Improving the Nutrient Efficiency of Tree Crops

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Introduction

Essential mineral nutrients applied to crops are a cost to growers and, poorly managed, contaminate air and/or water resources. Over the past 30+ years, fertilizer costs (USDA, 2006) and evidence of the negative impact of fertilizer nutrient contamination of air and water resources have increased significantly (Tilman et al., 2002). Therefore, an increase in nutrient efficiency, measured as net income, plant yield, or nutrient absorbed or applied per unit available nutrient, should benefit the grower and the environment*. Of particular interest to California agriculture is tree crop nutrient efficiency, as perennial crops continue to replace annual crops in many regions of the central valley – a region of the state with rapid population growth and subsequent pressures on air and water resources. The purpose of this paper is a brief review of factors affecting tree crop nutrient efficiency with a focus on nitrogen (N), potassium (K), and zinc (Zn) – the nutrients most commonly limiting tree crop production in California. A review of past advances in tree crop nutrient efficiency and current challenges in tree crop and orchard nutrient efficiency will be presented.

Much of the information presented in this paper was developed from research to improve N use efficiency (unit N absorbed by crop per unit available N) in tree crops. Nitrogen is frequently the most limiting essential nutrient in natural ecosystems (Tilman et al., 2002), and, in agriculture, combines the factors of high crop need and environmental risk associated with its use as a fertilizer (Tilman et al., 2002; Weinbaum et al., 1992)}.

Nutrient efficiency has different definitions, including economic and agronomic yield per unit applied or available N. Wide differences in production economics between tree crop species affect nutrient efficiency presented using economic factors. To avoid confusion, tree crop efficiency is defined in this paper as nutrient use efficiency, which is calculated as unit nutrient absorbed by the plant per unit nutrient available.

Tree Nutrient Efficiency

Research conducted in the last quarter century of the 20th century has led to a significant increase in knowledge useful for improving tree nutrient efficiency. These works document the influence of application timing, application method, soil type, rootstock, irrigation management, tree growth/crop load and other factors on tree nutrient efficiency. The affect of these different factors on nutrient efficiency varies between

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*The benefit to the grower and the environment may not be equal – at least in the short run (Raum and Johnson, 1999). However, since excessive nutrient application and tree uptake may reduce fruit quality or yield and/or increase production costs (Crisosto et al., 1997; Daane et al., 1995), economic and environmental goals may be closer than is immediately evident. Elements, and are particularly influenced by chemical form and soil mobility.

The use of destructive sampling of mature trees, an expensive and time consuming practice, has been key to many of these developments, as differences in tissue analyses do not necessarily reflect changes in whole tree nutrient content. Research into N efficiency also benefits from the availability of ^{15}N, the non-radioactive isotope of N.

In general, attempts to efficiently fertilizer tree crops has followed the process outlined tree nutrient budgets (Anderson et al., 2006; Brown et al., 2004; Tagliavini et al., 1996): 1) determine nutrient requirements through the season for adequate plant growth and high crop yield, 2) Evaluate stored or natural N availability, 3) determine if additional N is needed in excess of stored or natural N, 4) assess application efficiency, and 5) determine final amount of fertilizer to deliver (if any).

All these considerations assume biological and physical soil environment (adequate moisture, well drained soils, neutral soil pH, etc.) suitable for good tree health and crop production. Water management in tree crops affects growth and mobile nutrient movement (Quiñones et al., 2005).

Nitrogen

A nutrition program that delivers the most efficient N use in tree crops currently includes soil application of biologically realistic N fertilizer rates synchronized with periods of elevated tree N use applied and managed to reduce losses of N from the root zone. Foliar application of N fertilizer may be included in this program. Such a program may include some measure of soil N (non-fertilizer N) or early-season tree N status and was developed, at least in part, using research results discussed below.

Mineral nitrogen, as nitrate or ammonium, can be highly mobile in soil if managed improperly, which contributes to lower N efficiency. Fertilizer applied as ammonium or urea can volatilize as ammonia from the soil surface (Mattos et al., 2003). Nitrate-N, the form of N most commonly found in neutral pH, well-drained soils, can be absorbed by tree roots, immobilized in soil organic matter, absorbed by weeds, leached below the root zone with excess soil water, or lost as NO_x following denitrification (Havlin et al., 1999). Consequently, N fertilizer use efficiency (fertilizer N absorbed by the tree per unit fertilizer N applied) estimates range from <10-50% for soil applied N fertilizer in tree crop production with efficiencies in the middle to lower end of this range commonly reported (Huett and Stewart, 1999; Weinbaum et al., 1984).

However, despite these multiple competitive fates in orchard soils, fertilizer N can be rapidly absorbed by tree roots. Fertilizer N appears in the canopy of mature trees within 4 weeks of application to the soil (Huett and Stewart, 1999). Relatively rapid N uptake permits the use of multiple, small doses of fertilizer N to improve N efficiency (Quiñones et al., 2003).

Most efficient N applications are synchronized with tree N demand. There is a high correlation between healthy tree N absorption potential and tree N demand and tree N demand is highest during periods of rapid vegetative and/or fruit growth (Muñoz et al., 1993; Weinbaum et al., 1978). Differences in tree age, tree size, and crop load potential affect the relative amount of

N needed for the appropriate horticultural benefit (e.g. rapid tree growth or high quality crop production) depending on tree age.

The importance of relative crop load to N efficiency in mature tree crops can not be overestimated. Crop load is the most significant factor affecting mature, bearing tree N requirement and a key input to prescribing efficient fertilizer N applications. [Tree N crop content is second only to K in many crops, for an example, see (Weinbaum et al., 1994).] In addition, due to recycling of nutrients from fallen leaves and prunings, the crop represents the primary loss of nutrient from the orchard over time (Weinbaum et al., 1992)

Current soil N absorption is not needed to sustain tree growth at all times during the season. Consequently, fertilizing during periods of low N use and reduced potential for N use efficiency should be avoided. Trees store N in leaves and/or woody tissue (Niederholzer et al., 2001; Rosecrance et al., 1998b). Stored N can buffer growth from the need for current root N uptake and allows the temporal separation of tree growth and N absorption. However, storage sites are limited to woody tissue in deciduous trees during the winter, and N demand to fill this storage capacity is relatively small compared to that during periods of rapid growth in the summer (Niederholzer et al., 2001). Thus, fall N fall N fertilizer demand is significantly less than during the spring and summer in many tree crops.

Tree genotype, not human management practices; determine changes in tree N content. Trees appear to have a finite capacity to use available soil N and demonstrate the capacity to self-regulate net N uptake once that capacity has been met (Youssefi et al., 2000). Thus, since excess N cannot be forced into trees, matching accurate amounts of fertilizer N to periods of rapid growth and crop N requirements is a major step towards improving tree N efficiency. N application, without reducing application rate to reflect current tree N demand (growth and/or storage) in the early spring or fall risks highly inefficient losses of fertilizer N from the root zone via leaching water or denitrification.

Application methods and practices can also affect tree N efficiency. Foliar N application, particularly using urea (Furuya and Umemiya, 2001), can improve tree N efficiency. Foliar urea application provides significantly higher N efficiency than soil applied N (Rosecrance et al., 1998a), but repeated applications are needed to deliver total annual N requirement (Johnson et al., 2001). Peach trees fertilized with fertilizer N via foliar spray, only, produced smaller fruit than soil-fertilized trees (Johnson et al., 2001), but fruit size was not affected when apples were similarly treated (Dong et al., 2005). Nitrate leaching was reduced when apple trees were treated with repeated urea foliar applications compared with the same rates and timings of soil applied urea (Dong et al., 2005). Injection of soluble N fertilizers with irrigation water (fertigation) can facilitate more efficient use of fertilizer N (Quiñones et al., 2003), but excessive water application can push mobile N forms (nitrate and/or urea) below at least a portion of the active root zone (Hanson et al., 2006).

Areas of further research to improve tree nutrient efficiency as defined in this paper include use of slow release N fertilizer, evaluation of the potential for ammonia losses from trees and soil, plant breeding to select for genotypes that produce more crop per lower unit N, and the affect of root zone nitrate concentration in/on N uptake potential. An effective tool to estimate soil N available through mineralization from soil organic matter in a given year would be valuable to better predict the quantity of soil available N. An effective test to assess tree N status in spring time would also be helpful. Finally, research to develop low cost practices to increase soil organic matter could help to increase soil N availability, improve soil water holding capacity and reduce nitrate leaching.

<u>General guidelines to improve fertilizer N efficiency in California tree Crops</u>

- Match rates and application timing to tree demand (fruit growth, shoot growth, and storage). See N budget models (Anderson et al., 2006; Brown et al., 2004)
- Don't apply N when leaves are not present.
- On highly permeable soil (loamy sand, sands) multiple, small applications of fertilizer N should be used to reduce the potential of N leaching.
- Incorporate as quickly as possible, by water or cultivation, broadcast urea or ammonium fertilizers.
- Irrigate efficiently, using some form(s) of use-based scheduling (ET, soil moisture, plant moisture, etc.)
- Time fertilizer injection so that fertilizer is delivered just into the active root zone.
- Use leaf analysis and a visual examination of tree growth to help evaluate fertilizer program/rates and guide future practices.
- Consider foliar urea application instead of late summer/post harvest soil N application.

Potassium

While tree K needs are as much or more than for N in many crops, K use efficiency in tree crops presents different challenges and is much less studied. [K is generally believed to be less of a potential environmental contaminant than N.]

In soil, the K^+ is generally much less mobile that nitrate-N, especially in high-K affinity soils (e.g. soils high in organic matter and//or clay). Consequently, K losses from the root zone are significantly less than for N, but it is often necessary to apply K fertilizer in advance of crop need for effective and efficient K tree use. Use of fertigation compared with localized soil application (banding) of K fertilizer can accelerate plant availability of fertilizer K (Uriu et al., 1980). Calcium application (as gypsum) can be used to move K further into the soil and perhaps increase K availability (Carlson et al., 1974). Foliar application(s) of potassium nitrate deliver K more efficiently than soil applications (Southwick et al., 1996).

Zinc

Tree Zn requirement is very small relative those for N or K (Weinbaum et al., 1994). Zinc is highly immobile in most orchard soils, and annual or semi-annual foliar applications are commonly used to improve tree Zn status. Because of the risk of phytotoxicity form highly soluble foliar Zn materials sprayed in the growing season, inefficient rates of Zn are applied as insoluble Zinc oxide or in the fall or dormant periods as zinc sulfate. Research in California is currently underway to evaluate a range of different Zn foliar materials in an effort to improve tree Zn efficiency (Johnson and Brown).

Rootstocks for the same crop may display different Zn absorption potential (Brown et al., 1994). Thus, a long term strategy for improving Zn efficiency may be found in development of rootstock(s) with high Zn absorption capacity.

Orchard Nutrient Efficiency

Variability in tree size and yield across a field is common in California orchards. Yet, in the author's experience, fertilizer is applied in most of those orchards at a fixed rate across the entire field, regardless of tree health or size. Even when that fixed rate is developed with attention to all the factors listed in the section above for maintaining efficient tree nutrient use, variability in tree size, crop load, soil depth, soil texture and other factors will affect overall orchard nutrient efficiency.

Development and recent commercial availability of remote sensing technology now allows identification of distinct management zones within an orchard (Zaman and Schumann, 2006a), even down to a per tree basis (Zaman and Schumann, 2005a; Zaman et al., 2005b). Commercial availability and accuracy of variable rate fertilizer application technology to utilize this information differs between foliar or soil applied fertilizers.

Tree sensors, commercially available on existing sprayers, allow efficient fertilizer delivery to foliar and no application to gaps in the tree row. While inherent differences in canopy spray coverage result from radically delivered spray patterns common to most orchards sprayers (Manktelow et al., 2004), the combination of tree sensors with foliar fertilizers allows for the most efficient nutrient delivery systems currently available to growers

Soil applied variable rate fertilizer delivery (VRFD) is currently under study for use in orchards. Considerable research has been reported from Florida, where shallow water tables and readily leachable sandy soils present a significant challenge to efficient nutrient management in citrus production. In those orchards systems, tree canopy has been correlated with crop yield (Zaman et al., 2006b), and tree size mapping and variable rate fertilizer application on a per tree basis in large scale experiments in commercial orchards has reduced N and K application 38% without reducing tree nutrient status across the grove (Zaman et al., 2005b). Improvements in equipment response time to allow accurate tree to tree changes in fertilizer delivery are needed (Schumann et al., 2006). [Current VRFD equipment was developed for large soil management units in annual crop production developed from remote sensing of soil differences, and accurate rate delivery changes are made in 4 seconds – roughly the time it takes for the application equipment to pass from one tree to the next in a commercial citrus grove.] While research in pistachio orchards in California has documented individual tree yield differences across large orchards (P. Brown, personal communication), limited public research has, to the author's knowledge, been conducted into orchard-scale nutrient efficiency in California orchards.

Conclusions

Improvements in tree crop nutrient efficiency should improve grower's bottom line while reducing potential for environmental degradation due to nutrient movement out of the orchard. Use of established models for matching fertilization need and the rate of fertilizer to be used, should be extensively ground tested. More research is needed to apply those models to management zones within orchards to improve overall orchard nutrient efficiency.

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