EXPERIENCES WITH SPATIAL VARIATION OF YIELD AND FRUIT COMPOSITION IN PREMIUM VINIFERA VINEYARDS IN NIAGARA

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Theory and background

Sampling a vineyard to estimate yield and fruit composition is a basic required skill for all vineyard mangers and winemakers. It may seem like an easy task, and if done improperly, it probably is. To sample properly, it requires time, skill, and knowledge. Let's set aside the time component, and focus upon the skill and knowledge components.

First, let's consider an average Chardonnay or Riesling vineyard in the Finger Lakes or the Niagara Peninsula. Chances are, the vines are spaced about 4.5 feet apart and the rows are about 8 ft. wide. That leaves us with about 1200 vines per acre. Now, each vine is likely producing about 6.5 pounds of fruit with about 30 clusters per vine if the crop size is 4 tons per acre.

Now we need to think a bit more critically. How many clusters do these 4 tons represent? That's easy; actually, it's about 36,000. How about cluster weight, number of berries per cluster, and weight per berry? Well, mean cluster size for Riesling and Chardonnay varies from site to site, and is subject to variation due to vine size, crop load, clone, and other viticultural practices and decisions; however, all said and done, let's assume 110 g is a mean cluster weight. Now, what is the total number of berries per cluster that makes up that 110 g? Data we have collected through the years suggests a range of 70-85, so that makes an average berry weight of about 1.4 g.

All this basic math provides us with a figure of about 2.52 million berries on every acre of Riesling or Chardonnay! How can we possibly do a decent job of sampling for yield, fruit composition, or potential wine quality in order to arrive at an estimate in which we might have confidence?

Sampling for yield

In order to come up with a yield per acre value you need two basic things: 1. Number of clusters per vine, and; 2. Estimated weight per cluster at harvest. You also need to have as accurate a count as possible of the number of vines per acre or per block, and the number that are missing. Start with counting the number of clusters per vine on as many vines per block as you can. To deal with the spatial variability issue, choose several vines (at least 10 vines per acre equivalent) and sample in an "X" configuration from opposing corners across the block. Record the cluster number for every vine.

Next, it is time to estimate cluster weight. To do a decent job sampling for yield it is also very necessary at this point to have a full understanding of how miniscule your cluster sample really is in the whole scheme of things. Counting clusters on 10 vines per acre provides a 0.8% sample size. Collecting one cluster from each of those vines is equivalent to a 0.03% sample. What size of cluster sample will provide you with reliable data, assuming you are taking a sample from a population of 36,000 per acre? The experts have not agreed, other than the more samples, the better. Amerine and Roessler (1958b) suggested 40 clusters per 1000 vines to get a reasonable sample for estimating fruit composition, but they did not speculate whether this was sufficient for estimating yield.

The decision of how many clusters that are sampled must be done in accordance with some of the aforementioned rules: 1. Sample from normal, healthy vines; 2. Take a modal, stratified sample so that the final composite sample represents clusters from all portions of the canopy.

Moreover, WHEN do you sample? We know (Reynolds and Wardle, 1989) that berry weight increases by about another 40 to 50% of final weight from veraison to harvest as a result of cell expansion, provided that no water stress exists. For example, Gewurztraminer berries sampled at veraison weighed 0.7 g each, whereas those at harvest weighed 1.2 g. So, whatever cluster weight value you get from a veraison sampling will need to be adjusted upwards by roughly a factor of 1.7 to 2 to obtain as accurate a cluster weight as possible.

An excellent technical note describes a two-step method for estimating vineyard yields (Wolpert and Vilas 1992). The first step involves determining clusters per vine around bloom when clusters are easily visible. Cluster weights are determined around veraison when their weights have stabilized. The authors provided detailed tables prescribing sample sizes required at varying levels of precision. The general take-home message is that in vineyards with large variations in cluster numbers per vine and/or cluster weights, large sample numbers are required in order to have an error < 5%. The compromise is to accept a higher error rate and as a consequence take smaller samples.

Sampling for basic fruit composition

Just like yield sampling, one again needs to have an understanding of sample size and what it potentially represents. We have literally taken hundreds of berry samples from vineyard blocks < 5 acres in size and what really amazes me is the variability in berry weights, soluble solids, titratable acidity, pH, and other variables despite a rigorous sampling protocol. But, taking one hundred 100-berry samples is only equivalent to about a 0.4 % sample upon which to base a harvest decision.

Obviously this is an issue that has been studied. In 1950's California, Amerine and Roessler (1958a) published work on comparing berry, cluster, and whole vine sampling. Generally, collecting many berry samples gave composition values higher in soluble solids and pH and lower in titratable acidity than either multi-cluster or whole vine samples. They did not mention which method of sampling came closest to the actual values at harvest. A later report suggested that to be within 1 degree Brix, one would need to take two 100-berry samples, four 10-cluster samples, or 11 whole-vine samples per 1000 vines (Amerine & Roessler 1958b). Some follow-up work from this group (Roessler and Amerine 1962) more or less confirmed their previous conclusions, that 100 to 200 berries collected randomly from 1000 vines would give a value $\pm$ 0.6 ^{o}Brix of the value obtained from the load. They did indicate that both berry and cluster sampling gave slightly higher values than the figures from the harvested loads, but that these were less variable than full vine sampling.

In Australia, Rankine et al. (1962) did a detailed study that compared several sampling methods, and concluded generally that berry sampling provided as precise a result as cluster sampling. They addressed a number of issues of importance that are worth repeating here: 1. Greater variability exists in vineyards with immature fruit than those with mature fruit; 2. Spatial variability exists between and within vines, and both between and within clusters; 3. Use of irrigation can increase variability.

More recently, Kasimatis and Vilas (1985) recommended either two 10-cluster samples or two 50-berry samples per vineyard block, but recommended cluster sampling for greater accuracy.

Many of these authors argued against use of multi-cluster or whole vine samples for estimating fruit composition, mainly because of the time and labor cost factor associated with the removal of these large samples from the vineyard, the subsequent sample preparation notwithstanding. Berry sampling was described as being the most convenient and sufficiently accurate, provided that sampling was carried out properly.

Assuming that berry sampling is the method of choice, what is “proper” sampling. The sampler needs to realize that vines differ in terms of vigor and crop size, and hence crop load (crop size: vine size ratio) will therefore differ amongst vines. This will impact rate of soluble solids accumulation; overcropped vines, for instance, may have lower soluble solids on a given date than normally-cropped or under-cropped vines. Degree of fruit exposure plays a major part in determining fruit composition; exposed berries are usually lower in titratable acidity and pH, and higher in anthocyanins, phenols, and terpenes than partially-shaded and fully shaded fruit (Reynolds et al. 1986; Reynolds and Wardle 1989). Moreover, position on the cluster may also play a part; clusters tend to accumulate soluble solids from basal end to distal end, and therefore berries from close to the distal end of the cluster are normally lower in soluble solids than those adjacent to the basal end of the cluster (Wolpert et al. 1983; Wolpert and Howell 1984). Wolpert and Howell (1984) also pointed out that clusters on non-count shoots can provide estimates of soluble solids that may not accurately reflect the population mean.

The implications of this are significant: it suggests that one must take a modal sample from any vineyard block, and must do so with the assurance that berries from all portions of the clusters are obtained. In other words, the berry samples must reflect the crop load and fruit exposure in each block sampled.

Industry practice. A sampling protocol for determining fruit maturity from one Ontario winery.

The winery that I queried contracts several hundred tons of vinifera grapes throughout Niagara. Their procedure is to randomly sample 10 clusters per vineyard block. Rows are chosen randomly; samplers walk down several rows in the block and sample the clusters. Sampling is done at different heights and different levels of exposure (some exposed, some shaded). Samplers are instructed to try to make cluster selection as random as possible, and to not necessarily avoid selecting a cluster because it has some rot, etc. Samplers also do not collect samples from the two end panels or from outside rows. If the block is very large, two 10-cluster samples are taken – one from each “half” of the block. Other aspects of this company’s protocol: 1. Sampling is done in the morning whenever possible; 2. Samples that are wet are not taken because water can alter the results; 3. Sampling is not done on rainy days or when dew is very heavy; 4. Samples, once collected, are placed in a cooler so they don’t “bake” in a vehicle; 5. Samples are brought to the winery lab before 1:00 pm each day.

As to color, sampling is done on for blocks of Cabernet Franc, Cabernet Sauvignon, and Merlot at harvest in order to pay growers a “color bonus”. Color samples are taken the day before the grapes are to be harvested when possible. In addition to these, color samples may be taken at different times for selected varieties and blocks in order to monitor maturity. Samples for these blocks are taken at different soluble solids stages, in addition to the day before harvest. Sample collection is as follows: The sampler walks through the block in a random pattern (not specified); small portions of whole clusters are clipped off and collected into zip-lock bags; enough partial clusters are sampled so that at least 300 berries are collected (equivalent to about 10 whole clusters). After collecting the samples they are stored in a freezer. Frozen berries are counted into four samples of 50 berries each, plus another sample of 100 berries. These are subsequently analyzed for total anthocyanins, absorbance at 420 nm, and absorbance at 520 nm; the sum of the latter two variables gives intensity of color.

Sampling for flavor

Sampling of berries for flavor is fraught with difficulty not so much because of the sample size issues as much as for the qualitative aspects inherent in the data collection process. Ask yourself: "What is 'flavor ripeness' in Chardonnay"? Or for that matter, what about Pinot blanc, Auxerrois, Seyval, Vidal, and the many other varieties grown in the east that have no specific varietal aroma and flavor characteristics? When sampling for flavor ripeness, physiological maturity, or whatever term is ascribed to a crop that is ready to harvest, the labor expended in the careful collection of a sufficient number of samples can be all for naught unless an objective system is used to assess flavor ripeness. One, devised by Eschenbruch (pers.comm., 1986) has proven successful under some circumstances (Table 1).

Spatial variation in yield in commercial vineyards

The acceptance of the fact that spatial variations in yields, vine size, and fruit composition exist in commercial vineyards has led to the exploration of use of global positioning systems (GPS) mapping of vineyards with respect to soil texture and composition, petiole composition, yield components, and even vine vigor (Davenport et al. 2001; Greenspan 2001; Reynolds and de Savigny 2001). Yield data, for instance, can be collected using a yield monitor attached to a grape harvester. These data can then be used to create a geographic information system (GIS) that can portray the variability in map form. The next logical step is to employ variable-rate technology that can employ these data to precisely add nutrients, lime, spray materials, etc. in accordance with the data provided.

Although it is not the intent of this article to venture into the topic of precision viticulture in any depth, it is nonetheless relevant to provide some evidence of: 1. The differing magnitudes of spatial variation amongst vineyards with respect to yield and yield components; 2. The differing patterns in spatial variability within single vineyard blocks from season to season.

Spatial variation in yield between vineyards.

We have completed work in which we used GPS to delineate shapes of Chardonnay and Riesling vineyard blocks in the Niagara Peninsula, and to geo-locate vines at each location used for sampling. The number of vines varied from 75 to over 200, depending upon the size of the block. Soil and petiole sampling was done in 1998; data on vine size, yield, and fruit composition was collected on an individual vine basis from 1998-2002 inclusive.

An interesting observation presents itself when one examines yield patterns for these vineyards. For example, two vineyards less than 1 km apart and managed very similarly show very different magnitudes of yield variation (Fig. 1). The vineyard depicted in Fig. 1(a) consisted of a range of crop size from 6.9 to 11.5 tons/acre based on 1200 vines per acre, whereas the vineyard in Fig. 1(b) showed a range of 5.1 to 8.2 tons/acre. It is worth noting that these vineyards were situated on coarse-textured soils and were Scott Henry-trained; yields of this magnitude are not possible on the heavy clay soils further south in the Niagara Peninsula adjacent to the escarpment.

Spatial variation in yield within a single vineyard across several seasons. A single vineyard block may not have a consistent yield pattern from year to year. Consider the 4 year pattern of spatial variation in yield in the Falk vineyard (Fig. 2). The 1998-99 yield patterns were relatively similar, and the ranges were 5.1 to 8.2 tons/acre in 1998 and 7.7 to 11.0 tons/acre in 1999. However despite consistent management practices, yield patterns in 2000 and 2001 were very different from each other and from previous seasons. Their ranges were similar; 4.3 to 8.0 tons/acre in 2000 and 4.9 to 7.9 tons/acre in 2001. The range in yields was in the same ballpark (4.5 to 8.1 tons/acre) in 2002 (not depicted), but the spatial variation was radically different again. This, of course, presents a problem from the standpoint of sampling to assess yield, but moreover, it presents a nagging concern that implementation of precision viticulture based upon spatial variation in yield may be problematic. Davenport et al. (2001) reported a similar dilemma with Concord vineyards in Washington state where several years of data collection using yield monitors provided very different patterns of spatial variability.

Spatial variation in fruit composition:

Spatial variation in fruit composition between vineyards.

Much like yield, variation in vineyards with respect to soluble solids, titratable acidity, and pH can be large. This presents a challenge to the sampler, the vineyard manager, and, ultimately, the wine company that is accepting the grapes. Consider the two adjacent Chardonnay vineyards previously cited for their yield variabilities. The one in Fig. 3a ranged from 19.1 to 21.8 Brix, whereas the adjacent block had both lower Brix overall as well as a much narrower range (18.8 to 20.4; Fig. 3b). Again, we encounter the same issue as with sampling for yield: a nearly 3^{o} range in a < 5 acre parcel. Questions naturally arise in terms of when to harvest.

Spatial variation in fruit composition within a single vineyard across several seasons.

Following the block of Chardonnay through 5 seasons provides some insights into how the spatial variation in soluble solids can change over a short period in the life of a vineyard. Note how the ranges were similar in 1998 (Fig. 3b), 1999 (19.4 to 20.8; Fig.4a), and 2000 (18.0 to 20.9; Fig. 4b), but quite different in 2001 (21.0 to 22.5; Fig. 4c) and 2002 (20.0 to 21.3; Fig. 4d). Not only did the ranges change through the 5 years of observation, but the spatial patterns changed substantially as well. This provided a significant challenge to those engaged in sampling and deciding harvest dates.

Spatial variation in flavor potential:

Spatial variation in monoterpenes within a single Riesling vineyard across several seasons.

Monoterpenes are responsible to a large degree for the varietal intensity in Riesling and other aromatic white wine varieties. Sampling a Riesling vineyard in the Niagara Peninsula over a 3 year period revealed some interesting trends in the spatial variability in potentially-volatile terpenes (PVT). Ranges in PVT were relatively similar in the 3 years (Fig. 5): 1.67 to 2.99 mg/L (1998; Fig. 5a); 1.91 to 2.76 mg/L(1999; Fig. 5b), and; 1.31 to 2.14 mg/L (2002; Fig. 5c). However, the patterns of variation were markedly different. The zone in the vineyard with highest flavor potential was located in the north and east section of the block in 1998; in 1999, the zone of highest PVT was located in the western portion of the vineyard, whereas in 2002, the south-central section of the vineyard appeared to have highest PVT.

The spatial variation in free volatile terpenes (FVT) in the 3 years we collected data has implications for field sampling from a standpoint of flavor ripeness. Note that the ranges in FVT were very similar in 1998 (0.41 to 0.70 mg/L; Fig. 6a) and 1999 (0.40 to 0.84 mg/L; Fig. 6b), but the range was much lower in 2002 (0.15 to 0.24 mg/L; Fig. 6c). The pattern of spatial variability within this block was very different each season; the northeast quadrant appeared to be most mature in 1998; the entire east side of the vineyard had highest FVT in 1999, and; the western side of the vineyard was highest in FVT in 2002 (Fig. 6a-c). The question then emerges: how does one accurately predict physiological maturity when these perceptible flavor compounds vary both spatially and temporally?

Conclusions

How does one sample a vineyard for yield and fruit composition? It may seem that this article raises more questions than it provides answers. Some points that bear repeating are the following:

1. In sampling clusters at veraison for yield estimation, remember that the cluster weight should be multiplied by 1.7 to 2 to calculate final cluster weight.

2. Take into consideration any missing vines when calculating yields; a mere 5% missing vines will create a significant error.

3. The pattern of sampling for both yield and fruit composition is important. The "X" configuration method of sampling appears to be common. The grid pattern of sampling is also very acceptable. What is most important is the number of samples, and the method by which samples are obtained.

4. Both experience and research have shown that berry sampling can provide accurate data as long as enough berries are collected, and, provided that they are collected in a manner reflective of a particular vineyard block.

5. Sampling needs to be modal. If you have 20% shaded clusters, then make sure your sample reflects that level of cluster exposure. Realize that all clusters are basically conical, that most clusters have an exposed and a shaded "side", and that both sides need to be sampled to obtain accurate data. Note also that grapes tend to accumulate soluble solids from top to bottom, and that all sections of clusters need to be sampled.

Literature Cited

Amerine, M.A. and E.B. Roessler. 1958a. Methods of determining field maturity of grapes. Amer. J. Enol. 9: 37-40.

Amerine, M.A. and E.B. Roessler. 1958b. Studies on grape sampling. Amer. J. Enol. 9: 139-45.

Davenport, J.R., L.J. Mills, J.M. Tarara, F.J. Pierce, and N.S. Lang. 2001. Application of GPS, GIS, and yield monitors for effective vineyard management. Proc. Space Age Winegrowing Symp. (A.G. Reynolds, ed.), Amer. Soc. Enol. Vitic. Eastern Section, pp. 50-55. Presented at ASEV/ES meeting, July 11-12, 2001.

Greenspan, M.D. and J.J. O'Donnell. 2001. Evaluating the utility of remotely-sensed canopy density for the understanding of vineyard spatial variability. Proc. Space Age Winegrowing Symp. (A.G. Reynolds, ed.), Amer. Soc. Enol. Vitic. Eastern Section, pp. 27-41. Presented at ASEV/ES meeting, July 11-12, 2001.

Kasimatis, A.N., and E.P. Vilas. 1985. Sampling for degrees Brix in vineyard plots. Amer. J. Enol. Vitic. 36: 207-13.

Rankine, B.C., K.M. Cellier, and E.W. Boehm. 1962. Studies on grape variability and field sampling. Amer. J. Enol. Vitic. 13: 58-72.

Reynolds, A.G., R.M. Pool, and L.R. Mattick. 1986. Influence of cluster exposure on fruit composition and wine quality of Seyval blanc. Vitis 25: 85-95.

Reynolds, A.G., and C. de Savigny. 2001. Use of GPS and GIS to determine the basis for terroir. Proc. Space Age Winegrowing Symp. (A.G. Reynolds, ed.), Amer. Soc. Enol. Vitic. Eastern Section, pp. 79-102. Presented at ASEV/ES meeting, July 11-12, 2001.

Reynolds, A.G., and D.A. Wardle. 1989. Influence of fruit microclimate on monoterpene levels of Gewurztraminer. Amer. J. Enol. Vitic. 40: 149-54.

Roessler, E.B, and M.A. Amerine. 1962. Further studies on grape sampling. Amer. J. Enol. 13: 144-47.

Wolpert, J.A., G.S. Howell, and T.K. Mansfield. 1984. Sampling Vidal blanc grapes. II. Sampling for precise estimates of soluble solids and titratable acidity of juice. Amer. J. Enol. Vitic. 35: 242-46.

Wolpert, J.A., G.S. Howell, and T.K. Mansfield. 1983. Sampling Vidal blanc grapes. I. Effect of training system, pruning severity, shoot exposure, shoot origin, and cluster thinning on cluster weight and fruit quality. Amer. J. Enol. Vitic. 34: 72-76.

Wolpert, J.A., and E.P. Vilas. 1992. Technical brief. Estimating vineyard yields: Introduction to a simple, two-step method. Amer. J. Enol. Vitic. 43: 384-88.

Table 1. A checklist of subjective criteria for assessing grape maturity. Modified from a scorecard developed by Eschenbruch (pers. comm. 1986).

ATTRIBUTE	LEVEL OF ATTRIBUTE	POINTS AWARDED
Color	green (lack of color)	0
	color change; translucent	1
	fully-mature color	2
	over-mature color	1
Ease of removal of berries from pedicels	high resistance	0
	moderate resistance	1
	little/no resistance	2
Texture upon touch	firm	0
	soft/elastic	1
	shriveled; loss of shape	0
Texture-- initial bite		
ease of skin collapse	high resistance	0
	moderate resistance	1
	low resistance	2
mechanical features of the pulp	thin; watery	0
	viscous	2
	jelly-like	1
Aroma	none	0
	recognizable varietal aroma	2
Flavor upon chewing		
Initial character (upon chewing)	unripe; green; bland	0
	some varietal character	1
	high varietal character	2
Release from skin	none	0
	typical varietal character	1
Aftertaste	none	0
	bitter; astringent; phenolic	0
	typical varietal character	1
Maximum total		**15**

Figure 1. Spatial variation in yield in two adjacent Chardonnay vineyards, Niagara-on-the-Lake, ON, 1998.

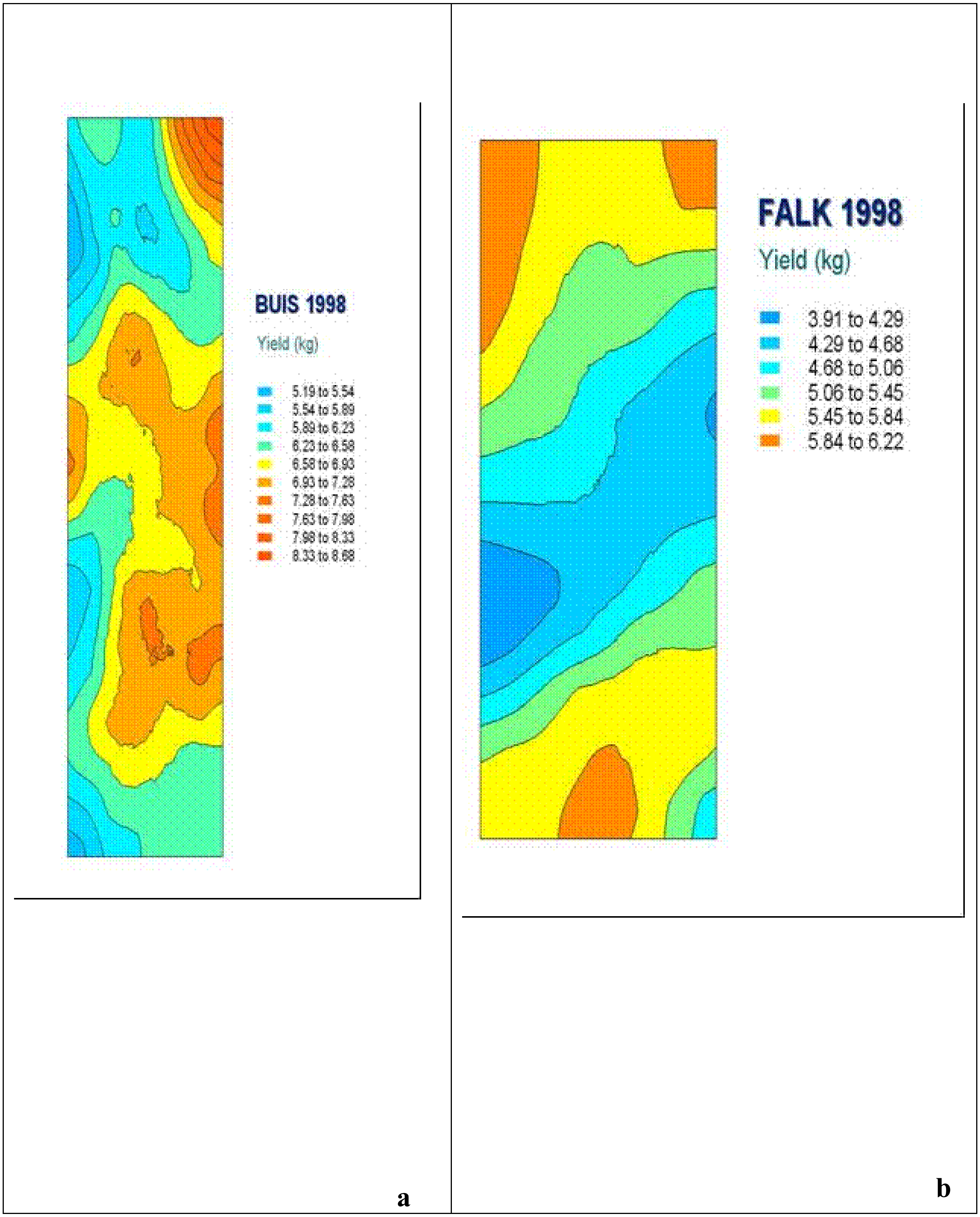

Figure 2. Spatial variation of yield in a Chardonnay vineyard, Niagara-on-the-Lake, ON, 1998 through 2001.

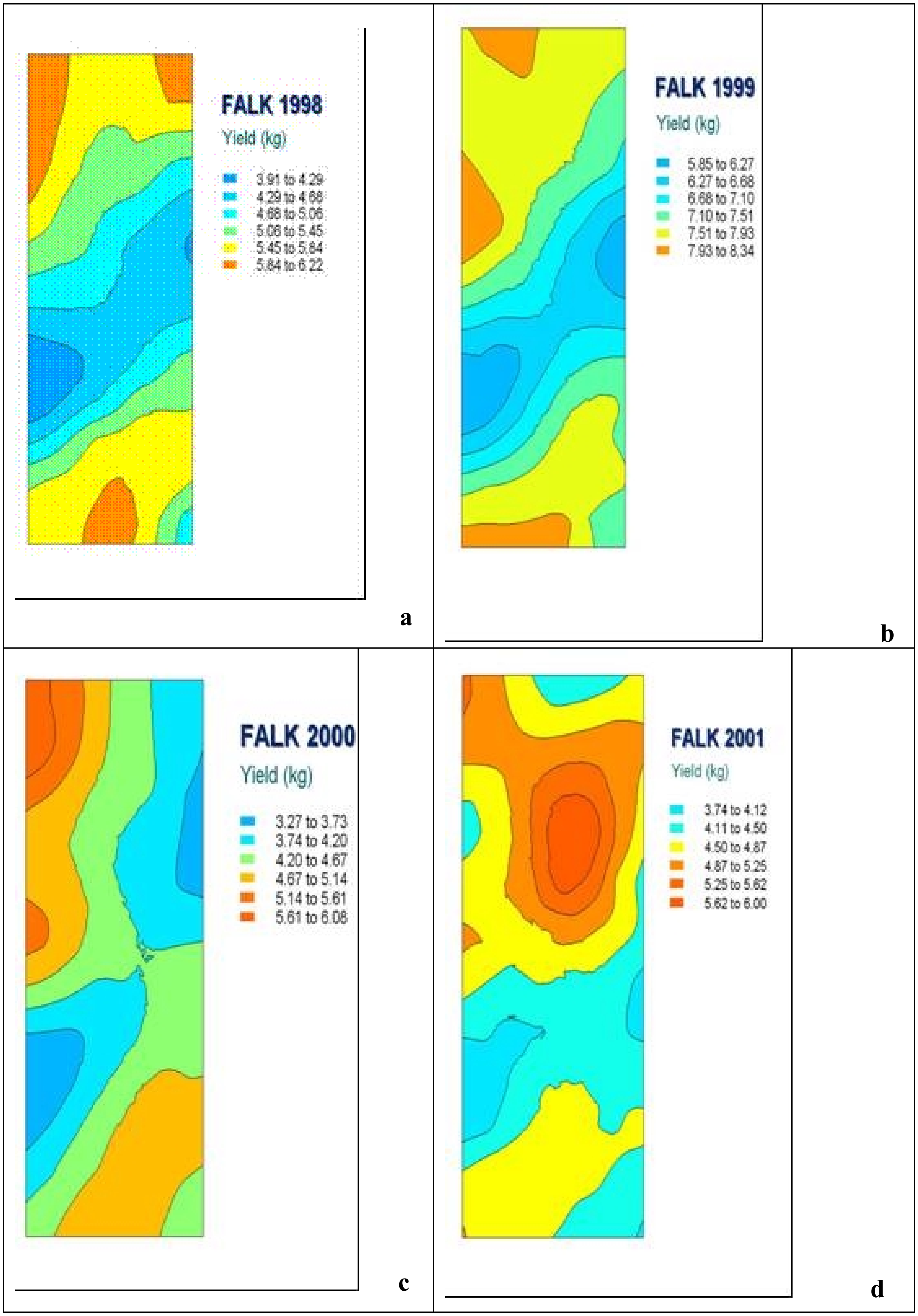

Figure 3. Spatial variation in soluble solids in two adjacent Chardonnay vineyards, Niagara-on-the-Lake, ON, 1998.

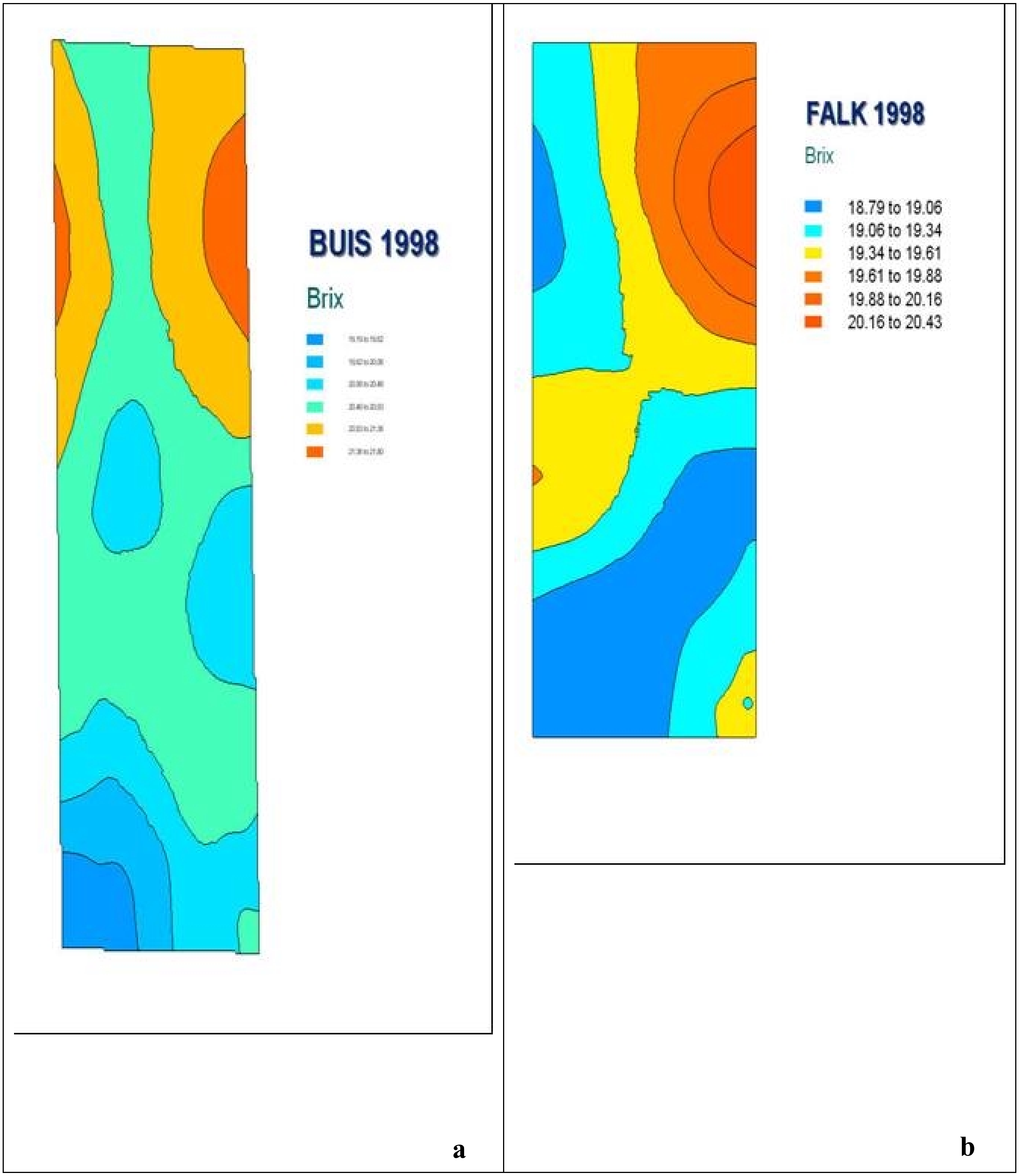

Figure 4. Spatial variation of soluble solids in a Chardonnay vineyard, Niagara-on-the-Lake, ON, 1999 through 2002.

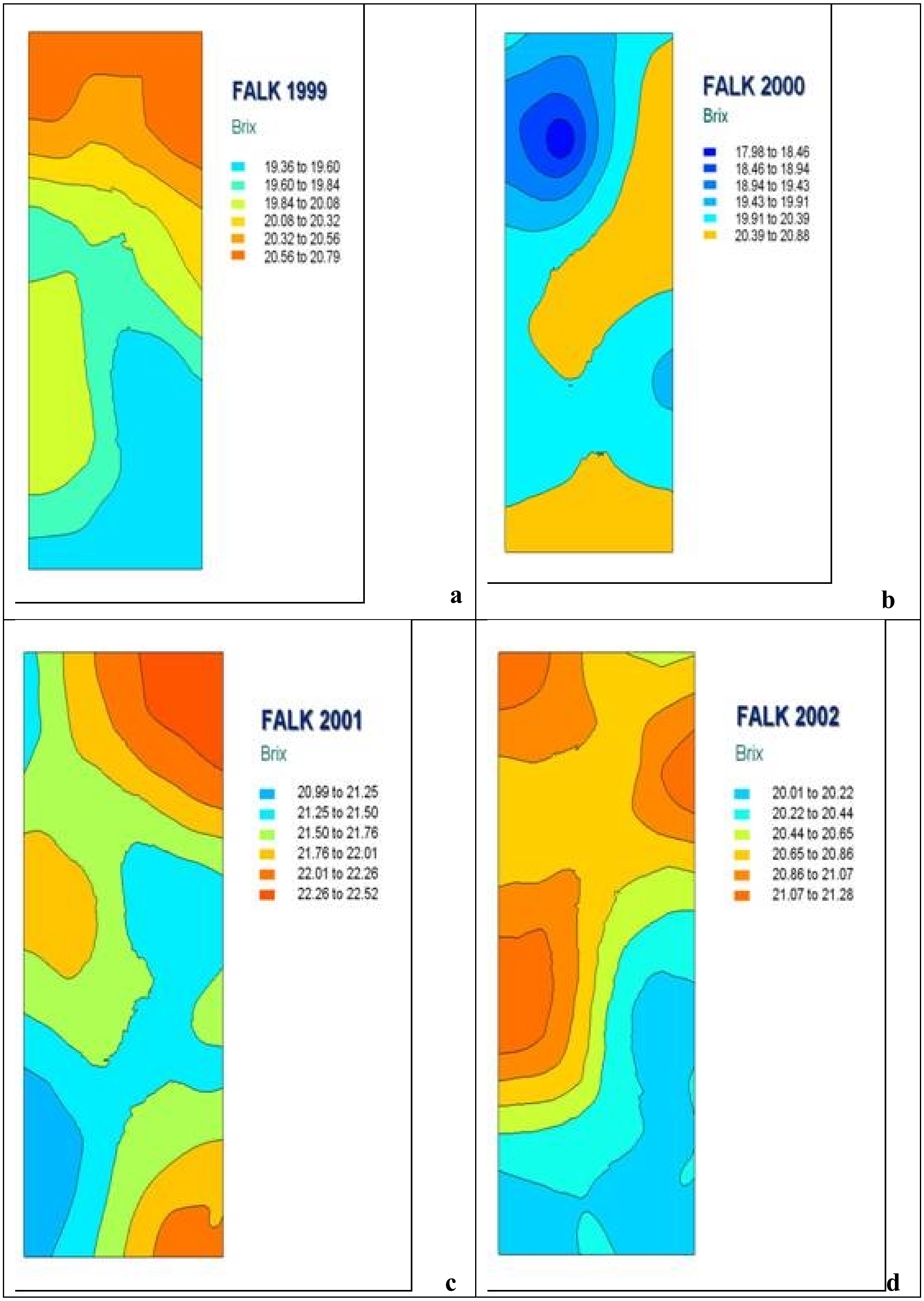

Figure 5. Spatial variation of potentially-volatile terpenes in a Riesling vineyard, Vineland, ON, 1999 through 2002.

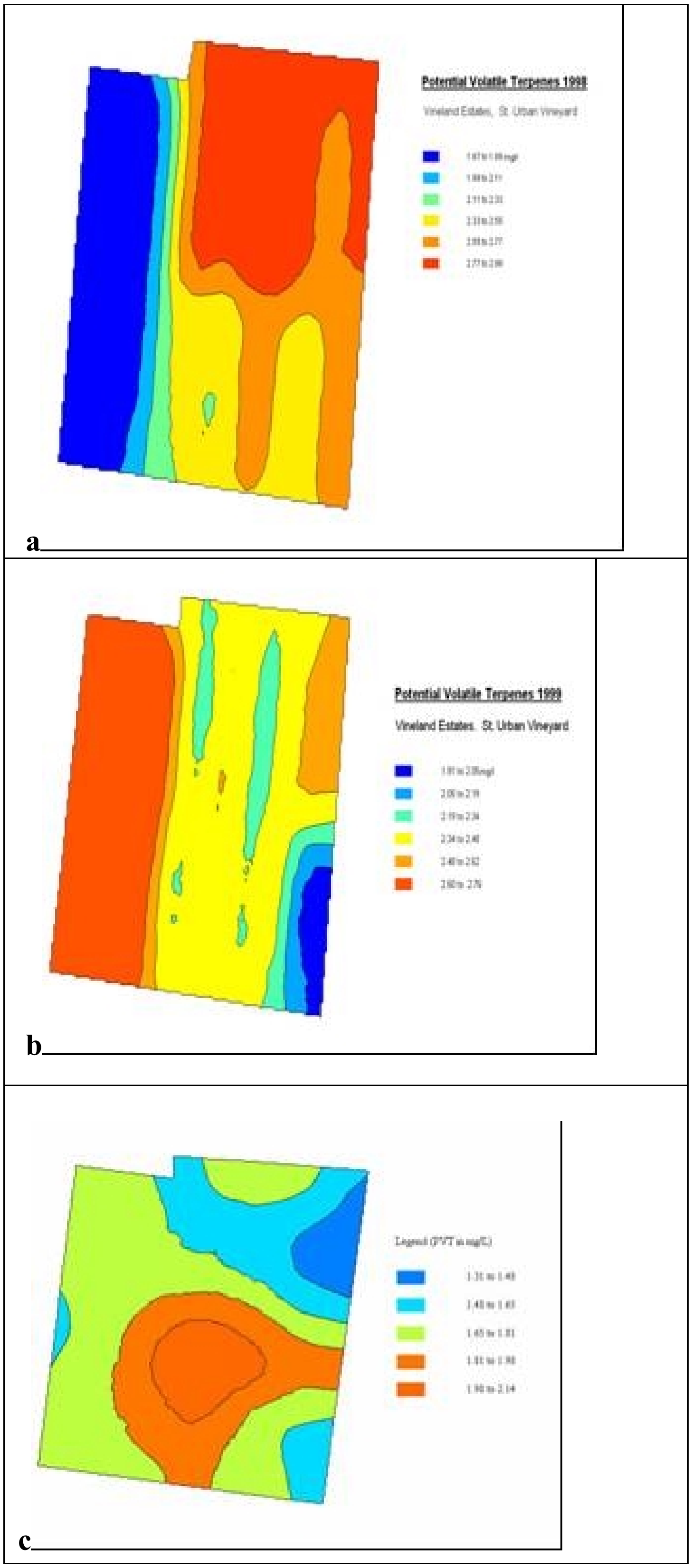

Figure 6. Spatial variation of free volatile terpenes in a Riesling vineyard, Vineland, ON, 1999 through 2002.