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Fertilizer management of fruit trees: evaluation of tree nutritional status and soil fertility

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ABSTRACT: In fruit tree fertilizer management, yearly nutrient application rate should be established according to the amount of nutrient removed, on the basis of soil nutrient availability. With regard to nitrogen (N), the fraction available for root uptake includes nitrate- and ammonium-N (N_{min}). Tree mineral status is traditionally evaluated through foliar analysis. However, new strategies for earlier tree nutritional evaluation are being tested (i.e. flowers, buds and young leaves analysis). Leaf nutrient concentration must be compared to the optimum range established for each variety in the different areas of cultivation and phenological stages. Foliar applications of N are recommended early after bloom, when a high fruit set is expected, with soil low temperature and high moisture or in post harvest to promote the building of N reserves. To prevent pre- and post-harvest fruit disorders, calcium foliar application should be scheduled for apple varieties such as Fuji, Braeburn, etc. susceptible to such disorders. Late season sprays with $CaCl_2$ are preferred to maintain the ratio K:Ca lower than 30.

Index terms: ammonium-N, calcium, foliar nutrition nitrate-N, leaf analysis, nutrient use efficiency.

EVALUATION OF SOIL FERTILITY AND TREE NUTRITIONAL STATUS

Sustainable orchard fertilizer management should take into consideration soil fertility, tree nutritional status, tree nutrient requirements, and kinetics of nutrient uptake. Soil fertility can be evaluated through soil chemical and physical analysis as well as observation of soil profile.Soil total nitrogen (N) gives an indication of the potential soil fertility, however it is not sufficient to understand N availability for root uptake. Soil mineral N (N_{min}) concentration is much more helpful to define the N availability for tree, and includes ammonium-N (NH_4-N) and nitrate-N (NO_3-N), the final products of organic N mineralization.

Tree nutritional status can be evaluated by foliar analysis that measure the nutrient concentration in leaves; it is however necessary to know the optimal ranges for each variety, grafting combination, area of cultivation, and phenological stage. To be helpful, these values should be obtained as early as possible, to prevent possible deficiencies that may occur during the vegetative season (Tab. 1 and 2). Apple young leaf N concentration is quite high, then it decreases fast in the first 40 days after flower petal drop and, at a slower rate, during fruit cell enlargement. While most of nutrient leaf concentration is steady through the season or at least decreases slightly (Aichner and Stimpfl, 2002), leaf calcium (Ca) concentration increases from flower petal drop to shoot apical bud set. Consequently, to avoid mistakes in the evaluation of tree nutritional status, it is important to compare leaf analysis with appropriate standards obtained in the same phenological stage.

To have an early diagnosis of nutrient deficiencies flower analysis might be recommendable in stone fruits. Results obtained on peach showed that flower iron (Fe) concentration is mostly related to the previous year Fe avilability (Toselli et al., 2000). For other nutrients (i. e. N, Ca and Mn) the possibility to predict summer leaf concentraton has been showed in cherry (Jimenez et al., 2004)

The amount of nutrients removed by trees depends on genotype, tree age, vegetative growth, soil and climate conditions, crop load, tree density, training system, soil management, water supply, etc. Macro and micronutrient taken up by Mondial Gala apple trees grafted on M9 in the first 6 years are reported in table 3 (Scandellari et al., 2010). Data show that potassium (K) and Ca are the two major nutrients taken up by tree, followed by N. At the end of the season, the percentage of nutrients in the leaves, and consequentely recycled with leaf fall, is maximum (50%) for Ca, followed by magnesium (Mg = 39%), K (34%), while fruits removes a high amount of K and a low amount of phosphorus (P), Mg and N. Similar study carried out on peach showed a yearly removal of N ranging from 90 to 130 kg ha^{-1}, P 25-35 kg ha^{-1}, K 70-10 kg ha^{-1}, Ca 25-30 kg ha^{-1}, Mg 11-16 kg ha^{-1} (Toselli, personl communication).This knowledge allow to define the application rate for each nutrient, considering that only the nutrients partitioned to the fruits and skeleton are removed from orchard ecosystem, while those found in leaves and in wood removed by pruning are recycled and will be released through mineralization (Tagliavini et al., 2007), at a rate that is uncertain, usually faster for K and slower for Ca and N. The knowledge of the kinetics of nutrient uptake is necessary to maximize nutrient uptake efficiency, particularly for N-NO_3, that easily moves through soil profile.

NUTRIENT FERTILIZATION MANAGEMENT

Nitrogen

In spring, tree vegetative growth of deciduous species relies on N stored the previous season in twigs, branches, trunk and roots (Toselli et al., 2000). At full bloom, about 95% of N in the spur leaves comes from re-mobilization through the N internal cycling (Millard, 1995). Later, from flower petal drop, N from root uptake increases and becomes dominant as a source of N for shoots and fruit growth (Neilsen et al., 1997).

In apple and pear trees, from fruit set to the end of shoot growth, N is partitioned to shoots and fruits, while at the end of summer, N taken up by roots and remobilized by leaves is stored in perennial organs while fruits do not represent a sink for N, consequently N applied the last 4 weeks before harvest does not increase fruit N concentration (Toselli et al., 2000).

Soil N availability for root uptake can be evaluated through the determination of N_{min} (Tagliavini et al., 1996), that can be compared to tree N requirement in the different stages, and eventually increased by applications of fertilizer.

Nitrogen foliar application is recommended when N deficiency has been established (Weinbaum, 1988); this condition is often observed after full bloom, when a high fruit set occurs, especially if soil conditions impair root uptake. This happens when soil temprature is low and moisture is high. Foliar application of urea-N can promote an increase in leaf chlorophyll with positive effect on carbon fixation and partitioning to leaves, seeds and fruits (Doroshenko and Alyoshin, 2002). Foliar applications of N are also often required in post-harvest to build N reserves (Tagliavini et al., 1998), stimulate bud formation, increase fruit set and yield the following season.

In apple Golden Delicious (Toselli et al., 2004) most of the urea-N sprayed to the canopy is absorbed by the leaves in the first 24 hours after application and around 80% is absorbed within a week. Among the characteristics that improve leaf N absorbion are leaf hair, that increase water retention (Hall et al., 1997).

Other macro and micronutrient fertilization

Optimal soil P concentration in the Po Valley is around 10-20 mg P kg^{-1}, considering that P is immobilized in soil, it can be applied at rates higher than tree requirements. If used in fertigation, P increases its mobility along the soil profile. In clay sois K availability can be reduced by high soil cationic exchange capacity, in this situation foliar applications repeated several times (Southwick et al., 1996) are recommended. Salts like KCl and KNO_3, can be sprayed at a rate of 7-10 g l^{-1} (equal to 3-4 g of K l^{-1}) dissolved in about 800-1000 l ha^{-1}. Also fertigation can be a suitable mean to apply K in clay soils, since water promotes K movement to the absorbing roots. The introduction of grass in orchard soil management is another strategy to promote K mobility. Unlike Ca, in most apple varieties (i. e. Braeburn, Fuji, etc.), K is partitioned to the fruits until harvest (Zavalloni et al., 2001), thus soil K availability should be carefully evaluate to avoid pre- and post-harvest fruit disorder-K:Ca-ratio-related.

Calcium promotes membrane and cell wall stability, in many fruit trees it allows a good quality at harvest and post- harvest and prevents fruit disorders (i. e. apple bitter pit, internal breakdown, etc.) particularly frequent in pomefruit (Sharpless and Johnson, 1977). The disorder incidence is often related to the ability of fruit to accumulate Ca during the season, the longer the time of accumulation, the lower the disorder susceptibility. The incidence of post-harvest disorders is stimulated by low crop load, high vegetative growth, low number of seeds. Consequentely, pollination is important to reduce disorder incidence, probably because seeds increase fruit strength as a sink (Bramlage et al., 1990). Calcium uptake of apple fruit is maximum early in the season (Schlegel and Schoenherr, 2002), then it decreases in summer and increases again few weeks before harvest. Foliar application of Ca are reported to be effective in increasing Ca concentration, however this reponse is environmental-, soil-, and variety-dependent. Number of sprays can vary from 2-3 in varieties with a low susceptibility (Gala and Rome Beauty), to 6-8 for the most susceptible to post harvest disorder (Fuji, Braeburn, etc.) at 10 day-intervals. Among salts, $CaCl_2$ showed good results at 0.1-0.6 g Ca l^{-1}.

Magnesium and Mn are involved in some apple disorders such as leaf necrotic spots and leaf early drop, reported in South Tyrol (Thalheimer and Paoli, 2002), that can be prevented by foliar application of Mg and Mn. Manganese can be deficient in sandy, calcareous, sub-alkalyne and with a high concentration of antagonists such as Ca e Mg.

Boron (B) application should be scheduled to promote pollen vitality and fruit set and prevent fruit drop. Usually B is applied before bloom, however, in *Rosacee* species, B is a mobile nutrient in plant and consequentely it can be applied in fall to be remobilized in the following spring.

The use of soil or foliar applied Fe synthetic chelates is recommended to prevent or cure Fe deficiencies that are frequent in peach, pear, kiwifruit, grape, citrus, etc. when grown on calcareous soil where Fe precipitates as $Fe(OH)_3$ resulting unavailable for root uptake. Intercropping fruit tree species susceptible to Fe-deficiency with graminaceous species is effective in increasing soil availability of soluble Fe, hence in alleviating Fe chlorosis symptoms.

Figures and Tables

Table 1 - Leaf macro and micronutrient concentrations (on dry matter) observed in apple orchards of cv Fuji in Emilia-Romagna region in three phenological stages.

Nutrient	Time (days after full bloom)		
	7	48	90
N (%)	3.40–3.90	2.40–2.80	2.40–2.70
P (%)	0.20–0.35	0.18–0.30	0.15–0.30
K (%)	1.20–1.80	1.20–1.70	0.80–1.40
Ca (%)	0.80–1.30	1.00–1.30	1.20–1.60
Mg (%)	0.20–0.30	0.25–0,30	0.20–0.40
Fe (ppm)	100–150	70–100	70–95
Mn (ppm)	11–220	15–45	22–55
Cu (ppm)	13–40	8–15	8–16
Zn (ppm)	30–70	28–50	20–30

Table 2 - Leaf macro and micronutrient concentrations (on dry matter) observed in peach orchards of cv Stark RedGold in Emilia-Romagna region in three phenological stages

Nutrient	Time (days after fool bloom)		
	15	55	120
N (%)	3.40–4.30	3.00–3.80	2.80–3.50
P (%)	0.20–0.50	0.15–0.30	0.15–0.25
K (%)	1.30–1.90	1.50–2.10	1.70–2.20
Ca (%)	0.80–1.40	1.60–2.50	2.40–3.60
Mg (%)	0.18–0.30	0.30–0.45	0.40–0.60
B (ppm)	14-50	20-60	15-60
Fe (ppm)	55–90	60–100	70–95
Mn (ppm)	20–40	20–45	20–50
Cu (ppm)	9–30	8–15	10–20
Zn (ppm)	35–50	25–50	20–40

Table 3 - Total amount of nutrients removed and nutrient partitioning in apple tree organs of cv Mondial Gala in the first 6 years after plantation.

Nutrient	total (kg/ha)	skeleton (%)	leaves (%)	wood (%)	fruit (%)
N	358	30	24	21	25
P	66	33	17	22	28
K	435	15	34	11	40
Ca	489	30	50	17	3
Mg	105	19	39	13	29

(Scandellari et al., 2010).

CONCLUSIONS

Orchard fertilization should be based on soil nutrient availability and tree requirements. To increase nutrient uptake efficiency, nutrients should be available according to kinetics of root uptake. Foliar fertilization is justified when soil conditions prevent availability of nutrient for root uptake.

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