Manipulating Grapevine Annual Shoot Growth, Yield and Composition of Grapes Using Fertigation

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Abstract

Grape producers are increasingly using pressurized water delivery systems to deliver soluble nutrient salts to vine roots. Coupled with tight water management, such systems allow control over the amount supplied and the timing of that supply, and hence greater control over shoot growth, leaf function and grape yield and composition. There are many permutations and combinations of timing of supply and amounts delivered, which, when coupled with the many environments, soil types, varieties and rootstocks used and grape end uses, makes the notion of a single universal program untenable. The timing of nutrient uptake by grapevines, which can be estimated using published data, and the amounts removed can be the basis of a fertigation program. The modifications required may need to address the specific needs of the variety being grown, the rootstock used and grape end use, and be site specific. Even with fine tuning, however, season-to-season variation in crop size is difficult to accommodate, raising the possibility that decision support frameworks that incorporate perenniality and encapsulate vine growth and development functions, yield potential determination and intra-vine nutrient dynamics may represent the next advance in the use of fertigation as a management tool in grape production.

Keywords: minerals, grapevines, grape composition.

Introduction

Grapes and grape products are an important part of many cultures around the world. World grape production is for the most part based on selections of *Vitis vinifera* L. Grapes are consumed fresh and dried, and crushed grapes are consumed as juice or as still, sparkling or fortified wines following vinification. Worldwide, *ca*. 60.9 million tonnes of grapes were harvested from 7.5 million hectares in 2003 (Anon., 2004). Generally, approximately 45% of the grapes produced worldwide are used for producing fermented beverages, 22% are consumed as table grapes, 16% are dried and the remainder consumed as grape juice.

For many of these end uses, grape berry appearance and composition are important drivers of production technology, and for other end uses yield remains the primary driver. Tools that confer some degree of control over shoot growth, leaf physiology and reproductive growth and development are an important part of meeting consumer demands profitably. Clearly, water and mineral nutrients are critical inputs in this regard, and the interaction between the two is recognized (*e.g*. Ussahatanonta *et al*., 1996), although some trial designs have not differentiated between the effect of water volume applied from the effect of fertilizer rate (Almela *et al*., 1999; Klein *et al*., 2000). When one factor is held constant, variation in the other usually results in significant responses.

Fertigation can be defined as the delivery of essential mineral nutrients as dissolved salts to the roots of plants in water primarily supplied to meet plant water needs. The concept's primary objective was ease of management, and efficiency and crop manipulation considerations were later spinoffs. There is a *prima facie* case that the interception and efficiency of uptake of nutrients supplied *via* a fertigation system should be higher compared to surface application. This would be particularly so if the duration and timing of irrigation events avoid waterlogging and leaching on the one hand and water stress on the other. But, it must be recognized that there has been no direct side-by-side comparison of the interception and uptake efficiency of dissolved nutrients delivered to the rootzone *via* irrigation water in pressurized systems compared to nutrients broadcast as dry fertilizers on to the soil surface. Nutrient use efficiency (*i.e*. mt output/kg input) is probably of lesser importance compared to the potential benefits to be derived from being able to better control shoot growth and grape composition.

Potentially, a bewildering number of permutations and combinations of timing, nutrient salts and amounts are possible using fertigation techniques. Equally daunting is the range of *vinifera* genotypes used as direct producers or scions on a range of *Vitis* species and interspecific *Vitis* hybrid rootstocks (see Ambrosi *et al*., 1994). Rootstock effects on scion mineral nutrient status and differences in the mineral nutrient status of different *vinifera* genotypes grown under the same conditions have been known for many years (*e.g.* Cook and Lider, 1964). Coupled with multiple end uses, varying specifications within general end use classes and widely differing soil and environmental conditions between grape growing regions, the notion that a universal fertigation program will meet all needs is unrealistic. Recognition of these complexities is reflected in industry publications - general principles are discussed, but definitive programs are not detailed (Conradie and van Zyl, 1989; Treeby *et al.*, 2004).

This article uses published data to illustrate some of the factors that may be important in designing aspects of a fertigation program to achieve particular grape yield and composition outcomes. Deficiencies in knowledge that limit realization of the potential benefits that can be obtained by grape producers from exerting control over mineral nutrient supply are highlighted. The discussion is principally confined to the macro-nutrients N, P and K because these mineral nutrients are the nutrients removed from vineyards in the largest amounts. Futhermore, their supply is relatively easily manipulated and, on the basis of the amount of data published, have the greatest impact on shoot growth, leaf function, reproductive development and grape composition in most situations where grapes are produced. Nonetheless, mineral nutrients other N, P and K are supplied in fertigation programs, for example Mg (Gurovich *et al.*, 1994) and B (Peacock, 2004). The hardware needed to deliver dissolved nutrients in irrigation water, and the nutrient sources available, are well covered by Burt *et al.* (1995).

Timing of nutrient uptake and nutrient dynamics within grapevines

Critical to the successful use of fertigation is an appreciation of the timing of nutrient absorption by vine roots during the growing season and the impact of nutrients taken up during particular periods on the performance parameters of interest. Approximate proportions of the total seasonal uptake that can be attributed to uptake during distinct phenological stages can be estimated using data collected from potted vines (Conradie 1980, 1981), intensive destructive sampling programs conducted on established vines in the field (Alexander 1957; Lafon *et al.*, 1965; Löhnertz, 1988; Schaller *et al.*, 1989; Wermelinger and Koblet, 1990; Williams and Biscay, 1991) and the impact of supply at particular stages (Peacock *et al.*, 1989; Conradie, 1990, 1991, 1992; Christensen *et al.*, 1994; Glad *et al.*, 1994). Using data from the aforementioned studies and data collected from local trials, estimates of the total uptake of N, P and K in a season by grapevines growing in a warm irrigated region of south eastern Australia are presented in Table 1. One would expect the proportions to change according to the growing environment: for example, the importance of uptake during the postharvest period would diminish if the length of time between grape harvest and leaf fall is short and increase if that length of time is greater.

Table 1. Estimates of approximate proportions of total seasonal N, P and K uptake attributable to uptake during particular growth stages for grapevines growing in a warm irrigated region of south east Australia. Estimates based on published data (see text) and regional data (Treeby and Wheatley – unpublished).

Nutrient	Growth stage				
	Budburst - bloom	Bloom - set	Set - veraison	Veraison - harvest	Harvest - leaf fall
	------------- *Total season's uptake in each stage (%)* -------------				
N	10	15	35	10	30
P	25	40	25	0	10
K	20	30	25	10	15

The estimates presented in Table 1 probably represent uptake behaviour if nutrient supply is non-limiting. Because the concentrations of these nutrients in the shoots over the course of the growing season will, to a greater or lesser extent, affect leaf function, annual biomass production, bud fertility and grape composition, uptake of these nutrients during these stages needs to be manipulated.

Amounts supplied and removed

The amounts of N, P and K removed may serve as an indication of the minimum amount needed to at least maintain soil fertility. In a warm irrigated grape growing region of south east Australia, N, P and K removals amounted to 18 and 43, 3 and 7 and 26 and 63 kg/ha in Sultanas used for producing dried vine fruit and in Cabernet sauvignon grapes used for wine, respectively (Table 2). For Sultana, the amounts removed per hectare were strongly correlated with yield ($r^2 > 0.9$), but the amounts of N, P and K per unit output were not as well correlated with yield (r^2 = 0.62, 0.44 and 0.41 for N, P and K, respectively). This could indicate that factors other than sink size affect transport of mineral nutrients to the berries. There is ample evidence that the amounts of N and K in grapes at harvest can be manipulated by supply (*e.g.* Spayd *et al*., 1994; Ruhl, 1989). The higher removals in Cabernet compared to Sultana may be related to the presence of seeds: approximately 50, 40 and 85% of the total amounts of N, P and K, respectively, in Cabernet berries are present in the seeds, while Sultana is seedless. Removals data are useful as a starting point to estimate needs, but may not relate to the levels required for particular grape end use, and do not give any indication as to what level of inputs are required to maintain canopy function while the berries are maturing and during the period from harvest to leaf fall.

Table 2. Yields and N, P and K removals from a Sultana vineyard and a Cabernet sauvignon vineyard in a warm irrigated region of south eastern Australia.

Variety	Mean yield	N	P	K
		---------------- *kg/ha*	----------------	
Sultana	4 (dried vine fruit mt/ha)	18	3	26
Cabernet sauvignon	22 (mt/ha)	43	7	63

Levels of nutrient inputs published in more recent years have tended to be more moderate, and more closely match estimates of removals (Table 3). The absence of rigorous comparative data may be a factor in the relatively high inputs used early in the development of fertigation as a means of supplying grapevine nutrient needs, as well as possibly reflecting the site-specific soil conditions used for those.

Nitrogen

Possibly because nitrogen supply frequently limits shoot growth and grape yield, there have been many studies conducted on the impact of various rates and timing of supply. When water is not limiting grapevines respond to increasing N supply by taking up more N, increasing annual biomass production (Kliewer, 1971; Alleweldt *et al*., 1984; Zerihun and Treeby, 2002), and floral bud initiation and hence final yield may be greater in comparison to vines not supplied N (Spayd *et al*., 1993). Nitrogen supply also affects the amount of N in berries: too much N results in too rapid fermentation and undesirable compounds potentially forming in the final wine, while too little results in stalled fermentations and H_2S production (Henschke and Jiranek, 1993). In addition, too much N can result in less anthocyanin in red grapes (Kliewer, 1977; Hilbert *et al*., 2003). Balancing producers' needs for profitable levels of productivity and wine makers' needs for grapes of a suitable composition and trouble free vinification remains a challenge. The limited data available suggests that, generally, N applied in autumn the previous season or during summer of the current season will result in more berry N at harvest, but that the response is affected by rootstock (Treeby *et al.*, 2000). The implication of this is that a fertigation program to supply sufficient N to ensure trouble free vinification may need to be rootstock dependent. A considerable gap in our knowledge exists regarding the ways in which rootstock genotypes affect scion N status and intra-vine N dynamics.

Phosphorus

There is much less understanding of the impact of varying amounts and availability of P to vine roots during the growing season on shoot growth and grape yield and composition at harvest. Chronic P deficiency is known in California (Skinner *et al.*, 1988) and Western Australia (Robinson, 1992), and poor supply of P can negatively affect vine productivity and wine quality (Bravdo and Hepner, 1987). Relative to N and K, P removals are low, and the chemistry of phosphate availability across the normal range of soil pH mean that it is difficult to supply too much P. Nonetheless, P-induced Zn deficiency has been observed in Germany, but is very dependent on rootstock (Marschner and Schrobb, 1977). A further complication encountered supplying dissolved phosphate salts is the formation of sparingly soluble calcium phosphates in hard water (Burt *et al.*, 1995).

Potassium

Potassium is needed in large amounts by grapevines, and significant amounts are removed from vineyards in the grapes at harvest. However, too much K in red wine grapes can be associated with wines of poor hue and low colour stability due to more malate relative to tartrate (Hale, 1977). Much of the potassium present in grape berries at harvest is translocated from the leaves to the berries concurrently with the transport of sucrose to the berries during the maturation process. Large amounts of K are frequently applied during this period to hasten grape maturation, particularly for table grape production. However, there is little evidence that sugar accumulation by berries is enhanced by large doses of K, but K accumulation by berries can be enhanced by K supply (*e.g.* Conradie and de Wet, 1985; Bravdo and Hepner, 1987).

Monitoring tools

Sampling and analysis of specific tissues at specific times remains the primary source of information to assess the efficacy of any fertilizer program. Debate continues on the most appropriate tissue to sample and the most appropriate time to sample. In some parts of the world, the petiole of the leaf opposite the basal bunch at 50% cap fall is used (Robinson and McCarthy, 1985), and in other parts, the leaf blade (Conradie, 1985). The analytical data are then compared to standards that are essentially a synthesis of experimental data and population statistics (*e.g.* Robinson *et al.*, 1997) and reflect the relationship between vine nutrient status and vine performance, usually yield. The development of interpretative nutrient standards in relation to other aspects of vine performance (*e.g.* grape composition at harvest), for other clearly discernible phenological milestones (*e.g.* veraison) would be of great use in assessing the efficacy of any fertigation program. Technically, the rapid measurement of NO_3^--N and K^+ in the expressed sap of grapevine leaf blades or petioles is relatively simple (Nagarajah, 1999), making it feasible to conduct measurements throughout the growing season. However, in the case of NO_3^--N, for reasons not well understood, levels are affected by which petioles are sampled and levels vary significantly within and between seasons (Christensen, 1969; Spayd *et al.*, 1993), making such measurements of limited use until a body of data is accumulated that allows the development of an interpretative framework. More structured approaches to removing the confounding effects of growth dilution on apparent mineral nutrient concentrations at flowering have been developed (Anon., 2005), and incorporation of this approach should be considered when developing interpretative frameworks including mineral nutrient data.

Decision support systems

Decision support systems are being used increasingly in modern agriculture systems, particularly in those systems exploiting annual plants. Such systems can be empirical, and relatively simple, or more complex multi-dimensional frameworks incorporating mechanistic models reflecting a deeper understanding of the underlying physiology (Le Bot *et al.*, 1998). The strength of mechanistic models lie in their ability - beyond the data set used for parametization - to predict the outcomes of various scenarios in a number of environments. As knowledge grows of the physiology underpinning temporal patterns of uptake, storage, re-mobilization and partitioning of mineral nutrients within grapevines, so too will the efficacy of models built on that understanding have in terms of predicting grapevine nutrient needs in relation to desired canopy behaviour and grape composition at harvest. The season-to-season variability in crop size (and hence the size of the sink to be manipulated) and the storage of carbohydrates and mineral nutrients in, and mobilization from, the perennial structures necessitates the incorporation of perenniality in any model that will be the basis of an advanced decision support framework in perennial horticulture.

The table grape fertigation decision support framework developed by Gurovich *et al.* (1994) (Fig. 1) incorporates models based on a simple mechanistic understanding of vine nutrient balance, and importantly, recognizes the differences between scion genotypes and modifies according to yield and petiole data from season to season. Soil water depletion is a key data input in the framework, but perenniality is not a structural feature.

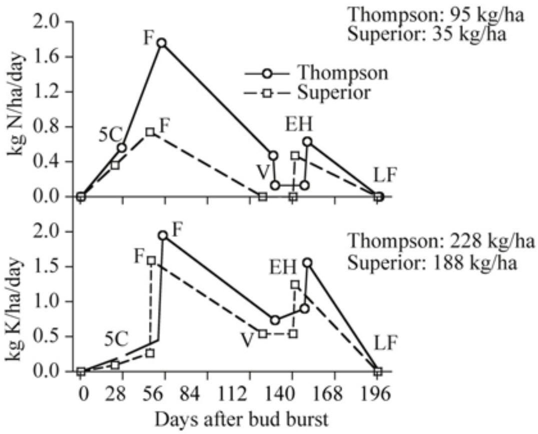

Fig. 1. Basic N and K fertigation program for 2 table grape varieties. 5C = average of 5 clusters visible on vine; F = flowering; V = veraison; EH = end of harvest; LF = leaf fall. Adapted from Gurovich *et al.* (1994) and reprinted by permission of the American Society for Enology and Viticulture -Proceedings of the International Symposium on Table Grape Production (1994).

Wermelinger *et al.* (1991) published details of a C and N partitioning model that partly addresses the perenniality issue by using a measure of N reserves at budburst as a starting input. This type of approach may allow producers to predict the effect of N supply scenarios for the current season on potential N reserves and demand for reserve and fertilizer N during the following season, and would be a significant advance. As indicated above, the development of suitable measurement tools and standards against which performance can be assessed will be integral to using the predictive power of such models.

Table 3. Published total seasonal inputs for N, P and K delivered *via* fertigation.

				kg/ha/season			
Location	Variety	Rootstock	End use	N	P	K	Source
Israel	Cabernet sauvignon	Richter 110	wine	40-250	65	0-470	Bravdo and Hepner (1980)
Israel	Cabernet sauvignon	Richter 110	wine	50-280	0-90	0-430	Bravdo *et al.* (1983)
Israel	Cabernet sauvignon	Richter 110	wine	44-358	60	0-520	Bravdo and Hepner (1987)
USA	White Riesling	Own roots	wine	0-224	-	-	Spayd *et al.* (1993)
Chile	Thompson Seedless Flame Seedless Superior Christmas Rose Redglobe	(not stated)	table	100-135 47-100 30-65 50-100 55-100	11-14 5-10 4-6 5-10 6-10	72-128 60-128 38-83 64-128 70-128	Gurovich *et al.* (1994)
Spain	Monastrell	Richter 110	wine	60-80	6-17	36-110	Almela *et al.* (1999)
Israel	Sauvignon blanc Merlot Cabernet sauvignon	(not stated)	wine	49-81 71-119 53-88	6-9 8-14 6-10	-	Klein *et al.* (2000)
Australia	Shiraz	Teleki 5 C Ramsey Schwarzmann	wine	0-40	-	-	Treeby *et al.* (2000)
Australia	Shiraz	Own roots	wine	40	-	-	Wade *et al.* (2004)

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