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Testing the Effectiveness of the European Cross-compliance Standard 3.1 "Ploughing in Good Soil Moisture Conditions"

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ABSTRACT: A three years monitoring was carried out at 9 sites in Italy to evaluate somephysical indicators of soil quality related to soil structure degradation and compaction: bulk density, packing density, surface roughness of the seedbed, and crop yields, and testeffectiveness of European cross-compliance Standard 3.1 'Ploughing in good soil moisture conditions'. Two plots were set up in each site: low soil moisture (L), with soil main tillage at lower water content, and high soil moisture (H) with soil main tillage at higher water content. The volumetric soil water contents at ploughing in the two treatments were compared with Upper Tillage Limit (¯$_{UTL}$) and Optimum Tillage Limit (¯$_{OTL}$). Grain yields of crops were lower as average when soil was tilled at high moisture content in comparison with the low moisture treatments. Thephysical parameters adopted as indicators of soil structure degradation proved effective in assessing the differences among the treatments, and could be adopted as a routine scheme in similar researches on the effects of soil tillage on soil degradation.

Key words: Cross-compliance,Soil tillage,Soil degradation,Soil structure

INTRODUCTION

Soil is the key component of the Earth System and interacts with the other environmental compartments such as air and water. It regulates the hydrological and erosive processes, supports the biotic activity within the terrestrial ecosystems and influences the biological and geochemical cycles. Moreover the soil system contributes with goods, services and resources to the humankind (Keesstra et al., 2012; Brevik et al., 2015; Keesstra et al., 2016).

In relation to soil quality, The European Standards of Good Agricultural and Environmental Conditions (GAECs) are applied to any agricultural surface which benefits from the direct payments after the EC Regulation 73/2009 (Annex III). In particular, the Issue 3 of GAEC -Soil structure- deals with the protection of soil structure through proper measures which are regulated in the Standard 3.1 "Appropriate machinery use". The Standard prescribes that soil is tilled at a proper water content, and that the machinery use must avoid the degradation of soil structure.

The protection of soil structure is not a stand-alone issue, but aims to achieve many positive effects such as the biological activity (Laudicina et al., 2015), the decrease of the soil erosion processes and runoff (Novara et al., 2011; Lieskovský et al., 2014), and the proper water infiltration and drainage (Cerdà, 1995; Ziadat et al., 2013; Gao et al., 2014). Actually, the excess or even the water logging result in a damage to crops and negatively affect the soil structure increas-

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ing the risk of compaction (Dexter 2004a, 2004b).

In general, the adoption of propersoil tillage management has proved to impact positively Soil Organic Carbon (SOC) and other physical, chemical and biological processes and functions (Laudicina et al., 2015; Asmamaw, 2016; Balota et al., 2016; Gao et al., 2016; Hassan et al., 2016; Singh et al., 2016). In addition, soil moisture is important to regulate different soil properties and soil characteristics (Niu et al., 2015; Yu et al., 2015;Hewelke et al., 2016).

In the present work it was assumed that the proper water content can be referred to the optimum range of soil water content which creates favourable workability conditions, and is equivalent to the soil tilth condition, i.e. the soil physical state in terms of ease of tillage, surface roughness after seedbed preparation, seedling emergence and root growth described by Schjonning et al. (2007).

An approach to define the tilth condition is the "OPtimum water content for Tillage" (θ_{OPT}), i.e. the water content at which tillage produces the greatest proportion of small aggregates or, conversely, the smaller proportion of large aggregates and clods (Dexter and Bird, 2001; Dexter and Birkas, 2004; Dexter et al., 2005; Keller et al., 2007).

The range of water contents around the θ_{OPT} is defined by the Upper Tillage Limit (θ_{UTL}), and the Lower Tillage Limit (θ_{LTL}). Their difference gives the estimation of the range of water content allowing a satisfactory soil tillage. These limits depend on several factors: the range decreases as soil organic matter decreases, and increases as clay content and bulk density increase.

The main aims of the present study were: i) to compare the calculated θ_{UTL} and θ_{OTL} with soil moisture contents measured at ploughing; ii) to adopt some easily measurable soil physical parameters to be used as possible indicators of soil structure degradation and compaction (bulk density, packing density, surface roughness of the seedbed after the main tillage); and iii) to evaluate the possible effects on crop yields of the different water contents at ploughing.

MATERIALS & METHODS

A three years monitoring was carried out in Italy, and two adjacent study plots with homogeneous soil type, topography, and main physico-chemical characteristics were set up in each site:

A.low soil moisture (L),with main soil tillage at lower water content;

B.high soil moisture (H), with main soil tillage at higher water content.

The plots were set-up in nine sites with different pedoclimatic characteristics, two in plain areas in the North (Lombardy and Veneto), three in hilly areas in the Centre (Tuscany and Latium), three in plain areas in the South (Apulia and Basilicata), one in the plains of Sardinia (Fig.1).

The main site, plot and soils characteristics are shown in Tables 1-2. All plots were moldboard ploughed at 40 cm of depth.

The water content corresponding to θ_{OPT} was determined from the soil water retention curve, obtained by fitting the values measured in the laboratory with the van Genuchten equation (1980) coupled with the Mualem (1976) restriction m = (1-1/n):

$$\theta = (\theta_{SAT} - \theta_{RES})\left[1 + (\alpha h)^{n}\right]^{-m} + \theta_{RES} \qquad (1)$$

where θ_{SAT} and θ_{RES} are the water content at saturation and the residual water content respectively, α a scaling factor for the suction h applied by the soil, m and n two parameters governing the shape of the curve. θ_{OPT} corresponds to the water content at the point of inflection of the van Genuchten equation ($\theta_{OPT} = \theta_{INFL}$), and can be derived from Eq. (1):

$$\theta_{INFL} = (\theta_{SAT} - \theta_{RES})\left[1 + \frac{1}{m}\right]^{-m} + \theta_{RES} \qquad (2)$$

The Upper Tillage Limit θ_{UTL} was calculated by the equation proposed by Dexter and Bird (2001):

$$\theta_{UTL} = \theta_{INFL} + 0.4(\theta_{SAT} - \theta_{INFL}) \qquad (3)$$

To determine soil water content,undisturbed samples were collected with soil sampling rings (Ø 53 mm, height 51.0 mm) in three replicates at 20 cm of depth for each field plot. Replicates were taken along the longitudinal field line. In the laboratory the gravimetric water content was measured at four different tension values: a) 0, 10, 33, 85 kPa, with a Special Sampling Vacuum Plate n. 1725D22 (Soilmoisture Equipment Corp., Santa Barbara, CA, USA) and, b) 1500 kPa with a WP4C DewpointPotentiaMeter (Decagon Devices Inc., Pullman, WA, USA). Samples were weighed after draining to soil matrix potentials. When the equilibrium at the maximum pressure was reached, samples were reweighed and the water contents were determined gravimetrically by drying the samples at 105°C for 24 h. Finally the gravimetric content was transformed in volumetric by multiplying for the soil bulk density corresponding to that soil moisture content. Data of the volumetric water content at each pressure were used for fitting with SWRC Fit (Seki 2007), to calculate the van Genuchten parameters (θ_{SAT}, θ_{RES}, α, n, m). From these parameters, the soil volumetric water content at θ_{OTL} and θ_{UTL} were calculated (Eqs. 1, 2 and 3).

To measure soil bulk density, undisturbed samples

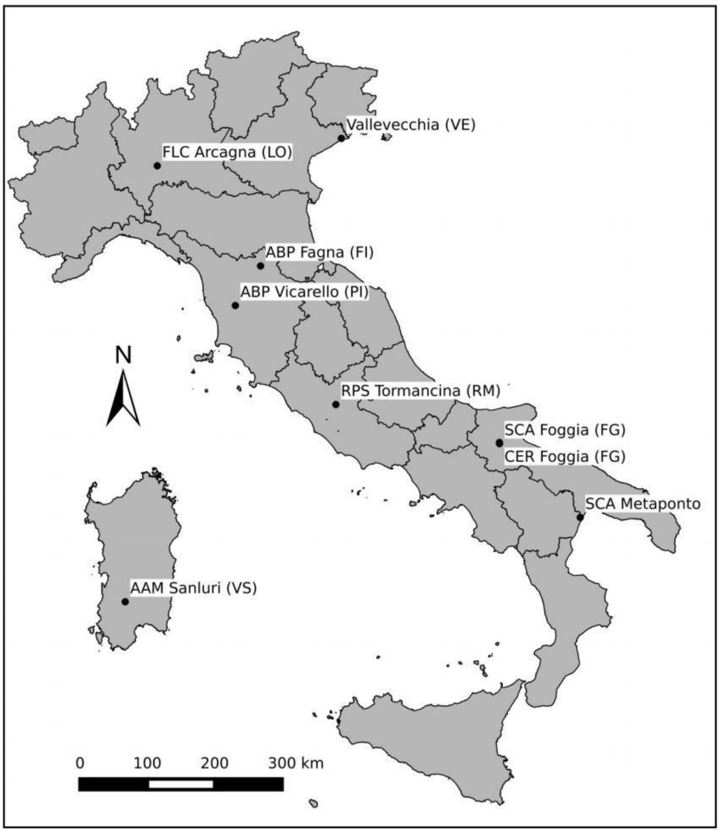

Fig. 1. Monitoring sites

Table 1.Main site and plot characteristics

Site	Location	Region	Altitude m a.s.l.	Latitude NLongitude E	MAPmm	MAT°C	Plot size m^2	Crop
AAM	Sanluri	Sardinia	50	39°31'16'' 8°51'33''	450	18.0	1500	Durum wheat-Egyptian clover
ABP	Scarperia	Tuscany	225	43°58'53" 11°20'57''	1178	12.6	5700	Common wheat
ABP	Volterra	Tuscany	200	43°27'48" 10°51'55"	833	14.2	4600	Common wheat
CER	Foggia	Apulia	79	41°27' 15°30'	526	15.8	5000	Durum wheat
FLC	Montanaso Lombardo	Lombardy	81	45°20'32'' 9°26'47''	800	12.2	3500	Common wheat
RPS	Tor Mancina	Latium	43	42°05'50'' 12°38'18''	800	15.2	1680	Durum wheat-common wheat
SCA	Foggia	Apulia	89	41°26' 15°30'	526	15.8	5000	Durum wheat +chickpeaDurum wheat
SCA	Metaponto	Basilicata	10	40°24' 16°48'	500	16.0	1270	Durum wheat
VEN	Caorle	Veneto	1	45°38'26'' 12°57'26''	970	13.7	3000	Corn

MAP, mean annual rainfall; MAT, mean annual temperature.

Table 2.Main soil characteristics

Site	Farm name	Slope %	Texture	Sand %	Silt %	Clay %	Organic matter %	pH	Soil type*
AAM	PodereOrtigara	plain	CL	43	26	31	1.7	8.0	StagnicFluvisol
ABP	Fagna	6-13	C	6	50	44	1.6	8.3	CalcaricRegosol
ABP	Vicarello	6-20	SiC	20	38	42	1.6	7.6	VerticCambisol
CER	Manfredini	plain	CL	19	43	38	2.4	8.8	Chromi-Calcic Vertisol
FLC	Arcagna	plain	SL	64	2	12	0.9	5.2	-
RPS	Tor Mancina	2-10	L	33	46	21	2.6	6.8	LuvicPhaeozem
SCA	Podere 124	plain	C	20	31	49	2.1	8.3	Chromic Vertisol
SCA	Campo 7	plain	C	19	39	42	2.6	7.8	StagnicVertisol
VEN	Vallevecchia	plain	Si	18	51	31	2.0	7.7	Gley-FluvicCambisol

* WRB classification (2014); CL clay-loam; C clayey; SiC silty-clay; SL sandy-loam; L loam; Si silty

were taken in three replicates for each plot using the same type of soil sampling rings used for soil water content (MiPAAF 1997). The soil cores were dried at 105 C° and weighed. Soil dry bulk density was determined as ratio of the mass of dry soil to the total volume of soil expressed in g/cm3.

In late autumn (winter crops) and early spring (summer crops), water contents at ploughing (20 cm of depth) were determined gravimetrically on three undisturbed cores. Samples were dried at 105°C for 24 h, and water content was transformed in volumetric content multiplying by the bulk density.

Packing density, packing density classes and susceptibility to compaction were evaluated for each monitoring site with the procedure proposed by Jones et al. (2003). The equation used is the following:

$$PD = Bd + 0.009\,C \quad (4)$$

where PD is the packing density in g/cm^{-3}, Bd is the bulk density in g/cm3, C the clay content in %. Three classes of PD are recognized: low <1.40, medium 1.40-1.75 and high >1.75 g/cm3. Soils with high PD are generally not very susceptible to compaction, whereas those with medium and low PD are vulnerable if the water content is high and the use of tillage machinery is inappropriate. Matching the soil texture according to FAO and the PD values, the inherent susceptibility to compaction was derived.

Soil surface roughness was determined to evaluate the soil surface condition after ploughing (soil cloddiness) when soils were tilled at low (L) or high (H) water contents during the main tillage. This measurement is also known as Profile index (Bertuzzi et al., 1990; Jester and Klik, 2005), and is done using a "roller chain" (length 100 cm). The chain is stretched on the soil surface following the cloddiness, and the actual length between the two ends of the chain is measured. Measurements were done along the tillage direction and perpendicularly to the tillage direction after the main tillage operation, and before the secondary tillage (e.g. harrowing) was done (Fig. 2).

The surface roughness index SR (dimensionless) is expressed by the following equation:

$$SR = \frac{\text{100 cm (length of the chain)}}{\text{X cm (measured between the two ends of the chain stretched on the soil)}} \quad (5)$$

The meaning of the ratio is as follows. In case of no surface roughness due to soil cloddiness the value is 1, i.e. the distance between the two ends of the chain stretched on the soil is equal to 100 cm, but this is unreal since all soils show some cloddiness. Thus, the expected values in actual field conditions are always higher than 1, and the higher the ratio the higher is surface roughness due to soil cloddiness (see Eq. 5).

One-way or two-ways ANOVA was performed on all the data using the Statistica software version 8.0 (Statsoft Inc. 2007, Tulsa, USA), and the separation of means was performed through Fisher's protected least significant difference test (LSD test), at $P \leq 0.05$.

RESULTS & DISCUSSION

$\overline{\ }_{UTL}$ and $\overline{\ }_{OTL}$ values and the soil water content at ploughing in the low (L) and high soil moisture (H) plots are shown in Table 3.In AAM plots, soils in the high plot and in the three years of treatment were tilled above the $\overline{\ }_{UTL}$. The low treatment in 2012 and 2014 was tilled above the $\overline{\ }_{UTL}$, in 2013 at a water content slightly below the $\overline{\ }_{OTL}$ (0.38 vs. 0.41 m3/m3).In ABP plots of Fagna, soils in both treatments were tilled at volumetric water contents below the $\overline{\ }_{OTL}$ Table 3.Main soil characteristics, soil water reference volumetric contents and at ploughing.Table 3.Main soil characteristics, soil water reference volumetric contents and at ploughing.Table 3.Main soil characteristics, soil water reference volumetric contents and at ploughing.Table 3.Main soil characteristics, soil water reference volumetric contents and at ploughing.. The high treatment at Vicarello was tilled at a mean water content higher than the $\overline{\ }_{UTL}$ (0.34 vs. 0.30 m3/m-3), the low plot at a water content below the $\overline{\ }_{OTL}$.In CER and RPS plots, soils of both treatments were tilled at water contents below the $\overline{\ }_{OTL}$. In SCA plots (Podere 124), soils in the high treatment were tilled at volumetric water contents above the $\overline{\ }_{UTL}$. In 2011 the low plot was tilled at a value of 0.30 m3/m3very close to the $\overline{\ }_{OTL}$.In VEN plots, soils in the high treatment in 2013 were tilled above the $\overline{\ }_{UTL}$. In the low treatment soil water content at ploughing was equal to the $\overline{\ }_{UTL}$.Considering the low difference between $\overline{\ }_{UTL}$ and $\overline{\ }_{OTL}$ (0.04 m3/m-3 as average), and the rainfall patterns characterised by heavy rainfall which are very common in Italy before sowing time, soil tillage at optimum moisture conditions to comply with the Standard can be difficult.

Differences in bulk density Bd were statistically significant ($P<0.05$) in FLC plots with sandy-loam texture and SCA plots (Podere 124) with clayey texture, with values lower by 26.4% and 11.0% in the low plot in comparison with the high treatment respectively, as given by the percentage difference Bd=(L-H)/L×100 (Table 4).

Lower but not significantly different values between the two treatments were found in AAM plots with clay-loam texture (-7.9%). Bulk density was 4% lower as average in the low treatment in the nine sites (1.26 vs. 1.31 g/cm3), and the linear regression between the two treatments (Fig. 3) was highly significant ($P<0.001$, $y = 1.04x$, $R^2 = 0.99$).Bulk density is dependent both on inherent soil properties, i.e. soil texture,

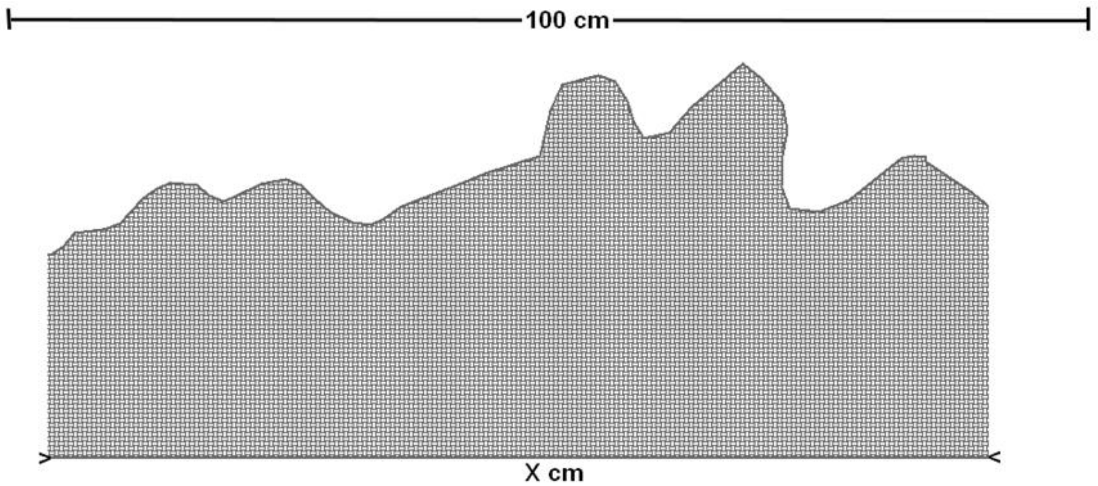

Fig.2. Diagram of the measurement with the roller chain method

Table 3.Main soil characteristics, soil water reference volumetric contents and at ploughing.

Site	USDA Texture	Plot/year	Bulk density g/cm^3	Packing density g/cm^3	Packing density class	FAO texture	Susceptibility to compaction	θ_{OTL} m^3/m^3	θ_{UTL} m^3/m^3	θ at ploughing m^3/m^3
AAM	CL	L 2012	1.24	1.52	Medium	Medium	Moderate	0.38	0.41	0.45
		H 2012	1.31	1.59				0.41	0.44	0.48
		L 2013	1.28	1.56				0.41	0.46	0.38
		H 2013	1.42	1.70				0.42	0.47	0.52
		L 2014	1.40	1.68				0.36	0.41	0.46
		H 2014	1.30	1.58				0.39	0.44	0.48
ABP Fagna	C	L 2011-2012	1.16	1.56	Medium	Fine	Low	0.37	0.41	0.15
		H 2011-2012	1.22	1.62				0.41	0.47	0.33
ABP Vicarello	SiC	L 2011-2012	1.61	1.99	High	Fine	Low	0.21	0.25	0.19
		H 2011-2012	1.43	1.81				0.26	0.30	0.34
CER	CL	L 2011	1.21	1.55	Medium	Fine	Low	0.46	0.49	0.29
		H 2011	1.21	1.55				0.49	0.52	0.38
		L 2012	1.39	1.73				0.43	0.46	0.35
		H 2012	1.37	1.71				0.44	0.47	0.43
FLC	SL	L 2012	1.22	1.33	Medium	Medium	Moderate	0.25	0.29	0.19
		H 2012	1.57	1.68				0.23	0.27	0.32
		L 2013	1.36	1.47				0.25	0.29	0.21
		H 2013	1.70	1.81				0.23	0.27	0.31
RPS	L	L 2012	1.24	1.43	Low	Medium	High	0.40	0.44	0.36
		H 2012	1.13	1.32				0.40	0.43	0.38
		L 2013	1.08	1.27				0.40	0.44	0.34
		H 2013	0.98	1.17				0.40	0.43	0.36
SCA Podere 124	C	L 2011	1.14	1.58	Medium	Fine	Low	0.32	0.34	0.30
		H 2011	1.34	1.78				0.29	0.34	0.45
		L 2012	1.04	1.48				0.17	0.22	0.34
		H 2012	1.07	1.51				0.22	0.26	0.36
SCA Campo 7	C	H 2011	1.28	1.66	Medium	Fine	Low	0.56	0.63	-
		H 2012	1.32	1.70				0.51	0.57	-
VEN	Si	H 2013-2014	1.32	1.59	Medium	Medium	Moderate	0.24	0.28	0.33
		L 2013-2014	1.30	1.57				0.22	0.26	0.26

L, low soil moisture treatment; H, high soil moisture treatment; ?OTL, ?UTL, water content at the Optimum Tillage Limit and at the Upper Tillage Limit.

Table 4.Average bulk density (Bd) and surface roughness (SR) in the low (L) and high soil moisture treatment (H)

Site	L B_d	H B_d	a B_d %	L SR	H SR	aSR%
AAM	1.26 ns	1.36 ns	-7.9	1.169 a	1.233 b	-5.5
ABP Fagna	1.20 ns	1.22 ns	-1.3	1.009 a	1.017 b	-0.8
ABP Vicarello	1.49 b	1.40 a	+6.4	1.013 a	1.034 b	-2.1
CER	1.30 ns	1.29 ns	+0.8	1.065 a	1.102 b	-3.5
FLC	1.29 a	1.64 b	-26.4	1.072 a	1.087 b	-1.4
RPS	1.16 ns	1.05 ns	+9.5	1.068 a	1.169 b	-9.5
SCA Podere 124	1.09 a	1.21 b	-11.0	1.084 ns	1.081 ns	+0.3
SCA Campo 7	-	1.30	-	1.052 ns	1.053 ns	-0.1
VEN	1.30 ns	1.32 ns	-1.5	1.083 ns	1.084 ns	-0.1

Percentage differences are given by =(L-H)/L×100; different letters within each row are significantly different at P<0.05 (LSD test); ns = not significant.

the densities of soil mineral (sand, silt, and clay) and organic matter particles (USDA 2008), and on the machinery traffic for the different management of field operations (Stranks, 2006; Antille et al., 2013). Regressions between bulk density and the main soil parameters (e.g. clay and organic matter contents) were tested. Only the linear regression for organic matter content as a function of bulk density (Fig. 4) was significant ($y = -1.94x + 4.35$, $P< 0.001$, $R^2 = 0.36$), in agreement with Sakin (2012). As expected, organic matter was inversely correlated to bulk density as reported in the scientific literature (Post and Kwon, 2000; Tremblay et al., 2002;

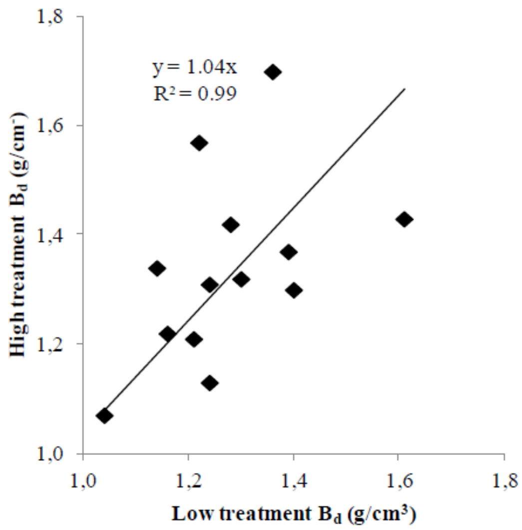

Fig. 3.Linear regression for bulk density in the two treatments

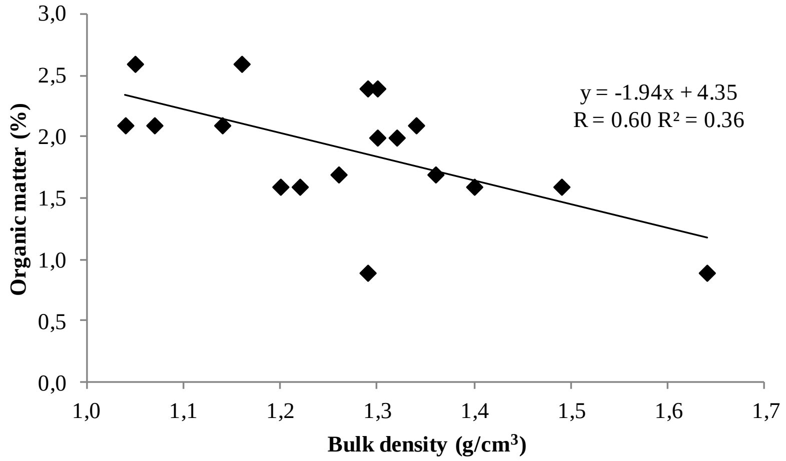

Fig. 4.Linear regression between bulk density and organic matter

Prevost, 2004; Mestdagh, 2006; Sakin et al., 2011).

Results for packing density PD (Table 3) indicated that soils with medium PD and fine texture (clay contents between 35 and 65%) were correlated with a low susceptibility to compaction (ABP, CER, and SCA). Soils with medium PD and medium texture (clay contents <35% and sand contents >15%) were correlated with a moderate susceptibility to compaction (AAM, FLC, and VEN). Soils with low PD and medium texture (clay content <35% and sand content >15%) were correlated a high susceptibility to compaction (RPS).The proposed vulnerability classes must be considered as assessments of average vulnerability under average climatic conditions, but do not consider the seasonal extremes. Moreover, attention should be given to the particular loads and pressures being applied by the machinery. In the future, land use, crop cover data and local climatic data can improve the evaluation of vulnerability to compaction (Jones et al. 2003).

Average results for the soil surface roughness index are reported in Table 4, and have been evaluated by the percentage difference given by SR=(L-H)/L×100.In AAM plots the index was statistically lower in the low treatment (-5.5%). In ABP plots a higher and statistically significant surface roughness was shown in the high treatment, both at Fagna and Vicarello farms, with a mean percentage difference equal to -0.8 and -2.1% respectively. In CER plots the index was significantly lower in the low treatment (-3.5%) in comparison with the high treatment. In FLC plots the index was significantly lower in the low treatment (-1.4%). In RPS plots the index was always significantly lower in the low treatment, with a difference equal to -9.5%. In SCA plots the index was not statistically significant between the two treatments due to a heavy rainfall before the measurements which has levelled the surface roughness. In VEN plots the index did not show significant differences between the two treatments as mean value (-0.1%).The average percentage difference was equal to -2.5%, confirming that soil cloddiness after the main soil tillage was higher in the treatment where the main tillage was done at high soil water content. The linear regression for this parameter between the low and high treatments (Figure 5) was highly significant ($P<0.001$, $y = 1.03x$, $R^2=0.99$). The proposed methodology is cheap and easily applicable for research purposes, is alternative to other time consuming and more expensive evaluation techniques, is easy to use and requires little training and no technical experience (Saleh 1993).

Yieldresults of the two treatments (L, low and H, high) have been evaluated by the percentage difference given by Δ Y=(L-H)/L×100, and are shown in Fig. 6.

AAM:durum wheat yields differences between the low and high treatment were significant (+51%,$P<0.05$). ABP:results showed higher yields of common wheat grain in the low treatment in comparison with the high treatment, both at Fagna (+33.7%, $P<0.05$) and Vicarello (+28.6%, not significant).CER:the low treatment showed a higher durum wheat grain yield (+16.5%, $P<0.01$) in comparison with the high treatment. FLC: significant differences and higher values were found in the low

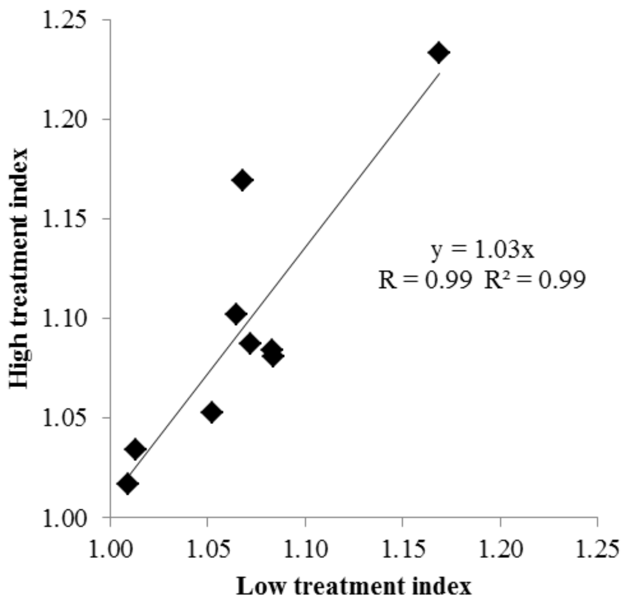

Fig. 5.Linear regression for the surface roughness index in the two treatments.

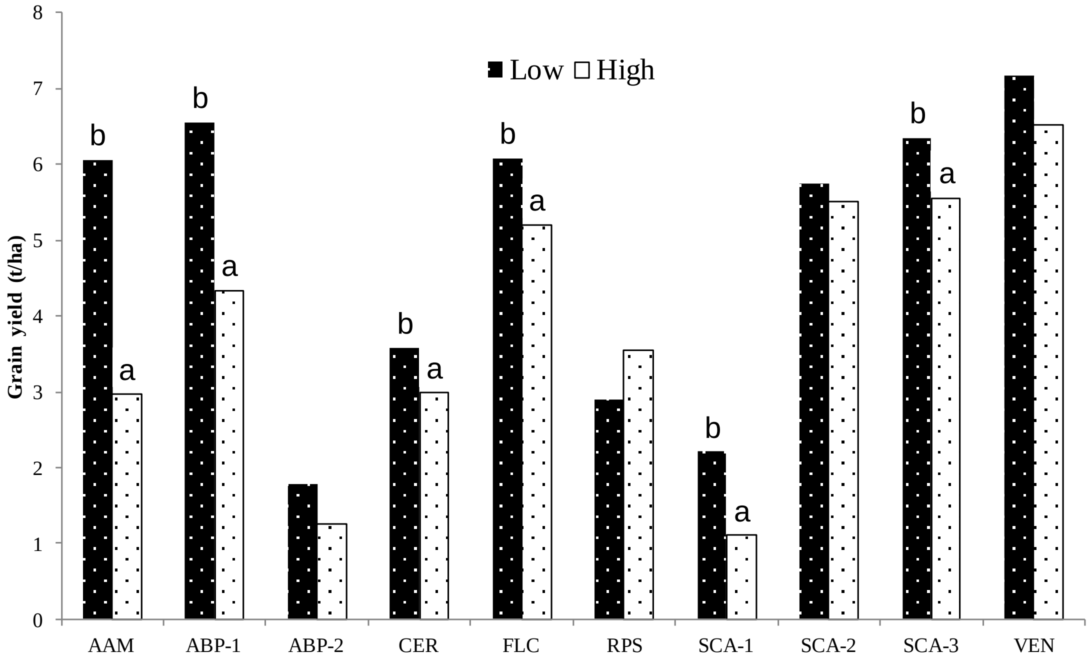

Fig. 6. Grain yields in the monitoring plots (L = low moisture, H = high moisture)*.

*Chickpea, SCA-1; common wheat, ABP-1, ABP-2, FLC; corn, VEN; durum wheat, AAM, CER, RPS, SCA-2, SCA-3. Bars with different letters are significantly different at P<0.05 (LSD test).

treatment (+14.5%, P<0.01).RPS:durum wheat grain yields were not statistically different, and the yield in the low treatment was lower in comparison with the high plot (-22.8%), probably due to the high presence of weeds (+21.6%). SCA (Podere 124): chickpea yield (SCA-1) was significantly higher in the low treatment (+49.7%, P<0.001).No significant differences were found in durum wheat (SCA-2), with a difference equal to +4% between the treatments.

SCA (Campo 7): durum wheat grain yield (SCA-3) was statistically higher in the low treatment (+12.4%, P<0.01).VEN: The grain yield of corn was not significantly different between the treatments,but was about 9% higher in the low treatment.

Linear regression for crop yields between the low and high treatments (Fig. 7) was highly significant (P<0.001, y = 0.80x, R^2=0.96), showing that yields were 20% lower as average in the high treatment (3.9 vs. 4.8 t ha-1). This is in agreement with Reintam et al. (2009), reporting a significantly lower barley grain yield in the compacted treatment under moist conditions, in soils moderately susceptible and moderately-to-very vulnerable to compaction when tilled in moist conditions. Heikonen et al. (2002) showed that the yield of oats was very sensitive to the soil and weather conditions after sowing, due to the concomitant effects on crop establishment and root density and penetration during the growth cycle.

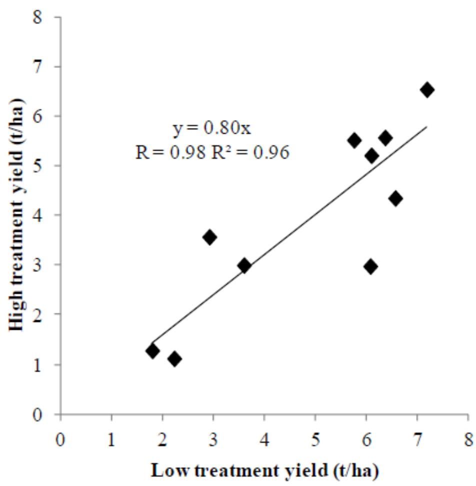

Fig. 7. Linear regression for crop yields in the two treatments

CONCLUSIONS

The study confirms that soil workability is the product of complex processes which include mainly the physical soil parameters as regulated by the local climatic conditions, and affecting soil surface roughness, seedling emergence, and plant growth.Upper Tillage Limit and Optimum Tillage Limit seem not suitable to define 'a priori' soil workability, due to the low difference between the two values. Thus, at least in the conditions of the present study, if farmers should comply with the standard, and till the soil at optimum soil water contents, maybe they cannot sow the crop and have an economic disadvantage. This would suggest also that the application of the European standard could not be effective in all the environments and soil types.Grain yields of crops were 20% lower as average when soil was tilled at high moisture content in comparison with the low moisture treatments, proving that soil tillage under higher soil moisture conditions negatively affects this important agronomic parameter.The monitoring of the physical parameters considered as possible indicators of soil structure degradation proved effective in assessing the differences among the treatments, and could be adopted as a routine scheme in researches dealing with the effects of soil tillage on soil degradation at different moisture contents.

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