NUTRITION OF APPLE ORCHARDS: NUTRIENT BUDGETS AND THEIR RELATION TO FERTILISER REQUIREMENTS

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ABSTRACT

The role of nutrient budgets as a tool for estimating fertiliser requirements of orchards is reviewed and discussed. Major losses of nutrients from the orchard can occur in the harvested fruit crop although appreciable losses can also occur by removal of pruned wood. The large amounts of nutrients stored in the standing stock of the trees (framework plus roots) means that responses to fertiliser applications in mature orchards may not occur for several years after the application.

Large amounts of Ca are held in the tree framework yet storage disorders of fruit related to Ca deficiency (e.g. bitter pit and lenticel blotch pit) are a common problem in apple orchards throughout the world. This highlights the importance of the internal nutrient budget within the tree. Levels of leaf nutrients are not necessarily a good reflection of nutrient concentrations in the fruit. Fruit nutrient levels not only reflect the nutrient status of the tree but also the relative mobility of nutrients within the tree, as well as other factors such as fruit size. Estimates of nutrient removals in fruit crop plus pruning wood, when used in conjunction with soil and leaf analysis are likely to give useful guides to the fertiliser requirements of orchards.

Additional Key Words: Fertiliser recommendations, leaf analysis, soil analysis.

INTRODUCTION

The fertiliser requirements of crops are often determined by carrying out field trials under the varying conditions in which the crop is normally grown. However, field experiments with fruit trees are considerably more expensive than those for annual agricultural crops because the trees take up an appreciable area for a relatively long period of time (e.g. 10 years). Furthermore, in fruit tree research one cannot expect to detect, at the 5% level of significance, differences between treatments of less than about 15% in fruit yields (Greenham, 1976). Thus, there is little precise information on the response of fruit trees to fertiliser treatments. Since fertilisers often constitute a small proportion of the total cost of fruit production there is little likelihood of further intensive research to determine the fertiliser requirements of apple trees.

Even so, fertiliser mismanagement in the orchard can lead to the development of nutrient imbalances within the tree. Such imbalances (e.g. high K/Ca ratio) can lead to the occurrence of physiological disorders in fruit during storage (e.g. bitter pit, lenticel blotch pit and perhaps watercore) and therefore low export quality. Matching the fertiliser nutrient inputs to an orchard with the nutrient requirements of the trees is therefore particularly important in order to consistently produce export quality fruit.

At present, both soil tests and leaf analysis are used as aids to making fertiliser recommendations for orchards. Useful indications of the probable fertiliser requirements of fruit crops can be obtained by studying the nutrient cycle in the orchard. Estimates of the quantities of nutrients removed from the soil by a crop of satisfactory performance can suggest the order of magnitude of appropriate fertiliser applications. In this paper the value of nutrient budgets as a tool for estimating fertiliser requirements of orchards is reviewed and discussed.

NUTRIENT BUDGET

Construction of a nutrient budget involves the measurement of inputs (e.g. fertilisers) and losses (e.g. removed in the harvested crop) of nutrients from the crop-soil system. For example, the amounts of nutrients removed in a crop can easily be calculated if the elemental nutrient content and yield of the crop is measured. The transfers of nutrients from one component of the system to another can also be quantified in a budget (e.g. return of crop residues to the soil).

The grassed-down deciduous orchard receives nutrient inputs in the forms of fertilisers, irrigation water, rain, orchard sprays and dust. The cyclic return of nutrients occurs in throughfall (nutrients washed or leached from tree leaves and bark by rainfall intercepted by the tree canopy), leaf-fall in autumn and by return of grass clippings following mowing. Nutrient losses occur through the removal of fruit crop and pruning wood from the orchard as well as leaching and gaseous losses.

Nutrient distribution within vegetation

Before discussing gains, losses and returns of nutrients within the orchard, it is interesting to look at the amounts of nutrients within the trees (tops plus roots) and orchard sward (tops plus roots). The results for a 14-year-old Golden Delicious orchard in Canterbury, New Zealand (trees spaced 4 m within rows 5 m apart) are shown in Table 1.

TABLE 1: Distribution of dry matter and nutrient content in the components of the total vegetation of a 14 year old Golden Delicious apple orchard in winter (kg/ha). Data from Haynes and Goh (1980a).

Orchard Component	Dry Matter	N	P	K	Ca	Mg
Apple Trees	20302	67.3	11.6	50.7	104.4	11.5
Grass Sward	5648	171.9	9.7	149.8	51.8	12.7
Total Vegetation	25950	239.2	21.3	200.5	156.2	24.2

Demand for nutrients by the sward followed the pattern N>K>Ca>Mg>P, while that for the trees followed the trend Ca>N>K>P>Mg. Over two thirds of the N and K in the total vegetation occurred in the sward component. For P and Mg, the nutrient reserves were equally distributed among the sward and trees, but two-thirds of the Ca reserves occurred in the tree wood. This highlights the large Ca requirement that a mature apple tree has.

Nutrient losses

The quantity of nutrient elements removed from orchards in the harvested crop is of course very dependent on both the variety of tree and the crop load. The amounts removed from the one orchard studied by Haynes and Goh (1980a) are shown in Table 2. Another estimate of the likely removals of nutrients in fruit (in kg nutrient per tonne of fruit produced) can be gained from the data presented in Table 3. Data for two apple varieties from five randomly chosen Canterbury orchards, are shown along with mean values. Results presented in Tables 2 and 3 incidate that considerable amounts of K and to a lesser extent N, are removed in the fruit crop. British data (Greenham, 1976) have confirmed this assertion. In fact, K is the most abundant nutrient in the apple fruit and a very high proportion of net annual uptake of this element is taken

TABLE 3: Amounts of nutrients in the fruit of Splendour and Braeburn trees from five Canterbury orchards.

Tree Variety and Orchard Number	Nutrient stock (kg nutrient per tonne fresh fruit)					
	N	P	S	K	Ca	Mg
Splendour						
1	0.51	0.10	0.03	0.89	0.05	0.04
2	0.44	0.11	0.03	1.1	0.04	0.04
3	0.44	0.08	0.03	0.98	0.06	0.04
4	0.54	0.10	0.03	1.2	0.04	0.05
5	0.60	0.11	0.04	1.4	0.02	0.05
mean	0.51	0.10	0.03	1.1	0.04	0.04
Braeburn						
1	0.57	0.09	0.04	0.89	0.04	0.04
2	0.48	0.10	0.03	1.3	0.04	0.05
3	0.43	0.14	0.063	1.4	0.03	0.05
4	0.54	0.13	0.03	1.3	0.03	0.05
5	0.71	0.14	0.05	1:5	0.02	0.05
mean	0.55	0.12	0.04	1.3	0.03	0.05

TABLE 2: Annual nutrient losses and returns for a mature Golden Delicious apple orchard (mean values for 2 years' data). Data from Haynes and Goh (1980a).

Losses and Returns	Amount /ha/yr	kg/ha/yr				
		N	P	K	Ca	Mg
LOSSES						
Removed in fruit	5950 kg	21.3	4.0	60.0	4.4	3.7
Removed in prunings	507 kg	3.9	0.5	2.3	5.6	0.6
Total removed		25.2	4.5	62.3	10.0	4.3
Leaching loss	381 mm	33.1	0.1	1.7	44.7	35.3
TOTAL LOSS		58.3	4.6	64.0	54.7	39.6
RETURNS						
Leaf-fall	2211 kg	32.6	3.9	25.7	53.5	6.7
Petal fall plus fruitlet drop	227 kg	3.2	0.3	4.3	1.5	0.4
Foliar leaching	133 mm	1.9	0.4	3.1	1.1	0.7
TOTAL RETURN		37.7	4.6	33.1	56.1	7.8
Grass Mowings	10873 kg	507.7	28.4	108.5	90.7	21.0

from the orchard each year in the crop. The data of Haynes and Goh (1980a) for example, showed that during winter the amount of K in the total tree biomass was 50.7 kg K/ha (Table 1); (33.9 kg K/ha in trunk and branches and 16.8 kg K/ha in roots). This is only slightly less than that which was taken from the orchard each year (60 kg K/ha) in the harvested crop.

Quantities of nutrients removed in the pruning wood do not seem to be large (Table 2), but they are significant particularly in the case of Ca. The large amount of Ca removed in the pruning wood in comparison with that lost in the crop illustrates the immobility of this element within trees. In fact, although only a small amount of Ca was lost annually in the crop (4.4 kg Ca/ha) the amount of Ca in the total tree biomass in winter was large (104.4 kg Ca/ha). In many cases, nutrients in pruning wood will constitute a nutrient return rather than a loss. This is because mulching mowers are used to break up the wood which is then left on the orchard floor.

Nutrients can also be lost from the orchard by being leached down the soil profile below the tree rooting zone. Such losses obviously differ tremendously between orchards due to differences in soil type, rainfall, irrigation, fertiliser rates and levels of available nutrients present in the soil initially. Leaching losses of all the major nutrient elements, except the immobile phosphate can be reasonably large. In the study of Haynes and Goh (1980a), leaching losses of K were small (Table 2), but this may not be typical of most situations. The small leaching losses of K from the orchard studied were probably due to the large amounts of K being taken up by the trees and removed annually in the fruit crop. Annual removals in this way were slightly higher than the annual fertiliser inputs of K (Tables 2 and 4).

Gaseous losses of N through denitrification (the gaseous loss of nitrogen, as N_2 and nitrous oxide, N_2O) have not been measured in the orchard. Such losses are sometimes estimated as about 10 per cent of the fertiliser N applied, although losses are highly dependent on environmental factors such as moisture content, aeration, temperature and pH.

Nutrient returns

The major returns of nutrients taken up by trees occur as leaf-fall (Table 2), but also include shed blossoms and fruitlets and nutrients washed or leached from trees leaves and bark (foliar leaching) during periods of heavy rainfall. As noted previously, pruning wood can also constitute a nutrient return where mulching mowers are used.

The largest nutrient return in leaf-fall was that of Ca. This is because as the leaves senesce in autumn, very little Ca is remobilised from leaves compared with other elements (Hill, 1980).

Nutrient returns to the orchard floor by the cut grass sward are very large in magnitude in comparison with leaf-fall from the trees. The quantities of nutrients returned in clippings on the orchard studied were in the same order as those found in many temperate pastures (Wilkinson and Lowrey, 1973). In all probability, the sward takes up most of the nutrients released by its mowings, thus rendering them unavailable to the trees.

However, the cycling effect of the mown sward can apparently maintain nutrients such as P and K in plant-available forms and thus increase uptake of these elements by the trees (Stott, 1976; Haynes, 1980). The growth of the grass may also reduce leaching losses of nitrate-N and hence reduce concomitant losses of nutrient cations such as Ca and Mg (Haynes and Goh, 1980b). The elimination of the grassy vegetation from the orchard floor often leads to a gradual loss of basic cations (e.g. Ca and Mg) from the surface soil and a consequent decrease in soil pH (Haynes and Goh, 1980c).

It should also be noted that the large amount of N used by the grass sward during its growth (Table 1 and 2) can have extremely detrimental effects on the growth of young trees (Goode and Hyrycz, 1976). This is because young apple trees do not possess a large extensive root system so that the tree roots compete directly with the roots of grasses for available soil N and also water. Thus, clean cultivation or very wide herbicide strips, to eliminate such competition, are used in the first 2-5 years of an orchard's life.

Nutrient additions

Nutrient additions may occur, to a small extent, in rainfall, irrigation water and dust. By far the greatest inputs are added as fertiliser applications (Table 4).

The quantities of fertiliser added to an orchard depend upon recommendations made to the grower and on his own judgement. In the particular orchard used by Haynes and Goh (1980a), Nitrophoska blue was applied in September and November of each year, each at a rate of 200 kg/ha. In the first year, an additional dressing of 100 kg/ha of urea was applied in February.

Additions of N to the orchard may also occur through symbiotic N_2 fixation if clover and other leguminous species are present in the swards. In comparison with all grass-only swards, the beneficial effect of a white clover sward on N uptake and growth of trees has been demonstrated in young apple orchards (Bould and Jarrett, 1962). However, in a mature apple orchard, shading of the ground near the base of the trees during summer plus the fact that orchard swards are often allowed to grow reasonably high before mowing means that the clover component of the sward is often out-competed by the faster, taller growing, less light-

TABLE 4: Annual nutrient inputs and budget for a mature Golden Delicious apple orchard (mean values for two years' data). Data from Haynes and Goh (1980a).

Inputs and Budget	Amount ha/yr	kg/ha/yr N	P	K	Ca	Mg
Rain	792 mm	—	—	5.0	4.2	2.9
Irrigation water	91 mm	9.6	—	1.9	17.1	1.3
Fertiliser		71.6	20.4	57.2	14.0	5.6
TOTAL INPUTS		81.2	20.4	64.1	35.3	9.8
Inputs minus losses		+22.9	+15.8	+0.1	−19.4	−29.8

demanding grasses (Haynes and Goh, 1980d). Input of N to orchards in this way is therefore difficult to assess and probably differs greatly among orchards.

Inputs minus losses

The budget of nutrients (inputs minus losses) for the orchard site studied by Haynes and Goh (1980a) is shown in Table 4. The values shown are only applicable to the particular site studied and the results cannot be applied directly to different orchard sites.

It is evident that losses of the nutrient cations Ca and Mg exceeded inputs so that a net loss occurred. The total annual input of K during the two years was about the same as the amount taken annually from the orchard at fruit harvest. Although total losses of Ca and Mg substantially exceeded total inputs, fertiliser inputs were similar in magnitude to losses in fruit crop plus pruning wood. Hence the negative budget values for Ca and Mg do not indicate that higher fertiliser applications are required, rather they probably reflect large leaching losses due to more-than-adequate fertiliser inputs in previous years.

The positive nutrient budget for N and P, plus the fact that fertiliser inputs greatly exceeded amounts taken from the orchard in fruit plus pruning wood, indicated that the rates of fertiliser N and P applied were higher than required.

IMPLICATIONS OF BUDGET

Potassium is the most abundant nutrient in the apple fruit, hence the level of cropping will greatly influence the demand for K and therefore the requirement for potash fertilisers. In direct contrast, the Ca content of fruits represents only a tiny proportion of the total uptake of the element by the tree. Indeed, the Ca requirement of the mature apple tree is remarkably high compared with that for other nutrients yet the amount of Ca reaching the fruit is very small. During a single fruit-growing season, the fruit accounts for 40% of the total dry weight accumulation by a mature apple tree while only about 2% of the total Ca uptake goes to the fruit (Dudley and Hadlow, 1973). The fact that Ca deficiency is a common nutritional disorder of apple fruits (Sharples, 1980; Vang-Peterson, 1980) emphasizes the fact that such a disorder is usually a problem of distribution within the tree which is caused by the characteristic immobility of Ca within plant tissues (Vang-Peterson, 1980). A deficiency of Ca, and sometimes Mg, in the fruit can be induced by an imbalance of cations within the tree, particularly if excess K applications have been applied (Greenham, 1980; Shear, 1980).

The contents of Mg and P in apple fruits are small and of the same order as are their contents within the trees themselves. Generally, the small quantities of these elements utilised by trees means that response to P and Mg fertilisers are not common except on very deficient soils.

Although the N content of the fruit is moderately high, as is its content in the tree framework, a deficiency of N is not common except on young orchards with grass competition. In fact, historically, fruit growers have had more problems in trying to restrict N supply than in trying to increase it. A high supply of N during late summer characteristically results in a depression in fruit redness and in keeping quality of the fruit. The use of grass in orchards was at one time seen as a means of limiting the availability of soil N during summer to improve fruit colour. Growers then found it necessary to apply fertiliser nitrogen probably, at least in part, to maintain the grass. Now that the herbicide strip is used down tree rows, competition between the tree and grass roots is substantially reduced (Atkinson, 1977; Atkinson and White, 1980). In Europe, where the herbicide strips are wide (one-third herbicide strip and two-thirds grass are sometimes used) there is again a problem of how to restrict the availability of N. Several workers have suggested that applications of N to mature orchards growing in the herbicide strips are not necessary (Bramlage *et al.*, 1980; Greenham, 1980).

ROLE OF SOIL AND LEAF ANALYSIS

Soil tests can give indications of potential deficiencies, oversupplies or imbalances of nutrients within the soil. At present, the decision on whether or not to apply fertiliser, and if so which nutrients need to be applied, is often reached on the basis of a soil test. The use of soil test data is particularly important during the developmental phase of an orchard. Once fertilisers have been applied to correct deficiencies and imbalances in the soil, and soil test values have reached adequate levels, then only maintenance fertiliser applications (to replace what is removed in fruit and pruning wood) need be applied.

Leaf analysis is an important monitoring technique since it records what has occurred within the tree. Thus foliar analysis can confirm and/or diagnose nutrient deficiencies, toxicities or imbalances within the tree.

The use of soil and leaf analysis is not, however, clear cut. Robinson (1980), for example, concluded that researchers had made little progress in the previous ten years toward establishing reliable techniques for predicting quantitatively the nutrient applications required for deciduous tree fruit crops. This is largely because although the nutrient status of some soils (as determined by soil tests) is found to be correlated with leaf nutrient content of fruit crops growing on them, in other cases no such relationship is found. In fact, the large reserves of nutrients within the framework and roots of mature fruit trees means that the nutrient content of leaves and fruits may not be related to that in the soil. Furthermore, fertiliser applications to a mature orchard may not affect the growth and leaf and fruit nutrient status of the trees for some years after their application.

Levels of leaf nutrients are often not a good reflection of concentrations of nutrients in the fruit. As already noted, fruit nutrient levels are not only a reflection of the nutrient status of the tree but also of the relative mobility of nutrients within the tree. In the case of Ca, factors such as fruit size and tree moisture status may greatly influence fruit Ca concentrations. There is, for example, a characteristic inverse curvilinear relationship between fruit Ca concentrations and fruit diameter (Perring and Jackson,

1975) so that fruit Ca concentrations decrease as fruit size increases. Thus, orchard management practices which influence fruit size will have important effects on fruit Ca concentrations. Tree moisture status can also be important since during hot sunny days when transpiration rates are high, moisture stress may lead to withdrawal of water and Ca from the fruit (Himelrick and McDuffie, 1983).

In view of the above discussion it is perhaps not surprising that in a recent survey of the nutrient status of apple orchards in Canterbury, it was found that levels of soil, leaf and fruit Ca, Mg and K were not generally significantly correlated with one another. Such a finding underlines the complexity of tree fruit nutrition. Whilst acknowledging that this complexity exists, the use of a nutrient balance approach provides a simple and reliable basis for fertiliser recommendations. This is because once the approximate yields of an orchard block are estimated, the major losses of nutrients can also be easily estimated.

CONCLUSIONS

Estimates of nutrient removals in fruit crop plus pruning wood, when used in conjunction with soil and leaf analysis, are likely to give useful guides to the fertiliser requirements of orchards. These measurements are the basis of a new nutrient model which is currently being developed jointly by MAFTech scientists at Ruakura and Lincoln to predict fertiliser requirements of apple orchards.

REFERENCES

Atkinson, D. 1977. Some observations on the root growth of young apple trees and their uptake of nutrients when grown in herbicide strips in grassed orchards. *Plant and Soil 49:* 459-471.

Atkinson, D., White, G.C. 1980. Some effects of orchard soil management on the mineral nutrition of apple trees. *Acta Horticulturae 92:* 241-254.

Bould, C., Jarrett, R.M. 1962. The effects of cover crops and N, P, K fertilisers on growth, crop yield and leaf nutrient status of young dessert apples. *Journal of Horticultural Science 37:* 58-85.

Bramlage, W.J., Drake, M., Lord, W.J. 1980. The influence of mineral nutrition on the quality and storage performance of pome fruits grown in North America. *Acta Horticulturae 92:* 29-39.

Dudley, P.J., Hadlow, W.C.C. 1973. The distribution of energy to the components of the tree. Report of the East Malling Research Station 1972, pp. 87-88.

Goode, J.E., Hyrycz, K.J. 1976. The effect of nitrogen on young, newly-planted, apple rootstocks in the presence and absence of grass competition. *Journal of Horticultural Science 51:* 321-327.

Greenham, D.W.P. 1976. The fertiliser requirements of fruit trees. *Proceedings of the Fertilizer Society, London* 157, 32 pp.

Greenham, D.W.P. 1980. Nutrient cycling, the estimation of orchard nutrient uptake. *Acta Horticulturae 92:* 345-352.

Haynes, R.J. 1980. Influence of soil management practice on the orchard agro-ecosystem. *Agro-Ecosystems 6:* 3-32.

Haynes, R.J., Goh, K.M. 1980a. Distribution and budget of nutrients in a commercial apple orchard. *Plant and Soil 56:* 445-457.

Haynes, R.J., Goh, K.M. 1980b. Seasonal levels of available nutrients under grassed-down cultivated and zero-tilled orchard soil management practices. *Australian Journal of Soil Research 18:* 363-373.

Haynes, R.J., Goh, K.M. 1980c. Some observations on surface soil pH, base saturation and leaching of cations under three contrasting orchard soil management practices. *Plant and Soil 56:* 429-438.

Haynes, R.J., Goh, K.M. 1980d. Some effects of orchard soil management on sward composition, levels of available nutrients in the soil and leaf nutrient content of mature 'Golden Delicious' apple trees. *Scientia Horticulturae 13:* 15-25.

Hill, J. 1980. The remobilisation of nutrients from leaves. *Journal of Plant Nutrition 2:* 407-444.

Himelrick, D.G., McDuffie, R.F. 1983. The calcium cycle: uptake and distribution in apple trees. *HortScience 18:* 147-151.

Perring, M.A., Jackson, C.H. 1975. The mineral composition of apples.. Composition in relation to disorders of fruit imported from the Southern Hemisphere. *Journal of the Science of Food and Agriculture 20:* 651-689.

Robinson, J.B.D. 1980. Soil and tissue analysis in predicting nutrient needs. *Acta Horticulturae 92:* 29-39.

Sharples, R.O. 1980. The influence of orchard nutrition on the storage quality of apples and pears grown in the United Kingdom. *Acta Horticulturae 92:* 17-28.

Shear, C.B. 1980. Interaction of nutrition and environment on mineral composition of fruits. *Acta Horticulturae 92:* 41-50.

Stott, K.G. 1976. The effects of competition from ground covers on apple vigour and yield. *Annals of Applied Biology 83:* 327-330.

Vang-Peterson, O. 1980. Calcium nutrition of apple trees: a review. *Scientia Horticulturae 12:* 1-9.

Wilkinson, S.R., Lowrey, R.W. 1973. Cycling of mineral nutrients in pasture ecosystems. *In* Chemistry and Biochemistry of Herbage (G.W. Butler and R.W. Bailey, eds.), pp 247-315. Academic Press, London.