaves respectively.

During the crop cycle, fertilization, weed control, irrigation and topping (removal of flower buds) were performed according to the traditional management adopted by the local farmers. Two topping operations were carried out on the 65th and 92nd DAT. The following fertilizers were distributed: 200 $kg \cdot ha^{-1}$ of K_2SO_4 and 200 $kg \cdot ha^{-1}$ of $Ca(H_2PO_4)_2$ in February, and 500 $kg \cdot ha^{-1}$ of a starter fertilizer (5:10:15) in May. The weed control was carried out distributing 4 l ha^{-1} of a herbicide (a.p. glyphosate acid 36%) on 1 May and on 13 June.

The plots were irrigated using a rain sprinkler irrigation system according to crop growth requirements. Irrigation was implemented when water depletion in the soil profile, owing to ETc, exceeded 40% of the AWC. This was calculated for the transplanting and initial plant development at a depth of 0 - 0.15 m, and for the following plant development at a depth of 0 - 0.40 m, obtaining an irrigation water amount of 8 mm and 20 mm respectively. There were no irrigations in May and June, because the rainfall was sufficient for satisfying crop water requirements. During July and August five irrigations were necessary on the 58th, 66th, 75th, 85th, and 99th DAT.

2.4. Measurements of Soil Proprieties

The relationships between the tillage treatments and the changes in physical and hydrological soil proprieties were monitored by measuring soil compaction and soil moisture levels. The samplings for moisture determination were carried out at a distance from rainy events or irrigations on three points per plot at three depths (0 - 0.10 m, 0.10 - 0.20 m, 0.20 - 0.30 m) using a Soil Core Sampler (cylinders with a diameter of 57 mm and length of 60 mm). Each sample was immediately sealed in hermetic plastic bags and then weighed to obtain the net fresh weight. The dry weights were taken after drying in the oven at 105˚C and the soil moisture was calculated as percentage of dry weight. The soil compaction was detected using a penetrometer (range 0 - 59 $N \cdot cm^{-2}$) on two points per plot at three depths (0.10 m, 0.20 m, 0.30 m), and three measurements repetitions were performed for each one. The sampling times to detect the soil compaction and moisture are described in **Table 1**.

Table 1. Timing of crop and soil surveys.

Survey time	Crop surveys: plants per plot					Soil surveys: points per plot
(*DAT*)	*ND*	*D*	*P*	*H*	*M*	*C*
13	10		10		9	
28	12	2	12		9	
44	10		10		9	
57		2	40		9	6
71	10		25			
77					9	6
85	12	2	12	20		
98	10		10		9	6
106	12	2	12	20		

Timing of crop and soil surveys with indications respectively of sampled plants per plot and sampled points per plot. Legend: DAT = days after transplant, ND = non-destructive measurements, D = destructive measurements, P = phenological observations, H = measurements at harvest time, M = moisture measurements, C = compaction measurements.

2.5. Measurements of Crop Growth and Development

The crop growth and development were monitored on plants selected randomly from the central area of each plot. Meanwhile, the weeds, aphids or virus diffusion were monitored observing the possible differences between the tillage treatments.

During the crop cycle the following were carried out: non-destructive measurements for detecting stem height, leaf number and mean internode length (height/leaf number); destructive measurements for detecting area and dry weight of the leaves; phenological observations for monitoring the plants development stage. In addition, during the two harvest times, surveys were carried out to measure the number and dry weight of the mature leaves per plant. The leaf area was measured with an electronic planimeter (Delta-T, Dias II image analysis system, UK). The dry leaf weight was determined after drying in a ventilated oven at 50˚C. With the approaching flowering stage, a growing lack of phenological homogeneity was observed in the population: therefore, during the shift period from the vegetative to the reproductive stage, the phenological observations were extended to a larger number of individuals per plot. The times of all crop surveys and measurements are illustrated in **Table 1**.

The growth stages suggested for tobacco by the CORESTA Guide (2009) [44] according to the BBCH scale [45] were grouped in several main development stages depending on the main tobacco growing periods reported by the FAO [33]. The CORESTA classification is founded on a universally-adopted extended BBCH scale for uniformly coding phenologically-similar growth stages of plants. The description of the phenological classification adopted in our research and its corresponding BBCH codes and FAO stages are illustrated in **Table 2**.

Table 2. Description and coding of the phenological stages for tobacco.

Adopted Classification			FAO Classification		BBCH Scale	
Code	*Stage*	*Description*	*Stage*	*Length (days)*	*Stage*	*Value*
E	Initial I	Early post-transplant stage. Less than 5 unfolded leaves, stem reaches less than 0.15 m.	Initial	20	LD	1100 - 1105
					SE	3100 - 3101
L	Initial II	Late post-transplant stage. 6 - 10 unfolded leaves, stem reaches less than 0.30 - 0.35 m.			LD	1106 - 1110
					SE	3102 - 3103
K	Crop Development I	First growth stage ("Knee high"). 11 - 20 unfolded leaves, steam reaches less than 0.55 - 0.6 m.	Development	30	LD	1111 - 1120
					SE	3104 - 3105
G	Crop Development II	Elongation and rapid growth stage. More than 21 unfolded leaves, steam reaches 1 m but there is no hint of reproductive organ formation.			LD	>1121
					SE	3106 - 3109
BF	Pre-flowering I	Bud Formation. Apical bud swelling but with inflorescence not yet visible or only visible between the apical leaves.	Med-season	30	IE	50 - 51
BE	Pre-flowering II	Bud Emerging. Inflorescence emergence continuous till 1st corolla visible but still closed.			IE	52 - 55
CF	Pre-flowering III	Close Flower. First petals visible but not yet open.			IE	56 - 59
OF	Flowering I	Open Flower. From beginning of flowering, first petals open, to 50% of flowers open.	Late season	30	FW	60 - 65
AF	Flowering II	Advanced Flowering. Continuous stage until more than 90% of flowers open			FW	66 - 69

Description and coding of the phenological stages observed for tobacco in the present study and compliance with the main growth stages suggested by the FAO and by BBCH classification of CORESTA. Legend: unfolded = leaves > 4 cm length, LD = leaf development, SE = stem elongation, IE = inflorescence emergence, FW = flowering.

2.6. Statistical Data Analysis

The statistical elaborations and the descriptive statistical analysis were carried out with the SPSS 15.0 software for windows. Three levels of significance were considered: at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$. One-way analyses of variance were carried out with the general univariate linear model (ANOVA) on plant growth data and soil moisture and compaction data. The data were analyzed for each measurement date and concerning the soil, for each depth level, considering blocks and tillage treatments as the fixed factor. Bonferroni's post-hoc test was performed for the multiple comparisons. The phenological data were analyzed using the Chi-square non-parametric test considering the frequencies of individuals at each phenological stage.

3. Results and Discussion

3.1. Environmental Conditions

Compared to 12-year means, May 2008 (from 0 to 17 DAT) was characterized by lower air temperature and ETP values and higher air humidity, while June (from 18 to 47 DAT) was a rainy month with a higher rainfall and air humidity. July and August (from 57 to 106 DAT) were particularly dry with rainfall and air humidity lower than the mean.

According to the USDA classification, the soil texture class was "clay-loam". The experimental field showed homogeneous soil conditions with uniform chemical, physical and hydrological properties among the plots (**Table 3**, **Figure 1**).

3.2. Response of Soil Physical and Hydrological Properties to Tillage Treatments

The soil compaction level was influenced by the treatment (**Table 4**). The measurements on three soil depths showed a significantly lower soil compaction in MT than in CT.

The soil moisture was influenced by the treatments during the drought periods from 57 to 98 DAT and higher values were observed in MT (**Table 5**). Compared to CT, the MT soil showed a significantly higher capacity to maintain and store the water at the three soil depths when the mean moisture content decreased, coming near or dropping below the permanent wilting point of 15%.

Table 3. Soil characterization.

Soil parameters					
Chemical		*Physical*		*Hydrological*	
				GWC (%)	
OC (%)	1 ± 0.18	BD (t·m^{-3})	1.45 ± 0.11	Saturation	32.5
Total N (%)	0.07 ± 0.01	Sand (%)	36.9	FC	24.1
P_2O_5 (mg·kg^{-1})	14.9 ± 2.1	Silt (%)	28	WP	15.1
K_2O (cmol + kg^{-1})	0.26 ± 0.05	Clay (%)	35.1	AWC	9
$CaCO_3$ (%)	7.45 ± 0.7				
EC (dS m^{-1})	0.06 ± 0.01				
CEC (cmol + kg^{-1})	20.7 ± 0.5				
pH	8.2 ± 0.1				

Soil characterization: chemical, physical and hydrological parameters measured in January 2008. Legend: OC = organic carbon, EC = electrical conductivity, CEC = cation exchange capacity, BD = bulk density, GWC = gravimetric water content, FC = field capacity, WP = wilting point, AWC = available water capacity.

Table 4. Values of soil compaction.

Time (DAT)	Depth (m)	Compaction level (N cm^{-2})		Statistical significance
		CT	*MT*	
57	0.10	38.85	21.48	***
	0.20	38.06	30.51	n.s.
	0.30	38.95	24.82	***
77	0.10	17.27	6.18	***
	0.20	58.08	15.21	***
	0.30	57.39	16.09	***
97	0.10	55.62	41.10	***
	0.20	64.65	46.60	*
	0.30	66.02	45.62	**

Mean values of soil compaction detected at three soil depths with the significant difference levels between tillage treatments. Legend: DAT = days after transplant, CT = conventional tillage, MT = minimum tillage, n.s. = not significant, * significant at $P \leq 0.05$, ** significant at $P \leq 0.01$, *** significant at $P \leq 0.001$.

Table 5. Values of soil moisture.

Time (DAT)	Depth (m)	Soil moisture (%)		Statistical significance
		CT	*MT*	
	0.10	15.85	15.76	n.s.
13	0.20	15.79	15.69	n.s.
	0.30	15.61	16.13	n.s.
	0.10	18.89	19.21	n.s.
28	0.20	18.89	20.02	n.s.
	0.30	20.06	20.46	n.s.
	0.10	17.33	18.57	n.s.
44	0.20	18.26	19.57	n.s.
	0.30	18.92	19.37	n.s.
	0.10	8.54	9.57	n.s.
57	0.20	10.48	11.73	***
	0.30	12.50	15.12	***
	0.10	9.38	13.71	***
77	0.20	10.48	13.20	***
	0.30	10.54	13.28	***
	0.10	7.54	7.98	n.s.
98	0.20	8.29	9.22	n.s.
	0.30	7.68	9.0	*

Values of soil moisture detected at three soil depths with the significant difference levels between tillage treatments. Legend: DAT = days after transplant, CT = conventional tillage, MT = minimum tillage, n.s. = not significant, * significant at $P \leq 0.01$, *** significant at $P \leq 0.001$.

The soil compaction results suggest that the CT was not able to create a stable structure and that its positive effects on the physical soil properties was annulled by the compression action due to wheel transit of the agricultural machines used to carry out the hoeing, propping up and topping during the crop growing season. Conversely, the lower soil compaction values recorded with MT show that via the reduction of the soil disturbance level, this tillage practice could be able to improve the physical soil properties and structure stability, minimizeing the negative consequences of the wheel transiting action.

Moreover, the results pointed out that MT was able to improve the hydrological soil properties, furthering the moisture retention during the drought period. This may be due to the increased capacity to capture and store moisture compared to CT, depending on the changes in soil porosity during the second half of the crop cycle caused by agricultural traffic.

3.3. Crop Phenology

During the vegetative phase, the crop showed homogeneous phenological development and there were no significant differences between treatments. At 13 and 28 DAT all the plants were respectively in the early (E) and late (L) establishment stage. Similarly, at 44 DAT all the plants were in the first vegetative growth stage (K). Instead, from the beginning of the reproductive phase the plantation showed a non-homogeneous phenological development with the simultaneous presence of plants at the vegetative growth, pre-flowering and flowering stages.

At 57 and 71 DAT, significant differences were observed between the treatments (**Table 6**). Compared to CT, the plants in MT showed the tendency to delay the reproductive stage and prolong the vegetative growth stage with a lower frequency in the flowering stages (FC, FO) at 57 DAT, and a lower frequency in advanced flowering stage (FF) at 71 DAT. Conversely, after 99 DAT, there were no differences between the treatments and all the plants reached the reproductive phase, which led to the advanced flowering stage (FF).

The shift period from vegetative to reproductive stage, between 57 and 77 DAT, coincided with the drought months characterized by a soil moisture content below or close to the permanent wilting point (**Tables 3** and **5**), so the flowering onset time and the duration of vegetative growth stage were probably influenced by the different soil moisture status due to the tillage treatment.

In fact many studies showed how water deficit is able to modify the phenology, enhancing flowering and causing an early switch of development from the vegetative to the reproductive stages in many horticultural, forestry and grain cultivations, including *Rhododendron* L. [46], *Litchi chinensis* Sonn. [47], *Picea engelmanni* Parry. [48], *Pyrus communis* L. [49], *Citrus* L. [50], *Eriobotrya japonica* Thunb. [51], *Triticum aestivum* L. [52,53], *Hordeum vulgare* L. [53], and *Glycine max* L. [54].

The results suggest that the higher soil moisture in MT, involving less water stress, was able to affect the phenological development of the crop, furthering vegetative growth thanks to the delay of flowering onset. The enhancing of the vegetative growth during the drought period is a very important aspect for tobacco, a crop for which the leaves represent the main product.

3.4. Crop Growth and Production

During the field surveys, no weed incidence differences were detected between the two tillage treatments. Moreover, no attacks by aphids or virus were observed during the tobacco growing season. Therefore, from this point of view the plants with MT were not disadvantaged and the conventional treatments for the weed and pathogen control were sufficient in both the MT and CT plots.

During the non-destructive surveys, significant differences were observed between the two treatments with regard to stem height, number of leaves and average internode lengths (**Table 7**). In the first three surveys the plant growth appeared significantly improved by CT treatment: however, after 45 DAT, this tendency changed and the plant growth increased in MT.

Table 6. Phenological stages frequencies.

Time (DAT)	Phenological Stage	Frequency		Statistical Significance
		CT	*MT*	
57	G	88	146	***
	BF	36	46	n.s.
	BE	135	121	n.s.
	FC	51	7	***
	FO	10	1	**
71	G	17	27	n.s.
	BF	4	12	*
	BE	3	11	*
	FC	16	11	n.s.
	FO	5	26	***
	FF	155	113	**

Frequencies of plants in the different phenological stages at 57 and 71 DAT with the significant difference levels between tillage treatments. Legend: DAT = days after transplant, CT = conventional tillage, MT = minimum tillage, G = II stage vegetative growth, BF = bud formation stage, BE = bud emerging stage, FC = closed flower stage, FO = open flower stage, FF = advanced flowering stage, n.s. = not significant, * significant at $P \le 0.05$, ** significant at $P \le 0.01$, *** significant at $P \le 0.001$.

Table 7. Non-destructive surveys: growth parameters.

Time (DAT)	Stem height (cm)		Statistical significance	Leaves number		Statistical significance	Average internode length (cm)		Statistical significance
	CT	*MT*		*CT*	*MT*		*CT*	*MT*	
13	8.60	7.9	**	4.35	4.06	*	2.02	1.99	n.s.
28	23.35	20.56	***	8.54	7.91	***	2.76	2.62	**
44	55.33	52.82	***	13.21	12.45	**	4.18	4.09	n.s.
71	109.71	130.78	***	18.10	21.50	***	6.10	6.12	n.s.
85	146.59	152.68	n.s.	22.35	21.56	n.s.	6.64	7.16	***
99	109.00	122.78	***	17.39	18.43	*	6.38	6.75	**
106	112.23	126.69	***	18.68	19.63	**	6.05	6.49	***

Growth parameters measured during the non-destructive surveys with the significant difference levels between tillage treatments. Legend: DAT = days after transplant, CT = conventional tillage, MT = minimum tillage, n.s. = not significant, *, significant at $P \le 0.05$; **, significant at $P \le 0.01$; ***, significant at $P \le 0.001$.

Table 8. Destructive surveys: growth parameters.

Time (DAT)	Stem height (cm)		Leaf number		Average internode length (cm)		Leaf area (cm^2)		Dry leaf weight (g)	
	CT	*MT*	*CT*	*MT*	*CT*	*MT*	*CT*	*MT*	*CT*	*MT*
28	22.44	21.50	7.81	7.81	2.89	2.78	837.53	732.54	3.92	3.50
57	99.94	93.37	16.56	16.87	5.95	5.52	6885.75	7384.42	55.96	56.78
85	166.37	188.00	24.87	26.12	6.74	7.24	13342.78	16071.0	88.91	101.66
106	112.50	116.00	18.87	17.87	6.06	6.51	12945.17	15149.0	107.83	115.08

Mean growth parameters measured during the destructive surveys. Legend: DAT = days after transplant, CT = conventional tillage, MT = minimum tillage.

Table 9. Yields.

Time (DAT)	Yield (g/plant)		Statistical significance	Yield (leaf number/plant)		Statistical significance
	CT	*MT*		*CT*	*MT*	
83	19.06	20.92	*	3.85	4.26	**
106	64.04	65.60	n.s.	10.41	11.07	n.s.

Tobacco yields with the significant difference levels between tillage treatments. Legend: DAT = days after transplant; CT = conventional tillage; MT = minimum tillage; n.s. = not significant; *, significant at $P \leq 0.05$; **, significant at $P \leq 0.01$.

During the destructive surveys, even though no significant differences were observed between the tillage treatments, the trend confirmed the results of the non-destructive surveys (**Table 8**). In fact, at the beginning (28 DAT), the CT plants showed higher values for all the growth parameters, while at 57 DAT the values of leaf area and dry weight were lower than those of MT, and after 85 DAT they showed lower values than MT for all the growth parameters.

The plant yield data confirmed that plants in MT produce a higher leaf number and dry weight than CT in both harvests, but the differences were only significant for the first one (**Table 9**).

The results suggest that the impact of MT on physical and hydrological soil properties positively affected the vegetative growth and productivity of tobacco. With MT, the plants tended to have higher values for the measured growth and harvest parameters than with CT. It is also possible to suggest that by influencing the tobacco phenology with the prolongation of the growth stage, the MT improved the leaf production in the second half of life cycle.

4. Conclusions

The adopting of MT on *Nicotiana tobacco* did not determine significant differences in the crop harvests compared to CT, however it had a positive influence on the physical and hydrological soil properties and the phenological development of the plants, without any increase in the incidence of weeds. In fact, the results showed that MT is capable of improving the physical soil stability and soil water content, while delaying the flowering and prolonging the vegetative growth which benefits the leaf yield of tobacco, a crop that is highly susceptible to water stress.

The tobacco production can benefit from the MT system firstly because, being a transplanted crop, it requires less tilled seedbeds than seed crops, and secondly, due to being an intensive cultivation system, conventional doses of chemical herbicides could suffice for containing the incidence of weeds without any changes to weed control management.

MT may represent a valid means of reducing environmental impact and obtaining economic savings for tobacco cultivation.

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