Delineation of management zones in an apple orchard: correlations between yield and soil properties

Katerina Aggelopoulou and Theofanis Gemtos

University of Thessaly, Department of Crop Production and Rural Environment, Fytoko Str., N. Ionia, Magnesia 38446, Greece
E-mail: aggelop@agr.uth.gr

Abstract: In the present paper the yield and soil spatial variability in an apple orchard was studied. Apples were collected manually and placed in plastic bins along the tree rows. Yield per ten trees was weighted and the geographical position in the centre of the ten trees was recorded, using a GPS, in order to create the yield map. The orchard was divided in management zones with the Management Zone Analyst (MZA) software, based on the yield map. In each zone soil samples were taken and analysed for the following characteristics: soil texture (% sand, % silt and % clay), pH, nitrogen (N), phosphorus (P), potassium (K), calcium carbonate ($CaCO_3$) and organic matter (OM) content. The correlation between yield and soil properties was performed in all zones. The results showed significant variability in yield and some soil properties. Yield was negatively correlated with pH, clay, organic matter, and $CaCO_3$.

Keywords: precision agriculture, management zones, apples

1 Introduction

Precision Agriculture is the management of crop and soil variability in order to increase profitability and reduce adverse environmental impact (Earl et al., 1996). Precision Agriculture has mainly focused in arable crops like cereals (Blackmore et al, 2003; Godwin et al, 2003), soybean (Dobermann and Ping, 2004) and cotton (Velidis et al., 2003; Gemtos et al, 2004). However, the opportunities to apply Precision Agriculture in high value crops, such as fruits, are very promising due to the fact that it is easier to pay the investment. Moreover field patterns (spatial and temporal trends) tend to be more stable in perennial than annual crops, which can facilitate the management of fields according to fixed management zones over time. Some of the applications in high value crops are in citrus (Zaman and Schuman, 2006, Mann et al, 2011), in olives (Granados et al., 2004, , Fountas et al, 2011), in apples (Aggelopoulou et al, 2010, Aggelopoulou et al, 2011a, Aggelopoulou et al, 2011b), in grapes (Bramley and Hamilton 2004; Tagarakis et al, 2006), in pears (Perry et al, 2010), in palm trees (Mazloumzadeh et al, 2009), in berries (Zaman et al, 2008) and in peaches (Ampatzidis et al, 2009).

The most common method to manage field variability is the use of management zones. Management zones are regions or areas of the field which have been

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differentiated from the rest of the field for the purpose of receiving individual management attention. Each zone gets the appropriate level of inputs (seed, fertilizers, pesticides, water) according to the plant requirements. Management zones are usually defined on the basis of soil (Fraisse et al, 2001; Taylor et al, 2003; Vrindts et al, 2005) and yield (Diker et al, 2004; Ping & Dobermann, 2005) information over several years. Other researchers have used aerial images, vegetation indices and combination of yield soil and remote sensing data to create management zones. Boydell and McBratney, (2002) used aerial images of the developing crop to delineate management zones in cotton. In citrus crop, Zaman and Schumann (2006) created nutrient management zones based on variation of soil properties and tree performance, while Mann et al (2010), produced productivity zones using fruit yield, ultrasonically measured tree canopy volume, normalized difference vegetation index (NDVI), elevation and electrical conductivity. In olive trees, Granados et al. (2004), created site-specific fertilization maps based on leaf nutrient spatial variability and Fountas et al. (2011), created management zones for fertilizers, using soil chemical properties. Aggelopoulou et al. (2011a), produced fertilization maps for apple trees based on the amount of nutrients that were removed from the soil with the previous year's yield.

The objectives of this paper were (i) to study spatial variability of yield and soil properties in an apple orchard, (ii) to delineate management zones in the orchard, based on yield variability and (iii) to correlate yield and soil properties in each management zone.

2 Materials and Methods

The present study was carried out in a 5 ha commercial apple orchard for the year 2005. The orchard was located in Agia area, Central Greece (22^o 35΄41΄΄ E, 39^o 40΄28΄΄ N and 160m elevation). The main cultivar was Red Chief and the pollinator was Golden Delicious. The tree spacing was 3.5m between the rows and 2m in the row. Trees were trained as free palmette.

For yield mapping apples were collected manually in September and placed in plastic bins. Yield per ten trees was weighted and the geographical position in the centre of the ten trees was recorded using a hand-held computer with GPS (Trimble pathfinder). The yield map was created only for the main cultivar (Red Chief).

In December twenty soil samples were taken before winter crop fertilization to a sampling depth of 0-30 cm in order to explore the variability of some soil physical and chemical properties. The samples were air-dried and passed through a 2mm sieve and analysed for the following properties: soil texture (% sand, % silt and % clay), pH, nitrogen (N), phosphorus (P), potassium (K), $CaCO_3$ and organic matter (OM) concentration. The sampling positions were geo-referenced using a hand-held computer with GPS.

The delineation of management zones in the orchard was performed using Management Zone Analyst (MZA) software with the fuzzy clustering method (Fridgen et al., 2004). Management Zone Analyst calculates descriptive statistics, performs the unsupervised fuzzy classification procedure for a range of cluster numbers, and provides the user with two performance indices [fuzziness performance index (FPI) and normalized classification entropy (NCE)] to aid in deciding how many clusters are most appropriate for creating management zones. The optimum number of zones is when FPI and NCE have the lower values (Fridgen et al, 2004).

3 Results and Discussion

From the yield map (Fig 1) it can be seen that yield ranged from 0-91.2 ton/ha. Yield spatial variability was significant (the coefficient of variation was about 51%). The coefficient of variation, which is the ratio of the standard deviation divided by the mean, is a measure of the spatial variability. In this orchard there was a high yielding zone in the central part of the field while there were two zones with lower yield in the left and the right of the high yielding zone.

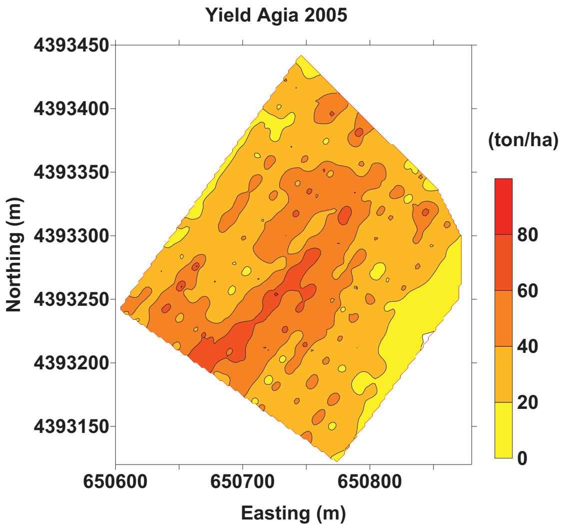

Figure 1. Yield map of the orchard for year 2005 (Red Chief cultivar)

The descriptive statistics (average, minimum, maximum and coefficient of variation (CV)) of the soil properties are presented in Table 1. Soil texture was sandy clay loam. Soil pH ranged from 6.9-8.1. The optimum for apple trees is from 6.5 to 6.8 (Vasilakakis, 2004). The organic matter content was from 1.1 to 3.2 and it was moderate (Koukoulakis, 1995). Soil variability was small for texture, pH, $CaCO_3$ (CVs from 3.7-21.9%) , moderate for organic matter, N, K (CVs from 28.6-52.7%) and high for P(CV=76.9%).

The calculation of the FPI and NCE indices was performed for a number of zones form 2-8 (Table 2). The results showed that the lower values of the FPI and NCE were for 6-7 zones, and therefore the optimum number of zones for this orchard was six to seven. The orchard was divided in six management zones, which is a number that the farmer can handle (Fig 3). In each zone the average values of yield and soil properties were calculated (Table3). Linear correlation between yield and the soil properties was performed in each zone. It was assumed that liner correlation was suitable for yield and soil data as many researchers use this method for this kind of data in the orchards (e.g. Zaman and Schuman, 2006).

Table1. Descriptive statistics of the soil properties

Soil property	Average	Min	Max	CV(%)
Sand(%)	59.5	51.7	65.6	6.9
Clay (%)	23.5	15.1	31.3	19.4
Silt (%)	17	13.3	21.8	13.8
pH	7.6	6.9	8.1	3.7
$CaCO_3$(%)	15.1	11.8	24	21.9
NO_3(mg kg^{-1})	4	0	8.9	70
P(mg kg^{-1})	2.9	0.5	9.2	76.9
K(mg kg^{-1})	179.6	60.4	354.8	52.7
Ca(mg kg^{-1})	295.1	125	492	31.8
Mg(mg kg^{-1})	212.2	104	298	28.2
Fe(mg kg^{-1})	9.8	2.8	35.3	84.1
Na(mg kg^{-1})	124.7	18	323	54.4
Zn(mg kg^{-1})	1.3	0.81	2.71	43.3
Mn(mg kg^{-1})	4.5	1.4	9	50.2
Cu(mg kg^{-1})	0.6	0.1	2.9	103
OM(%)	1.9	1.1	3.2	28.6

Table 2. FPI and NCE indices for a number of classes 2 to 8.

Classes	FPI	NCE
2	0.0399	0.0152
3	0.0319	0.017
4	0.0268	0.0159
5	0.0251	0.0154
6	0.0219	0.136
7	0.0181	0.0127
8	0.0276	0.0173

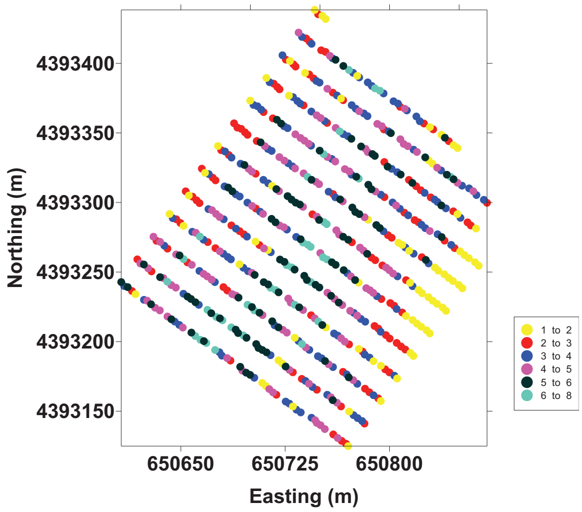

Figure 3. Map of the orchard showing six management zones based on yield

Table 3. Average values for yield and soil properties in each of the six management zones

Zone	1	2	3	4	5	6
Yield	1.1	2.24	3.28	4.34	5.52	7.3
pH	7.67	7.82	7.75	7.47	7.56	7.57
K	211	136	204	214	168	121
Na	106	144	119	137	121	109
Mg	249	197	199	242	208	145
Ca	284	318	366	361	215	156
Cu	0.37	1.11	0.35	0.70	0.73	0.34
Zn	1.5	0.89	1.08	1.63	1.67	1.2
Mn	5.13	3.78	5.65	4.9	3.8	2.5
Fe	8.9	4.6	9.4	14	12.7	8.9
NO_3	2.2	5.5	5.2	3.8	4.4	4.6
P	4.9	4.2	1.9	1.5	2.9	1.1
Clay	27.3	23.4	26.8	21.4	20.9	18.5
Sand	55.9	61.2	57.9	59.4	61.1	60.9
Silt	16.8	15.3	15.3	19.1	18	20.6
OM	2.3	1.9	2.1	1.8	1.7	1.6
$CaCO_3$	16.1	17.5	15	13.8	14.4	12.6

In the six zones that were created with the MZA software, yield was negatively correlated with pH with a coefficient of correlation r= -0.62 which was not statistical significant. The negative correlation between yield and soil pH was probably due to the fact that soil pH ranged from 6.9-8.1 (alkaline region) when the optimum for apples is

6.5-6.8 (Vasilakakis, 2004). Yield was also negatively correlated with $CaCO_3$, with r= -0.88, which was statistical significant at p=0.05, probably for the same reason because $CaCO_3$ rises soil pH.
Yield was negatively correlated with clay content (r=-089) and organic matter (r=-0.85). Both the correlation coefficients were statistical significant at p=0.05. The negative correlation between yield, organic matter and clay content is probably due to the fact that both organic matter and clay release nitrogen in the soil which enhances vegetative growth, that is competing yield (Stylianidis, 2002).

4 Conclusions

From the results of the presented experimental data it can be concluded that:

1. The orchard showed significant spatial variability in yield and soil properties, which indicates the potential of applying site-specific managements in this orchard according to the needs of the trees.
2. Yield variability was high with a coefficient of variation about 50%. Soil variability was different depending on the soil property. Soil texture, pH, and $CaCO_3$ showed small variability, organic matter, N, and K exhibited moderate variability and P showed high variability
3. Yield was negatively correlated with pH, clay, organic matter, and $CaCO_3$.

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