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Field-Scale Variability and Homogeneous Zone Delineation for Some Qualitative Parameters of Durum Wheat Semolina in Mediterranean Environment

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Abstract: Wheat yield and quality parameters are spatially variable because of inherent spatial variability of factors affecting crop at a field scale. The following semolina quality parameters were analyzed in 100 georeferenced locations, in a 12-ha durum wheat field in southern Italy: protein content (PC, %), dough strength (W = Jx10^{-4}) and tenacity/extensibility ratio (P/L). The study identified few homogeneous zones by geostatistical procedure called factorial co-kriging. Co-kriging was also used to map the quality parameters in the field. It is suggested that the delineation of homogeneous within-field areas should allow to segregate the harvested grain on the basis of the field-scale semolina qualitative parameters, so to obtain uniform grain lots being sent to the pasta industries.

Key words: Field variability · Semolina quality · Geostatistical procedures · Grain segregation

INTRODUCTION

Spatial and temporal variability of soil properties at the field scale and meteorological pattern may affect wheat growth, yield and quality parameters. In Mediterranean environments, yield variability is often caused by the uneven weather pattern, particularly low and irregular rainfall and high temperature during grain ripening stage and by the distance from the sea [1, 2]. Moreover, it has been reported that periods of heat stress with temperatures higher than 35°C may alter flour, dough and baking quality, probably because of an increased gliadins/glutenins ratio [3].

Farmer's profitability increase and environment protection might be obtained by fitting the farm management practices to the variable site conditions [4]. Precision fertilization of wheat, carried out by matching the timing of added nitrogen (N) to local crop demand, has the potential to optimize the use of N fertilizers and to reduce the risk of nitrate leaching [5]. The magnitude of the within-field variability is a good indication of the suitability of implementing a spatially variable farm management [6]. A site-specific grain harvesting, in particular, could have the potential to differentiate grain quality grades for pasta industry. Otherwise, because of the sensible variation of the agronomic attributes, conventional agricultural systems have a limited capacity to respond to the requests of increasingly tighter grain quality specifications [7].

The first step is to delineate homogeneous subfield areas within which the effects on the crop of seasonal differences in weather, soil and management are expected to be more or less uniform [8]. Since the determination of these areas in the field is difficult, due to the strong interactions among several biotic and abiotic factors affecting crop yield, a multivariate geostatistical approach is preferred. In particular, "factorial co-kriging" uses information coming from both relationships among variables and spatial dependence between observations, to subdivide an agricultural field into more homogeneous units with respect to soil and crop properties [9]. Such approach can be used to map the grain wheat quality parameters within a field. Some factors that affect crop response might have a short-range action, whereas others operate at longer distances, therefore the delineation of homogeneous zones is expected to be scale-dependent.

Durum wheat grain quality is one of the most important parameters for pasta industries [1]. The optimization of agronomic practices to produce wheat and so semolina with enhanced nutritional value, health and sensory properties, is a challenge.

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It is necessary that semolina possesses certain characteristics, among which optimum protein content and composition, for obtaining pasta of good quality, with a pleasant typical taste and exhibiting low stickiness grade as well as good strength after cooking [10].

The N nutrition is largely considered as the decisive factor both in producing high yields and affecting the technological quality of the grain because it increases protein concentration [11, 12]. According to Stewart *et al*. [7], protein concentration is also the major quality attribute that, if properly standardized, could actually allow growers to obtain interesting monetary incentives. The qualitative characteristics of gluten, such as viscosity, elasticity ad extensibility, are usually investigated with rheological equipments [13, 10].

Since protein content of a durum wheat crop is certainly not uniform in the field, a reduction of the premiums to farmer could occur when lots of grain of different quality are mixed. Consequently, a strategy to overcome this problem could be the analysis and mapping of such variability in the field, in order to harvest, segregate and store grain of different quality.

The main goal of this study was to use the geostatistical approach on three durum wheat semolina parameters for delineating homogeneous field areas for such qualitative characteristics.

MATERIALS AND METHODS

Site of Study, Experimental Set-up and Measurements: The study was carried out in the Experimental Farm of the CRA-CER, Cereal Research Centre (Foggia, 90 m a.s.l., 41° 27' N, 15° 36' E, Southern Italy), during the 2006-2007 season, on a 12 ha durum wheat (*Triticum durum* Desf. cv. ''Gargano'') field.

The soil, typical of the Apulian plane "Tavoliere" (south Italy), is a silty-clay Vertisol of alluvial origin, classified as Fine, Mesic, Typic Chromoxerert by Soil Taxonomy-USDA. The climatic conditions were those of a typical Mediterranean environment characterized by the presence of a dry season between May and September and the possibility of cold return in the spring months (March-April) [14]. On the basis of 52 years climatic data, the mean temperature can vary from -8°C in winter to 35.5°C in summer, while the annual average rainfall can range from 272 to 786 mm.

The site was tilled for sowing by plowing to 30-35 cm depth, during late summer in 2006 and by disk harrowing to prepare seedbed. The nitrogen fertilizer (90 kg N ha^{-1}) was applied in two times: 1/3 N, as diammonium phosphate, before sowing and 2/3 N, as ammonium nitrate, at the tillering, corresponding to Stage 20 of the Zadoks scale [15].

Sampling Scheme and Data Collection: One hundred georeferenced locations were selected within the field. Total number of samples was dictated by financial constraints and considerations on the precision of estimation: approximately 10 samples per hectare were deemed acceptable. The locations of the samples were chosen so that they evenly covered the field by using a modified version of spatial simulated annealing [8].

The field was harvested mechanically in July and grain yield (t ha^{-1}) was normalized at 13% moisture content. Geographical coordinates for each yield measurement were determined with a differentially corrected (OMNISTAR signal) Trimble 132 receiver with meter accuracy. The yield data were 'cleaned' by removing data points differing from mean more than 2.5 standard deviations before analyzing them geostatistically.

The following semolina quality parameters were determined in the 100 locations: protein content (PC; % dry matter of the kernels) after multiplying Kjeldhal grain nitrogen content by 5.7 [16]; dough strength (W; $Jx10^{-4}$) and tenacity/extensibility (P/L) ratio by a Chopin's alveograph, using the standard alveographic procedure [17].

Statistical Analysis: Geostatistical analyses were performed for each of the measured variable. The yield was submitted to univariate analysis whereas for quality parameters a multivariate analysis was preferred. All data were interpolated at the nodes of a 1 x 1 m grid using cokriging or kriging.

Multivariate spatial data set was analyzed by Factorial co-Kriging Analysis (FKA), a geostatistical method developed by Matheron [18]. The three basic steps of FKA are the following:

- Modelling the coregionalization of the set of variables, using the so called Linear Model of Coregionalization;
- Analyzing the correlation structure between the variables, by applying Principal Component Analysis at each spatial scale;
- Cokriging specific factors at each characteristic spatial scale and mapping them.

The geostatistical analyses were performed with ISATIS [19].

Table 1 (a): Descriptive statistics of the three commercial and technological semolina quality parameters

VARIABLE	Min	Max	Mean	Std. Dev.	CV	Skewness	Kurtosis
PC (% d.m.)	8.80	17.39	11.57	1.76	0.15	0.95	3.97
W ($Jx10^{-4}$)	56.00	241.00	130.78	38.06	0.29	0.50	2.79
P/L	1.07	3.10	2.14	0.38	0.18	0.15	3.04

PC = protein content; W = dough strength; P/L = tenacity/extensibility ratio

Table 1 (b): Correlation matrix between protein content, dough strength and tenacity/extensibility ratio

	PC	W	P/L
PC	1.00	0.74[a]	0.09[b]
W	0.74[a]	1.00	0.19[b]
P/L	0.09[b]	0.19[b]	1.00

a = significant at the probability level p< 0.01; b = not significant

RESULTS AND DISCUSSION

The descriptive statistics of the three quality parameters analyzed are summarized in Table 1(a), which shows a sensible variability within the field, as it results from the CV values. In particular, it can be observed a substantial variation in W, ranging from 56.00 to 241.00 $Jx10^{-4}$, i.e. from low to medium quality values. The mean value of P/L (2.14) was typical of a high quality wheat [20], but it corresponded to a low mean protein content (<13%), which seems a likely explanation of low extensible dough as suggested by Dexter *et al*. [21]. Furthermore, P/L did not show sensible departure from Gaussian distribution, differently from the other variables whose distributions were generally positively skewed.

The correlation matrix between PC, W and P/L shows a strong and positive correlation between PC and W but no among these latter and P/L (Table 1(b)). These results led us to use a multivariate analysis.

The Factorial co-Kriging procedure obtained two significant regionalized factors: F1 positively correlated with W and PC and F2 negatively correlated with P/L. The map of F1 showed a central-north part in the field characterized by the highest values (Fig. 1a), whereas the map of F2 showed higher values in the central-south zone (Fig. 1b). The field can then be divided with good approximation into two main areas: the northern and southern parts characterized by lower grain quality (despite some "hot" spots) and the central zone of the field with generally higher values.

Fig. 2 shows the map of the estimated yield varying from 0.90 to 2.24 Mg (tonnes) per hectare. The overall low productivity level was probably due to the scarce growing season precipitation, equal to 404.20 mm.

The yield map can be compared with the factors ones. The visual assessment of the yield map displayed the lowest yielding areas at north-west and in the central zone, where the protein concentration was higher.

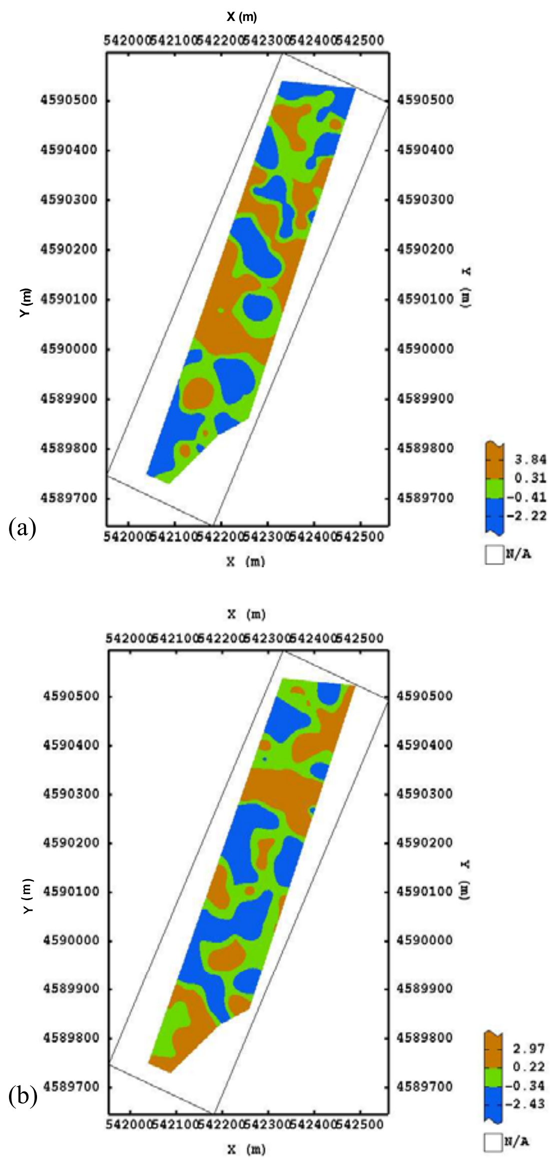

Fig. 1: Maps of the two regionalized factors produced using the Factorial co-Kriging procedure: F1 (a) and F2 (b)

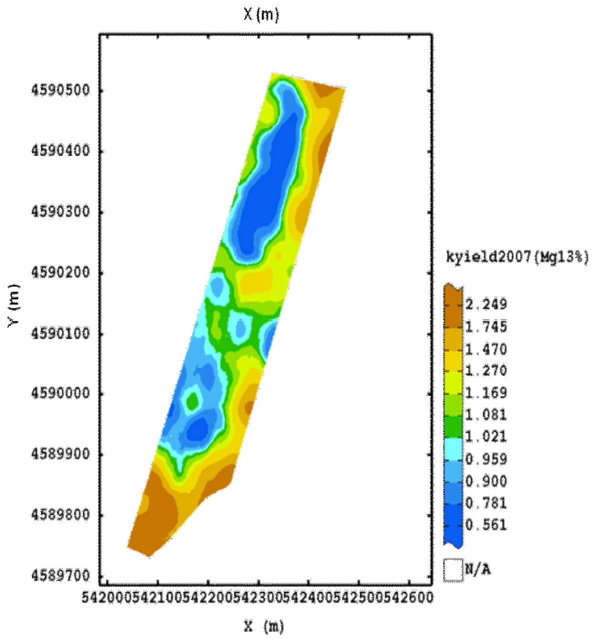

Fig. 2: Spatial map of wheat grain yield at 13% moisture content (Mg ha^{-1})

The results confirmed the known inverse relation between wheat quality parameters and grain yield, also reported by Montemurro *et al*. [22].

An advantage of such delineation of homogeneous subfield areas consists in producing lots of different grain quality. The topic has been discussed by Stewart *et al*. [7], who observed that a possibility for the use of protein mapping is the segregation of the crop during harvest into various grades to take advantage of the higher areas of protein. Such separation of grains into different fractions of specific qualities could be achieved by harvesting by homogeneous zones or with specific on-line sensors [23, 24].

The separation of different qualities can create incentives for producing higher quality on heterogeneous fields and could obtain uniform grain lots to be sent to the pasta industries. However, many trial years may be needed to define stable homogeneous zones in terms of grain quality.

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