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Soil Spatial and Temporal Variability, Assessment for site Specific Management

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A chi non ci sta,
A chi veste i panni del guerriero,
To who thinks outside the box.

Acknowledgments

I would like to thank all persons that participate at field tests and made it possible to perform the whole research.

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Abstract

The soil varies from place to place, and many of its properties vary in time too. Within-field variation is the result of both spatial and temporal variation of biological, edaphic, climatic, topographic and anthropogenic factors. There is a need in modern agriculture of understanding spatial and temporal variability within fields.

The objective of this study was to analyze, to quantify and to assess the within agricultural field spatial and temporal variability for site specific management.

Some soil physical-chemical parameters were investigated by means of georeferenced samplings in order to study the variability of multiple soil variables and to find soil indicators.

Performance of machineries during soil tillage and agricultural operations were also investigated and analyzed with the aim of finding field efficiency indicators.

Geostatistical analyses were implemented to interpolate the acquired data and to perform the cluster analysis.

The results of tests performed during the whole experimentation highlighted the presence of high spatial variability of soil physical-chemical properties within the agricultural fields examined.

Georeferenced sampling of soil physical-chemical parameters allowed to identify soil quality and soil strength indicators, furthermore monitoring the performance of machineries during soil tillage and agricultural operations allowed to identify field efficiency indicators (i.e.: area specific consumption, global energy employed and fuel energy requirements).

The assessing process of spatial variability within agricultural fields, the identification of soil indicators and the definition of management zones can be considered as an adaptation technique to Climate Change enhancing the efficiency of agriculture. In fact, the defined management zones could provide information for site-specific management, including the application of different soil tillage methods.

Furthermore, variable-rate application (VRA) instead of uniform-rate application (URA) of inputs might be carried out, decreasing fertilization in the more productive area and minimizing the application of chemical substances as a strategy to obtain a more cost-effective field management.

INDEX

1. Introduction

The soil varies from place to place, and many of its properties vary in time too. Within-field variation is the result of both spatial and temporal variation of biological, edaphic, climatic, topographic and anthropogenic factors. Information about soil variability is important in ecological modeling, environmental prediction, precision agriculture, and natural resources management. With growing interests in precision farming to address diverse environmental, ecological, agricultural, and natural resource issues, an adequate understanding of soil variability as a function of space and time becomes essential.

However, in spite of voluminous literature published in the past three decades or so, knowledge about soil variability is still dispersed and requires further synthesis (e.g., Burrough, 1993; Heuvelink and Webster, 2001). In particular, there is a need to quantify soil variability across multiple scales, which will undoubtfully enhance the use of soils information in diverse applications.

Considerable work has been done investigating soil variability at a single scale, which provides useful information at that particular scale (e.g., Beckett and Webster, 1971; Webster, 1985; Agbu and Olson, 1990; Gaston et al., 1990; Schellentrager and Doolittle, 1991; Moore et al., 1993; Mahmoudjafari et al., 1997; Thompson et al., 1997; Boehm and Anderson, 1997). However, quantification of soil variability at multiple scales is often desirable for modeling and prediction, which provides a basis for developing an understanding regarding scales of influence on variability and a framework upon which scaling of data may be possible. Limited studies have been done so far to investigate soil spatial variability across multiple scales (Burrough, 1983a, b; Edmonds et al., 1985; Wösten et al., 1987; Pennock and de Jong, 1990; Sylla et al., 1996; Dobermann et al., 1997).

Soil variability is influenced by different combinations of soil-forming factors acting through space and time. In a general framework, soil variability may be considered as a function of five space–time factors, i.e., spatial extent or area size, spatial resolution or map scale, spatial location and physiographic region, specific soil property or process, and time factor. Exact expression of such a function is very difficult, if not impossible, to establish, in part because of the diversity and complexity of the relationships.

Variation within soil units is acknowledged, but described quantitatively in vague terms. Soil surveys have traditionally overlooked spatial variability within map units for a variety of reasons including scale limitations and inadequate quantitative data. Field observations are made at a selected number of locations chosen by soil surveyors using formal knowledge and intuitive judgment. Sampling the soil at a finite number of places or points in time yields incomplete pictures; in fact soil surveys traditionally have lacked appropriate sampling design to present quantitative estimates regarding spatial variability within and across map units.

There is a need in modern agriculture of understanding spatial and temporal variability within fields. Understanding such variation is essential for site-specific crop management, which requires the delineation of management areas.

Traditionally, agricultural fields have been managed as single units, although it has long been known that soil condition and crop yield are not homogeneous within them (Frogbrook & Oliver, 2007; Vitharana et al., 2008; Alletto et al., 2010; López-Lozano et al., 2010). In fact, variability of soil properties may affect crop growth, yield, and quality at the within-field scale (Diacono et al., 2012). In this scenario, uniform field management often results in over-application of inputs in areas with high nutrient levels, and under-application of inputs in areas with low nutrient levels (Ferguson et al. 2003; Servadio et al. 2010). The magnitude and structure of such variability may suggest the suitability of site-specific management, with the aim of increasing both profitability of crop production and environment protection (Godwin & Miller, 2003; Mzuku et al., 2005; Vitharana et al., 2006). Site-specific management can regulate production inputs and, consequently, can reduce the risks and the negative impacts of pollution due to over-application of chemicals (Di Fonzo et al., 2001; Basso et al., 2009; Basso et al., 2011). Moreover, the enlargement of single management units, resulting from the enlargement of arable lands, can encourage the application of non-uniform management techniques (Sylvester-Bradley et al., 1999). The management zone (MZs) approach (Mulla et al. 1992) is a site-specific management method, based on the determination of sub-regions characterized by homogeneous combination of yield-limiting factors (Vrindts et al. 2005), generally acknowledged as a possible way to address this problem (Cahn et al. 1994; McKinion et al. 2001; Keller et al. 2012). The subdivision of the field in management zones (MZs) is based on the knowledge of the spatial variability of soil parameters that are, generally, stable with respect of time, and related to crop yield (Schepers et al., 2000; Schepers et al., 2004). To delineate such zones, various parameters were evaluated in literature. For example, MZs were defined considering yield (Vrindts et al., 2005; Xiang et al., 2007; Diacono et al., 2012), soil fertility (Ortega & Santibáñez, 2007; Davatgar et al., 2012; Van Meirvenne et al., 2013) or soil electrical properties (Morari et al., 2009; Moral et al., 2010; Naderi-Boldaji et al., 2013; Doolittle & Brevik, 2014). A combined use of different sets of parameters, such as a combination of physical and chemical soil parameters, could lead to an in-depth investigation into spatial heterogeneity and to a more comprehensive knowledge of soil plant system (Guastaferro et al., 2010; De Benedetto et al., 2013). Among the physical parameters, soil strength influences many aspects of the cultivation, such as performance of tillage and root growth. Furthermore, when compaction occurs, soil permeability and regeneration can be reduced (Manuwa & Olaiya, 2012). Variations of soil texture can also have a significant effect on soil management, as studied in previous investigations (Vitharana et al., 2006; Gooley et al., 2014; Havaee et al., 2015). Once the data set has been acquired, cluster analysis can be performed to define the management areas (Taylor et al., 2003; Fleming et al., 2004), by implementing, for instance, fuzzy k-means or Gustafson-Kessel algorithms (Höppner, 1999; Stafford et al., 1999; Vrindts et al., 2005; Guo et al., 2013). The application of such analises allows taking into account the continuous variation of natural soil variables (Burrough 1989) and it has been used to identify potential within-field management zones in precision agriculture (Boydell and McBratney 2002).

Cluster analysis or clustering is the task of grouping a set of objects in such a way that objects in the same group (called a cluster) are more similar (in some sense or another) to each other than to those in other groups (clusters). It is a main task of exploratory data mining, and a common technique for statistical data analysis, used in many fields. Cluster analysis groups similar multivariate data points into distinct classes in the p-dimensional attribute space, defined by the p properties measured at each data point within a field. The application of fuzzy set theory to clustering has enabled researchers to account for the continuous variation in natural soil variables. It may be more appropriate to consider any data point as having some similarities to more than one cluster. Fuzzy classification determines the degree of resemblance of an object to a cluster by its membership to the cluster. In practice, it may be necessary to assign each data point to a unique class using the one of maximum membership, a process called 'defuzzification' (Guastaferro et al., 2010). The clustering procedure called fuzzy k-means has been used to identify potential within-field management zones in precision agriculture (Boydell and McBratney, 2002). Cluster analysis itself is not one specific algorithm, but the general task to be solved. It can be achieved by various algorithms that differ significantly in their notion of what constitutes a cluster and how to efficiently find them. Popular notions of clusters include groups with small distances among the cluster members, dense areas of the data space, intervals or particular statistical distributions. Clustering can therefore be formulated as a multi-objective optimization problem. The appropriate clustering algorithm and parameter settings (including values such as the distance function to use, a density threshold or the number of expected clusters) depend on the individual data set and intended use of the results. Cluster analysis as such is not an automatic task, but an iterative process of knowledge discovery or interactive multi-objective optimization that involves trial and failure. It will often be necessary to modify data preprocessing and model parameters until the result achieves the desired properties.

The management zone approach is based on the creation of areas (clusters) within the agricultural field characterized by similar values of soil physical-chemical parameters. Because such analysis is not modeled but based and influenced by the soil parameters used for it, some problems arises in how and which parameters to select. For example concerning texture in Vitharana et al., 2008 is reported to use as input parameter only one fraction to avoid the spurious correlations due to the compositional nature of the texture (individual elements sum to 100%). Some other properties show correlation between each other such as for example soil strength parameters (cone index, shear strength, bulk density) and water content, furthermore these are dynamic soil properties that vary during the growing season but they are determined only once with soil samplings.

Fuzzy k-means or Gustafson-Kessel algorithms are applied with original soil variables as inputs that are selected by the users. Unconstrained classical k-means and fuzzy k-means do not include spatial autocorrelation or any reference to the geographical position of data points from which variables are recorded. A few attempts (Ping and Dobermann, 2003; Frogbrook and Oliver, 2007; Milne et al., 2012) have been made to spatially constrain the clustering algorithm to produce management zones, but these have not been widely adopted.

Alternatively, a linear combinations of soil properties could be used to overcome the problem in selection inputs variables of cluster analysis (Schepers et al., 2004; Li et al., 2007; Xin-Zhong et al., 2009). Principal Component Analysis (PCA) (Hotelling, 1933) has been used to build those linear combinations. Classical PCA is used to reduce the number of original variables available for classification and to summarize the variability of several variables in new synthetic variables. There are as many Principal Components as variables included in the analysis. Generally, the first few components explain most of the total variance in the data set and contain the main signal in the joint variability, instead the last principal component is commonly associated with noise or spurious variability. Usually only Principal Componens with eigenvalues ≥1 are selected for cluster analysis and to develop the MZs as suggested by Jolliffe (1986).

The objective of this study was to analyze, to quantify and to assess the within agricultural field spatial and temporal variability for site specific management.

Some soil physical-chemical parameters were investigated by means of georeferenced samplings in order to study the variability of multiple soil variables and to find soil indicators.

Performance of machineries during soil tillage and agricultural operations were also investigated and analyzed with the aim of finding field efficiency indicators.

Geostatistical analyses were implemented to interpolate the acquired data and to perform the cluster analysis. The geostatistical analyses were conducted using the FuzMe, MatLab and the Geostatistical Analyst extensions of the ArcGIS 10.0 software (Esri Inc., Redlands, CA, USA) that was used also for graphical representation.

Case studies were analysed and field tests were established, and results are reported as follows.

2. Spatial variability of some soil properties and wheat yield within a trafficked field

2.1. Introduction

All soil properties are susceptible to vary with time and space as a consequence of land use, water content level and management system adopted. The implementation of intensive agricultural production systems has led to the use of heavy machines with high working capacity requiring high traction forces. Repeated passes on the field can cause soil compaction creating pans, having a low permeability to water and nutrients and a high resistance to root penetration (Servadio, 2010). The intensity and distribution of the traffic of agricultural machines may cause a high spatial variability of soil physical properties and yield, even in soils characterised by spatial homogeneity of physical properties (Mouazen et al., 2001; Carrara et al., 2007). Consequently, uniform management of fields often results in over-application of inputs in areas with high nutrient levels and under-application in areas with low nutrient levels (Ferguson et al., 2003; Servadio et al., 2010). Site-specific management has been acknowledged as one means of addressing this problem (Cahn et al., 1994; McKinion et al., 2001). The most popular approach for managing spatial variability within fields is the use of management zones (MZs) (Mulla et al., 1992), which are field subdivisions that have relatively homogeneous attributes in yield and soil condition.

The objectives of this study were: (1) to investigate the spatial variability of some soil properties and crop yield, within a trafficked field just after two fertilizing operations, to evaluate whether these soil properties could be used as indicators of crop yield; (2) to develop statistical correlations among the measured soil parameters and yield and (3) to represent the spatial variability within the field using georeferenced maps as basis for zone management.

2.2. Materials and methods

Field tests were carried out in a farm near Rome (41°52'502'' Latitude (N); 12°12'866'' Longitude (E) on a clay soil classified as Vertic Cambisol (FAO, 1998). The soil was previously tilled with a cultivator at 0.40 m depth, harrowed at 0.20 m depth with a rotary harrow in October and afterwards was sown with wheat.

The fertilizations were carried out in March and in April using the following machines respectively:

1) a wheeled tractor (73.5 kW engine power) equipped with extra large and low aspect ratio tyres (4620 kg mass, front and rear tyres inflation pressures were 70 and 60 kPa respectively) and its trailed broadcaster, for a total of four axles (1520 kg mass + 1200 kg fertilizer with an operative width of work of 14 m; front and rear tyre inflation pressures were 60 and 70 kPa respectively) coded WTEL;

2) a self propelled broadcaster (sprayer) (130 kW engine power) fitted with isodiametric-narrow tyres (11700 kg mass with front ballast + 2500 kg fertilizer tank with an operative width of work of 24 m; front and rear tyres inflation pressures were 290 kPa) coded WTN.

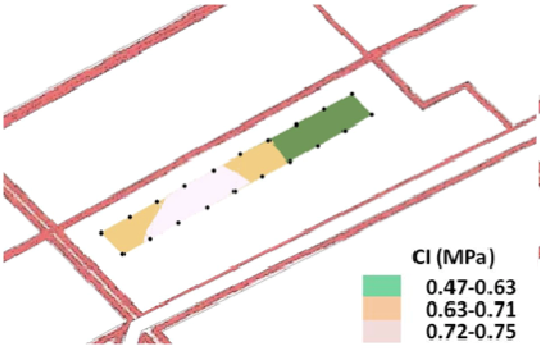
During the wheat fertilizing, a DGPS receiver was placed on the tractors to monitor passes across the whole field and saving position data. The total track area covered by the machine tyres during the fertilization were calculated with help of the software ArcGis 10 (Kroulik et al., 2009). In April, on the whole field, a 60-m grid sampling of 20 samples of soil was performed to determine physical-chemical properties: particle size, water content, total nitrogen (N) and organic matter (OM) and 20 penetration resistance were measured from 0 to 0.20 m depth both taking the GPS position to produce interpolated maps describing spatial variability. Penetration resistance of the soil (CI) was measured using a penetrologger with GPS (Eijkelkamp). Total soil N was measured by the Kjeldahl method; total organic carbon (C) with the wet oxidation (Walkley and Black 1934). Soil water content at the time of field tests was 33.2 g $(100\ g)^{-1}$ (over field capacity), it was measured from 0 to 0.20 m depth. Field capacity, determined by pressure plate extractor was 28 g $(100\ g)^{-1}$.

At the end of the crop cycle, during the wheat harvesting, a grain yield map was acquired with a combine harvester, equipped with grain mass flow sensor, GPS and Precision Land Management Software that was used to read out the yield data.

Interpolation of soil properties and grain yield maps was performed using the software ArcGIS and the spatial analyst tool natural neighbor (Servadio and Blasi, 2003; Servadio et al., 2011). To develop correlations, twenty yield values were taken from the grain yield map using the same georeferenced grid sampling corresponding to the soil samples.

2.3. Results

From the analysis of penetration resistance (Fig. 1) and water content (Fig. 2) maps, it emerged the presence of homogeneous and well defined areas that highlighted the spatial variability within the field. Areas characterized by high values of soil water content ranging between 33 up to 45 g 100g^{-1}, over field capacity, and high degree soil strength, due to the different intensity of the traffic of agricultural machineries were found.



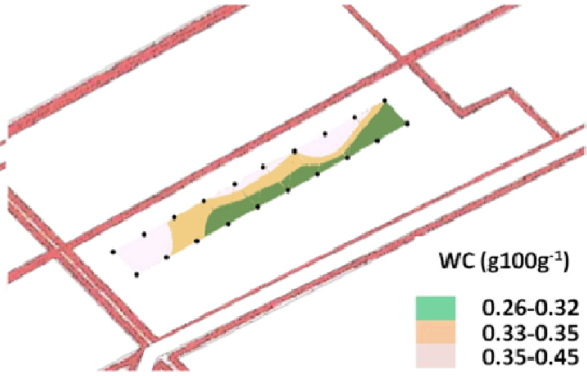


Figure 1(Left). View of field map of penetration resistance (MPa)(0-0.20 m depth)
Figure 2 (Right). View of field map of water content (g 100g^{-1}). (Sampling locations)

Spatial variability within field was highlighted also by soil chemical parameters maps. From the analysis of the results of Table 1 and of the maps it emerges high value of CV and the presence of homogeneous and well defined areas that highlight the spatial variability within the field.

Table 1. Mean value [g(100 g)$^{-1}$] and CV (%) of soil physical-chemical parameters

Properties	Mean value^{a} g (100 g)$^{-1}$	CV (%)
Sand (2000-50 mm)	20.3	85.0
Clay (<2 mm)	53.0	20.1
Silt (50-2 mm)	26.7	30.7
Water content	33.2	7.58
Organic matter	2.5	16.3
Nitrogen	0.20	19.2
Cone index	0.64 MPa	15.6

Properties	Mean value[a] g (100 g)$^{-1}$	CV (%)
Yield	4.52 t/ha	28.5

Grain yield (Fig. 3) also shows spatial variability with high, mean and low yielding zones. In fact, significant correlations found between soil nitrogen and yield and between soil organic matter and yield confirmed that in agricultural ecosystems, N and OM are the major determinants and indicators of soil fertility and quality, which are closely related to soil productivity.

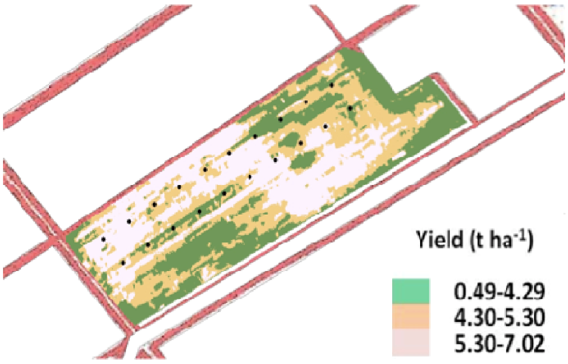


Figure 3. View of yield map

The results obtained show that agricultural management can affect the spatial patterns of soil properties that are spatially correlated. Geo-referenced measurements and interpolated maps are needed to describe the spatial variation of soil parameters and crop yield. Field maps would provide the basis of information for rationally managing soil nutrients and soil tillage. In fact, spatial variability within field suggested that variable rate fertilization application and variable depth tillage may be helpful to maximize environmental benefits and to improve quality of the crop and to reduce soil compaction.

Kind and intensity of soil tillage can be adapted at the different zones and variable depth tillage could be applied working only on the compacted area. According to Vrindts et al (2004), Keller et al (2010), Servadio et al (2011), each management zone gets the appropriate level of inputs and is usually defined on the basis of soil and yield information. Therefore fuel, labour, equipment wear and tear and environmental costs could be reduced.

2.4. Conclusion

To traffic the soil during fertilization, carried out with high soil water content, the use of a tractor fitted with extra large tyres was necessary. With lower soil water content, the use of narrow tires allowed carrying out fertilization avoiding excessive crop trampling and covering smaller (more compacted) field area with respect to a tractor equipped with extra large tyres.

The within-field spatial variability of soil properties and crop yield was highlighted both from the high values of CV and from the presence of homogeneous and well defined areas found in the fields maps.

Obtained correlations between soil properties (OM and N) and yield confirmed that in agricultural ecosystems, N and OM are the major determinants and indicators of soil fertility and quality, which are closely related to soil productivity.

Spatial variability of field maps highlighted that management zone could be applied for rationally managing soil tillage and fertilizing operations.

3. Soil mapping to assess workability in Central Italy as climate change adaptation technique

3.1. Introduction

Soil tillage represents the most influential manipulation of soil physical properties because of repetitive application, its depth range extending up to tens of centimeter and because it influences the type of residue management applied. The need of sustainable agriculture and the increased cost of fuel in tillage operations forced farmers to change the farming methods (Yalcin and Cakir, 2006). In fact, many studies have been done to compare tillage practices, particularly tillage versus no-tillage (NT). Conventional tillage may accelerate mineralization of organic matter, reduce soil fertility, increase water consumption, and deteriorate chemical and physical properties of soil (Chen et al., 2007).

On the contrary minimum-tillage and no-tillage, characterized by minimal soil disturbance (Paremelee et al., 1990), may be a good choice for land preparation because it has potential benefits including reduced production costs, saving in fuel, equipment and labor (Allmaras and Dowdy, 1985) as well as soil conservation (Uri, 1997), furthermore direct seeding may be an efficient technology to replace transplanting because it is simple and labor-saving (Wu et al., 2005). Improvements in the design of minimum and no-till drills, lower cost and more effective herbicides, a better understanding of the role of tillage in crop production systems, and an increased emphasis on residue management have been key factors in the successful shift to direct seeding (Fowler, 1995), that have slowly become an accepted alternative to conventional tillage systems (Collins and Fowler, 1996). According to Yalcin and Cakir (2006) no-tillage seems to result one of the most sustainable soil management systems, because it reduces labour requirements and machinery costs, fossil-fuel inputs, and soil erosion, while it increases available plant nutrients, soil organic matter content, soil quality, and improves the global environment.

The major sources of GHG fluxes associated with crop production are soil N_2O emissions, soil CO^2 and methane (CH^4) fluxes, and CO^2 emission associated with agricultural inputs and farm equipment operation (Adler et al., 2007). Loss of soil organic carbon (SOC) under conventional tillage have been extensively documented (West and Post, 2002; Conant et al., 2007), on the contrary conservation tillage practices (minimum and no tillage) may play a leading role in sequestering CO^2 achieving a mitigation effect of CC. In fact NT farming is recommended to conserve soil and water but its potential to sequester SOC varies widely due to complex interactions among climate, soil type, crop rotation, duration and management factors (Vanden Bygaart et al., 2002; Puget and Lal, 2005). Long-term (>10 yr) of NT practices have also the potential to reduce greenhouse gas emissions in humid climates (Chatterjee and Lal, 2009).

The objectives of this study were: 1) to investigate spatial variability of soil properties, to found soil quality indicators and to asses soil workability 2) to investigate the machine performance, the fossil-fuel energy requirements and the CO_2 emissions from agricultural machinery in summer soil tillage operations both on hilly and plain field carried out at very low water content, compared with direct-seeding.

3.2. Materials and methods

The study was conducted in Central Italy in two adjacent on-farm sites on a hilly (178 m.a.s.l.), (43°33'17.181" N, 13°03'59.684" E) and on a plain fields (119 m.a.s.l.), (43°33'21.664" N, 13°04'12.49" E) on a silty clay soil seeded with common wheat (Triticum aestivum).

3.2.1. Sampling test and mapping

In order to assess the soil workability, two adiacent on-farm sites, an hilly (1.1 ha) and a plain field (1 ha) were selected for field tests. Geo-referenced sampling tests based on a grid of 50 x 50 m for each field were carried out investigating some soil physical properties from 0 to 0.20 m depth. To produce interpolated maps and to describe spatial variability of soil properties the software ArcGIS and the spatial analyst tool natural neighbor (Servadio et al., 2011; Servadio and Bergonzoli, 2013) were used. Detected physical-mechanical soil parameters were: particle size distribution, shear strength (SS), dry bulk density (DBd), water content (WC), field capacity (Fc) and structural stability of soil aggregates (Sssa). Soil shear strength was measured using a field inspection vane tester from 0 to 260 kPa (Eijkelkamp). In each field ten shear strength readings were taken in increments of 0.05 m to a depth of 0.20 m. Dry bulk density was measured by taking ten samples of soil using a corer sampling ring of 100 cm^3 of volume at 0-0.20 m depth. Soil water content at the time of field tests was measured from 0 to 0.20 m depth by taking samples of soil that were weighed and dried until they reached a constant weight. Soil field capacity was determined using the pressure plate extractor.Structural stability of soil aggregates was determined on the 0.25 mm fraction through the method of Kemper (1965).

Total organic carbon (C) was determined with the wet oxidation method (Walkley and Black, 1934), organic matter content (OM) was derived from the total organic carbon (C x 1.72) and cation exchange capacity (CEC) by the barium chloride ($BaCl_2$)–triethanolamine (TEA) method. Exchangeable bases [sodium (Na)], was determined using 1 M ammonium acetate (NH_4OAc) solution (soil/solution ratio 1:10, shaking time 30 min), available phosphate (P_2O_5) was determined with the Olsen method, colloid index (Ci), a parameter used to evaluate colloid behavior, was calculated as follows:

$$Ci = 10\ X1 + X2$$

Where: X1 is organic-matter content (%) and X2 is clay content (%), (Beni et al., 2012). During the overall experimentation time, (2011 and 2012), meteorological data (monthly rainfall, minimum and maximum temperatures) were also recorded.

3.2.2. Soil tillage

Conventional soil tillage was carried out in July 2011 both on hilly and plain fields on Silty Clay soil at very low water content (0.25 and 0.31 of the field capacity respectively), in addition direct-seeding + fertilizing was carried out in plain field in September 2011 at 0.25 of the field capacity. Same field conditions during the tests are shown in Table 2.

Plowing was carried out with the following work sites layout: 1) a very high power wheeled tractor (217 kW engine power; 9684 kg mass + 1600 kg front ballast) with reversible semi-mounted four furrow plow (2300 kg mass) operating on hilly field (WT-hilly). 2) a mean power metal tracked tractor (120 kW engine power; 14000 kg mass) with trailed three furrow plow (1100 kg mass), operating on plain field (TT-plain).

Soil tillage operations were performed at very low water content, 9.8 % and 11.6 % for treatments WT and TT respectively.

Direct seeding was carried out by means of a very high power wheeled tractor (265 kW engine power; 18000 kg mass) with hydro-mechanical power transmission with trailed grain drill, a seeding unit, which consists of a seed and fertilizer box mounted above two rows of opener assemblies (for a total of 16 no till opener) operating on plain field (GD+F-plain). The front of the unit is supported by the tractor hitch, the back of the unit is supported by two wheels. Direct seeding was performed at 9 % water content.

The performance of the tractors and machineries during tillage operations were quantified through the following parameters: forward speed, tractors slip (%), effective work capacity (ha h^{-1}), measured work width (m), work depth (m), soil rise and roughness (m), clod size distribution (%), energy power output (kW), hourly (kg h^{-1}), global energy employed (kWh ha^{-1}), fossil-fuel energy requirements (GJ/ha) and carbon dioxide emissions (kg C ha^{-1}) (Servadio and Bergonzoli, 2012; Marsili and Servadio, 1998). In addition field data collected has allowed to appraise the global energetic efficiency of the tractors that depends from the area (ha) covered in function of the time and from the ability of the tractor to convert the energy of combustion in useful power. As a result, two field oriented performance indicators consisting in time efficiency (h ha^{-1}) and area specific consumption (kg ha^{-1}) are applied (Burgun et al., 2013).

3.3. Results

3.3.1. Sampling test and mapping

Results of the sampling tests of the soil properties are shown in Table 2 and in Figs. 4. Results of Table 2 show, both on plain and hilly fields, very high values of shear strength (over 180 kPa) and its CV% and high values of dry bulk density (over 1.39 Mg m^{-3}). Values of structural stability of soil aggregates were higher on hilly field (56%) with respect to the plain (31.5%). Higher values of organic matter (1.54 %), P (11.5 ppm) and Na (3.10%) were found on plain field.

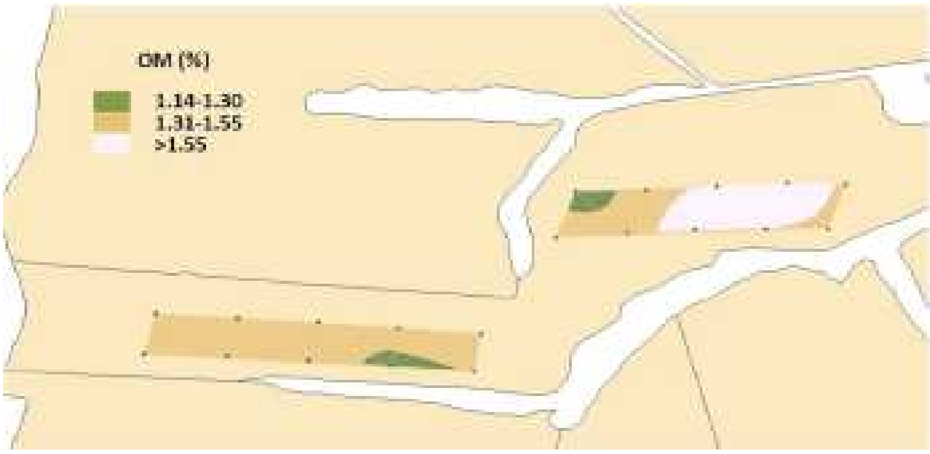
Table 2. Mean values (0-0.20 m depth) and coefficient of variation of some soil chemical-physical properties (June 2011)

Soil properties	Plain		Hilly	
	Mean[a]	CV (%)	Mean[a]	CV (%)
Sand (g/100g)[b]	9.25	25	8.06	27.8
Silt (g/100g)[b]	43.1	6.35	41.6	5.63
Clay (g/100g)[b]	47.6	5.47	50.3	6.76
Texture[b]	Silty Clay			
Shear strength (kPa)	188	33.8	222	41.4
Dry bulk density (Mg m^{-3})	1.39	9.79	1.48	8.50
Water content (%)	31.2	9.69	29.1	11.7
Structural stability of soil aggregates(%)	31.5	-	56	-

Soil properties	Plain		Hilly	
Field capacity (%)	36.7	-	37.9	-
OM (%)	1.54	14.8	1.30	14.9
TOC (%)	0.89	14.8	0.75	14.9
P (ppm)	11.5	13.2	5.87	36.7
CEC (meq %)	27.5	4.50	27.2	4.21
Na (%)	3.10	47.6	1.92	34.6

[a]Average of ten values, [b]USDA classification; OM, organic matter; TOC, total organic carbon; CEC, cation exchange capacity.

Figures 4 a, b, c and d. Results of the interpolation of soil properties maps performed by using the software ArcGIS and the spatial analyst tool natural neighbour.



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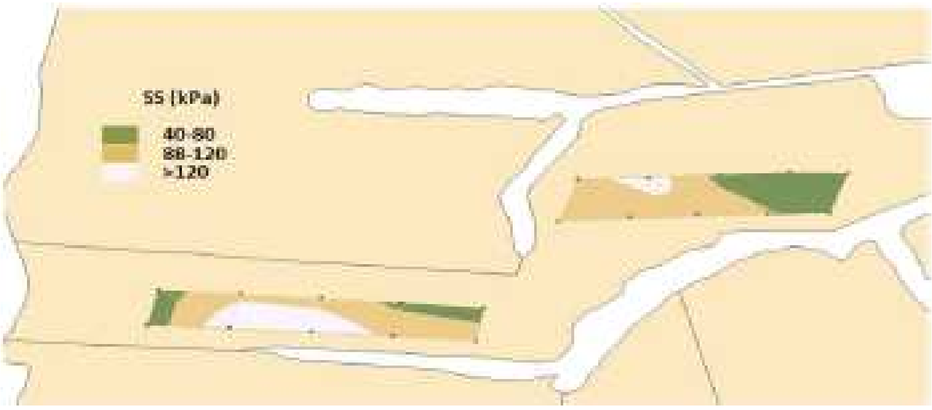

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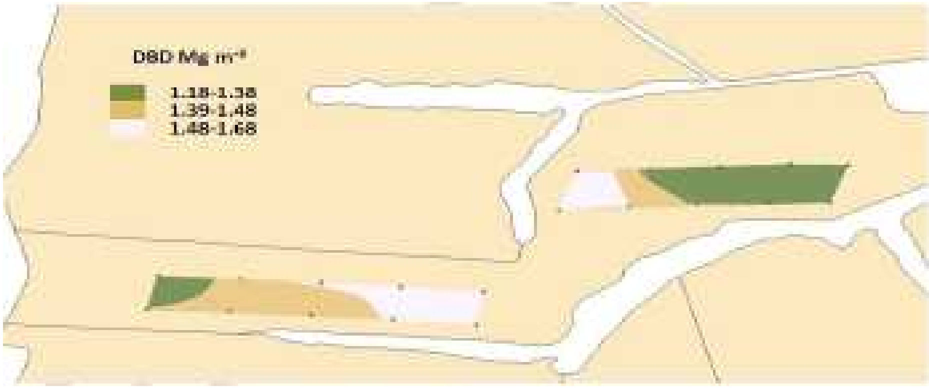

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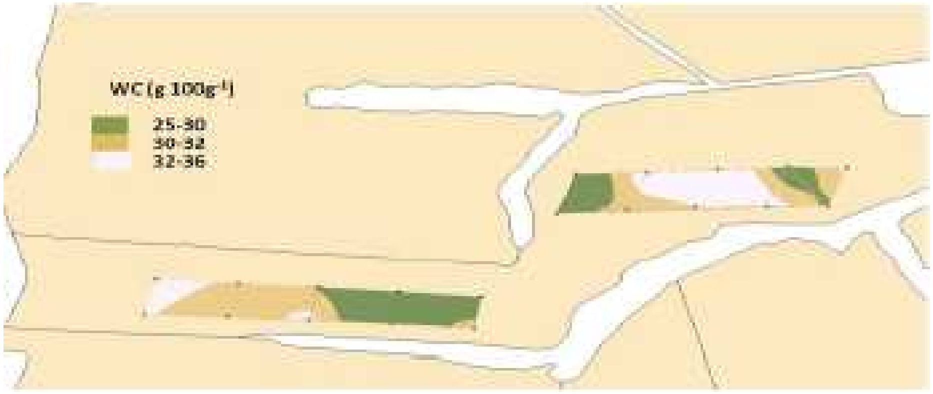

d

Figure 4. View of field maps of soil parameters studied: a) organic matter (%); b) shear strength (kPa); c) dry bulk density (Mg m-3); d) water content (g/100g)

From the analysis of OM (Fig. 1a), SS (Fig. 1b) and DBD (Fig. 1c) interpolated maps it emerged the presence of an homogeneous and well defined zone in the eastern part of the plain field characterized by low level of soil strength (SS < 80 kPa and DBD <1.38 Mg m^{-3}) and high organic matter content (OM>1.55%). Therefore this area was assessed to perform the direct seeding of common wheat. The analyzed soil parameters can be considered good indicators of the soil strength and according to the soil water content, useful to assess workability.

3.3.1. Soil tillage and wheat yield

Results of machineries performance during plowing and direct-seeding are shown in Table 3.

During CT operations carried out at 0.40 m work depth, both work sites layout showed good traction performance indicated from slip values always lower than 15%

(Table 2). This result, besides to the low soil water content and high soil strength, were also due to the high contact area of the tracks on soil of TT-plain and to the high engine power of WT-hilly (Servadio, 2010). For wheeled tractor, hourly fuel consumption was higher (47 kg h^{-1}) with respect to the tracked tractor (27 kg h^{-1}); time efficiency of WT-hilly was enhanced from the larger work width 1.07 h ha^{-1} with respect to the 1.78 h ha^{-1} of the TT-plain; furthermore area specific consumption was of similar magnitude (48-50 kg ha^{-1}).

According with Burgun et al., (2013), this prove that the use of the wide implements enhance the time efficiency and simultaneously reduce the area specific consumption more than to use of higher forward speed. Regarding the grain-drill+fertilizing operating in plain area, due to the high forward speed and work width, time efficiency resulted 0.26 h ha^{-1} and area specific consumption resulted 11 kg ha^{-1}.

Table 3. Performances of work sites layout during ploughing (July 2011) and direct-seeding (September 2011) and yield (June 2012)

	Work site layout		
	TT-plain	WT-hilly	GD+F-plain
Forward speed (m s^{-1})	1.25	1.21	3.5
Mean rise (m)	0.20	0.30	-
Mean roughness (m)	0.22	0.31	-
Measured work width (m)	1.25	2.13	3.0
Measured work depth (m)	0.40	0.40	0.03
Effective work capacity (ha h^{-1})	0.56	0.93	3.8
Time efficiency (h ha^{-1})	1.78	1.07	0.26
Reliefs on the tractors			
Slip (%)	14.1	6.93	-
Energy power output (kW)	120	217	200
Fuel consumption			
Hourly (kg h^{-1})	27	47	40
Specific (g kWh^{-1})	225	220	210
Area specific consumption (kg ha^{-1})	48	50	11
Global energy employed (kWh ha^{-1})	214	232	52
Energy (GJ ha^{-1})	2.24	2.35	0.52
CO_2 emission (kg C ha^{-1})	47.6	50.0	11.0

Despite to the higher energy power output of the very high power wheeled tractor (WT-hilly), global energy employed were of similar magnitude of the mean power metal tracked tractor (TT-plain) because of the good time efficiency. Global energy employed was of only 52 kWh ha^{-1} for direct-seeding. According to Yalcin and Cakir (2006), conventional tillage method had the higher fuel consumption and the lower field efficiency as compared to the direct seeding. Fossil-fuel energy requirements from the two tractors used during plowing were of similar magnitude, in fact it was 2.24-2.35 GJ ha^{-1} during conventional tillage while it was significantly lower (0.52 GJ ha^{-1}) during direct-seeding. Carbon dioxide emissions were of similar magnitude during plowing, it was 47.6-50.0 kg C ha^{-1} during conventional tillage while it was significantly lower (11.0 kg C ha^{-1}) during direct-seeding.

Yield results of wheat (Table 4) can be ascribed to the climatic trend. The monthly mean temperature and rainfall recorded during the growing season (2011-2012) shown the maximum temperature values higher than 10 °C during phase of culm growth.

Furthermore the rainfall distribution from February to May ensured water requirements of the crop during the phases of culm growth and physiological maturity. Trends of precipitation and temperatures allowed a good development of the crop that did not undergo stress and recorded yield value similar to the crop under conventional tillage management. In fact wheat yield of direct seeded field resulted of similar magnitude (only 9% lower) than that recorded on fields under conventional tillage.

Table 4. Wheat yield (June 2012) and Total cost of the crop cycle

	Work site layout		
	TT-plain	WT-hilly	GD+F-plain
Wheat yield (t ha^{-1})	5.6	5.6	5.1
Total Cost (€/ha)	1145	1145	960

The total cost of the crop cycle (€/ha) of the field under direct seeding practice resulted 16% lower of the field cultivated using conventional tillage techniques.

Results of soil roughness acquired in more sampling location, perpendicularly to the forward speed of the tractors showed higher values for WT-hilly (0.30 m) with respect to the TT-plaine (0.20 m).

Results of clod size distribution highlighted as 15 and 20 % of the clods created by tillage operations were bigger than 200 mm.

Therefore the degree of crushing of the soil required further operation to seedbed preparation. Using a wheeled tractor of 167 kW, p.t.o. power with mounted rotary harrow having 6.0 m work width and 0.74 m s^{-1} forward speed, time efficiency was 0.62 h ha^{-1} area specific consumption was 22 kg ha^{-1}, global energy employed was 97 kWh ha^{-1} Energy was 1.04 GJ ha^{-1} and CO_2 emission was 22 kg C ha^{-1}. All these parameters must be added to the TT-plain and WT-hilly treatments.

3.4. Conclusion

As the field sampling and mapping have allowed more efficient resource management, the use of precision agricultural practices and information technologies (IT) have enhanced our understanding and the possibility to predict temporal and spatial variability of soil properties in response to management practices. For instance, some indicators of soil compaction/strength as SS, BD and OM were found and an area to perform direct seeded was selected. During CT, good traction performance, with slip values always lower than 15%, were found. Area specific consumption, global energy employed and fuel energy requirements were significantly higher during CT operation compared to direct seeding. Consequently, carbon dioxide emissions from different agricultural machineries were lower during direct-seeding. Due to the favorable climatic trend during the wheat growing season, the wheat yield of direct seeded field was of similar magnitude (only 9% lower) of that recorded on fields under conventional tillage; the total cost of the crop cycle (€/ha) was 16% lower compared to the field cultivated under CT techniques. In conclusion, with the use of IT, hydro-mechanical power transmission and the direct seeding technique, saving in energy and in CO_2 emission can be achieved and can be considered as good Climate change adaptation techniques.

4. Soil workability and wheat yield in climate change scenarios

4.1. Introduction

The number of days available for field work is frequently central, either directly or indirectly, to farm planning decisions. The number, and distribution, of working days influences the type and acreage of crops grown, and the corresponding labour and machinery requirements. The condition of land for field operations can be classified in terms of trafficability and workability. Trafficability is concerned with the ability of soil to provide adequate traction for vehicles, and withstand traffic without excess compaction or structural damage. If land is considered trafficable, then it is deemed suitable for non-soil-engaging operations (e.g. fertilizer application and crop protection). Workability is concerned with soil-engaging operations and can be considered to be a combination of trafficability and the ability of soil to be manipulated in a desired way without causing significant damage or compaction. The most influential factor in determining the suitability of land for field operations is the soil moisture status. When a soil is trafficked or worked when in an unsuitable condition, damage to the soil's structure and the consequent effect on crop production can persist for many years (Earl, 1997). In mechanised agriculture, high axle loads cause major concern regarding the risk of soil compaction, especially if wheeling and tillage are conducted at high soil moisture content (Koch et al., 2008). Tillage is a fundamental factor influencing soil quality, crop performance and the sustainability of cropping systems (Munkholm et al., 2012) because represents the most influential manipulation or alteration of soil physical properties due to repetitive application, its depth range extending up to tens of centimeter, and because it influences the type of residue management applied (Mark et al., 2008).

Soil penetration resistance measurements have been effectively used in many studies as a tool for characterizing soil strength after tillage (Utset and Cid, 2001). However, soil penetration resistance as well as other soil property is affected by the soil spatial variability and has been shown to strongly depend on soil water content (Becher, 1998; Servadio, 2010; Servadio 2013). Therefore the spatial and temporal variability of soil compaction should be affected by soil moisture. Lyles and Woodruff (1962) found that soil moisture content during tillage affected the size distribution of aggregates produced and that aggregates formed at low moisture content had three to four times more resistance to crushing than those formed at greater moisture contents. The type of tillage implement also affects the soil structure produced. Tillage implements vary in terms of both width and depth and in terms of the intensity in soil overturn administered by the implement design (disc versus ploughing, etc.). Furthermore, interactions between natural factors (e.g., soil type, climate and weather) and crop selection determine the intensity, depth, frequency, and timing of tillage (Strudley et al. 2008) which highlights the need for understanding the tillage effects on soil properties, tractor performance and crop yield (Servadio and Bergonzoli, 2012a; Servadio and Bergonzoli, 2012b). Tillage systems are location specific, so the degree of their success depends on soil, climate, and management practices (Hajabbasi and Hemmat, 2000; Servadio et al., 2014).

The objectives of this study were to assess which tillage techniques could be considered as adaptation in CCS. For this, the effects of three different main preparatory tillage operations of wheat: ploughing at 0.4 m and 0.2 m depth and minimum tillage (harrowing at 0.20 m depth), each of them carried out at two different soil water contents (58% and 80% of field capacity) were compared and quantified. The quality of the different tillage operations were assessed through wheat yield, clods size, soil water infiltration, structural stability, cone index, shear strength.

4.2. Materials and methods

The study was conducted in Central Italy on a hilly plateau (57 m.a.s.l.), (42°05’57.84” N, 12°38’09.59” E) on a silt loam soil seeded with wheat (Triticum durum variety Duilio).

Table 5. Soil conditions during field tests (0-0.20 m depth).

Particle size distribution (%):	Sand (2000 - 50 mm)	24.7
	Silt (50 - 2 mm)	52.5
	Clay (< 2 mm)	22.7
Texture		Silty loam
pH		6.4
Organic matter (%)		2.4
Field capacity (%)		31
Moisture content (%) measured during:		
Sampling tests carried out on 20.10.2010	(LH)	18
Soil tillage carried out on 21.10.2010	(LH)	18
Soil tillage carried out on 15.11.2010	(HH)	25
Sampling tests carried out on 15.02.2011	(HH)	22

Three tillage treatments were compared: Minimum tillage, (harrowing 0.20 m depth) coded MT; Ploughing, superficial (0.2 m depth) coded P20 and deeper (0.4 m depth) coded P40. All treatments were carried out at two different soil conditions: high water content (25%, treatments HH), corresponding to 80% of field capacity and low water content (18%, treatments LH), corresponding to 58% of field capacity. The main factor was the soil tillage, (MT, P20 and P40), while the secondary factor was soil water content (LH and HH). The six treatments: P40 LH, P40 HH, P20 LH, P20 HH, MT LH, MT HH, were arranged according to the split plot design; divided in three blocks of six plots and replicated three times for a total of eighteen plots each of 200 m^2.

4.2.1. Sampling test

Two sampling tests of these soil properties were carried out: one on 20 October 2010, with water content at 58% of field capacity, to assess soil physical conditions before starting the trials; another, on 15 February 2011, with water content at 78% of field capacity, to evaluate and compare the strength of the soil after the tillage (Tab. 5). The Richards water extraction apparatus was used to determine soil field capacity. Every parameter detected into the experimental site was georeferenced.

4.2.2. Soil tillage

Soil tillage was carried out at two different moisture content: in October at low water content (58% of field capacity) and in November at high water content (80% of field capacity). Same field conditions during the tests are shown in Table 5.

Ploughing was carried out using: 1) a mean power wheeled tractor (62 kW engine power, 3400 kg mass front ballasted) with mounted one furrow plow while minimum tillage was carried out using a mean power metal tracked tractor (62 kW engine power, 4100 kg mass front ballasted) with trailed disk harrow.

The performance of tractors carrying out tillage operations were evaluated through: forward speed, slip, global energy employed, effective work capacity, real work width and work depth, fossil-fuel energy requirements (GJ/ha) and carbon dioxide emissions (kg C/ha). In addition field data collected has allowed to appraise the global energetic efficiency of the tractors that depends from the area (ha) covered in function of the time and from the ability of the tractor to convert the energy of combustion in useful power. As a result, two field oriented performance indicators consisting in time efficiency (h/ha) and area specific consumption (kg ha^{-1}) were applied (Burgun et al., 2013; Servadio et al., 2014).

In order to evaluate the quality of the tillage operations, the followings parameters were measured: clod size distribution was determined by taking samples of tilled soil, sifting them through sieves with holes of 200, 100, 50, 25 and 10 mm of diameter and then separating into size classes (Servadio et al., 2012a and 2012b); structural stability of soil aggregates on the 0.25 mm fraction through the method of Kemper (1965). Besides, the wheat harvesting was carried out by hand into the sampling areas consisting in 1 m^2 (for 6 replications), sampling areas were chosen trough a subjective method suggested by Barbour (1998).

4.2.3.Statistical methods

Statistical analyses of differences between treatments were made with analysis of variance by means of the student's test conducted, at different depth between the same treatment and at the same depth between different treatments. Mean results are flanked on the same line by letters. Each mean, which share a letter, does not differ significantly, level of significance 0.01 (Gomez and Gomez, 1976).

4.3. Results

4.3.1. Sampling test

In recent years, the weather conditions in Central Italy have been unstable. In summer time soil was very dry and strength, in autumn and spring time soil was too mach wet and the rainfall has generally been delayed until November-December. Hence, farmers did not accomplish the seedbed preparation at the proper time. As a result, the drilling of cereals such as wheat and barley has been so delayed that there has been a decrease in yield. Meteorological data (rainfall) and the monthly mean rainfall during the overall experimentation time were also recorded. During the sampling tests carried out before tillage, with a soil water content corresponding to 58% of the field capacity (case B), soil was very strength. In fact, the values of penetration resistance in the deeper layer and of shear strength (Tab. 6 and 7) were very elevated with CI up to 4 MPa and SS up to 189 kPa. Due, both to the de-compacting action of soil tillage and to the higher water content (71% of field capacity), these values decreased significantly (▯>50%) in the sampling tests carried out after tillage (case A).

Table 6. Mean values of soil layers from 0 to 0.40 m depth of penetration resistance carried out before (case B) and after (case A) tillage and its increment ratio Δ.

Treatments	Depth (m)	Mean Penetration Resistance[a] (MPa) (21.10.2010) (B)	Mean Penetration Resistance[a] (MPa) (15.02.2011) (A)	$\Delta = \frac{B-A}{B}$
MT LH	0.0-0.20	2.77 a	1.34 b	0.52
	0.21-0.40	4.36 b	1.91 a	0.56
P20 LH	0.0-0.20	2.53 c	0.91 e	0.64
	0.21-0.40	3.99 e	1.55 f	0.61
P40 LH	0.0-0.20	2.19 d	0.92 e	0.58
	0.21-0.40	3.89 e	1.30 f	0.66
MT HH	0.0-0.20	2.48 a	1.32 b	0.47
	0.21-0.40	4.41 b	1.91 a	0.57
P20 HH	0.0-0.20	2.42 ac	1.26 a	0.48
	0.21-0.40	3.75 d	1.83 b	0.51
P40 HH	0.0-0.20	2.78 a	0.96 e	0.65
	0.21-0.40	3.96 de	1.31 f	0.67

[a]Average of 240 values.

Table 7. Mean values from 0 to 0.20 m depth of shear strength carried out before (case B) and after (case A) plough and its increment ratio Δ

Treatments	Depth (m)	Mean shear strength[a] (kPa) (21.10.2010) (B)	Mean shear strength[a] (kPa) (15.02.2011) (A)	$\Delta = \frac{B-A}{B}$
MT LH	0.0-0.20	172.83 a,b	83.83 a	0.51
P20 LH	0.0-0.20	155.67 a	42.33 b	0.72
P40 LH	0.0-0.20	188.67 b	56.50 bc	0.70
MT HH	0.0-0.20	154.50 a	72.75 ab	0.52
P20 HH	0.0-0.20	165.33 a	45.42 b	0.72
P40 H	0.0-0.20	177.50 a	37.67 b	0.78

[a]Average of 18 values.

4.3.2. Soil tillage

Due to the high soil strength in term of CI and SS obtained in the tests carried out at low water content, the tractor performance during ploughing was not so good if compared with that of other studies carried out, for instance, on silty clay soil (water content at 0.25 of the field capacity) with 217 kW powered wheeled tractors (Servadio et al., 2014). In fact, the two field oriented performance indicators consisting in time efficiency (h/ha) and area specific consumption (kg ha^{-1}) applied, showed:

1) in the tests carried out at water content of 58% of the field capacity, the results of the time efficiency were very low (8 and 6.3 h ha^{-1}) for 0.40 and 0.20 m respectively

(Tab. 8). Accordingly, the results of area specific consumption for 0.40 and 0.20 m respectively were 120 and 91 kg ha^{-1}, fossil-fuel energy requirements (4.67 and 3.54 GJ ha^{-1}) and CO_2 emission (101 and 77 kg C ha^{-1}) were very high. Besides, tractor slip were very high (32.4%), particularly during ploughing at 0.40 m depth.

2) in the tests carried out at high water content (80% of the field capacity), the results were significantly best: the time efficiency were (6 and 4 h ha^{-1}) for 0.40 and 0.20 m respectively (Tab. 9). Accordingly, the results for 0.40 and 0.20 m depth were: area specific consumption 91 and 60 kg ha^{-1}, fossil-fuel energy requirements 3.54 and 2.33 GJ ha^{-1} and CO_2 emission 77 and 51 kg C ha^{-1} respectively. Tractor slip (16 and 17%) can be considered as good for a wheeled tractor during plough. Tractor slip is an index of traction performance and to obtain the maximum of the traction efficiency, slip mast be from 15 to 20% on dry soil and from 15 to 25% on wet soil (Servadio, 2010).

3) Between the two different field conditions (low and high water content), performance of the tracked tractor during harrow were of the same magnitude for the MT treatment: time efficiency was 1.2 h ha^{-1}. Accordingly, the results of area specific consumption was 15 kg ha^{-1}, fossil-fuel energy requirements was 0.58 GJ ha^{-1} and CO_2 emission was 13 kg C ha^{-1}.

Table 8. Performance of tracked and wheeled tractors during soil tillage carried out at low soil water content (58% of the field capacity).

	P40 LH	P20 LH	MT LH
Forward speed (m s^{-1})	0.73	0.93	0.93
Measured work width (m)	0.5	0.5	2.5
Effective work capacity (ha h^{-1})	0.13	0.17	0.84
Time efficiency (h ha $^{-1}$)	8.09	6.28	1.19
Slip (%)	32.4	14.3	5.0
Hourly Fuel consumption (kg h^{-1})	15	14.5	12.5
Area specific consumption (kg ha^{-1})	120	91	15
Global energy employed (kWh ha^{-1})	310	235	183
Energy (GJ ha^{-1})	4.67	3.54	0.58
CO2 emission (kg C ha^{-1})	101	77	13

Table 9. Performance of tracked and wheeled tractors during soil tillage carried out at high soil water content (80% of the field capacity).

	P40 HH	P20 HH	MT HH
Forward speed (m s^{-1})	0.90	1.34	0.94
Measured work width (m)	0.5	0.5	2.5
Effective work capacity (ha h^{-1})	0.16	0.24	0.85
Time efficiency (h ha $^{-1}$)	6.25	4.17	1.18

Slip (%)	15.8	17.0	5.1
Hourly Fuel consumption (kg h^{-1})	14.5	14.5	12.5
Area specific consumption (kg ha^{-1})	91	60	15
Global energy employed (kWh ha^{-1})	250	166	182
Energy (GJ ha^{-1})	3.54	2.33	0.58
CO2 emission (kg C ha^{-1})	77	51	13

As it regards the quality of the developed tillage, results of clod size distribution shown a good quality of work particularly for treatments P20 HH and MT HH where an high percentage of clods having dimension lower than 50 mm and absence of clods higher than 200 mm were found (Fig. 5b). Treatments P40 HH shows higher percentage of clods bigger than 200 mm (50%) while P40 at low humidity shown the 30% of clods bigger than 200 mm. MT LH shown almost the same trend of HH condition, while treatment P20 LH shown the opposite trend of P20 HH recording more than 40% of clods bigger than 200 mm and about 10 % of clods smaller than 10 % (Fig. 5a).

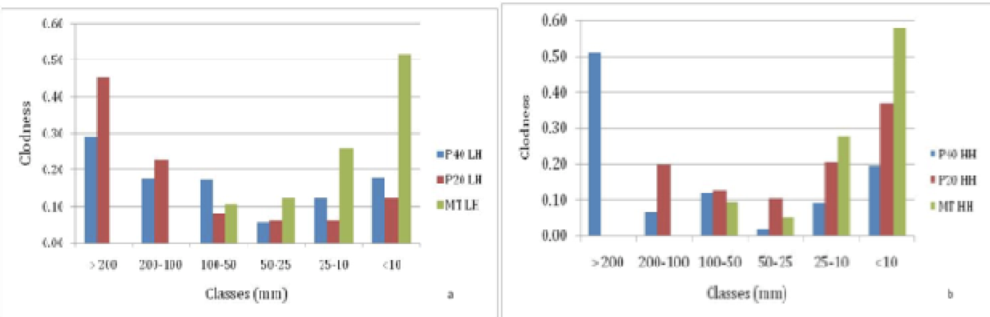

Fig. 5. Clods size distribution of different treatments: a) for LH field conditions and; b) for HH field conditions.

Due to the too cohesive soil status, on treatment MT both on HH and on LH conditions, the infiltration rate was equal to 0 while treatment P20 LH recorded highest values of infiltration rate; treatments P40 LH and P20 HH recorded similar values.

Findings of structural stability of soil aggregates show that treatment P40 had the highest structural stability value within LH treatments (68.7%). Treatments P20 and MT show quite similar values, 66% and 65.3% respectively (Fig. 2a). Tests conducted on HH treatments show that the best effect on structural stability was created by the treatment MT (70%), while ploughed plots show values of 65.3% and 64% for what concern P20 and P40 respectively (Fig. 6b).

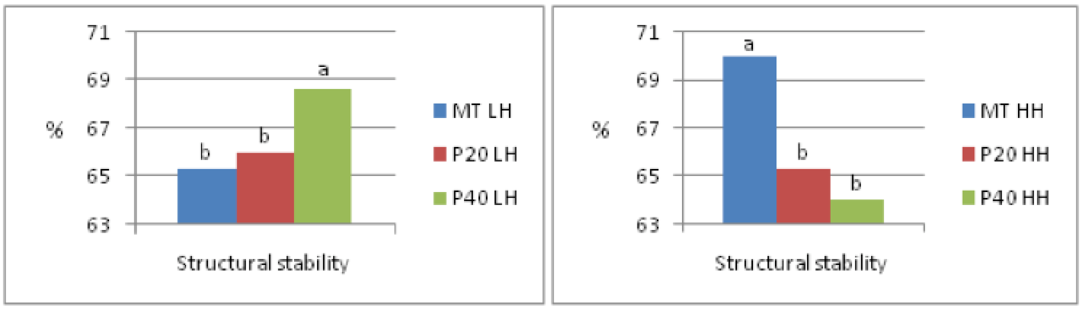

Fig. 6. Structural stability of soil aggregates related: LH) to low humidity treatments (58% of field capacity) and HH) to high humidity treatments (80% of field capacity). Average of 18 values.

According with structural stability of soil aggregates, results of wheat yield (Fig. 7) show that grain yield under LH condition was higher for P40 treatment (2.1 t ha^{-1}) and for P20 (2.05 t ha^{-1}) it follows MT with 1.7 t ha^{-1}. The trend of grain yield under HH was similar to that of LH condition: higher for P40 (1.9 t ha^{-1}) and for P20 (1.5 t ha^{-1}) it follows MT with 1.3 (t ha^{-1}). Figure 7 shows also values of differences of grain yield respect to the treatment P40 (treatment P40 was chosen as control because represents the traditional tillage of this crop). Concerning condition LH, P20 produced the same amount of P40 while MT produced 23% less; regarding HH condition, P20 and MT produced 26 % and 46 % less than P40. Grain yield of each treatment LH was higher than the respective treatment HH and treatment P40 produced the highest, MT the lowest and P20 the mean value of grain yield either for HH that for LH conditions.

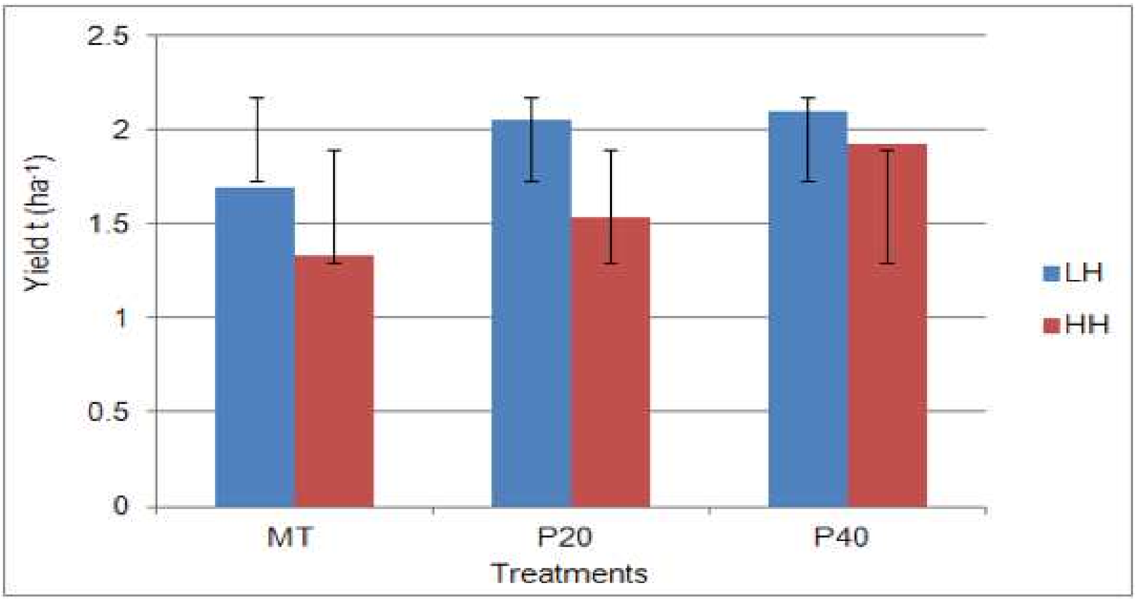

Fig. 7. Results of wheat harvesting (Error bars represent the standard deviation. Average of 18 values.)

Besides, According with other authors (Marsili et al., 1998), a significant linear correlation between soil penetration resistance and yield for different treatments was found (Fig. 8).

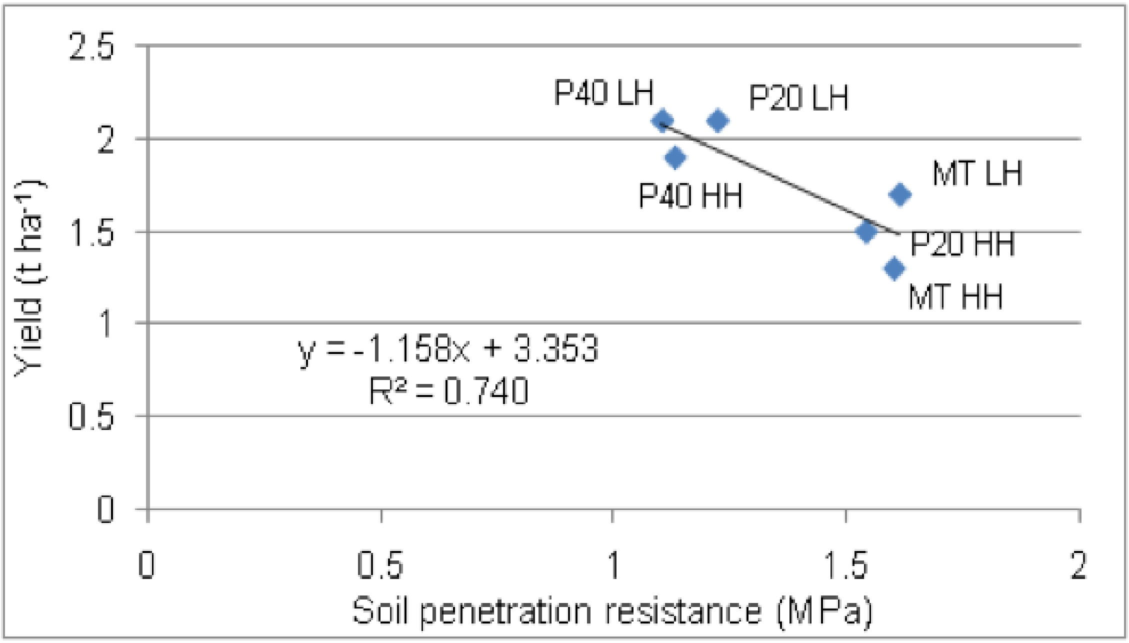

Fig. 8. Correlation between grain yield and soil penetration resistance.

Raper (2005) suggested to only traffic and till when soil moisture is less than 60% of field capacity. Vehicle traffic conducted when soil moisture is greater than approximately 60% of field capacity can lead to excessive soil compaction that may be battled for many cropping seasons. Or worse, the damage may be permanent. The correlation (Fig. 8) shows that in the field condition of tests, according with other studies carried out by Servadio (2013), tillage can be carried out at the water content up to 0.8 of field capacity as the P40 HH case shows.

In this region, the mouldboard ploughing is widely used as primary tillage but as the results showed it has several disadvantages compared with other tillage operations such as greater energy requirement as shown in Tabs. 8 and 9, excessive water loss from the soil and it produces greater surface roughness as shown in Fig. 5.

4.4. Conclusion

The results obtained in this research show that soil water content had significantly influenced the tractors performance during ploughing at low water content while MT was not influenced. In fact in low water content plots, area specific consumption, global energy employed and fuel energy requirements were significantly higher during ploughing operation at 0.40 m and 0.20 m depth compared to high water content plots. Better tractors performance during ploughing at 0.20 m with high water content and during minimum tillage were found. Regarding soil quality, treatments P20 LH and P40 LH showed good effects on structural stability and on grain yield, furthermore soil structure created by treatment P20 LH allowed an optimal water infiltration rate, meaning that runoff is reduced and an high percentage of rainwater is stored. A significant correlation between grain yield and soil penetration resistance was found highlighting how soil physical-mechanical parameters may be good indicators of its productivity. Even if do not exists the best tillage operation ever, it exists a compromise among targets: machineries, meteorological conditions, yield, soil status, costs, etc., and obtained results during these field tests allow to consider MT and P20 treatments suitable for this type of soil in climate change scenarios because MT is not influenced by soil water content and P20 was a good compromise among targets.

5. Delineation of Site-Specific Management Zones in Wheat Field based on Soil Structural Stability, Shear Strength, Water Content, and Nitrogen

5.1. Introduction

Natural variability of soil properties can be affected by several factors, such as land use, water content level, management system adopted, and climatic conditions. Intensive agricultural production systems, generally, rely on heavy machinery. Repeated passes of high working capacity machines on the field can cause soil compaction and, consequently, low permeability to water and nutrients and high resistance to root penetration (Servadio 2010). Traffic of agricultural machines may vary in terms of intensity and geographical distribution on the field. As a consequence, high variability of soil physical properties and crop yield can occur, even in soils characterized by homogeneous distribution of physical properties (Mouazen et al. 2001; Carrara et al. 2007). In this scenario, uniform field management often results in over-application of inputs in areas with high nutrient levels, and under-application of inputs in areas with low nutrient levels (Ferguson et al. 2003; Servadio et al. 2010). Sub-zones within the field can be identified by gathering information with high precision measuring techniques (Bullock et al. 2007). Within-field variability may determine a site-specific management, generally acknowledged as a possible way to address this problem (Cahn et al. 1994; McKinion et al. 2001; Godwin and Miller 2003; Mzuku et al. 2005; Keller et al. 2012).

The management zone (MZs) approach (Mulla et al. 1992) is a site-specific management method, based on the determination of sub-regions characterized by homogeneous combination of yield-limiting factors (Vrindts et al. 2005). The definition of the management zones generally rely on spatial information relative to soil properties (organic matter, total Nitrogen, texture, soil strength, etc.) that are stable or predictable over time, and related to crop yield (Franzen et al. 2003; Schepers et al. 2000, 2004).

Among several techniques, cluster analysis of soil and crop data has been used by Taylor et al. (2003) as a basis for such zones definition, and by Fleming et al. (2004) to delineate areas of different yield potential. Fuzzy k-means clustering algorithm has been widely used to classify management areas by Anderberg (1973) and Stafford et al. (1999). Furthermore, in order to detect clusters of different geometrical shapes, Gustafson and Kessel (1979) extended the fuzzy k-means algorithm (Höppner et al. 1999, Vrindts et al, 2005).

The application of such analysis allows to take into account the continuous variation of natural soil variables (Burrough 1989) and it has been used to identify potential within-field management zones in precision agriculture (Boydell and McBratney 2002). Several parameters representing the soil conditions can be considered in the definition of management zones. Parameters related to the crop yield are usually selected, in particular the chemical and physical soil properties (Trangmar et al. 1987: Cambardella et al. 1994: Ortega et al. 1999; Còrdoba et al. 2013). For example, in (Li et al. 2007a), organic matter, bulk electrical conductivity, total Nitrogen, available Nitrogen, and available Phosphorus were selected as main limiting factors for the crop yield. Electrical conductivity, associated with other soil parameters (such as pH, total Nitrogen, organic matter), was also considered by several authors (Ortega and Santibànez 2007; Morari et al. 2009; Moral et al. 2010; Van Meirvenne et al. 2013). Davatgar et al. (2012), considered as limiting factor the cation exchange capacity, while in (Li et al. 2007b), NDVI image was taken into account.

Soil mechanical properties were less considered as input parameters for the delineation of management zone, even if many efforts have been made also to analyze their spatial variability. For example, Vrindts et al., 2005, Yao et al. 2014 considered Bulk density; Duffera et al., considered Penetration resistance and Bulk density.

In the present paper, the within field spatial variability of some soil properties was investigated by means of soil sampling, measurements and geostatistical analysis. The novelty of this work lies in the selection of shear strength and structural stability as limiting yield factors. In particular, shear strength results highly correlated with soil strength and soil tillage (Servadio et al. 2005; Servadio 2013). Havaee et al. (2015) reported that soil shear strength plays a key role in soil structure and/or erodibility, and is usually used as primary indicator of soil resistance to erosion. Structural stability was selected because is a key factor in determining soil quality, in fact the loss of structure is a type of physical soil degradation which is usually related to specific land uses, particularly to soil tillage. Several authors have observed a loss of soil structural stability under the influence of cultivation which frequently involves a decrease in SOM contents (Barral et al., 2007). In addition to the previous parameters, water content and total Nitrogen were also considered.

The objectives of this study were to analyze within field spatial variability of crop yield acquiring yield data of three consecutive growing seasons of wheat (*Triticum durum*) and to define potential management zones for adoption of precision farming techniques.

Potential management zones (MZs) were defined using soil parameters as data source through fuzzy clustering technique. Two cluster analyses are carried out, taking into account the soil properties. In particular, shear strength, structural stability and water content were considered in the first cluster, while in the second one total Nitrogen was added to the previous parameters. Finally, the performance of the multivariate classification method has been evaluated considering the crop yield in the defined zones.

5.2. Materials and methods

5.2.1. Site and data acquisition

The site of the performed tests was a field characterized by clay loam soil (2.7 ha), classified as Vertic Cambisol (FAO 1998), belonging to a farm in center of Italy, 4152’502” Latitude (N); 1212’866” Longitude (E). The climatic conditions are those of a typical Mediterranean environment, characterized by a dry season between May and September and a cold season from October-November to March-April. Every year the soil was ploughed at 0.40 m depth and harrowed at 0.20 m depth with a rotary harrow.

Finally, the seedbed was prepared and then sowed with wheat. Fertilizations were carried out just after sowing, 150 kg/ha of ammonium nitrate and at half of the crop cycle 200 kg/ha of urea. The crop was sowed in the second half of October and harvested in mid July for each growing season. At the end of the crop cycle, during the wheat harvesting, a grain yield map was acquired with a combine harvester (New Holland, NH CX860) equipped with a grain header with a floor travel of 575 mm and a cutting width of 7.62 m. The GPS sensor (for the acquisition of EGNOS signal) has 15.24 – 20.32 (6”-8”) accuracy and a grain mass flow sensor composed by a plate mounted to a pivoting device with a counter weight, thus neutralising the rubbing effect of the grain. In addition, the throwing angle of the paddles that throw the grain onto this sensor plate is set so that shear grain volume does not cause deviation in the sensing system.

Acquired data were processed with the Precision Land Management Software (Case New Holland, inc.). Yield map data were available for the years 2008, 2009 and 2010. The speed of the combine harvester machine during harvesting was 4.6, 5.0 and 4.2 km/h in 2008, 2009 and 2010, respectively. During the overall experimentation, from October 2007 to July 2010, meteorological data (monthly rainfall, minimum and maximum temperatures) were also recorded.

5.2.2. Meteorological data

The acquired monthly mean temperatures and rainfall for each wheat cropping season are depicted in Fig. 9.

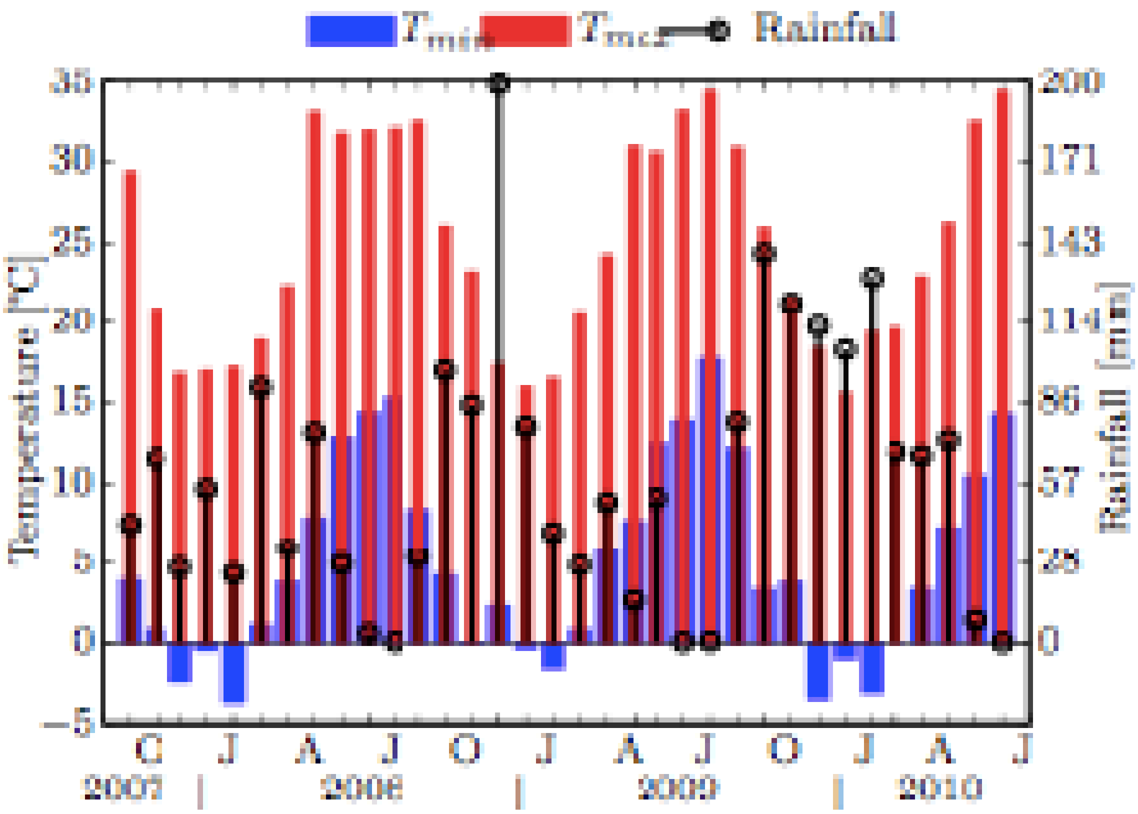

Figure. 9. Monthly min and max temperature and monthly precipitation sum in each growing season (2007-08, 2008-09, 2009-10);

Considering the temperature trend, no differences were found concerning the minimum and maximum values among the three cropping seasons, with recorded values within -3 °C and 34 °C. Referring to the rain precipitation, in the period October - July, mean values of rainfall were higher in 2009-2010 (824 mm) and 2008-2009 (642 mm) than 2007-2008 (446 mm). More specifically, during March, April and May 2009, rainfall values resulted very low (27, 51, 15 mm, respectively) with respect to the same period of 2008 (91, 34, 75 mm, respectively) and 2010 (68, 67, 73 mm, respectively). Furthermore, in June 2009, a very high rainfall value (52 mm) was recorded with respect to the same month of 2008 (28 mm) and 2010 (8 mm). The acquired rainfall data shown an erratic weather pattern, in particular during the grain filling stage. As a rainfed crop, durum wheat is particularly sensitive to year-to-year climatic changes. Generally, in the

Mediterranean environment, yield variation is mainly caused by low and irregular rainfall distribution and high temperatures during such phenological phase (Diacono et al. 2012).

5.2.3. Sampling test, measurements, and mapping

At the end of the third growing season, a georeferenced grid sampling on the soil, previously tilled, was performed to investigate soil physical-chemical properties. The grid sampling was based on a grid composed by squares sizing 30 x 30 m (900 m^2). We collected one sample for each corner of the squares, so each sample was 30 m away from the other. We took approximately ten samples per hectare that according to Diacono et al. (2012), were deemed acceptable. Geographical coordinates of each sampling point were recorded using a GPS device (Trimble GEO XM) and then differential correction was performed using the post processing software Trimble Pathfinder Office (www.trimble.com). Twenty samples of soil (from 0 m to 0.2 m depth) were taken using an Edelman auger (Eijkelkamp) type chosen in respect of the soil type in question. Using a wing auger of 0.1 m length and 0.2 diameter, samples were taken to determine structural stability, water content, and total Nitrogen (N).

Furthermore, as indicator of soil strength, twenty georeferenced measurements of shear strength were performed, from 0 m to 0.2 m depth. Structural stability of soil aggregates was determined on the 0.25mm fraction by means of the Kemper method (Kemper and Chepil 1965). The structural stability was determined on the principle that unstable aggregates will break down more easily than stable aggregates when immersed into water. To determine the stability, 8 sieves were filled with a certain amount of soil aggregates. These sieves were placed in a can filled with water, which moved up and downward for a fixed time. Unstable aggregates fallen apart and passed through the sieve and were collected in the water-filled can underneath the sieve. After drying the cans with the aggregates, the weight of both stable and unstable aggregates was determined. Dividing the weight of stable aggregates over total aggregate weight gives an index for the aggregate stability

Soil water content was determined considering samples of soil extracted with a corer sampling ring. Hence, the samples were weighed and dried until they reached a constant weight. Soil total Nitrogen was measured with the Kjeldahl method (Bremner, et al 1996). Finally, soil shear strength was measured using a field inspection vane tester from 0 to 260 kPa (Eijkelkamp).

Interpolation of soil properties and grain yield maps was performed using inverse distance weighting interpolation, yielding 1026 data points (Vrindts et al. 2005). The minimum and the maximum number of neighbours and the optimal power value were determined by minimizing the root-mean square prediction error (RMSPE) estimated by cross-validation. The geostatistical analyses were conducted using the Geostatistical Analyst extensions of the ArcGIS 10.0 software (Esri Inc., Redlands, CA, USA).

5.2.4. Management zone identification

According to Vrindts et al. (2005), Gustafson-Kessel algorithm was applied using soil variables as inputs. Four soil attributes, considered yield limiting factors (water content, shear strength, structural stability, and total Nitrogen), were selected as data sources. Two cluster analyses were carried out to the interpolated maps in order to identify potential management zones. The first cluster analysis was performed considering the following indicator parameters: water content, shear strength and structural stability.

In order to evaluate the impact of the chemical fertilization on the crop yield and to compare such impact with the soil mechanical properties effects on the crop yield, a second cluster analysis was performed by adding to the previous soil parameters the total Nitrogen.

Soil water content was used as input parameter in the cluster analysis because influences soil hydraulic properties, which produce crucial effects on infiltration, surface runoff and soil erosion process that are critical in variuos fields of practical interest, even though this parameter varies in time and was surveyed once. In fact Vachaud et al. (1985) were among the first to show that spatial patterns of soil moisture changed little with time despite large variation over time and space in the field. This phenomenon has been called temporal stability. The temporal stability for soil moisture, however, is widely recognised by most authors (Gao and Shao, 2012; Brocca et al., 2009; Coppola et al., 2011; Cosh et al., 2004, 2008; da Sivaro et al., 2001; Martínez-Fernández and Ceballos, 2003). In other words, the pattern of variation across the study area remains more or less the same, even though the average soil water content changes. Soil water content temporal stability has been demonstrated and only a small number of soil moisture samples at are needed to monitor the average soil water content across relatively large areas (Guber et al., 2008; Starr, 2005).

Yield data were used to evaluate the performance of multivariate classification based on soil variables, rather than as layer for delineating management zones, according to Cordoba et al. (2013). Fuzzy classification produces a continuous grouping of objects by assigning partial class membership values, according to the properties variability in the soil continuum. In the present investigation, Gustafson-Kessel algorithm was applied by using the FuzMe software functions from the Australian Centre for Precision Agriculture (Minasny and McBratney, 2002) in MatLab environment (www.mathworks.com). Cluster analysis was performed following the data-processing steps presented by Vrindts et al. 2005. The first steps in cluster analysis require the definition of the number of classes and the fuzziness exponent. According to Davatgar et al. (2012), Fridgen et al. (2004), Reyniers et al. (2006), Vrindts et al. 2005, the number of class range from 2 to 8 or 9. Considering the fuzziness exponent □, different values can be considered. For example, Odeh et al., 1992 set it equal to 1.35, while Bezdek et al., 1984 suggest a possible range equal to [1.5, 3]. Most researchers have proposed □ =2 (Yu et al, 2004). In this investigation, calculations were performed considering the number of clusters from 2 to 10 and the fuzziness exponent ranging from 1.1 to 3 in 0.1 steps. The optimal number of clusters were selected by minimizing the FPI and NCE indexes (Fridgen et al., 2004, Wang and Zhang, 2007), while the optimal fuzziness exponents were determined using the derivative of the objective function J values with respect to the fuzziness exponent □ (McBratney and Moore, 1985). According to Vrindts et al, 2005, the calculations with the optimal fuzziness index and with the optimal cluster number was repeated 10 times with different initial cluster centres, choosing the results with best separation considering the validity function S (Xie and Beni, 1991).

5.3. Results and discussion

5.3.1. Wheat yield

In the present investigation, yield data acquired during the three consecutive growing seasons (2007-10) showed a great temporal variability, as depicted in Fig. 10, and also high spatial variability between three years, in fact different yields were acquired from same areas of the field..

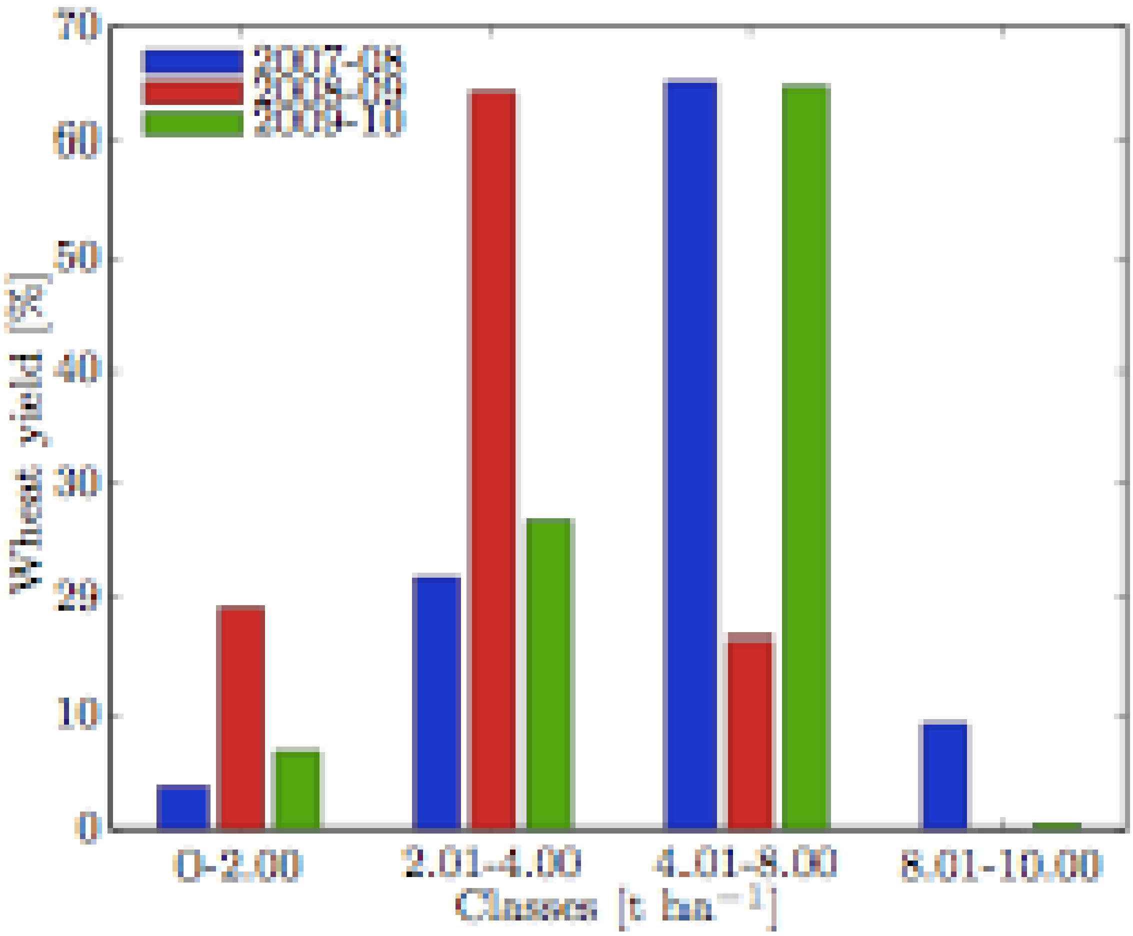

Figure. 10. Wheat yield distribution for the three growing season;

In particular, considering the yield of seasons 2007-08 and 2009-10, about 65% of the field surface presented yield values in the range (4.01-8 t ha^{-1}), while, considering the yield of the season 2008-09, the same field surface presented yield values in the range (2.01-4 t ha^{-1}). Furthermore, wheat crop yield per hectare relative to 2008-09 (2.8 t ha^{-1}) was lower than the ones relative to 2007-08 and 2009-10 (6.5 and 5.0 t ha^{-1}, respectively).

Such temporal variability could be ascribed particularly to the meteorological pattern recorded during the three seasons. In the evaluation of the performance of the multivariate classification, the yield mean value of the three growing seasons was adopted as reference parameter, in order to mitigate the seasonal effects. The mean-yield map is depicted in Fig. 11(a).

5.3.2. Sampling test and mapping

Within field spatial variability of soil physical-chemical parameters is represented by means of the interpolated maps. The maps of water content (b), total Nitrogen (c), structural stability (d), and shear strength (e) are shown in Fig. 11.

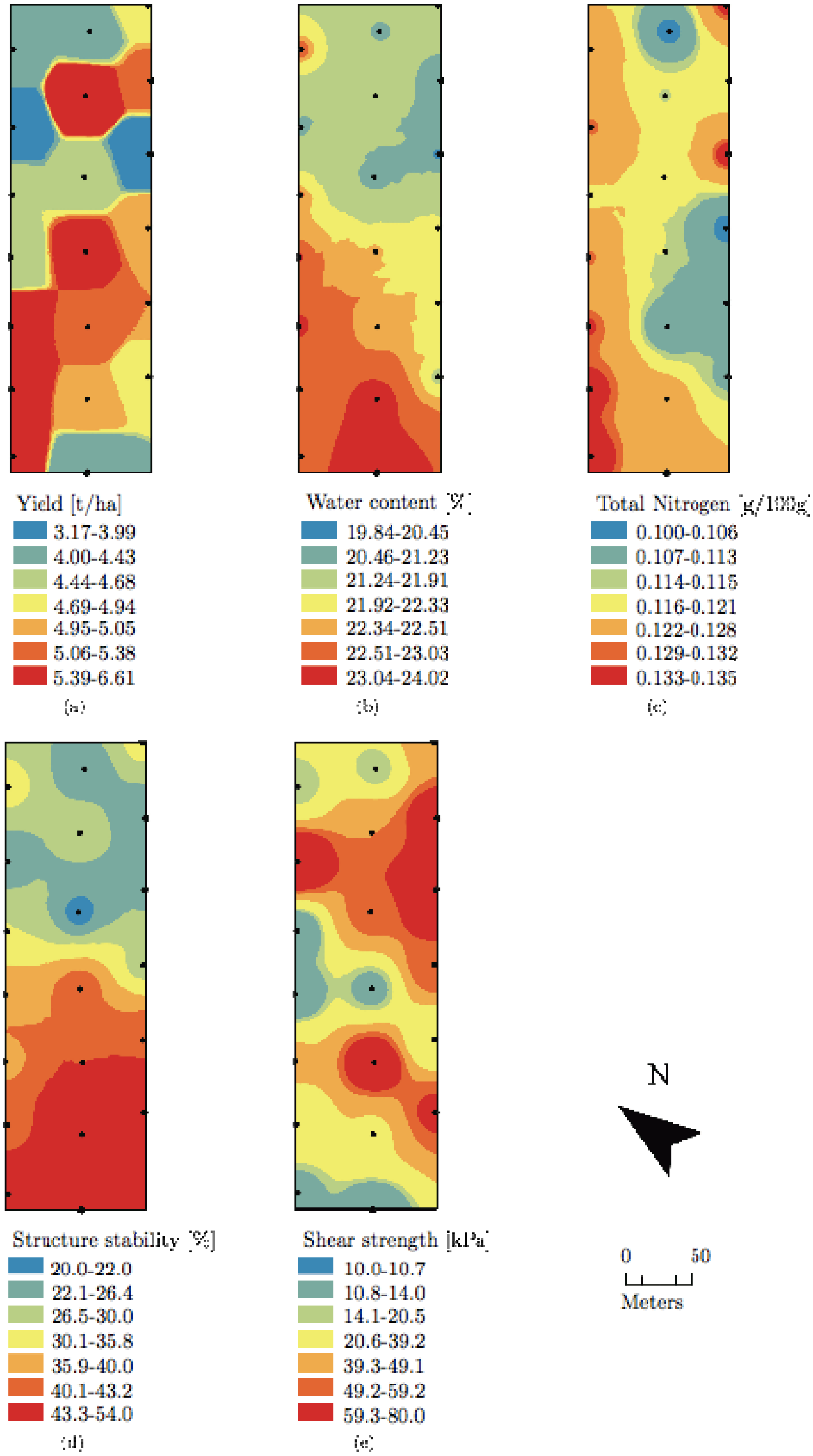

Figure 11. Interpolated maps of soil physical-chemical parameters and Wheat yield elaborated using IDW interpolation

Descriptive statistics for soil physical-chemical properties are given in Table 10. Water content and total Nitrogen had medium coefficient of variability (CV) (5.3 and 9.2%, respectively), while shear strength and structural stability presented high value of CV (66 and 28.5%, respectively).

Table 10. Descriptive statistics of the soil parameters

Soil parameter	Mean	SD	CV [%]
Water content [%]	22	1.16	5.3
Shear strength [kPa]	33	22	66
Structural Stability [%]	33.2	9.5	28.5
Total Nitrogen [%]	0.12	0.01	9.2

5.3.3. Management zone identification

In this scenario, the definition of management zones could be of use in the identification of specific input applications, such as soil tillage and fertilization, and, consequently, in the improvement of energy efficiency, environment protection, and wheat quality. In order to define such zones, two cluster analyses were performed.

5.3.4. Cluster analysis

In the first cluster analysis, shear strength was selected as soil strength indicator, and structural stability was selected as soil quality indicator. Furthermore, water content was chosen as additional limiting yield factor. By applying the data-processing steps described in Section 5.2.4, the optimal clustering results were obtained with a number of clusters equal to 3 and with a fuzziness exponent equal to 2.2.

Fig. 12 shows the values of FPI and NCE with respect to the number of classes c. The mean values and the coefficients of variability of the parameters relative to the first cluster analysis are reported in Table 11, together with the yield data.

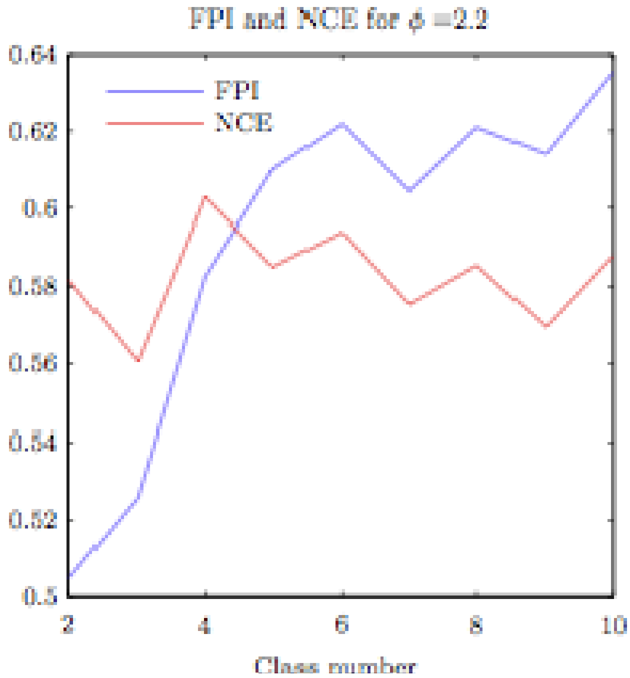

Figure 12. FPI and MPE indices for the first cluster analysis

Table 11. First cluster analysis: mean values and coefficients of variation of soil parameters for each zone

Zone	Water content		Shear strength		Structural Stability		Yield	
	Mean [%]	CV [%]	Mean [kPa]	CV [%]	Mean [%]	CV [%]	Mean [t ha^{-1}]	CV [%]
1	21.2	1.6	41.7	41.6	25.4	7.9	4.5	14.7
2	22.3	1.7	16.8	32.1	37.1	11.1	5.1	12.7
3	22.5	1.3	34.3	39.9	42.8	8.8	4.9	12.9

The management zones map is depicted in Fig. 13. Referring to the yield limiting factors, it can be noticed that:

- zone 1 presented the lowest mean values of water content and structural stability, and the highest mean value of shear strength;
- zone 2, registered a mid-range value of water content, an upper-mid-range value of structural stability, and the lowest value of shear strength;
- zone 3 grouped an area with the highest value of water content and structural stability, and a mid-range value of shear strength.

Referring to the crop yield:

- zone 1 presented the lowest mean value;

- zone 2 registered the highest value;
- zone 3 presented an upper-mid-range value.

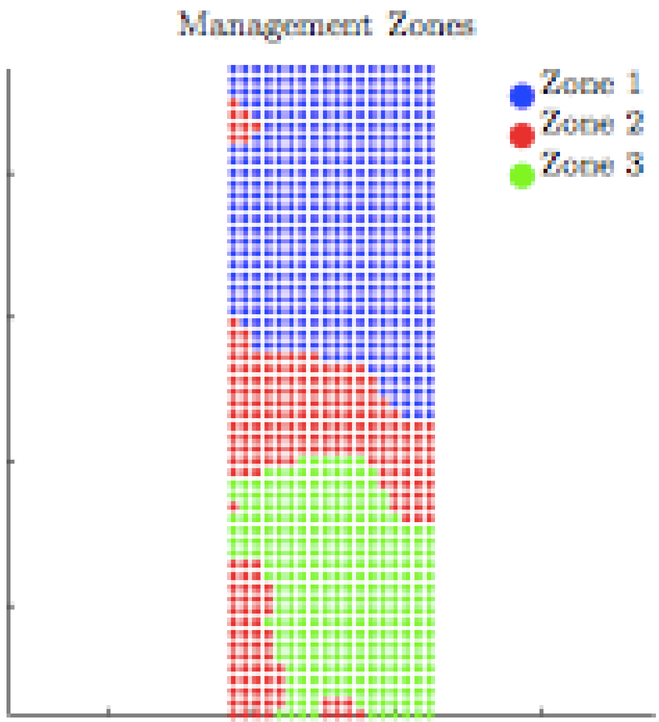

Figure 13. First cluster analysis: the management zones

The management zones were analysed mapping the limiting yield factors with respect to the crop yield. Figures 14, 15, and 16 show the soil structural stability, the shear strength, and the water content versus the grain yield, respectively.

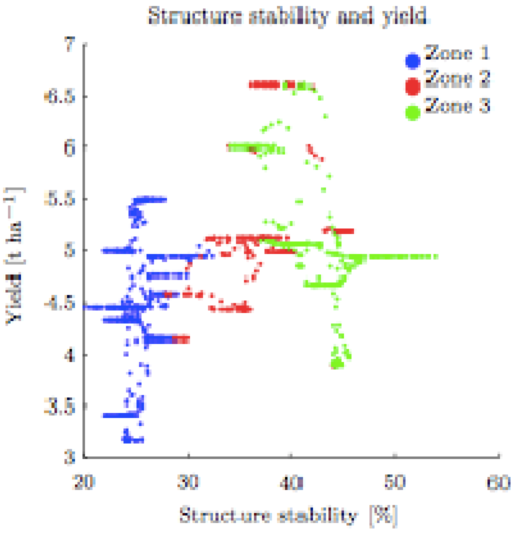

Figure 14. Cluster 1: structural stability and crop yield

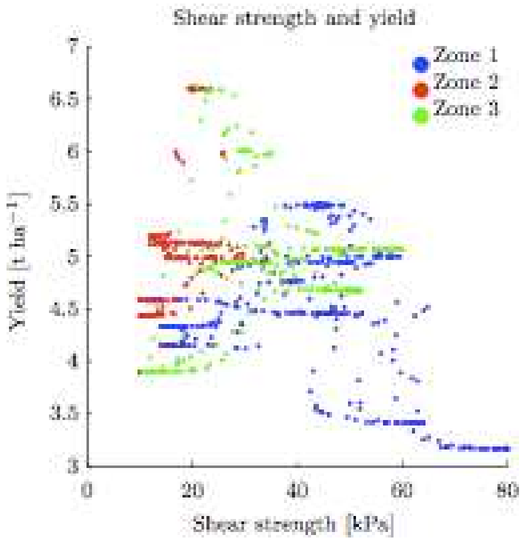

Figure 15. Cluster 1: shear strength and crop yield

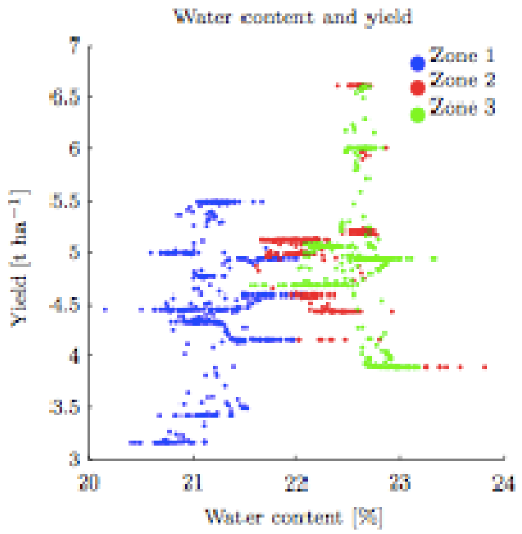

Figure 16. Cluster 1: water content and crop yield

By analysing the results reported in Table 11, it can be noticed that water content values range from 21.2 to 22.5 %, presenting low coefficients of variation. Considering the other soil parameters, high values of shear strength and low values of structural stability correspond to low values of crop yield, see zone 1. On the other hand, high or upper-mid-range values of structural stability coupled with mid-range or low values of shear strength correspond to upper-mid-range or high values of crop yield, see zones 3 and 2.

The second cluster analysis was performed considering shear strength as soil strength indicator, structural stability as soil quality indicator, and water content as additional limiting yield factor. In order to compare the impact of the chemical fertilization with the soil mechanical properties effects on the crop yield, Total Nitrogen was added to the previous parameters as environmental indicator. As in the previous case, the optimal clustering results were obtained with a number of clusters equal to 3 and with a fuzziness exponent equal to 2.2.

Fig. 17 shows the values of FPI and NCE with respect to the number of classes c. The management zones map is shown in Fig. 18. The mean values for each parameter for four clusters are reported in Table 12, together with the yield data.

Referring to the limiting yield factors mean values, it can be noticed that:

- zone 1 presented the lowest mean values of water content, structural stability and Nitrogen, and the highest mean value of shear strength;
- zone 2, registered the highest mean value of water content, structural stability and Nitrogen, and upper-mid-range value of shear strength;
- zone 3 grouped an area with an upper-mid-range value of water content and structural stability, the lowest mean value of shear strength and a mid-range value of Nitrogen.

Referring to the crop yield:

- zone 1 presented the lowest mean value;
- zone 2 registered the highest mean value;
- zone 3 presented an mid-range value.

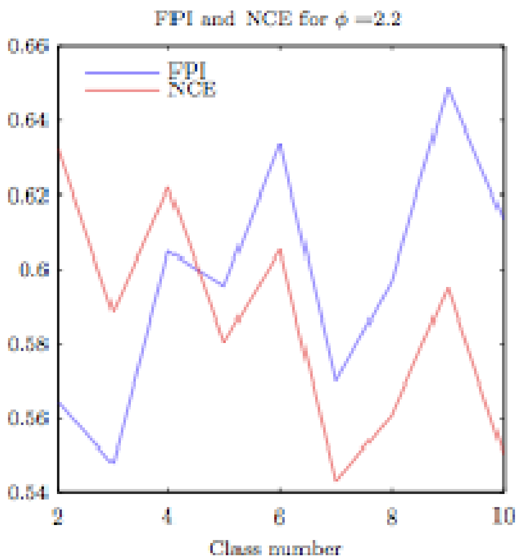

Figure 17. FPI and MPE indices for the second cluster analysis

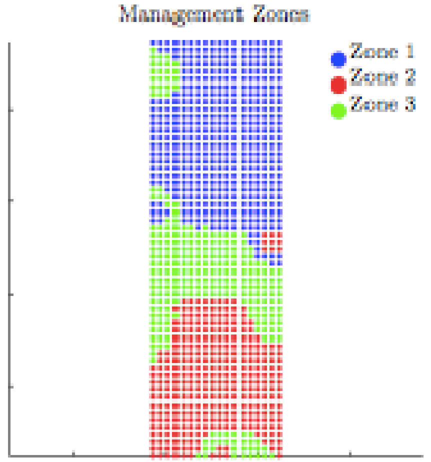

Figure 18. Second cluster analysis: the management zones

Table 12. Second cluster analysis: mean values and coefficients of variation of soil parameters for each zone

	Water content		Shear strength		Structural Stability		Total Nitrogen		Yield	
Zone	Mean [%]	CV [%]	Mean [kPa]	CV [%]	Mean [%]	CV [%]	Mean [%]	CV [%]	Mean [t ha^{-1}]	CV [%]
1	21.2	1.5	42.8	39.7	25.2	7.6	0.117	4.2	4.6	15.1
2	22.5	1.3	33.3	43.7	42.7	10.1	0.120	5.8	5.1	13.0
3	22.2	1.8	18.3	39.7	36.0	12.6	0.118	4.8	4.8	11.8

Considering the limiting yield factors with respect to the crop yield, Figures 18, 19, 20, and 21 show the soil structural stability, the shear strength, the water content, and the total Nitrogen versus the grain yield, respectively.

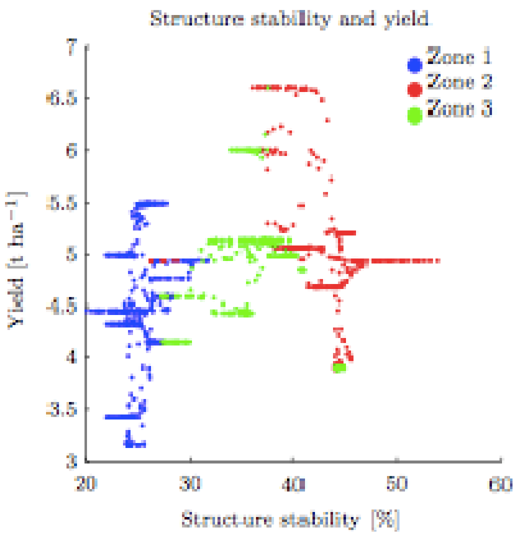

Figure 18. Cluster 2: structural stability and crop yield

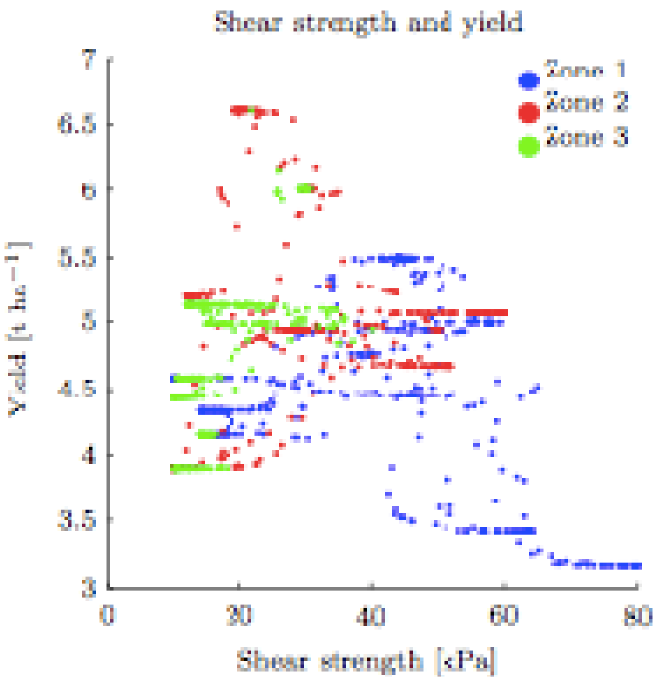

Figure 19. Cluster 2: shear strength and crop yield

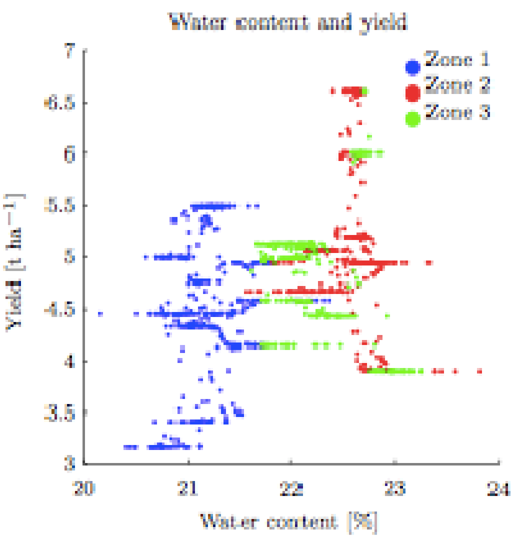

Figure 20. Cluster 2: water content and crop yield

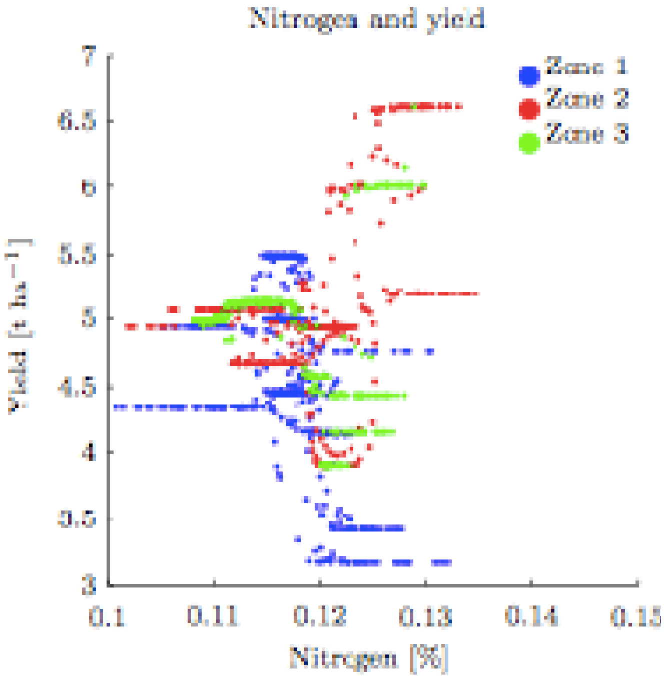

Figure 21. Cluster 2: total Nitrogen and crop yield

Considering the results reported in Table 12, the Nitrogen mean values in each zone seem to follow the trend of the soil parameters with respect to the yield showed in the previous cluster. In fact, high values of shear strength and low values of structural stability and Nitrogen correspond to low values of crop yield, as in zone 1. On the other hand, high or upper-mid-range values of structural stability and Nitrogen coupled with mid-range or low values of shear strength correspond to high or upper-mid-range values of crop yield, as in zones 2 and 3.

5.4. Conclusion

In the present investigation, a geo-referenced grid sampling on the soil was performed to investigate soil physical-mechanical parameters and chemical properties.

Three year yield data were acquired with a combine harvester equipped with GPS sensor. Interpolation of soil properties was executed to generate field maps. Two cluster analyses were performed. In the first one, shear strength was selected as soil strength indicator, structural stability was selected as soil quality indicator, and water content was chosen as additional limiting yield factor. In the second one, total Nitrogen was added to the previous limiting factors as environmental indicator to compare the impact of the chemical fertilization on the crop yield with the soil mechanical properties effects. Results of both clusters revealed that the optimum number of management zones was three. The mean value of the three years yield was considered in the evaluation of the performance of the multivariate classification in order to mitigate the seasonal effects. In the first cluster analysis, results show that, among the input parameters, shear strength and structural stability were the most significant limiting factors for the wheat yield. Such results were confirmed in the second cluster analysis, where Total Nitrogen was considered as additional environmental parameter.

As indicators of soil strength and quality, shear strength and soil structural stability are correlated with agricultural practices, in particular in soil tillage. Hence, the defined management zones could provide information for site-specific management, including the application of different soil tillage methods. Furthermore, variable-rate application (VRA) instead of uniform-rate application (URA) of inputs might be carried out, decreasing fertilization in the more productive area and minimizing the application of chemical substances as a strategy to obtain a more cost-effective field management.

Finally, for the specific examined site, the adoption of precision farming techniques could lead to an optimization of the soil-machinery interaction and to a reduction of soil compaction and greenhouse gas emissions.

6. Perspectives

Further researches were conducted in order to optimize the procedure of management zone definition and the selection criterion of soil parameters for cluster analysis.

Soil condition and crop yield were examined in three fields, characterized by different soil texture, belonging to a farm in the center of Italy. Spatial variability of chemical and physical properties was investigated by means of soil sampling and geostatistical analysis. Potential management zones (MZs) were defined by means of an optimised fuzzy clustering algorithm, evaluating three soil attributes: clay percentage and organic matter, considered as indicator parameters, and water content, considered as yield limiting factors. For each field, the effects of such attributes on the soil mechanical properties were evaluated, considering the set of parameters constituted by soil structural stability, shear strength, and penetration resistance as test data set. Sand percentage and yield were also included in the test data set. An extra-field analysis was also performed to compare the intra-field results and to identify the most important factors affecting the soil mechanical properties and the crop yield.

Furthermore a study was conducted for comparing the results obtained by management zone definition performed selecting empirically input soil parameters with the results obtained by management zone definition performed selecting input soil parameters using a Principal Component Analysis in MatLab environment.

Final results of both researches are still in elaboration.

7. Main conclusions

The results of tests performed during the whole experimentation highlighted the presence of high spatial variability of soil physical-chemical properties within the agricultural fields examined. Assessing such spatial variability becomes essential for enhancing the efficiency of crop management, lowering economic and environmental costs. Such result can be achieved only through site specific management which requires the delineation of management zones. Georeferenced soil sampling resulted as a proper technique for investigating spatial variability within agricultural fields, even though the soil parameters vary in time and were surveyed once. In fact some authors (Brocca et al., 2009; Coppola et al., 2011; Cosh et al., 2008; Martínez-Fernández and Ceballos, 2003; Vachaud et al., 1985) stated that spatial patterns of soil properties changed little with time despite large variation over time and space in the field. This phenomenon has been called temporal stability. In other words, the pattern of variation across the study area remains more or less the same, even though the average content changes.

Georeferenced sampling of soil physical-chemical parameters allowed to identify soil quality and soil strength indicators, furthermore monitoring the performance of machineries during soil tillage and agricultural operations allowed to identify field efficiency indicators (i.e.: area specific consumption, global energy employed and fuel energy requirements).

Obtained results showed that soil water content had significantly influenced the tractors performance during tillage and traffic in the field. Furthermore correlations between soil properties (OM and N) and yield confirmed that in agricultural ecosystems, N and OM are the major determinants and indicators of soil fertility and quality, which are closely related to soil productivity. Moreover a significant correlation between grain yield and soil penetration resistance was found and results of cluster analysis showed that, among the input parameters, shear strength and structural stability were the most significant limiting factors for the wheat yield highlighting how soil physical-mechanical parameters may be good indicators of its productivity.

Such indicators can be utilized as input parameters in cluster analysis or can be utilized to select the more efficient soil tillage operation, such as direct seeding.

Geostatistical analysis conducted using the FuzMe, MatLab and ArcGIS 10.0 softwares for interpolating the acquired data was an useful tool to assess spatial variability within agricultural fields and for delineating and representing management zones.

In future researches Principal Component Analysis (PCA) could be of use to overcome the problem in selection empirically inputs variables of cluster analysis enhancing the delineation process of management zone as well as the acquisition of remote sensing data that can provide more accurate and numerous data and develop new vegetational indexes.

In conclusion, the assessing process of spatial variability within agricultural fields, the identification of soil indicators and the definition of management zones can be considered as an adaptation technique to Climate Change enhancing the efficiency of agriculture. In fact, the defined management zones could provide information for site-specific management, including the application of different soil tillage methods. Furthermore, variable-rate application (VRA) instead of uniform-rate application (URA) of inputs might be carried out, decreasing fertilization in the more productive area and minimizing the application of chemical substances as a strategy to obtain a more cost-effective field management.

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