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Plant sampling: a review

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Summary. The steps involved in collecting and handling samples for plant analysis are described under the following headings: purpose for which the sample is collected; sampling statistics; sampling strategies; choice of tissue; sample handling; special sampling techniques.

In any application of plant tissue analysis close attention should be given to the approaches which are used to develop the critical values or ranges that are used.

In diagnostic and prognostic use of plant analysis the statistics of the sampling procedure should be well understood, so that a sample which properly represents the crop or planting can be collected. When diagnosis is the primary objective the sampling unit may be as small as a single plant.

It is important that contamination of the sample with nutrient sprays or other materials is understood and recorded. Washing may not be possible, particularly when samples are collected by unskilled people at a site distant from the analytical laboratory. Although washing with detergents or weak acids can remove contamination, there will remain some doubt as to the efficiency of the washing procedure.

Samples which are to be used for sap tests immediately after collection for nitrate-nitrogen should be handled more carefully than those destined after drying for multi-element analysis at a remote laboratory. Ideally the respiratory loss of dry weight from samples should be minimised when the samples are destined for conventional multi-element analysis. Where certain aspects of sample handling are critical to the success of the test they should be emphasised to potential users.

A wide range of plant tissues other than the commonly collected leaves and petioles has been used for assessment of mineral nutrient status, including juice, fruit, and shoot tips. Each of these presents different problems in sample collection handling and storage. Tests based on enzyme activity and other biochemical or physiological indicators probably present the most difficult sample handling problems, but these tests are not widely used.

A number of sampling issues which arise from the author's experience with commercial tissue analysis services are raised. These include such matters as the extent of training of the personnel who do the sampling, contamination and transport to the laboratory. Although more attention to these issues is needed in practice, plant tissue analysis continues to be a most valuable tool in the hands of the informed manager.

Introduction

A primary producer will gain considerable benefit from plant tissue analyses if the collection and handling of plant samples meet precise specifications. These are: (i) the sample is collected according to a standard procedure with respect to the plant species, the position on the plant and time of sampling; (ii) the area of crop being sampled is well defined; and (iii) the group of plants sampled is representative of the total population of plants.

The sample must also be conveyed to the laboratory in a way that will not substantially alter its analytical values. The sample must be large enough to be handled easily and to leave enough tissue in reserve for follow-up testing or repeat analyses. A sample which has not been collected or handled properly will produce spurious data and lead to incorrect decisions (e.g. see Jones and Case 1990; Reuter and Robinson 1986; Jones 1985).

Purpose for which the sample is collected

The first question which should be addressed is 'Why is the sample being taken?' because this will determine both the kind of sample to take, and the way the task of sampling is approached. The range of options is presented briefly in Table 1 and is covered in more detail by Lewis, Grant and Maier (1993).

It is clear that a good understanding of both the agronomy and physiology of the crop is important if a good decision about the purpose of a plant tissue sample is to be made. This is not a decision that an untrained person can make without help.

Sampling statistics—is the sample representative?

Early work with tree crops such as citrus emphasised that the sampling procedure should be chosen in the light of an understanding of the amount of variability which can be introduced at the sampling stage. Important sources of variability include: (i) within tissue of similar age from the same plant; (ii) between plants or plots; (iii) between samples.

Studies of tissue variability from a single plant have been reported. An example is that of Wallace *et al.* (1953) who collected 2 sets of 100 individual leaves of

Table 1. Reasons for taking a sample for plant analysis

Reason	Sampling options	Comparison to be drawn with	Example
Diagnosis (e.g. seeking reasons for a problem or confirming a visual diagnosis)	Defined plant part and time of sampling (e.g. from plants with symptoms), or	Standards	Defining copper deficiency in wheat (e.g. Gartrell 1979)
	'Good' and 'Bad' plants—timing not so critical. Plant part may not be defined	'Good' and 'Bad'	Unknown growth problem in any crop
Prognosis (e.g. predicting yield and/or need for immediate treatment)	Defined plant part and time of sampling	Standards	Deciding if treatment of manganese deficiency in lupins is likely to be economically effective (e.g. Hannam *et al.* 1985)
Annual monitoring (e.g. checking nutrient status in relation to defined standards)	Defined plant part and time of sampling	Standards (and in perennials with previous years' data)	Annual monitoring in relation to nutrient values or ranges in vineyards or orchards (e.g. Robinson 1986)
Within season monitoring or logging (e.g. following one or more nutrient through the season aiming to adjust fertiliser practice for maximum yield, quality etc.)	Defined plant part at a number of sampling times	Standards and plot progress	Sampling during the growing season to follow nitrogen status of potatoes or tomatoes aiming to maximise yield or specific quality attributes (e.g. Williams and Maier 1990*a*, 1990*b*)
Regulatory standards	Defined plant part. Method of handling may be defined too	Statutory standards	Sampling root vegetables for possible infringements of food regulations for cadmium

identical age from a Valencia orange tree and analysed each leaf either for nitrogen or for phosphorus, potassium, calcium and magnesium. Some of the data they obtained are shown in Table 2. [Note that the between-sample variability is confounded with the analytical variability.] Their conclusion was that a sample size larger than 100 leaves is of little practical value and that very large samples are needed to reduce the error to <2.5%. Other work has demonstrated that position on the tree, aspect and exposure, contribute to the variation which is observed (see Smith 1962).

Studies of the relationship between sample variability and replication [e.g. citrus and avocado; Jones *et al.* (1957)] have shown that it is important to understand the variability of the sample before determining sampling intensity and experimental design, particularly with any new crop.

Table 2. Elemental concentrations in leaves collected from a single eight-month-old Valencia orange tree

Values from Wallace *et al.* (1953)

	Mean ± s.d. (%)	Range (%)	CV (%)
Nitrogen	2.09 ± 0.247	1.61–2.65	11.8
Phosphorus	0.119 ± 0.010	0.089–0.145	8.4
Potassium	1.24 ± 0.194	0.63–1.68	15.6
Calcium	3.92 ± 0.589	2.42–6.35	15.0
Magnesium	0.22 ± 0.045	0.10–0.34	20.6

In Australia the detailed work reported by Leece (1972) for peach describes the errors involved in sampling very well. More recently the papers of Cresswell (1989) for kiwifruit and Cresswell and Wickson (1986) for pecan show how one can define the changes which can be expected in leaves of a perennial plant, the sampling variation which can be expected and hence the value of the data which might be collected in leaf analysis programs.

The possibility that the sampler will introduce systematic variation is also important, but has not often been studied. It seems logical that appropriate training of personnel entrusted with sampling will reduce bias and lead to a more reliable sample.

Sampling strategies

Examples of sampling strategies which have been devised to minimise variability are described in Reuter *et al.* (1986) and are summarised in Table 3. There are clear differences in the philosophy behind each kind of strategy. In the case of sugar beet the authors are clearly trying to measure differences between quarters of a field so that the variability can be understood and taken into account during the interpretation and recommendation steps.

Choice of a small uniform area to concentrate on offers an option which is economical of sampler's time and easy to find. Using a set traverse tries to include various parts of an orchard or a field without allowing the possibility of 'clustering' that might occur if a truly random approach were to be used in monitoring work. Sampling a single plant is clearly appropriate if one is

Table 3. Sampling techniques which are designed to provide sufficient replication to minimise uncontrolled variation

Sampling technique	Crop	Reference
Multiple composite samples of 2–4 quarters of the field	Sugar beet	Ulrich and Hills (1952, 1973)
Select a typical uniform area in each quarter and collect a composite sample in each	Sugar beet	Ulrich and Hills (1952, 1973)
Select a single uniform area in a field or planting and collect a composite sample	Wide range of species	See individual crop summaries in Reuter and Robinson (1986)
Select a fixed number of plants or trees in a traverse through planting and sample 2–4 leaves/petioles/fruit from each. Number may be 20–25 trees, 50–100 vines	Trees and vines	See individual crop summaries in Reuter and Robinson (1986)
Select a sample from a single plant	Wheat	Gartrell (1979)

trying to diagnose the reason for the poor performance of that particular plant.

In any situation different samples should be taken from parts of plantings on different soil types, varieties or rootstocks. Pegging or labelling the sampled area is useful if it is to be sampled over time.

Leece (1972) in Australia followed other workers (e.g. Steyn 1961) in estimating the numbers (n) of peach trees to be sampled to achieve a minimum percentage difference (D) between the population mean and the sample mean which will be significant. Leece (1972) derived the equation:

$$n = 2t^2 \times d^2/D^2$$

where d is the average coefficient of variation of previous experiments or sampling exercises and t is Student's t-value for the desired probability and the number of degrees of freedom on which d was estimated. He showed that the number of samples required to achieve an average sampling error ≤ 10 or 20% was 14, 4 for macronutrients; 18, 4 for micronutrients (except Mn); 105, 26 for Mn.

In more recent studies Leece (1972) showed that if 20 trees were sampled per orchard the predicted average maximum error for macronutrients would be 7% and for micronutrients 24%. The sampling routine normally chosen in orchards involves sampling 4 leaves from each of 20–25 free standing trees or 2 leaves per tree, one from each side of 50 trees in a hedgerow planting.

There are few studies on the statistics of sampling for annual field crops and pastures. It is possible that the statistics of sampling have been more intensively studied in perennial crops than annuals and that there may be scope for increased emphasis on this aspect of work with annual crops.

Choice of tissue

The simple answer to the question 'Which tissue should be sampled?' is precisely that tissue which was used in the calibration work upon which the assessment and recommendations will be based. From first principles, it is desirable to select a sampling unit which is most appropriate on the basis of what we know about the function of each nutrient in the physiology of the plant, and particularly the information on nutrient mobility which has been summarised in Table 2.2 of Robson and Snowball (1986). For immobile nutrients concentrations are measured in young or mid-aged leaves, while for mobile nutrients older leaves are usually used.

In keeping with the empirical nature of plant analysis the choice of sampling unit has been wide ranging (see examples in Table 4). As more is known about the physiology of individual mineral nutrients in particular plant species this list will doubtless be extended. An example showing the need to select the tissue for sampling carefully is the recent discovery that when in excessive supply, boron behaves differently in almond (where it is sequestered in the stem and fruit) than in citrus or pistachio (where it moves into the leaves) (P. H. Brown pers. comm.).

There is, however, an economic component in choice of sampling procedure which limits the ability of the

Table 4. Some plant tissues which have been used as sampling units in tissue analysis studies

Sampling unit	Crops	Comments
Whole tops	Herbaceous species	Bulky
Youngest fully expanded leaves (or parts of leaves such as blades or petioles).	Annual crops, some perennials	Fall back position in most crops (sometimes hard to define)
Mid shoot leaves or leaves on non-fruiting spurs	Deciduous tree crops	Usually for monitoring purposes
Basal shoot blades or petioles	Grapevines	Usually for monitoring purposes
Specially defined parts (YOL, YEB, basal stem)	Annual crops	'Selective' tissue analysis
Fruit, juice	Perennial crops	Specific problems including 'quality'
Seeds, grain	Annual crops (cereals)	

primary producer to pay for all the selective tests which might be applied. Often only one sample is taken in a growing season. Some compromises must be and are made, and it is important that the farmer who is using the system and the scientist or adviser who is making recommendations know that such compromises are being made and what the risks of mis-diagnosis might be.

Criteria for choosing an appropriate sampling unit (adapted from Smith 1962) can be described in the following terms: (i) nutrient concentration should be responsive to both the supply of nutrients to the plant and to some index of plant performance (e.g. yield, quality, appearance); (ii) it should not be subject to rapid nutrient fluxes which would make interpretations subject to error [e.g. contrast the rapid decline of nitrate-N concentration in the youngest fully expanded leaf of Brussels sprouts (Robinson 1991) with nitrate-N concentration in grapevine petioles which declines slowly over the sampling period (Robinson and McCarthy 1985)]; (iii) it should be easy to locate (e.g. contrast the problem of deciding which leaf is YOL and YOL + 1 in a deficient clover or medic or the difficulty of finding precisely YEB + P for a Brussels sprouts plant with the simplicity of locating the leaf opposite a bunch in the grapevine) (Reuter and Robinson 1986).

Stage of growth

The appropriate time for sampling during the plant growth cycle should be closely and carefully defined (e.g. see Reuter and Robinson 1986). Two approaches have been used for annual species. Sampling may be specified as due at: (i) a specified number of days from planting; or (ii) at a defined stage of physiological development. Both approaches are satisfactory if used carefully as it is clear that critical values can decline as plants age so precise definition of sampling time becomes extremely important; for example see the changes in the satisfactory range of petiole nitrate-N concentration for potato described by Williams and Maier (1990*a*).

In perennial crops, sampling strategies are defined with the objective of selecting a time during the year when nutrient fluxes in the sampled tissue are at a minimum. Data such as those which describe nutrient fluxes in leaves during one or more growing seasons as summarised in Figure 1 of Cresswell and Wickson (1986) are used as a basis for deciding when to collect samples for a new crop or in a new environment. In some cases, authors (e.g. Leece and Gilmour 1974) have shown how empirically described trends in concentration may allow values obtained when samples have been taken outside recommended times might be 'adjusted' if samples are collected too early or late for direct comparison with standards.

Sample handling

The basic requirements of adequate or acceptable sample handling from the field to the laboratory are that: (i) there should be no important losses in dry weight as a

Table 5. Steps involved in sample handling and some assessments of the extent to which various approaches are used

Step	Procedure and/or equipment	Application of technique
Collection	By hand (unprotected)	Most fruit, nut and grape monitoring samples Most crop logging samples
	By hand protected with a rubber glove	Not widely used
	Using stainless steel or plastic tweezers	Most micronutrient diagnostic samples
	Using sharp blade	Pineapple
Time of day	Takes no account of diurnal changes	Most fruit, nut and grape monitoring samples
	Takes account of diurnal changes	Some crop logging and diagnostic N samples
	Takes account of recent fertiliser foliar sprays or rainfall	Few although timing may be noted
Sample container	Brown paper bags	Most
	White paper bags	Few
	Vials	Very few
Transport to the laboratory	Over ice or dry ice to prevent spoilage and respiratory losses	Most experimental samples and crop logging samples for immediate nitrate testing Some fruit, nut and grape monitoring samples
	No special precautions	Most fruit, nut and grape monitoring samples
By to laboratory	Plastic courier bags	Most samples
	Paper courier bag to prevent sweating	Few samples
	Special timing to catch mails	Most samples
Washing	Acids (e.g. dilute HCl), detergents (e.g. Teepol), rinsing	Few samples
	No washing	Most samples
Drying	Temperature 60–70°C forced draft oven	Most samples
	Other approaches: air drying at room temperature, freeze drying, or microwave drying	Few samples

consequence of respiration; and (ii) the sample should not be contaminated at the time of sampling, or during transport.

Some important components of sample handling are tabulated in Table 5. Ideally a sample should be collected using hands protected by rubber gloves, or with stainless steel tweezers. It should be placed in a paper bag known to contain no leachable nutrients. Immediately following collection it should be placed in an insulated container over melting ice at 0°C, quickly transported to the laboratory for rapid forced draft drying at 65–70°C. The icebox should permit adequate air circulation.

In reality, commercial samples are usually collected with ungloved hands and placed in paper bags which may lie in the back of a farm vehicle for some hours before being mailed to the laboratory in plastic courier bags.

The most comprehensive study of sample handling in Australia has been that of Leece (1972) who compared factorially the effects of slow air drying *v.* refrigerated storage, and washing *v.* non-washing of peach leaves. It was clear that the air-dried samples lost dry weight and gave higher concentrations of most nutrients. Washing leaves resulted in losses of dry weight, and potassium and iron.

Where tissue analysis procedures have been developed to the commercial stage the specific attention of the user should be drawn to steps which are essential in sample collection and handling which, if not followed, would jeopardise the results.

Special sampling and handling considerations

Some issues which are particularly important are considered below.

Washing of plant tissue samples. There are many studies of the effectiveness of leaf washing prior to drying and nutrient analysis. Labanauskas (1968) showed that a detergent wash was sufficient to remove dust and zinc and manganese spray residues from citrus leaves and concluded that acid washing was unnecessary. Smith and Storey (1976) examined the influence of washing procedures on removal of surface zinc contamination and leaching from pecan leaflets and showed removal of absorbed micronutrients with a washing procedure which included a wash in Alconox detergent followed by a 1% v/v HCl rinse and 3 subsequent deionised water rinses. The work does not compare leaves sprayed with micronutrients with those left unsprayed.

My conclusion is that while washing with detergent followed by acid and distilled water rinsing removes gross contamination there is not a high enough degree of certainty that all contaminants have been removed to make the general use of the technique worthwhile. Most authors (e.g. see individual recommendations in Reuter and Robinson 1986) recommend removal of gross contamination by rinsing or wiping but this is not possible if there is any spoilage or desiccation between the time of sampling and arrival at the laboratory. For this reason washing is not widely practised in commercial leaf analysis services.

Diurnal changes in nutrient concentrations. Diurnal changes in nitrate-N concentration have been reported in some studies as a response to such environmental factors as temperature, light intensity (conversely cloudiness), growth dilution. In a study of diurnal variation (D. L. Heanes pers. comm.) found that nitrate-N concentrations in basal stems of wheat were more stable than in the youngest expanded leaf blades, and that values were most stable within 2 h of sunrise.

In studies with vegetable crops (e.g. Scaife and Stevens 1977) diurnal changes have also been reported. Their response was to suggest that samples should be taken at the time of day at which the critical levels were established.

Cook and Kishaba (1956) found large changes in nitrate concentrations in grapevines in those coastal parts of California subject to spring rains, in ways not seen in the interior valleys.

Clearly, a detailed knowledge of the behaviour of the system is an important precursor of use of a particular sampling procedure. In hot weather it is usual to try to take samples before noon to avoid that time of the day when plants may be in temporary water stress or before peak metabolic rates have been established.

Leaching of nutrients from leaves. Apart from redistribution of nutrients within the plant as the growing season progresses (e.g. in deciduous crops) losses from the leaves as a result of leaching can occur (e.g. Tukey 1970). I am not aware of any studies on the influence of leaching on plant analysis values.

Posting and transport to the laboratory. Attention to postal schedules is important if the time between collection and drying is to be kept to a minimum. The widespread use of plastic posting bags, and courier bags, has in my experience led to problems of spoilage and accelerated decomposition.

Juice sampling. The proposition that sampling for monitoring purposes could be simplified by collecting samples of fruit for juicing or juice itself at the packing shed, juice factory or winery has been studied for citrus and winegrapes. There had been previous reports from Florida but the modern work with citrus began with a report by Moss and Higgins (1978) working with Valencia oranges in the Murrumbidgee Irrigation Area.

Seasonal changes in juice composition were found to be small and good correlations were reported between fruit quality factors (important in citrus) and nutrient concentrations. Moss and Higgins (1978) pointed out that there were both positive and negative aspects to the sampling and analysis of juice as a means to

understanding the nutritional status of citrus. Positive factors included rapidity, better correlation with fruit quality factors than leaf tests, and samples were easy to collect. Negative factors included low calcium in juice, storage and transport of juice samples was more difficult than dry leaf tissue, and the lack of standards.

Gallasch *et al.* (1984) at the Loxton Research Centre have taken this work further by establishing relationships between juice nutrient concentrations measured in different ways and those from standard leaf samples from 50 well managed orchards.

In 1982 and 1983 linear correlations (r^2 values varied between nutrients) were obtained between concentrations of most nutrients in leaves and juice but the correlations are not the same from year to year.

Further possible advantages of juice sampling are that surface contamination, as occurs with leaves, is avoided and sampling can be more timely.

In the search for more precise standards against which nitrogen status in winegrapes can be measured, the concentrations of arginine and other amino acids in grapejuice (must) collected at maturity have been examined by Kliewer and Cook (1974) for Sultana in California. They found a correlation between arginine and crop yield. The technique was simple in that all that was required was simple filtration and dilution before running the assay. Unfortunately there are differences in the major amino acids in various varieties of grapevines (proline is common in some) and substantial calibration work is needed if this technique is to be widely used.

Tuber analysis: potatoes. Maier (1986) reported that potato tubers sampled at harvest gave a good representation of the potassium status of potato crops. A composite of a single 1–2 mm thick slice taken from each of 30–40 tubers was the sample size chosen. This sampling unit explained 31% of the variance of relative yields. It would be informative to know if different sample sizes would alter this relationship.

Nitrate nitrogen analysis: potatoes. Williams and Maier (1990*a*) have investigated the relationship between yield and petiole nitrate-N concentration in potato. Their sampling unit was a minimum of 30 petioles to represent an experimental plot. It is clear from this work that good reproducibility in defining critical nutrient ranges can be achieved using this sampling procedure. These authors emphasise that samples should be taken at closely defined stages of development rather than on the basis of days from planting. In extending this work to the nitrate-N quick test (Williams and Maier 1990*b*) retained the 30-petiole sample but excised a 10–20 mm section from near the centre of each petiole and extracted sap from a composite sample. An extremely good correlation between sap nitrate-N and dry matter nitrate-N was obtained which allowed them to calculate values for a quick test critical nutrient range. Samples collected for the quick test are normally collected in the morning and transported to the laboratory over melting ice.

Fruit analysis: apples. Reasons for variability in the storage behaviour of apples have long been the subject of intensive research. It has been shown that the incidence of many of the common pre- or post-harvest disorders of apple fruits are related to different concentrations of a number of inorganic nutrients within the fruits (e.g. Ferguson and Watkins 1989) have reviewed the literature relating to a single disorder, bitter pit. Differences in mineral concentration which lead to changes in fruit behaviour have been found to be small so precision is important. Various approaches to sampling have been used in the study of apple fruit disorders (skin, cortex, whole fruit, wedges or sectors minus seeds etc.). Statistical work has been done on the numbers of fruit required to represent a population. Perring (1978) suggests 20 fruit as a minimum. Other literature emphasises the need to represent the population of fruit in the orchard.

Waller (1980) discussing the use of fruit analysis in a commercial situation, reported some unpublished work of D. A. Holland which showed that the number of fruit in a sample to give 95% confidence limits for differences of ± 10% was as follows: nitrogen, 30; phosphorus, 10; potassium,10; calcium, 80; magnesium, 25. Holland's group at Wye chose a 30-fruit sample. Samplers were instructed to avoid: (i) abnormally small or large fruit; (ii) abnormal trees in relation to disease or size; and (iii) to take samples in relation to the numbers of fruits on any section of trees.

Clearly more fruit are needed if calcium status is to be estimated accurately so the 30-fruit sample was a practical and economic compromise.

To make commercial apple fruit analysis practically possible, each fruit is sub-sampled to reduce the amount of fresh tissue which must be macerated. Opposite sectors of as little as 8–12% of the whole fruit were found to be as representative as large sectors (Samuelson and Holland 1983).

Time of sampling studies have shown that the predictive value of apple fruit analysis is better the closer to harvest the sample is taken (Waller 1980).

Zinc and copper: shoot tip sampling. There are a few reports which suggest that the growing shoot tips of deciduous woody perennials may be useful to provide an indication of tree or vine zinc and copper status. [e.g. P. A. Watkins pers. comm. with apples, and Christensen and Jensen (1978) with grapevines]. Where the efficacy of foliar sprays is being studied this approach may have some added value as samples which have not received spray application can be analysed.

Biochemical tests. These tests usually rely on measurement of enzyme activity in the plant as an

indicator of the functional supply of the mineral nutrient in question (e.g. Bouma 1983) or induction of the enzyme by addition of the deficient nutrient. Some examples include: molybdenum, nitrate reductase; iron, peroxidase; copper, ascorbate oxidase; zinc, carbonic anhydrase.

In all such cases fresh unstressed material is needed to allow appropriate extraction and assay of enzyme activity without any complications which might follow wilting and re-hydration (e.g. Snir 1983). Great care must, therefore, be taken in the transport step.

Discussion

In summing up the important issues raised at the Goolwa Workshop more than 10 years ago Loneragan (1981) pointed out with respect to sampling that: (i) workers with perennial crops had a different approach to those who were concerned with annual crops because they often had different objectives [he contrasted comparative sampling as used for trouble shooting with the more sophisticated requirements involved in collecting monitoring samples]; (ii) selected tissues were seen generally as preferable to whole plant samples; (iii) age of material was important; (iv) environmental conditions were important (e.g. insect or disease stress, drought or waterlogging); (v) who should take the sample was of concern (i.e. farmers or trained technical personnel).

Since then there has been strong growth in the use of diagnostic and prognostic plant analysis in annual crops and some growth in the use of monitoring services in perennial crops in Australia.

While current concerns with respect to sampling are not much different from those expressed in 1981 they may be better focussed. The major issues relating to sampling and sample handling are: (i) is the user of plant analysis fully aware of its limitations and in particular those imposed by inadequate attention to sampling protocols?; (ii) can the untrained person take a proper sample or should a specified level of training be encouraged before samples are accepted by a laboratory? (This season I have received grape leaf blades instead of petioles and whole almond spurs instead of spur leaves submitted to our commercial service.) It seems that the need for a proper sample cannot be stated often enough. The sorts of difficult judgements in leaf identification which must be made by untrained people have been mentioned earlier. Better diagrams and photographs might help the unskilled but on-the-spot training would be better; (iii) are the collection and handling specifications for normal samples, and 'sap test' samples precisely enough defined with respect to numbers required to represent an area, time of day, sample handling, etc?; (iv) how well is contamination understood? Our company's questionnaires have been refined over many seasons but we continue to find unexplained contamination, e.g. a grower may report copper sprays instead of Copper Curit (R) which contains the fungicide Zineb, or a non-copper fungicide such as Ridomil (R) may be reported when Ridomil Plus (R), which contains copper, has been applied. Should we, in fact, specify use of gloves for routine sampling?; (v) should washing be added to the procedure recommended by commercial laboratories? When leaves or other tissues are mailed or sent by courier to the laboratory the samples are often wilted by the time they arrive, and Australian laboratories have chosen not to wash even to remove dust because of the risk of leaching nutrients from the tissue; (vi) how can we improve sample transport from the farmer to the laboratory?

Difficulties encountered in commercial services include inappropriate posting or consignment, unexplained delays and postal system errors resulting in delays in notification of arrival. Polyethylene lined padded mail bags and plastic courier bags are widely used which can lead to sweating and rot.

Conclusions

In commercial services the precision of sampling needs to be improved and transport to the laboratory should be re-examined. For many crops the statistics of sampling have apparently not been well tested. Despite these inadequacies the robust nature of plant analysis for many crops has meant that it continues to be an extremely valuable tool in the hands of the informed crop manager.

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