Spatial and Temporal Variation in an Apple Orchard

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Abstract. One important goal of precision horticulture (PH), as well as precision agriculture (PA), is to measure and manage spatial and temporal variation in orchards. In this study, temporal and spatial analysis of yields were carried out over 2 years for a 0.5-ha apple orchard (at the Haymana Research Station of Ankara University, Turkey, from 2017 to 2018) to determine the variability of yields over time and included seven apple varieties: ‘Royal Gala’, ‘Red Chief’, ‘Braeburn’, ‘Mondial Gala’, ‘Jonagold’, ‘Fuji’, and ‘Mitch Gala’. To achieve this, yield data for two different years were analyzed for mean yield, temporal variance, and cv in terms of spatial and temporal stability, and their yield maps were produced. The results showed that ‘Jonagold’, ‘Braeburn’, and ‘Red Chief’ varieties yielded less than the average yield, whereas the other varieties produced average yields when the yield from 2 years was taken into account. Calculation of the values for determining temporal stability over time resulted in all existing varieties being identified as stable over time. For example, the ‘Jonagold’ and ‘Red Chief’ varieties showed 100% stability in terms of temporal variance. Results also showed that the ‘Gala’ varieties were stable for 2 years and produced high yields, whereas the other varieties were specified as stable and low yielding when spatial and temporal variability was considered in combination.

PA is an agricultural production system to optimize production efficiency through the application of crop information, technology, and management practices. To achieve this, PA must begin at the planning stage of crops through to the harvest and postharvest processing production stage. So, collecting data at every phase of production is known to be an important factor for each production process. Among these data, getting spatial and temporal information on the crops, soils, disease, and weather conditions during the production season is necessary (Roberson, 2000).

With the increasing use of PA processes in agricultural crop production, use of these processes for horticulture crops has shown significant progress. Most of the PA studies have concentrated on arable crops such as grain production (Türker et al., 2011). However, PH and spatial analysis applied to orchards are an increasing growing and evolving part of PA technology (Luigi, 2009).

The advantages seen with PH offer the same benefits: increasing production efficiency to match inputs to targets, reducing the environmental impact by linking inputs to objectives, predicting the yield and quality for entire orchards, and managing variations. To manage spatial and temporal variation, it

is necessary to map yields for each tree in an orchard and use these data to determine the cause of variability in the orchard, and also optimize input applications on a site-specific basis (Brown and Rosenstock, 2006).

Initial investigations have been carried out on high-value horticultural crops such as citrus, olives, apples, grapes, cranberries, and tomatoes. In some of these studies, detailed analyses of yield, soil, quality, and the relationships among them were performed before the transition from conventional farming practices to PA (Aggelopoulou et al., 2010). For instance, in a study by Shamsi and Mazlounzadeh (2009), spatial treatment by PA in the production of a date palm orchard was evaluated. Spatial yield maps produced in that study showed the weak points to be managed included an extra number of male trees, the location of low-production trees, and the health of the trees.

In another study, Aggelopoulou et al. (2010) produced yield and quality maps for an apple orchard and determined the opportunities for PA management. In their study, the yield maps of two apple varieties, ‘Red Chief’ and ‘Fuji’, were produced, and significant spatial and temporal variability was found in both yield and fruit quality.

Seavert et al. (2005) measured per-tree yield variability in a highly productive pear orchard using site-specific management procedures and estimated the variability of profit per tree yield. Rey Pedro (1995) determined the spatial and temporal variability of olive trees to find the relationship between olive

availability and the abundance of frugivorous birds in the orchard. The result showed positive spatial and temporal associations between the two parameters.

Blackmore et al. (2003) carried out a quantitative analysis of yield data to determine spatial and temporal trends. To achieve this purpose, overall differences in yield between one year and the next were identified. Also, the amount of change at a particular point over time was shown as a temporal variance.

In our study, the aim was to determine the yield variability via temporal and spatial analysis of yield over two seasons for seven different apple varieties in the orchard, and then produce a yield variability map to show the stable and unstable parts of the orchard for varieties over time.

Material and Methods

Site description. The study was conducted in 0.5 ha of an apple orchard at Ankara University Research Station, ≈50 km from Ankara city center (Universal Transverse Mercator zone 36, lat. 4384978 N, long. 4737222 E). The orchard was planted in 2003 and included seven apple varieties: ‘Royal Gala’, ‘Red Chief’, ‘Braeburn’, ‘Mondial Gala’, ‘Jonagold’, ‘Fuji’, and ‘Mitch Gala’. Each variety was planted in three 3-m rows, with 38 trees in each row and 1.5 m between the rows (Fig. 1). The soil survey for the orchard showed that it was composed of clay. Two hundred ten sampling points were selected to get yield data using ≈30 points for each variety.

Data collection and map production. Before the 2017 and 2018 harvest seasons, the location of the trees was determined and plotted on an xy coordinate system. Then, 10 trees were selected in each row and their crops were harvested for apple yield data on an individual tree basis to monitor yield variability. Each tree was harvested, and fruit was gathered into individual bins. The bins were weighed and recorded to produce precise yield maps. To create yield maps, the predetermined coordinates of each sample tree—produced by a GPS receiver (Magellan SporTrak Color; Thales Navigation, San Dimas, CA; accuracy, ±50 cm)—were converted to xyz files using Excel software. Then, the two sets of data (for 2017 and 2018) were converted to maps using Surfer® 8 from Golden Software, LLC. All the classical statistics related to the study were also extracted by Surfer® 8.

Spatial variability. Yield maps show yield variability for the 2 years separately, but to identify a high- or low-yielding area of the orchard over 2 years, the spatial trend map for the yield is needed. Because the horticulture crop position does not change over the years, it was assumed that there were single crops in the field. We used a methodology described by Blackmore (2000) to produce the spatial trend map for a single crop. The mean and variance at each point in the orchard was found over the 2 years and was summarized as follows:

Fig. 1. Position of sampling points (left) and a small part of the orchard (right).

Table 1. Descriptive statistics value for all varieties.

Variety	Yr	Min (kg/tree)	Max (kg/tree)	Mean (kg/tree)	Variance	SD	CV (%)
Mitch Gala	2017	12.4	37.82	22.14	32.92	5.73	25.91
	2018	4.1	51.5	21.7	135.65	11.65	53.66
	Total	10.67	43.82	21.92	52.85	7.27	33.16
Fuji	2017	5.61	26.2	12	24.83	4.98	41.53
	2018	8	32.9	17.02	43.54	6.6	37.45
	Total	9.49	29.55	14.80	21.25	4.61	31.13
Jonagold	2017	4.31	9.93	7.31	2.08	1.44	19.73
	2018	2.2	26.8	13.54	31.92	5.65	41.73
	Total	4.41	17.64	10.42	9.06	3.01	28.9
Mondial Gala	2017	2.3	11.51	8.04	7.08	2.66	33.10
	2018	5.3	42.2	26.88	107.37	10.36	38.55
	Total	5.52	26.85	17.46	32	5.66	32.4
Braeburn	2017	1.31	16.94	6.8	14.73	3.84	56.46
	2018	7.9	28.9	15.02	26.97	5.19	33.25
	Total	7.12	22.92	11.21	11	3.32	29.6
Red Chief	2017	0.45	13.62	6.57	16.18	4.02	61.23
	2018	1.5	18.4	9.99	15.9	3.99	39.93
	Total	3.35	14.68	8.28	8.92	2.99	36.1
Royal Gala	2017	3.38	36.85	13.51	62.5	7.91	58.51
	2018	1.5	48.2	26	140.8	11.87	45.65
	Total	7.49	30.67	19.75	37.65	6.13	31.06
Total	2017	0.45	37.82	10.74	48.67	6.97	64.93
	2018	1.5	51.5	18.73	105.7	10.28	54.89
	Total	3.35	43.82	14.74	46.25	6.8	46.25

Fig. 2. Yield of sampling points in ascending order.

$$\bar{y}_i = \frac{\sum_{t=1}^n y_{ti}}{n}, \quad (1)$$

where $\bar{y}_i$ is the mean of y_i (both measured in kilograms per tree), the interpolated yield at point i over n years. After calculating $\bar{y}_i$, the spatial trend map was produced based on the mean yield per tree over 2 years.

Temporal stability. Temporal variance, as suggested by McBratney and Whelan (1999), shows effects over time. With this approach, it is possible to identify which part of the orchard has a relatively high yield one year and a relatively low yield in another year, when compared with the mean (Blackmore et al., 2003). Using this approach, the variance between 2 years over all points in the orchard was calculated as follows:

$$\sigma_i^2 = \frac{\sum_{t=1}^n \frac{1}{2} (Y_{2,t} - Y_{1,t})^2}{n}, \quad (2)$$

where σ_i^2 is the temporal variance in year t , Y is the yield at a point i in year 1 and year 2, and n is the number of points in the field.

This technique gives a single number, and this single number cannot be used to measure the temporal variance. To resolve this issue, another definition of temporal variance was proposed by Blackmore et al. (2003). The value of this method shows the variance from the mean over time:

$$\sigma_i^2 = \frac{\sum_{t=2017}^{2018} (Y_{t,i} - \bar{Y}_i)^2}{2}, \quad (3)$$

where σ_i^2 is the temporal variance at point i , t is the time in years between 2017 and 2018, Y is the yield in year t at point i , and $\bar{Y}$ is the mean of the yield for the whole field in year t .

This definition of temporal variance determines a low value if an area of the field always has a yield close to the mean. This is considered *stable in time* because it has a low temporal variance. If another area has a yield that is high sometimes and low at other times relative to the mean, it would be unstable temporally and has a high temporal variance value (Blackmore et al., 2003). It should be noted that temporal variances were calculated separately based on the mean for each variety.

Furthermore, by calculating the cv at each point, maps can be produced that indicate how much the yield varied at a single point over time. The cv recommended by Blackmore et al. (2003) is calculated for a single crop as follows:

$$CV_i = \frac{\left(\frac{n \sum_{t=1}^n y_{ti}^2 - \left(\sum_{t=1}^n y_{ti} \right)^2}{n(n-1)} \right)^{0.5}}{\bar{y}_i}, \quad (4)$$

where cv_i is the cv at point i over n years.

As mentioned in the previous method for investigating temporal variability, the temporal cv was calculated based on the mean value for each variety.

Fig. 3. Yield map for 2017 (1), yield map for 2018 (2), and spatial average map (3).

Results and Discussion

Descriptive statistics and statistical analysis results of yield are presented in Table 1 for seven varieties of apples ('Mitch Gala', 'Fuji', 'Jonagold', 'Mondial Gala', 'Braeburn', 'Red Chief', and 'Royal Gala') using 2 years of yield data from the orchard.

'Mitch Gala' and 'Red Chief' varieties were determined to be high- and low-yielding varieties in 2017, respectively, in terms of the means of their yields, whereas the 'Mondial Gala' and 'Red Chief' varieties were specified as high- and low-yielding varieties in 2018, respectively. Regarding the average yield over two seasons, the high- and low-yielding varieties were 'Mitch Gala' and 'Red Chief', respectively.

According to the results, when considering the cv, 'Jonagold' (at 19.73%) experienced the minimum change in yield distribution among all the varieties with respect to the mean of 2-year data. The minimum calculated values for cv percentage in 2017 and 2018 were produced by the 'Jonagold' and 'Braeburn' varieties, respectively.

Table 2. Percentage of yield within the different classes of yield.

Variety	RLY (%)	BA (%)	A (%)	AA (%)	RHY (%)
Mitch Gala	0	29.6	48.1	18.5	3.8
Fuji	0	80	16.7	3.3	0
Jonagold	37.9	62.1	0	0	0
Mondial Gala	13.3	33.3	53.4	0	0
Braeburn	22.6	74.2	3.2	0	0
Red Chief	63.3	36.7	0	0	0
Royal Gala	6.7	26.7	53.3	13.3	0
Total	20.8	49.3	24.6	4.8	0.5

RLY = relatively low yielding; BA = below average; A = average; AA = above average; RHY = relatively high yielding.

Also, regarding the curves drawn in Fig. 2, based on arranging the yield data in ascending order, a considerable increase is seen in 2018 compared with 2017. From these curves, in consideration of the classical statistics table, the greatest yield in 2017 and 2018 is related to a variety of 'Mitch Gala', whereas the lowest yield belongs to a variety of 'Red Chief' for both years.

By comparing the entire orchard data as a total over the years studied, it was found that

despite the high yield in 2018 in terms of mean yield compared with 2017, if the high sd and low cv values are considered, it can be concluded that the orchard had more spatial variability in 2018 than the previous year.

Assuming the orchard was a single crop in the field, the mean yield for each variety at each tree point was calculated and a map was produced using five categories to classify the 2-year average yield. The five tree-average groups were defined to be: relatively

Fig. 4. Yield classes in terms of varieties (upper) and total yield (lower).

Fig. 5. Temporal variability map.

Table 3. Statistics about the stability rate of apple varieties based on temporal variance.

Variety	Temporal variance				
	Stable	Lower moderate	Moderate	Upper moderate	Unstable
Mitch Gala	74.1	25.9	0	0	0
Fuji	93.3	6.7	0	0	0
Jonagold	100	0	0	0	0
Mondial Gala	80	16.7	3.3	0	0
Braeburn	96.8	3.2	0	0	0
Red Chief	100	0	0	0	0
Royal Gala	63.3	20	16.7	0	0
Total	87	10	3	0	0

high-yield (RHY; 36–45 kg/tree) area, above-average (27–36 kg/tree) area, average (18–27 kg/tree) area, below-average (BA; 9–18 kg/tree) area, and relatively low-yield (RLY, 0–9 kg/tree) area. All the maps for 2017 and 2018, and the spatial average map are presented in Fig. 3.

By considering the total number of all existing varieties (as shown in Table 2), it can be concluded that more than half the yield is situated in an RLY area, whereas the remaining yields are located either side of the average value (no significant tree numbers were found in RHY areas).

Regarding the five classifications for each variety, it can be concluded that most of the 'Mitch Gala' trees were equally situated on either side of the average, but the 'Red Chief', 'Jonagold', and 'Braeburn' varieties were shown to have significant points in RLY and BA areas, whereas about half the remaining varieties were in BA areas. Figure 4 shows the diagram of point (tree) numbers for different varieties and the total number of points (trees) situated in quintuplet intervals.

To determine temporal variability for the whole orchard, a temporal variability map (Fig. 5) was produced. For this purpose, temporal variance values were calculated for each point and divided into five classifications to identify the most stable and unstable areas and varieties.

The values of temporal variance changed from 0.11 to 542, so the range of each class was chosen between 0 to 550 kg/tree, with an interval of 110 kg/tree. The values from 0 to 110 were considered as a stable point over 2 years, whereas the values from 440 to 550 were considered as an unstable point for these years.

As can be deduced from the temporal variance map in Fig. 5, all existing varieties were situated in a stable area. 'Jonagold' and 'Red Chief' varieties were found to be 100% stable. Statistics about the stability of different apple varieties are listed in Table 3. Considering the numbers in this table and the numbers related to the total orchard, a major part of the orchard was in a stable area, which is obvious from Table 3. A diagram of the distribution of points (trees) in the five areas related to the varieties and based on calculated temporal variance is given in Fig. 6.

Furthermore, by calculating temporal sd and specifying a particular threshold value, the sensitivity of temporal stability can be determined for each variety (Blackmore et al., 2003). Figure 7 gives the frequency histograms of the stability level for each variety. The curves in this figure show the cumulative percentage of points on the y-axis; the x-axis shows the temporal sd divided into 10 classes from 0 to 24 kg/tree.

According to this Fig. 7, and selecting the value of 10 kg/tree for temporal sd, the 'Red Chief' variety is more stable than the other varieties and has the least points affected by temporal variability, whereas 'Royal Gala' has the least stability among all the varieties. These results supported the interpolation of the temporal variance map.

Fig. 6. Yield distribution for different varieties in the orchard.

Fig. 7. Frequency histograms of the stability levels.

Fig. 8. Temporal cv map.

Another parameter that shows temporal stability is the cv, as described in the Materials and Method section. So, the maps of the cv (Fig. 8) were produced based on calculating this value for each sampling point (tree). The value obtained was divided into five classes with the limits of the value ranging from 0% to 130%. The five classes on this map—as well as the temporal variance map—were called stable, lower moderate, moderate, upper moderate, and unstable.

According to the map produced, and the cv percentage for each variety in Table 4, it can be concluded that a significant portion of 'Mitch Gala', 'Fuji', and 'Jonagold' were in stable and lower moderate areas, whereas more than 50% of points related to the 'Mondial Gala' variety were in the upper moderate area. Figure 9 shows the stability (cv) distribution for each variety point in the areas.

Useful information can be derived to make management decisions by producing spatial and temporal variation maps. The preparation and interpretation of spatial variability maps associated with crop yield in the orchard, and the identification and classification of the areas of low and high yield can be used to increase the production efficiency by eliminating the causes of yield loss. Also, besides introducing a decision-making guide to manage the orchard, the determination of temporal variability over time can identify some limitations, such as weather conditions and their effect on crop yield. It should be mentioned that the decision-making guide would benefit if the necessary information was collected in subsequent years.

In this experiment, low- and high-yielding areas, and information about production efficiency for each apple variety, were identified by using the mean yield map over 2 years. As can be deduced from the spatial variability in 2017 and 2018 (Fig. 3), the distribution of yield in individual years was significantly different. So, the 'Mondial Gala' variety was appreciably different in the two individual years compared with other varieties, whereas the 'Mitch Gala' variety did not show any significant differences over time in terms of mean yield. According to the study carried out by Aggelopoulou et al. (2010), the 'Fuji' variety had different spatial distribution over two consecutive years; however, this variety did not have any differences in spatial distribution based on the calculation using the cv as the sd per mean in our study.

Assuming a similar treatment and fertilizing schedule over 2 years for all varieties, and regarding bad weather conditions as a yield reduction factor—especially during the 2017 season—it can be said that, in comparison with other varieties, the extended 'Gala' varieties are much more productive in the amount of yield according to the calculated mean values, which were greater than the others. On the other hand, the 'Red Chief' variety achieved the least yield over 2 years.

According to the temporal variability maps produced, stable and unstable areas of the orchard over 2 years were identified. As a

Table 4. Stability percentage (cv) for each variety.

Variety	cv (%)				
	Stable	Lower moderate	Moderate	Upper moderate	Unstable
Mitch Gala	33.3	40.7	11.1	14.9	0
Fuji	50	26.7	16.7	6.6	0
Jonagold	31	31	31	7	0
Mondial Gala	13.3	6.6	30	33.3	16.8
Braeburn	22.6	25.8	19.3	22.6	9.7
Red Chief	33.3	16.7	13.3	16.7	20
Royal Gala	10	36.7	13.3	23.3	16.7
Total	27.5	26	19.3	17.9	9.3

Fig. 9. Points from each variety in terms of their cv.

result of temporal variance calculations and the related map, the most stable varieties over the years were the 'Jonagold' and 'Red Chief' types, demonstrating 100% stability, which is supported by the temporal variance map in Fig. 5. Besides the results of temporal variance, calculation of the cv for these years, despite the dissimilarity of the two maps, showed that the calculated values supported the fact that most of the varieties were in a lower moderate zone of stability.

From a combination of spatial and temporal variation and all the calculated values, the following combinations can be deduced (Blackmore et al., 2003): low yield and stable area, low yield and unstable area, high yield and stable area, high yield and unstable area. Given these possible combinations, it can be deduced that the 'Gala' varieties occupied the areas of high yield and stability; the others

were in low-yield and stable areas during the trial.

Conclusions

In our study, spatial and temporal variability in a small apple orchard was determined using different methods. The mean values of yield and the corresponding maps were used to show the high- and low-yielding areas in two individual years, as well as the production efficiencies for each variety. Calculation of temporal variance and the cv for 2 years was also used to determine variability over time. Furthermore, using sd values for 2 years helped to specify varieties by stability.

From the results of the study, it was concluded that 1) distribution in yield for each year was significant and the 'Royal Gala' variety

showed the most variability; 2) determination of temporal stability in terms of temporal variance showed there is no significant variability over time, so all varieties were in stable areas; and 3) calculation of the cv confirmed that all varieties were situated in areas with lower than moderate values. Using sd values over 2 years helped to specify varieties in terms of stability.

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