

A. Cover Page

FREP Project Title: European Pear Growth and Cropping: Optimizing Fertilizer Practices Based on Seasonal Demand and Supply with Emphasis on Nitrogen Management

ABBREVIATIONS: nitrogen (N), potassium (K), calcium (Ca), phosphorus (P), zinc (Zn), potassium thiosulfate (KTS), Best Management Practices (BMP), acre (A), per year (/yr), ton (t), actual N (N_{act}), gallon (gal), critical values (CV)

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CPAB's funding cycle: submission of proposals Dec. 1; acceptance or rejection recommended by research committee immediately after the Research Proposal meeting (late January or early February) in which the proposals are presented by the researchers. Subsequently, the research committee's recommendations for an annual research budget are voted on by the Board and announced in mid-March. Thus, we are unable to get a commitment for funding at the time of FREP submissions. However, 2009 funding by CPAB of project by Glozer and Ingels, Efficient Nitrogen Fertilization for Control of Vegetative Growth, \$16,277) is considered to be the initial phase of this project. We might reasonably expect a commitment by CPAB to this project of ~\$10,000 on an annual basis for a 3-year period to augment CDFA funding; we will apply to CPAB for funding during the usual funding cycles.

4. CDFA Funding Request Amount/Other Funding:

CDFA Funding Request for: 2010 (\$50,000), 2011 (\$50,000), 2012 (\$50,000)

In-kind Funding: (please see Scope of Work for Chuck Ingels within annual work plans)

UCCE Farm Advisor Salary and benefits (calculated at 33%)

Chuck Ingels, 'in-kind' Years 1 – 3 = 8% of salary and benefits (\$5,920 annually, \$17760 total)

TOTAL IN-KIND FUNDING (2010-2012) \$17760

Although not calculated into the budgets, CPAB is also providing funding of \$12,122 for 2010 project on postharvest fruit quality and nutrition (in concert with this project) and fertilizer survey of growers for Lake and Mendocino Counties.

B. Executive Summary

Problem: N fertilization recommendations for California European pear trees have been modified from 1991 -- 75 to 125 lb actual N per acre per year ($\#N_{act}/A/yr$) to 2007 -- 2 lb actual N per ton of crop per acre per year ($\#N_{act}/t/A/yr$). The 2007 recommendation establishes BMP based on two physiological premises for N management: (1) efficiency of N use in cropping -- a 30 t/A orchard should receive 60 $\#N_{act}/A/yr$; (2) vegetative vigor control-- no N if average shoot growth exceeds 12 inches. A 2008 survey (Ingels, CPAB report) found N usage in the main production region of the Sacramento River Delta varied from 40-60 $\#N_{act}/A/yr$ (a single organic producer) to a typical rate of $\#N_{act}/A/yr$. Annual shoot growth is often 3-5 ft. Vigor control is difficult with high water tables and leads to higher fire blight (FB) susceptibility; FB management is the highest production cost. BMP should reflect N partitioning spatially in tissues and temporally during the growth and rest cycles to minimize over-usage, increased vigor, and ground water leaching. Growers tend to perceive reduction in N as a risk for reduced crop load and fruit size and that CV's established when tonnage was lower and most fruit went to processing (thus fruit size was less important), or fresh fruit were not stored (often stored 2+ months at present), should be re-evaluated. California's Delta trees are 30 to 100+ years old, may retain tissue nitrogen for years without applied N (1997-2000 unpublished study, Ingels), and are intensively farmed in the single most endangered national waterway (April 7, 2009; <http://www.ens-newswire.com/ens/apr2009/2009-04-08-01.asp>). Fruit quality is dependent on N, Ca, K and P (and their 'balance'); optima should reflect current strategy of maximum yield and 'target fruit'. When fertilizer prices remained low there was less incentive for growers to reduce and closely manage usage; with recent cost increases, growers are more likely to adopt BMP. There is increased interest in alternatives such as early tissue sampling, applications based on in-season crop load evaluation, and 'informed choices' for maximum cost-benefit outcomes, i.e. when reduced or 'skipped' annual nutrient applications result in significant net loss vs. gain.

Project Objectives and orchards in which they will be tested (Elliot 1 and 2, McCormack):

1. Determine the relationship between seasonal tissue N partitioning and concentration and tree productivity and growth (i.e. reassess the currently-accepted leaf N critical values, timing of sampling and tissues tested). **Elliot 1 and McCormack**
2. Compare typical and reduced N to validate recommended N management and the possibility of customizing BMP based on tissue levels, fruit quality and crop load **Elliot 1, McCormack**
3. Quantify effects on crop load and fruit quality due to N, K and Ca as influenced by application amount, form and timing **Elliot 2**
4. Refine current management guidelines for N, K and Ca usage to maintain productivity and fruit quality while reducing potential of over-fertilization **Elliot 1 and 2, McCormack**
5. Monitor and quantify growers' irrigation practices in each trial site with the goal of optimum irrigation management to reduce nitrate leaching. Cooperate with growers to follow recommended irrigation frequency as outlined by UC recommendations (see Pear Production and Handling Manual, UCANR Publication 3483, Mitcham and Elkins (eds), 2007) **Elliot 1 and 2, McCormack**

Project Approach: Pear trees may respond gradually to changes in applied Ca (Raese, 1996) and N (Ingels, 2005). Ingels found gradual reduction in tissue N from 1997 to 2000 with no N-applied (Figure 1; unpublished). Similar gradual change in K status has been reported in apple (Moulton et al. 1998). A practical approach toward the objectives is to identify and use orchards with existing conditions that allow

manipulation, as in the current CPAB project which examines N partitioning, early vs. June sampling, vigor and cropping in 'High N' and 'Low N' orchards (Table 1). These orchards have similar yields (25-30 t/A/yr), tree age, density, soil and growing conditions. The 'Low N' orchard (Elliot 1) has not had 'full N' (120 #N_{act}/A/yr) applied since 2007 as a cost-saving measure, but rather 60 #N_{act}/A/yr. Working with PCAs and growers, we have identified 3 orchards for this project.

Elliot Orchard 1 is our current 'Low N' orchard in which we will compare current 'Low N', which is the recommended N rate (2 #N_{act}/t/A/yr) to the typical grower practice (120 #N_{act}/A/yr). This orchard has had 60 #N_{act}/A/yr since 2007 as a cost-saving measure. Elliot 1 orchard was planted about 100 years ago, probably on 'Winter Nelis' rootstock at an original spacing of 16'x 17' and interplants have been continually added for approximately 30 years, as trees are removed, and to decrease the in-row spacing. The orchard is adjacent to the Sacramento River, on Columbia series silty loam soils. Yields are typically about 25 tons/acre. In 2008, leaf analyses at the end of July showed 3.04%N, 0.17%P, 1.25%K, 1.69%Ca, 0.42%Mg, 24ppm Zn, 24ppm Mn, 112ppm Fe, 10 ppm Cu, 28.1ppm B and 0.011%Na. Of these, only the N is excessive by UC standards. Soil pH was 6.33, nitrates 10.9ppm, ammonium 1 ppm, and of other nutrients tested, only Mg exchangeable appeared excessive at 588ppm. 'Low' to 'very low' soil nutrients included: soluble K, Ca, Mg, and boron. The soil is a mixture of sandy and silty clay-loam.

Elliot Orchard 2 is on Sutter Island in the Delta and has had NO #N_{act}/A/yr since 2007 as a cost-saving measure, adjusted in 2009 to 60 #N_{act}/A/yr. Until 2007 the typical fertilizer program was 100 'units' (#N actual) nitrogen/acre/year immediately after harvest and a fall application of potash (application of K is 'budget dependent'). In 2007 and 2008, no fertilizer was applied. Beginning in 2009, the block was fertigated in spring with KMend (potassium thiosulfate K₂S₂O₃), soluble potash (K₂O) at 25% and S at 17%, by weight, for a total of 150 lb K/acre. The grower reported that he saw little to no reduction in vigor and no loss of yield or fruit quality from 2007 onward. Typical yield is 25 tons/A and this is also fairly regularly cropped, with the yield varying year-to-year by no more than 1-2 tons. Fruit quality has been consistent and without disorders. The fruit has not been 'hard to size' and is picked twice for size.

Until 2007 the typical fertilizer program was 100 'units' (#N actual) nitrogen/acre/year and a fall application of potash (application of K is 'budget dependent'). In 2007 and 2008, no fertilizer was applied. Beginning in 2009, the block was fertigated in spring with KMend (potassium thiosulfate K₂S₂O₃), soluble potash (K₂O) at 25% and S at 17%, by weight, for a total of 150 lb K/acre. In 2010, 2 applications will be made to the soil of calcium nitrate for fast uptake and best influence on fruit size, with the first application the first week of May and the second in mid-June, for 30 units of N each time. Urea (1#/100 gallons/acre) is applied in each fireblight spray for 'fruit finish', for a total of 0.7-2.76 #N/acre.

- Total N usage for 2010 will be 61-63 lb/A
- Ca total will be 47 lb/A

K total will be 150 lb/A (same for fertigation and fall application unless fertigation is reduced)

We will use Elliot Orchard 2 as a test orchard for N:K:Ca effects on fruit quality and cropping, as well as 'budgeted' low N. We will compare the grower's 'traditional' K application (500#-K₂O=150 #K_{act}/A/yr applied to soil in fall) to K fertigation (K₂S₂O₃=28 #K_{act}/A/yr, 3 equal applications during fruit development). Responses to treatment as it affects cropping and fruit quality will be evaluated at harvest.

McCormack Orchard will be used to compare 'optimized' and 'reduced' N to test customizing BMP. McCormack Orchard rows have a N-S orientation with a 'drop' towards the south half, with higher water table and better soil, resulting in increased vigor, earlier harvest and much larger fruit than in the N half. Trees are larger and more productive in the S half of the orchard. Recent management changes (flood changed to solid set sprinkler irrigation, running E-W; better pruning) have increased yields from 20-23 t/A/yr to 30-32 t/A/yr. We propose reducing the #N_{act}/A/yr on the S half from 152 to 90 (fertigated in May-June). The N half N regime will be increased from at 152 #N_{act}/A (fertigation + 60 #N_{act}/A in fall) to 192 #N_{act}/A at the grower's discretion, (fertigation 6-7x May-June = 90 #N_{act}/A from CAN17 + Ca(NO₃)₂ soil-

applied 2x May-June = 40# N_{act}/A + 60 N_{act}/A in fall as urea in a custom blend that includes K muriate potash (300 #/A) and micronutrients) to equalize fruit development rate and vegetative vigor between the N and S halves of the orchard.

In Elliot Orchard 1 and McCormack Orchard the relationship between tissue N partitioning and concentration and tree productivity and growth will be addressed. We will compare early and late sampling of both vegetative and reproductive leaf tissues with 'standard' sampling (non-bearing spur leaves in late June-July) as follows:

1. Timing 1 = fully-expanded shoot and spur leaves from bearing and non-bearing spurs in late April-early May
2. Timing 2 = preharvest (late June, early July); shoot, non-bearing and bearing spur leaves
3. Timing 3 = pre-leaf fall (late September, early October); shoot and spur leaves

Tissue collection and analysis strategy may be altered from year-to-year, as results warrant; in the current study, no differences were found between orchards ('Hi N' vs. 'Low N' orchards), but only among tissue types and by collection timing during spring and preharvest, however, significant differences between 'high' and 'low' N orchards on October 1 were found for N content (Table 3, Figure 2), that varied between orchard. Partitioning into different plant organs and by vegetative vs reproductive organ was significantly different and leaf N values were below the critical values set for mid-summer levels, illustrating both movement of N into storage tissues and probably removal of N with cropping. Buds may not be the best early indicators of N status and earlier collections of leaves during the initial period of fruit growth may be better suited to this problem. The values for buds from the 'low' N orchard are useful for the 2010 cropping year.

In all 3 orchards water nutrient levels, growers' irrigation practices and vegetative growth will be evaluated, as will crop load and fruit quality (size, firmness) at harvest. In addition, at , storage fruit quality and disorders will be evaluated in 2010 in a supporting project funded for 2010 by the California Pear Advisory Board and performed by Dr. Elizabeth Mitcham, Postharvest Specialist, Dept. of Plant Sciences, UC Davis. Fruit will be evaluated for quality and potential physiological diseases/disorders evident at harvest or after storage. The FREP and CPAB projects are intended to complement each other.

In Elliot Orchard 2, leaf tissue sampling will determine the levels of macro- and micronutrients present at the same timings as the other orchards, although sampling will be per replicate block only, not with subsamples within the blocks. Fruit will be stored at 32-34°F for 10-15 weeks and evaluated for external and internal quality immediately before ripening and after ripening. The CPAB project will collect and store fruit tissues from fruit exhibiting disorders, should they arise. Analyses of fruit tissues may follow, should funding be approved for it.

Should yields or fruit quality be substantially reduced as a result of project treatments in any orchard, such that the cooperating grower suffers unsupportable profit loss, we will conclude detrimental treatments and consider the results to be sufficient for purposes of the study; treatment regimes will then be readjusted to optimize the benefit to the grower. Project results and recommendations will be reported in annual FREP conference and annual grower meetings (Delta district and 'Late' district), as well as through popular and scientific publications, internet resources, and educational extension programs.

A survey for fertilizer practices used by Lake and Mendocino Counties growers was also funded by CPAB for 2010, similar to that made for the Delta growing district. When available, this information will be reported with the results of this project.

Project Evaluation Criteria:

1. Were one or more relationships established between N application variables, seasonal N tissue partitioning and fruit, yield and vigor indices?

2. Were one or more relationships established between N application variables, spring tissue N levels and fruit, yield and vigor indices that justify use of early sampling for early nutrient adjustment?
3. Were one or more relationships established between N and K application variables and leaf tissue N, Ca and K levels, fruit, yield and vigor indices?
4. Were recommendations developed for nutrient management to affect with maximum yield, optimum fruit quality and controlled vigor while controlling potential for over-fertilization and excess cost?
5. Were irrigation practices by growers consistent with UC recommendations for pear?
6. Were project data and recommendations communicated to growers via publications, internet resources, and educational extension programs, and to peer scientists via journal articles?

Audience: While California European pear production acreage is declining in favor of other crops, California is the second most important state for pear production, accounting for 32% of U.S. production on only 23% of the national acreage. Many orchards in the Sacramento River Delta, the main-producing district, are 100+ years old with annual production of 25-35 tons per acre. 'Bartlett' is the major summer variety (>98% acreage) in California, with minor varieties that have been included in the statewide marketing order. Grower choice, market demand and packer/shipper preference dictates 'target' fruit production for fresh market and prolonged storage, with very limited demand for smaller, lower quality fruit for canning. Fertilizer costs have risen sharply, challenging growers to produce the maximum tonnage and highest fruit quality within a cost-benefit structure that necessitates re-visiting fertilizer practices. Endangered habitat in the State's waterways similarly dictates fertilizer management for environmental reasons. California's tree fruit producers have never been responsive to these challenges than they are now, as members of an informed and competitive industry.

C. Justification

Problem

N fertilization recommendations for California European pear trees have been modified from 1991 (moderate amount = 75 to 125 lb actual N applied to the soil per acre 'Integrated Pest Management for Apples & Pears') to 2007 (2 lb actual N/ton of crop/acre; Pear Production and Handling Manual). The 2007 recommendation establishes two physiological premises for N management. The first is based on cropping, so that a 30 ton/acre orchard should receive 60 lb actual N per acre per year. The second premise, based on controlling vegetative vigor is to apply no nitrogen if the average shoot length is greater than 12 inches. These criteria address two of the main concerns in nitrogen Best Management Practices (BMP): efficiency of nitrogen use based on crop load and control of vigor through nitrogen management. Despite adjusted recommendations, nitrogen usage among California pear growers in the main production region of the Sacramento River Delta (2008 survey, Ingels; CPAB report) found that N usage among 11 pear growers farming 4,300 acres in Sacramento County varied from 40-60 lb actual N/acre/year (a single organic producer) to 150 lb or more N/acre/year. Most growers reported applying 120-150 units annually, split into 2-3 applications (spring, early summer, and fall), broadcast or injected. Annual shoot growth is often 3-5 times more than the 12-inch shoot growth guideline indicated for no N applied. Vigor control is difficult with high water tables, leading to higher fire blight (FB) susceptibility; FB management is the highest cost of production, requiring frequent foliar applications and pruning out of affected shoots, limbs and sometimes necessitating tree replacement. Pruning for FB exacerbates vigor by encouraging more shoot growth and resulting in subsequent production of FB-susceptible blooms in the following year (Moran et al., 2001). Excessive canopy production shades the inner and lower canopy, reducing flower production and fruitfulness with permanent consequences to cropping. Despite many studies and much 'conventional wisdom' linking excessive vigor to high N fertilization, one California study conducted over a 3-year period with 400 #N_{act}/acre/N vs 0 N applied to 'Bartlett' pear, found no relationship to pruning weights (mass of 1-year-old shoots pruned), but did find a relationship to irrigation level and tree water status (Ramos et al., 1993).

BMP should reflect N partitioning spatially in tissues and temporally during the growth and rest cycles, with emphasis on application of N in forms and at timings that minimize over-usage, increased vigor, and

ground water leaching. Yet, growers tend to perceive reduction in N use as an unacceptable risk for reduced crop load and smaller fruit size and that critical leaf N values are outdated as they were established when tonnage was lower, tree density per acre was lower and most fruit went to processing (thus fruit size was less important), or fresh fruit were not stored (often stored 2+ months at present). Knowledge of BMP for California's Delta orchards is inadequate, where most trees are 30 to 100+ years old, are often inter-planted to increase tree density, may retain tissue nitrogen for years without applied N and crop well (1997-2000 unpublished study, Ingels), and are intensively farmed in the single most endangered national waterway (April 7, 2009; <http://www.ens-newswire.com/ens/apr2009/2009-04-08-01.asp>). Preliminary results from the current study comparing tissue N between 'High N' and 'Low N' orchards shows no difference in %N between orchards, but only among tissue types and timing of sampling (Tables 1 and 2).

Macronutrient balances for fruit quality should also be addressed, as fruit quality for fresh market is more important now than in the past. High nitrogen is considered detrimental to fruit quality, as a balance among nitrogen, calcium and potassium, particularly. In a recent study on 'black end' disorder in pear, Ingels (2005 CPAB Report) found that pears with the disorder exhibited peel levels of potassium far greater, and calcium levels lower, than in healthy fruit (Table 3). Tissue sampling for effects on fruit quality and fruit disorders typically uses fruit tissues. Significant relationships between preharvest fruit mineral composition and corkspot has not been shown, although postharvest measures of fruit with and without corkspot does show a significant relationship (Curtis et al., 1990). Furthermore, fruit vary a great deal with respect to quality and mineral content within the tree canopy (Jackson et al., 1971; Sanchez et al., 1990; Sugar et al., 1992), thus collecting fruit prior to disorder development will not necessarily yield informative results. Comparison of fruit and leaf nutrients associated with fruit quality and disorders sometimes show good correlation between tissues for a given nutrient or binary relationships, but often do not, and the results depend on a number of factors including rootstocks and scion cultivar (Fallahi and Larsen, 1984; Raese and Drake, 1996). This project will measure nutrient levels in leaves to provide a 'baseline', as well as make a comparison among leaf types for sampling. The study by Fallahi and Larsen (1984) used mid-shoot leaves, not non-bearing spur leaves, as recommended by UC for California pear growers.

Growers must depend on past knowledge of orchard performance against their prior management practices, published recommendations, and the cumulative knowledge and outreach by UC researchers, UCCE farm advisors and skilled PCAs. Changing 'what has worked' in the past requires revisiting the criteria for recommended practices. Often growers continue an annual program without sufficient knowledge as to the 'need' for that program to be flexible. Many studies have shown that trees do not accumulate more nutrients via soil uptake when tissue levels are adequate or when nutrients are soil-bound, as occurs with K, Ca and Mg ions. Deficiency symptoms or adverse effects on cropping, growth and fruit quality may take more than one season to develop. Similarly, trees and soils store/sequester nutrients over a period of years and significant declines may only occur after more than one season of reduced or zero application. Some forms of nutrients or methods of application are more effective at producing desired results than others. BMP require evaluation of a complex system of variables.

Figure 1. Tissue N in 'Bartlett' pear, comparing 4 year average leaf levels in trees treated with 90lb actual N/acre/year to trees with no N applied. 'Critical' leaf level of N is 2.2%; 'adequate' N range is 2.3-2.6% (ANR Publication 3483). Ingels,unpublished study.

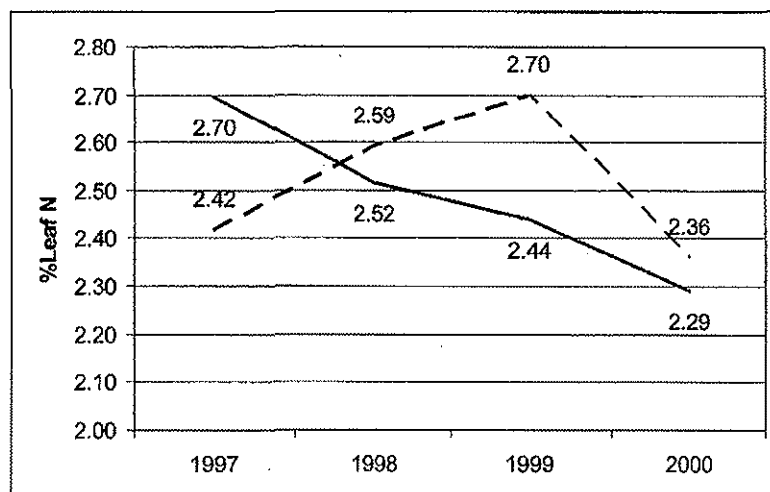


Table 1. Tissue N in expanding pear buds, March 2009 in 'High N' (120 #N _{act} /A/yr) and 'Low N' (60 #N _{act} /A/yr) orchards, 2009 CPAB N management project.		
Orchards	Vegetative terminal bud (%N)	Inflorescence bud (%N)
Low N	1.60 b	2.50 a
High N	1.62 b	2.43 a
Analysis of Variance of nested model N = orchard rep(orchard) bud rep*bud		
Source	df	MS
Model	59	0.32***
Orchard	1	0.1
Rep(orchard)	38	0.06
Bud type	1	14.5***
Rep*bud type	19	0.07
Error	20	0.04

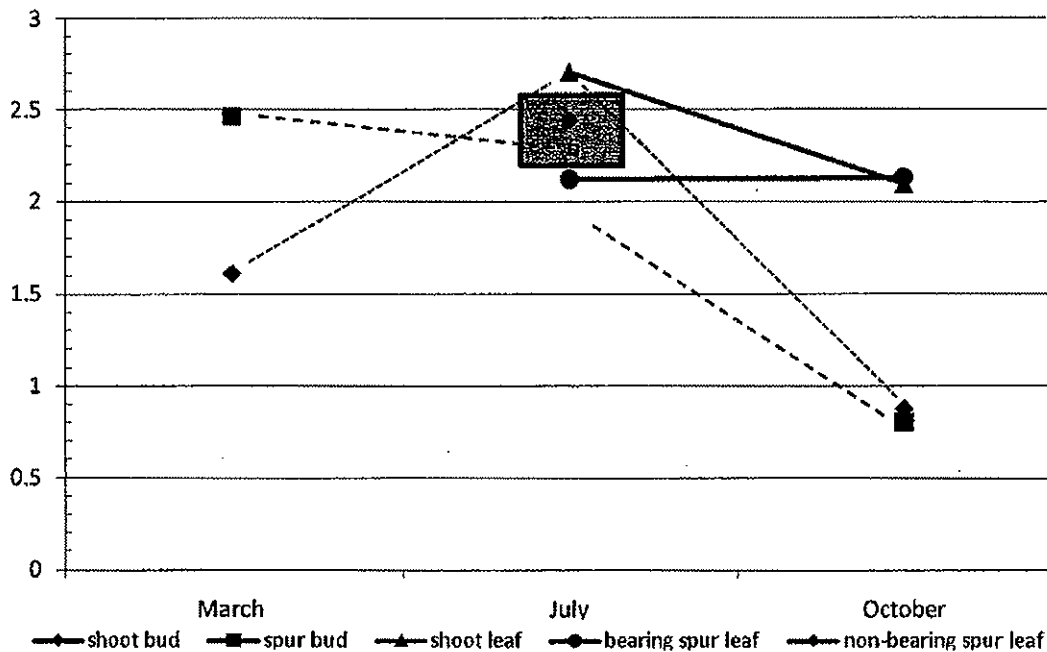
^x Mean separation within orchard for bud type N (within row) by DMRT, $P=5\%$; *** $P = 0.1\%$.

Table 2. Tissue %N in pear leaves, June 2009 in 'High N' (120 #N _{act} /A/yr) and 'Low N' (60 #N _{act} /A/yr) orchards, 2009 CPAB N management project. 'Adequate' leaf level of N is 2.2% (current recommendation).			
Orchards	Vegetative shoot	Bearing spur	Non-bearing spur
Low N	2.75 a	2.09 c	2.48 b
High N	2.64 a	2.15 c	2.41 b
Analysis of Variance of nested model N = orchard rep(orchard) bud rep*bud			
Source	df	MS	
Model	79	0.105***	
Orchard	1	0.05	
Rep(orchard)	38	0.034***	
Leaf type	2	3.323***	
Rep*leaf type	38	0.626	
Error	40	0.009	
* Mean separation within orchard for bud type N (within row) by DMRT, $P=5\%$; *** $P = 0.1\%$.			

Table 3. Tissue N in pear leaves, Oct 1 2009. Within and between orchard comparison of %N in shoot leaves (current year extension shoots, mid-shoot sample), bearing, and non-bearing spur leaves.

Within each orchard (Low N or High N)		Leaf		Bud		Significance			
		Spur	Shoot	Spur	Shoot	Replicate (tree)	Across types	Leaf type	Bud type
120 units N/year	Across sample types	2.17 a	2.13 b	0.89 c	0.81 d	**	***		
	Within leaf or bud type	2.17 a	2.13 b	0.89 a	0.81 b				***
60 units N/year	Across sample types	1.89 b	2.02 a	0.79 c	0.86 c	***	***	NS	
	Within leaf or bud type	1.89 b	2.02 a	0.79 b	0.86 a			*	***
Means separation by LSMeans, P = 0.05. Means with the same letters within rows (a given orchard) do not significantly differ. Error term is rep*leaf type); ***, **, * NS = significant at 0.1, 1, or 5%, non-significant, respectively.									
Comparison within both orchards (combined) and between orchards (compared) testing leaf types for significant differences in %N						Significance			
						Orchard		Sample type	
Combined orchards (Low N + High N)		2.01 b	2.10 a	0.83 c	0.84 c	***		***	
Means separation by Proc Mixed, 'sample type' as fixed effect, orchard and replicate as random effects. LSMeans, P = 0.05; means with the same letters within row (sample types combined across orchards) do not significantly differ. Error term is rep(orchard); ***, **, * NS = significant at 0.1, 1, or 5%, non-significant, respectively.									
Comparison between orchards (combined sample types) for significant differences in %N total									
120 units nitrogen/year			1.50 a ***						
60 units nitrogen/year			1.32 b						
Analysis of Variance of nested model N = orchard rep(orchard) leaftype rep*leaftype; error term is rep(orchard).									
Source		df			MS III				
Model		99			0.619***				
Orchard		1			0.737***				
Rep(orchard)		38			0.030***				
Sample type		3			15.35***				
Rep*Sample type		57			0.010				
Error		60			0.007				

Figure 2. Change in %N content (percentage of dry weight) in 2009 tissues sampled from 'High N' and 'Low N' orchards illustrating cycling and partitioning of nitrogen from expanding buds into actively growing tissues, and finally, into leaves prior to leaf-fall and dormant buds in 'Bartlett' pear. The actual values for both orchards are shown in 'legend' table while average values are represented in the graph. The highlighted rectangular area shows the currently-accepted 'adequate' values for California 'Bartlett', mid-summer shoot leaf %N.



Orchard	bud		shoot leaf	spur	
	shoot	spur		bearing	non-bearing
High N					
March	1.6	2.5			
July			2.75*	2.09**	2.48
October	0.89	0.81	2.17**	2.13**	
Low N					
March	1.62	2.43			
July			2.64*	2.15**	2.41
October	0.86	0.79	2.02**	1.89**	

* Indicates excessive level, ** Indicates inadequate level, based on UC recommendation for non-bearing spur leaves, June-July

Table 34. Potassium and calcium content (ppm) of peel and flesh tissues of whole diseased and healthy fruits, sampled in July 2003.

	Potassium (K)		Calcium (Ca)		K/Ca Ratio	
	Peel	Flesh	Peel	Flesh	Peel	Flesh
Black end	3690	5640	740	430	5.0	13.1
Healthy	741	4290	1050	360	0.7	11.9

Ingels, 2005. CPAB report.

CDFA/FREP Goals

This project directly addresses the research-based development of cost-effective N fertilization practices to improve N fertilizer use efficiency and minimize environment impacts in European pear production. Similar benefits can result from adjustment of other macronutrient fertilization practices for fruit quality and yield. The FREP program goals aligned with this project include 1) nutrient uptake by tree crops, including determination of tissue nutrient thresholds, and 2) guidelines for orchard fertilization patterns, including foliar nutrient management and effective fertilizer timing.

Impact

The California European pear industry represented a value of over \$90 million grown on approximately 15,000 acres in 2002. While production acreage is declining in favor of other crops, California is the second most important state for pear production, accounting for 32% of U.S. production on only 23% of the national acreage. Many orchards in the Sacramento River Delta, the main-producing district, are 30-100+ years old with annual production of 25-35 tons per acre. The 'Late' District in Lake and Mendocino Counties, while smaller in production than the Delta, is an important component of the seasonal production of a number of European pear varieties. 'Bartlett' is the major summer variety (>98% acreage) in California, with minor varieties that have been included in the statewide marketing order. Grower choice, market demand and packer/shipper preference dictates 'target' fruit production for fresh market and prolonged storage, with very limited demand for smaller, lower quality fruit for canning. Fertilizer costs have risen sharply, challenging growers to produce the maximum tonnage and highest fruit quality within a cost-benefit structure that necessitates re-visiting fertilizer practices. Endangered habitat in the State's waterways similarly dictates fertilizer management for environmental reasons. California's tree fruit producers have never been responsive to these challenges than they are now, as members of an informed and competitive industry.

The data and recommendations that will result from this project are expected to provide improved strategies for monitoring N needs in order to manage a fertilizer program by the in-season crop load as well as the actual tissue demand for nutrients on a seasonal and annual time-table, and on a reproductive vs. vegetative growth balance of physiologically-timed applications. Typically, European pear is grown in sandy loam soils in California and the area of greatest annual European pear acreage growth is in areas with highly sandy soils, thus, the potential for point source contamination of ground and surface water is an important issue for growers to address. Optimizing macronutrient balances via BMP necessitates understanding crop load and fruit quality outcomes. Growers will have a better understanding of necessary inputs for a better cost-benefit ratio. Soil and water nutrient content will be better protected.

Long-term solutions

This project has excellent potential for measurable progress toward long-term adoption of improved techniques for more efficient, more effective, and less environmentally risky fertilizer use in California European pear production.

Related research

The 2008 survey of 11 pear growers farming 4,300 acres in Sacramento County showed that N use varies widely, from 40-60 lb actual N/acre/year to 200 lb or more (Ingels et al., 2008 CPAB report). Form of nitrogen used varies a great deal, as well as application timing. Current N fertilization recommendations for mature trees in California are 75 to 125 lb actual N applied to the soil per acre, which is considered a 'moderate' amount (UC IPM manual 'Integrated Pest Management for Apples & Pears. ANR Publ. 3340, 1991). In Oregon high-yielding 'Comice' pears require 40-50 #N_{act}/A/yr with only half of the soil uptake from current-season fertilizer application, the other half from the soil N pool (Hart et al., 1997). This finding is consistent with the current California recommended application timing, which is split as half postharvest and half in spring, to support bloom and growth, respectively. 'Excessive' N causes excessive shoot growth, shading out floral development, reducing yields and encouraging fireblight (van der Zwet and Beer, 1995) and pear psylla due to increased succulent growth (IPM manual).

No means to control new, succulent growth is available except N management and deficit irrigation, the latter of which is impractical in the Sacramento Delta region where water tables are high.

Ingels' 4 year study (1997-2000; unpublished) of N management included a 0-N treatment (no N applied for 4 years), yet leaf N only slightly declined during the study period, never reaching inadequate levels (Fig. 1; 2.2% leaf N is considered adequate; Pear Production and Handling Manual, 2007). Ramos et al. (1994) compared leaf N levels and fruit quality in 'Bartlett' pear trees fertilized with 400 #N_{act}/A/yr to trees without applied N and found that leaf N content on 2 July showed no significant difference (2.31% vs. 2.26%, respectively), yet a highly significant difference was found by August (2.04% vs. 1.89%, respectively). No effect of N treatment was found on fruit yield, size or quality, although this was a single-year trial. Soil nitrate was substantially higher in the fertilized trees.

Our recent study that utilized 2% (v/v) foliar urea for defoliation and dormancy-induction compared to untreated controls found leaf N levels in the excessive range, regardless of leaf type, treatment type or analysis timing (Ingels et al., 2008). A 1995 FREP project found that splitting the N required by peach between soil-applied (50%) and foliar (50%) urea produced a crop of equal fruit size and yield to that obtained by soil-applied nitrogen alone, affording peach growers in California an alternative to reduce soil-applied N (Johnson et al., 2001; www.cdfr.ca.gov/is/frep/projects/completed/Johnson95.pdf). Despite recommended guidelines for N application and growers' use of leaf and soil analyses to manage N application, it is likely that N fertilization is excessive in many Sacramento River Delta orchards, and possibly pear orchards in other districts as well. The harvest of pears removes 1.3 lbs/ton (Weinbaum et al., 1992), thus, a 20-ton crop removes only 26 lbs. N/acre. While additional N is required for vegetative growth, even assuming 50% efficiency of uptake from soil-applied N and equal amount of N required for vegetative and reproductive growth, a typical River Delta orchard may require no more than 100 lb N/A annually if all were applied to the soil. Once trees approach maximum yields, their capacity to absorb more N from the soil is reduced and residual soil N is more likely to contribute to nitrate pollution as well as not being cost-effective (Weinbaum, Pear Production and Handling Manual, 2007; Youssefi et al., 2000). If sufficient N is available, pear trees will not respond to increased N application by improved yield, tree growth or leaf N content (Weinbaum, 2007).

Application timing and method, as well as nutrient form, are critical to optimize uptake, partition to appropriate tissues and minimize leaching and volatilization, sources of N pollutants. Fertilizer N applied a month before harvest is allocated into branches, trunk, roots, and flower buds, while fruit N is not greatly affected (Sanchez et al., 1992). Nitrogen from applications made at or shortly after harvest is sent mainly to the roots, which is utilized for early spring growth and flowering. Early spring applications may be unnecessary since most of this N is allocated into shoot growth, resulting in undesirable vigor. For macronutrients N, Ca and K, spaced, incremental applications made starting 2 months before harvest, when applied as foliar or fertigated treatments, may be adjusted for crop load and current tissue status as opposed to fall soil applications for a crop that is yet uncertain. The relative strengths of vegetative and reproductive sinks (affected by crop load and vegetative vigor) are among the controlling factors of nutrient partitioning into fruits, as well as the particular nutrient. Zavalloni et al. (2001) applied frequent canopy sprays to apple trees and found that Ca was accumulated in apple from fruit set until harvest with preferential accumulation in the peel; K and Mg showed a longer period of accumulation and K flesh content was nearly twice that of the peel.

The current recommendation is to sample mature leaves on non-bearing spurs in late June or early July yearly or every other year, or if deficiency or toxicity is suspected. We know very little about tissue levels for different tissues (bearing spurs, non-bearing spurs, fruit, vegetative shoots) or different periods of growth through the season, other than data from the current study, which has examined vegetative and reproductive buds (March) and, in June, the 'standard' measure of adequacy from current season vegetative shoot leaves, with both bearing and non-bearing spur leaves, as well as bud and leaf tissues in October. These have been compared in a 'High' N orchard vs. a 'Low' N orchard and results for early sampling and traditional sampling times indicate no differences between orchards, but only differences among tissue types and sampling dates (Tables 1 and 2). Indeed, the mid-shoot leaves sampled in June indicated that both orchards had 'high' (2.4-2.6%) to 'excessive' (>2.6%) levels of nitrogen. Nonetheless, bearing spur leaves are generally understood to be the main source of carbohydrates and structural

nutrients to the growing fruit, thus their nutrient level may be more indicative of overall productivity potential. In the current study, non-bearing spur leaves averaged 2.4-2.5% N in June, while bearing spur leaves had 2.09-2.15% N (Table 2). These levels were not significantly different among orchards, despite different N management practices during recent years. October nutrient values, however, indicated significant differences between orchards and within orchards, depending on tissue sampled, whether it was vegetative or reproduction, and whether the orchard had received a low level of N or a 'standard grower practice' level of N (Table 3; Figure 2). Tissue levels for N showed a clear reduction from preharvest levels, that reflect movement of N into storage tissues and removal of N for growth and cropping. These levels were below the critical limits set for mid-summer, non-bearing spur leaves and may provide information about the actual N usage.

Traditional tissue sampling in mid-summer is too late to make adjustments for current season needs. A clear understanding of which tissues sampled will give the best information of N levels relative to cropping in pear is lacking; the leaves sampled are recommended to be from non-bearing spurs, although bearing spurs may have the highest demand for N. Sampling terminal vegetative shoot buds and spur buds prior to bloom has provided an early picture of N status; sampling the same buds in fall prior to leaf drop showed both N status due to cropping and N status due to longer-term postharvest N uptake than mid-summer sampling of leaves would. Sampling tissues prior to harvest, furthermore, doesn't necessarily provide sufficient information about the consequences of nutrient levels as a function of 'mining' by the crop (Ramos et al., 1994).

Macronutrient balances for fruit quality and postharvest disorder reduction have not been adequately addressed for California pear orchards; growers make applications of Ca, K, Zn and 'anything else they think is necessary' (grower comment in survey), in different forms, application methods and timings without having concrete evidence of the value of those practices, other than anecdotal evidence or packing house records. While these sources of information are valuable, they are not incorporated into a widely available or widely accepted knowledge base. This is particularly true for macronutrient effects on fruit size, quality and yield. While growers maintain high N levels for maximum yields, high N ratios with other macronutrients (binary ratios) critical for fruit quality may lead to poor skin color, soluble solids, flavor and fruit density (Hart et al., 1997). In a recent study on 'black end' disorder in pear, Ingels (2005 CPAB Report) found that pears with the disorder exhibited peel levels of potassium far greater, and calcium levels lower, than in healthy fruit (Table 2), yet most California pear orchards are considered 'K deficient' (Pear Production Manual, 2007). Optimum nutrient values for pear trees expressed as binary ratios of macronutrients and based on maximum yield response may provide the best evidence for fertilizer management (Sanz et al., 1997).

Tree demand for nutrients during the critical fruit development period may exceed the tree's capacity for uptake, thus inadequate to meet tree nutrient demand. This problem can be especially true for K which tends to be immobilized by adsorption to soil particles while fruit create a strong sink demand. Thus, incremental foliar or fertigated K applications during fruit development may provide more benefit than fall soil applications. KNO_3 is often added to blight sprays (3-6 lb/A) until oil sprays after petal fall and may be added to codling moth sprays until leaves harden off in spring (B. Zoller, personal communication). KNO_3 may suppress hatching European red mite nymphs when applied at this timing (B. Zoller) and has been reported to inhibit pear psylla in Europe (personal communication, S. Carruthers).

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Contribution to knowledge base

There is need to reassess N need of California European pear for maximum crop yield and good fruit quality for today's market. Whether tissue sampling can be earlier for greater flexibility of fertilizer management in-season is not known, nor whether nutrient content of tissues other than non-bearing spur leaves may correlate better with cropping, fruit quality and vigor control. Seasonal characterization of nutrient levels of bearing spur, non-bearing spur and shoot leaves and buds will provide important data to fill these gaps, and the determination of how various fertilization strategies affect those levels will result in recommendations that will provide improved strategies both for monitoring pear nutritional needs.

Grower use incentives

There are multiple incentives for European pear growers to adopt revised fertilization practices, ranging from environmental stewardship to improved crop yields and fruit quality to reduced labor costs. If this project results in the adoption of reduced rates of N fertilizers for European pear production, the potential for contamination of surface and ground water resources will similarly be reduced. If applications of N are timed to better meet the N demands of the key tissues for fruit production, fruit quality and/or yields may improve crop value. If N applications are timed to prevent excessive vegetative growth, labor costs for annual pruning will be reduced. Targeted N applications timed to satisfy N demand for only the key stages of crop production could reduce unnecessary fertilizer and application expenses. When fertilizer prices remained low there was less incentive for growers to reduce and closely manage usage, however, with current high pricing of fertilizers, growers are more likely to adopt BMP. This project proposes to look at nitrogen management for optimal actual N per year, per acre to control vigor while maintaining high yield and high fruit quality. Readdressing recommended fertilizer application (annual rate, timing and form), particularly of nitrogen, will equip growers with the tools for BMP and reduce potential over-fertilization. Irrigation practices that may impact nitrate leaching should be identified during monitoring of grower practices.

D. Objectives and orchards in which they will be tested (Elliot 1 and 2, McCormack):

1. Determine the relationship between seasonal tissue N partitioning and concentration and tree productivity and growth (i.e. reassess the currently-accepted leaf N critical values, timing of sampling and tissues tested). **Elliot 1 and McCormack**
2. Compare typical and reduced N to validate recommended N management and the possibility of customizing BMP based on tissue levels, fruit quality and crop load **Elliot 1, McCormack**
3. Quantify effects on crop load and fruit quality due to N, K and Ca as influenced by application amount, form and timing **Elliot 2**
4. Refine current management guidelines for N, K and Ca usage to maintain productivity and fruit quality while reducing potential of over-fertilization **Elliot 1 and 2, McCormack**
5. Monitor and quantify growers' irrigation practices in each trial site with the goal of optimum irrigation management to reduce nitrate leaching. Cooperate with growers to follow recommended irrigation frequency as outlined by UC recommendations (see Pear Production and Handling Manual, UCANR Publication 3483, Mitcham and Elkins (eds), 2007). **Elliot 1 and 2, McCormack.**

E. Work Plans and Methods -- Note: all orchards are routinely tested for soil analyses and leaf levels of macro- and micronutrients. We will obtain the growers' records for comparison to our analyses. We will not repeat soil analyses, but will obtain water analyses for N.

This project will be conducted on commercial orchard trees of the standard industry variety 'Bartlett'. Elliot Orchards 1 and 2 are adjacent to the Sacramento River, Elliot 1 on Columbia series silty loam soils; Elliot 2 is on Sutter Island. The orchards have similar yields per acre of ~25 tons and tree ages (original trees ~100 yrs old and interplants or replants approximately one-third as old). Rootstocks are not clearly identifiable due to orchard age, which is typical for the Delta. McCormack orchard, however, is several

miles east of the River Delta, on heavier, shallow soil (Twin Cities Rd). This orchard historically yielded moderate tonnage when flood-irrigated. In the last 4 years fertigation and soil applications of various forms of calcium, nitrogen and potassium at specific intervals and seasonal timings have increased production from 20-22 tons/acre to 30 tons/acre with significantly improved fruit quality. Soils, therefore, are more similar to those of the 'Late District' than in the Elliot Orchards. The rootstock is unusual in that it is *Pyrus ussuriensis*, an Asian pear rootstock.

Treatments will vary within orchards as outlined below, however, sampling procedures will be similar throughout unless otherwise indicated. To characterize the treatment effects on N partitioning for supply and demand, seasonal sampling will be conducted for the key tissues associated with reproduction (bearing spur leaves and non-bearing spur leaves as indicated within the work plan) and vegetative growth (shoot leaves, shoot growth). Random samples from uniform canopy locations and branches (e.g., repeatable units of the canopy, mid-branch segment spur leaves, fully mature shoot leaves, etc.) will be collected, dried and ground for total N analysis by the DANR Analytical Lab at UC Davis. In addition to analysis of total N (and other macro- and micronutrients at Elliot 2) in sampled tissues, field data will be recorded for yield, fruit size, fruit quality at harvest, and new shoot growth (length and number of shoot breaks of sampled branches and/or by pruning weights).

Standard statistical analyses will be performed as appropriate on data (ANOVA, mean separations, etc.).

Task 1: Determine the relationship between seasonal tissue N partitioning and concentration and tree productivity and growth (i.e. reassess the currently-accepted leaf N critical values, timing of sampling and tissues tested; effects on vegetative and reproductive growth). **Elliot 1 and McCormack**

Period of activity: Entire project term

Task product (the same as for Task 2 as an integrated activity): Seasonal characterization of the total N levels in bearing and non-bearing spur and shoot leaves under 'Low N' and 'High N' fertilization practices, leading to a recommendation for the most appropriate time and leaf type to sample for diagnosis of N adequacy and potential for remediation of insufficient levels, as well as optimum N for vigor control, maximum yield and fruit quality.

Subtask 1.1 Elliot Orchard 1: Compare 'Low N' with 'High N'

Subtask 1.1.1 Apply treatment regime

We began a limited regimen of N treatments in 2009 while collecting baseline tissue N data, including KNO_3 spring applications and foliar urea in fall, 2009, 'Low' N treatment regime will be adjusted to conform with UC guidelines, with application of $2\# \text{N}_{\text{act}}/\text{A}$ per ton of crop/A, using the average yield obtained in 2009 (~25 tons/A) as the baseline. Thus, the 'Low' N total amount per year will be ~50 $\# \text{N}_{\text{act}}/\text{A}$. Treatment regimes will be scheduled by cropping year (fall + spring), not by calendar year.

N practices at this orchard:

2006 Spring: $\text{Ca}(\text{NO}_3)_2$ 2x, 200lb each application (mid May, end of June) = $62 \# \text{N}_{\text{act}}/\text{A} + 84 \# \text{Ca}_{\text{act}}/\text{A}$

2006 Fall: $60 \# \text{N}_{\text{act}}/\text{A}$ from ammonium sulfate in early October

Total $\# \text{N}_{\text{act}}/\text{A}/\text{yr} = 122$

2007 Spring: $\text{Ca}(\text{NO}_3)_2$ 2x, 200lb each application (mid May, end of June) = $62 \# \text{N}_{\text{act}}/\text{A} + 84 \# \text{Ca}_{\text{act}}/\text{A}$

2007 Fall: $60 \# \text{N}_{\text{act}}/\text{A}$ from ammonium sulfate in early October

Total $\# \text{N}_{\text{act}}/\text{A}/\text{yr} = 122$

2008 Spring: $\text{Ca}(\text{NO}_3)_2$ 2x, 200lb each application (mid May, end of June) = $62 \# \text{N}_{\text{act}}/\text{A} + 84 \# \text{Ca}_{\text{act}}/\text{A}$

2008 Fall: no N applied

Total $\# \text{N}_{\text{act}}/\text{A}/\text{yr} = 62$

Treatments for FREP project

2009 Fall: urea + zinc sulfate for defoliation and mild thinning (20 #/A each, urea is 46% N to a total of 3.6 A), \pm soil-applied ammonium sulfate (60 #N_{act}/A). Discontinued after 2009.

1. 7.7 #N_{act}/A from urea + 60 #N_{act}/A from ammonium sulfate
2. 7.7 #N_{act}/A from urea

2010 Spring: application of Ca(NO₃)₂ : Ca(NO₃)₂ 2x, 135 lb each application (mid May, end of June) = 42 #N_{act}/A (15.5% N) + 51 #Ca_{act}/A (19% Ca)

Actual #N/A applied, by year			
for 2010 crop			
	Fall 2009	Spring 2010	total
T1	67.7	42	109.7
T2	7.7	42	49.7
for 2011 crop and for 2012 crop			
	Fall 2010	Spring 2011	total
T1	60	50	110
T2	0	50	50

Replicate 'blocks' are based on harvest pattern, as 4 rows per block of 50+ trees each, in a complete randomized block design, however, the grower's pattern of harvest with regard to numbers of rows is quite irregular, changes from year-to-year, and is too unpredictable for treatment blocks to be based upon for yield data. Thus, yields will be assessed by counting fruit on subsampling trees and/or rating crop load and associating fruit size grade percentages with crop load.

A section within the orchard, consisting of 27 trees per row x 4 rows per treatment/replicate combination, was treated with urea in fall, 2009. Three replicate blocks per treatment (N level) were assigned. Four 'subsample sets' of 4 trees each will be assigned to each replicate, at scattered locations. The subsample trees will be as uniform as possible, chosen as adjacent or close to each other and of similar size among the older trees in the orchard. These trees will provide tissue samples, vigor data, cropping data and fruit quality data, with results combined across the subsampled trees within each set to minimize variation among trees and to enlarge the total number of trees sampled compared to individual trees.

Subtask 1.1.2 Begin seasonal tissue N partitioning and concentration

1. Timing 1 = fully-expanded shoot and spur leaves from bearing and non-bearing spurs in late April-early May
2. Timing 2 = preharvest (late June, early July); shoot, non-bearing and bearing spur leaves
3. Timing 3 = pre-leaf fall (late September, early October); shoot and spur leaves

For 2009 trial, 20 trees were selected prior to budbreak, randomly spaced throughout the trial block. Trees were chosen for uniformity and represent the majority of the population (100+ years old). These trees are individually sampled for tissue N. Four 'subsample sets' of 4 trees each within replicates replace individual trees for sampling. Timing 1 (sampling dormant shoot and spur buds) for 2009 (CPAB project) has already occurred; results (Table 1, Table 2 and Table 3, Figure 2) indicate differences between vegetative and reproductive tissue levels of N, depending on whether tissues are vegetative or reproductive, when they were collected, and whether they were from the 'high' or 'low' N orchards. The current sampling schedule may be adjusted as results warrant, to more closely address the project goals.

Reassessment of currently-accepted leaf N critical values will largely be addressed by the combined treatments of 'High' and 'Low' N (spring N \pm fall N) without urea subplots, as yield, quality and vigor components related to tissue N.

Subtask 1.1.3 Assess treatment effects on vegetative and reproductive growth

Begin seasonal growth measurements of cropping, fruit quality, and shoot growth. Fruit will be sampled from harvest bins or subsample groups representing a bulk sample per treatment/subsample replicate for quality (size, weight, firmness, soluble solids). Yield/crop load will be evaluated as number of bins per replicate, or from subsample groups within the replicates. Pruning weights will be obtained for sample trees as a measure of vegetative growth and will be used for reduced tree-to-tree variation.

Subtask 1.1.4 Dry, grind, and analyze tissue samples for total N.

Subtask 1.1.5 Conduct statistical evaluation and interpretation of data; develop interim and annual reports (fall of each year).

Subtask 1.2 McCormack Orchard: Compare 'Low N' with 'High N'

This orchard will be used to compare 'typical' and reduced N to test customizing BMP. McCormack Orchard rows have a N-S orientation with a 'drop' towards the south half, with higher water table and better soil, resulting in increased vigor, earlier harvest and much larger fruit than in the N half. Recent management changes (more aggressive nutritional program with increased inputs, flood changed to solid set sprinkler irrigation, running E-W; better pruning) have increased yields from 20-23 t/A/yr to 30-32 t/A/yr. We propose reducing the $\#N_{\text{act}}/\text{A}/\text{yr}$ on the S half from 192 to 90 (fertigated in May-June) and maintaining the N half at 192 (fertigation + 60 $\#N_{\text{act}}/\text{A}$ in fall) to equalize fruit development and vigor.

Subtask 1.2.1 Apply treatment regime

Beginning in 2010, we will apply all spring fertigation N as is the current practice throughout the block (irrigation runs E-W), applied as 90 $\#N_{\text{act}}/\text{A}$ total (May and June as CAN17 (calcium ammonium nitrate, 17% N). The 'high' N treatment will also receive $\text{Ca}(\text{NO}_3)_2$ (15.5% N) applied to the soil in split applications during May and June and urea in a nutrient blend will be applied in fall. The orchard will be divided in the North and South halves that show differences in vegetative and reproductive vigor and will serve as the 2 treatment groups.

Recently, about 1/3 of the orchard was 'top-worked', grafting over Bartlett into other varieties. The grafted rows alternate 4 rows each with 4 rows ungrafted over 2/3 of the orchard. The grafted trees will not take up a full amount of nutrients, thus, using that part of the orchard would not be representative. We will restrict our trial to the area of original planting with 4-row 'guards' on the outside of the trial block of 16 rows for a 'buffer'. Thus, the trial is replicated, but not at random.

Four replicates of 4 rows each (based on harvest setup) will be used. Yields for each replicate of 4 rows, for each treatment, will be obtained by bin counts. Four 'subsample sets' of 4 trees each will be assigned to each replicate, at scattered locations. The subsample trees will be as uniform as possible, chosen as adjacent or close to each other and of similar size among the older trees in the orchard. These trees will provide tissue samples, vigor data, cropping data and fruit quality data, with results combined across the subsampled trees within each set to minimize variation among trees and to enlarge the total number of trees sampled compared to individual trees.

Treatment 1 (N half)	192 #N/A	fertigation 6-7x May-June = 90 #N from CAN17
		CaNO3 soil 2x May-June = 40# total
		60# fall as urea in custom blend that includes K muriate potash (300#/A) and micronutrients
Treatment 2 (S half)	90 #N/A	fertigation 6-7x May-June = 90 #N from CAN17

Subtask 1.2.2 Begin seasonal tissue N partitioning and concentration (as in Subtask 1.1.2)

The tissue sampling schedule will continue as part of the FREP project in all 3 years. Reassessment of currently-accepted leaf N critical values will largely be addressed by the combined treatments of 'High' and 'Low' N (spring N \pm fall N) with the North and South halves representing soil and vigor differences within the orchard to allow customizing BMP, as yield, quality and vigor components related to tissue N.

Subtask 1.2.3 Assess treatment effects on vegetative and reproductive growth (as in Subtask 1.1.3)

Subtask 1.1.4 Dry, grind, and analyze tissue samples for total N.

Subtask 1.1.5 Conduct statistical evaluation and interpretation of data; develop interim and annual reports (fall of each year).

Task 2: Compare typical and reduced N to validate recommended N management and the possibility of customizing BMP based on tissue levels, fruit quality and crop load **Elliot 1, McCormack**

Period of activity: Entire project term

Task product (the same as for Task 1 as an integrated activity): Seasonal characterization of the total N levels in bearing and non-bearing spur and shoot tissues (leaves) under 'Low N' and 'High N' fertilization practices, leading to a recommendation for the most appropriate time to sample tissues for diagnosis of N adequacy and potential for remediation of insufficient levels, as well as optimum N for vigor control, maximum yield and fruit quality.

Subtasks 2.1 and 2.2 are as above for Task 1, with the potential outcome for customizing BMP based on tissue levels, fruit quality and current season crop load, using Year 1 and Year 2 to evaluate potential for choice prior to harvest, or postharvest, for reducing applications in Spring and reducing Fall application of N or eliminating the Fall application. Should data from Years 1 and 2 provide convincing evidence of benefit for either 'High' or 'Low' N regimes, in Year 3 the optimum regime will be applied to the orchard overall and the outcome tested against the previous 2 years' data.

Task 3: Quantify effects on crop load and fruit quality due to N, K and Ca as influenced by application amount, form and timing of potassium. **Elliot 2**

Period of activity: Entire project term

Task product: Characterization of crop load and fruit quality due to N, K and Ca as influenced by application amount, form and timing of potassium will lead to better understanding of macronutrient balances as they relate to fruit quality and potential correlation to tissue N level, time of sampling and type of tissue sampled. BMP recommendation for macronutrient fertilization under California growing conditions may be revised based on results. The orchard used has been on a 'zero to low' N regime since 2007, thus, the 'typical' relationships for N and other nutrients may provide information on fruit quality and yield in a BMP approach that has been in place for 3 years prior to start of the trial.

Elliot Orchard 2 has had NO $\#N_{act}/A/yr$ since 2007 as a cost-saving measure, adjusted in 2009 to 60 $\#N_{act}/A/yr$. Until 2007 the typical fertilizer program was 100 'units' ($\#N$ actual) nitrogen/acre/year immediately after harvest and a fall application of potash (application of K is 'budget dependent'). In 2007 and 2008, no fertilizer was applied. Beginning in 2009, the block was fertigated in spring with KMend (potassium thiosulfate $K_2S_2O_3$), soluble potash (K_2O) at 25% and S at 17%, by weight, for a total of 150 lb K/acre. The grower reported that he saw little to no reduction in vigor and no loss of yield or fruit quality from 2007 onward. The orchard is 18 acres of Bartlett, planted starting in 1926 with the oldest trees on unknown rootstock (there could be seedling *Pyrus communis* and some Old Home x Farmingdale, and a French rootstock), originally planted to 22 x 22', but periodically interplanted to a final spacing of 22' x 11'. The interplanted trees were put in beginning in the 1960's with *P. calleryana*, which has proven to be too vigorous, light-cropping and prone to fireblight. Since then, additional trees have been put in on Winter Nells. The block is 25 rows with the original trees spaced at 22 feet, 65 trees per row, but with interplants the rows are 130 trees long and 180 trees per acre. Typical yield is 25 tons/A and this is also fairly regularly cropped, with the yield varying year-to-year by no more than 1-2 tons. Fruit quality has been consistent and without disorders. The fruit has not been 'hard to size' and is picked twice for size.

Until 2007 the typical fertilizer program was 100 'units' ($\#N$ actual) nitrogen/acre/year and a fall application of potash (application of K is 'budget dependent'). In 2007 and 2008, no fertilizer was applied. Beginning in 2009, the block was fertigated in spring with KMend (potassium thiosulfate $K_2S_2O_3$), soluble potash (K_2O) at 25% and S at 17%, by weight, for a total of 150 lb K/acre. The block is fertigated one half at a time, with the main line for fertigation running diagonally across the block. Fertigation will be the first of 2 treatments for the CDFA FREP project, the second being No Fertigation, but fall 150 $\#K_{act}/A/yr$, soil-applied in fall as muriate of potash (500# K_2O per acre). Because the block is fertigated in halves, split down the diagonal, we will lay out 4 replicates per half, each replicate consisting of a harvest 'set' of 4 rows each, but without randomization possible. Sampling will be from the oldest trees in the replicates, with tissue and fruit samples combined for each replicate. We will use Elliot Orchard 2 as a test orchard for N:K:Ca effects on fruit quality and cropping, as well as 'budgeted' low N. We will compare the grower's 'traditional' K application (500# $K_2O=150 \#K_{act}/A/yr$ applied to soil in fall) to K fertigation ($K_2S_2O_3=28 \#K_{act}/A/yr$, 3 equal applications during fruit development). Responses to treatment as it affects cropping and fruit quality will be evaluated at harvest.

The Fall application precludes the ability to adjust in-season once the crop load level is determined, while the Spring fertigation schedule allows a range of adjustment depending on crop load level. The Spring application is 10 gal./A potassium thiosulfate fertigated in mid-May, then 2 weeks later, then again 2 weeks after that. Cost \$45/A each application. In addition, 200 lbs. of $Ca(NO_3)_2$ soil is applied twice in spring: 1) early May, and 2) end of June. It has 20% soluble Ca, and it provides 62 $\#N_{act}/A/yr$ as part of the overall N management practice.

This site will be used to compare macronutrient balances of N:Ca:K as affecting fruit quality, based on indices of production and fruit quality.

Additional fertilizer that will be applied starting 2010:

- 2 applications of calcium nitrate for fast uptake and best influence on fruit size, with the first application the first week of May and the second in mid-June, for 30 units of N each time. Calcium nitrate is 15.5% N, so 30 units of N would be 124lb/acre of calcium nitrate. Ca is 19%, so that is 23.56# Ca per acre per application. 2 applications = 60 $\#N$ and 47 lb Ca/A
- Urea (1#/100 gallons/acre) is applied in each fireblight spray for 'fruit finish' as per Dan Strydom. The applications started mid-April, 2x weekly with 3 applications by 4/22 and there will be 3-4 more applications. These go on anywhere from 25-100 gpa each time, for a range of urea total =1.5-6# or 0.7-2.76 $\#N/acre$.
- Total N usage for 2010 will be 61-63 lb/A

- Ca total will be 47 lb/A
- K total will be 150 lb/A (same for fertigation and fall application unless fertigation is reduced)

CPAB-funded project (2010): Fruit will be evaluated for quality and potential physiological diseases/disorders evident at harvest (FREP project) and after ripening, before and after storage (CPAB project). Fruit will be stored at 32-34°F for 10-15 weeks and evaluated for external and internal quality immediately before ripening and after ripening.

The FREP project will continue for 3 years, with potential adjustments made annually depending on each year's results. Tree responses to nutrient changes are generally gradual and disorders may become manifest over time. Should identifiable disorders become significant, using fruit tissue (peel and flesh) analyses are indicated to ascertain the nutrient imbalance that leads to the disorder. In this event, we may choose to freeze fruit tissue samples for future analyses and request funds from CPAB to pursue that work.

Subtask 3.1 Apply treatment regime

Until 2007 the typical fertilizer program was 100 'units' (#N actual) nitrogen/acre/year and a fall application of potash (application of K is 'budget dependent'). In 2007 and 2008, no fertilizer was applied. Beginning in 2009, the block was fertigated in spring with KMend (potassium thiosulfate K₂S₂O₃), soluble potash (K₂O) at 25% and S at 17%, by weight, for a total of 150 lb K/acre. The block is fertigated one half at a time, with the main line for fertigation running diagonally across the block.

Irrigation starts once the orchard dries out and bloom stops (to control fireblight), usually about the 3rd week of May. Each irrigation is once a week, for 9-15 hours, but averaging 12 hours over time, at the rate of 0.1"/hour. Fertigation begins around the 1st of June and will be applied 3-4 times up to harvest, which is typically the first week of July. Fertigation will be the first of 2 treatments for the CDFA FREP project, the second being No Fertigation, but fall 150 #K₂O/A/yr, soil-applied in fall as muriate of potash (500# K₂O per acre).

Should crop load be light in any given year, the fertigation will be reduced to reflect reduced demand – dependent on the grower's decision.

Additional fertilizer that will be applied starting 2010:

- 2 applications of calcium nitrate for fast uptake and best influence on fruit size, with the first application the first week of May and the second in mid-June, for 30 units of N each time. Calcium nitrate is 15.5% N, so 30 units of N would be 124lb/acre of calcium nitrate. Ca is 19%, so that is 23.56# Ca per acre per application. 2 applications = 60 #N and 47 lb Ca/A
- Urea (1#/100 gallons/acre) is applied in each fireblight spray for 'fruit finish' as per Dan Strydom. The applications started mid-April, 2x weekly with 3 applications by 4/22 and there will be 3-4 more applications. These go on anywhere from 25-100 gpa each time, for a range of urea total = 1.5-6# or 0.7-2.76 #N/acre.
- Total N usage for 2010 will be 61-63 lb/A
- Ca total will be 47 lb/A
- K total will be 150 lb/A (same for fertigation and fall application unless fertigation is reduced)

The treatments will not be replicated and randomized in blocks due to the nature of fertigation.

Subtask 3.2 Tissue macro- and micronutrient concentration in leaves (as in Subtask 1.1.2)

The tissue sampling schedule will continue as part of the FREP project in all 3 years. Leaf nutrients will be used as a guideline for future indicator of BMP, as related to yield and harvest fruit quality. Leaf tissue sampling will determine the levels of macro- and micronutrients present at the same timings as the other orchards, although sampling will be per replicate block only, not with subsamples within the blocks.

Subtask 3.32 Assess treatment effects on vegetative and reproductive growth and fruit quality at harvest

Begin seasonal growth measurements of cropping and fruit quality and vegetative growth. Fruit will be stored at 32-34°F for 10-15 weeks and evaluated for external and internal quality immediately before ripening and after ripening. The CPAB project will collect and store fruit tissues from fruit exhibiting disorders, should they arise. Analyses of fruit tissues may follow, should funding be approved for it.

Yield/crop load will be evaluated as either fruit counted on trees or rating of crop load within replicate blocks. Pruning weights will be obtained for sample trees as an additional measure of vegetative growth. Fruit quality (size, weight, firmness, soluble solids) and potential physiological diseases/disorders evident at harvest) will be evaluated from combined samples within the replicate blocks. Disorders associated with low Ca include: bitter pit, cork spot, sunburn, lenticel breakdown, watercore, internal breakdown, low temperature breakdown. Disorders associated with excessive N include: maturity delay, short shelf life, and the same disorders as low Ca, exacerbated by high N. Fruit size is highly dependent on K, less on N (Pear Production Manual, 2007).

Storage fruit quality and disorders will be evaluated in 2010 in a supporting project funded for 2010 by the California Pear Advisory Board and performed by Dr. Elizabeth Mitcham, Postharvest Specialist, Dept. of Plant Sciences, UC Davis. Fruit will be evaluated for quality and potential physiological diseases/disorders evident at harvest or after storage. The FREP and CPAB projects are intended to complement each other. Fruit will be stored at 32-34°F for 10-15 weeks and evaluated for external and internal quality immediately before ripening and after ripening.

Subtask 3.43 Dry, grind, and analyze tissue samples for total N, Ca and K and other macro- and micronutrients in leaf tissues. Conduct statistical evaluation and interpretation of data; develop interim and annual reports (fall of each year).

Task 4: Refine current management guidelines for N, K and Ca usage to maintain productivity and fruit quality while reducing potential of over-fertilization **Elliot 1 and 2, McCormack**

To be initiated: Fall, 2011 To be completed: Dec, 2012

Task product: Based on the results from the 2010-2011 experiments (Tasks 1 to 3), preliminary recommendations will be devised for optimizing N nutrient management to reduce potential over-fertilization and meet production demands of current European pear in California. Potassium and calcium fertilization for optimal fruit quality will also be delineated based on trial results. These will be tested and refined for final recommendations to be compiled for the 2012 CDFA final report.

Subtask 4.1: Data from Years 1-3 will be compiled and analyzed statistically across years and within orchards due to different treatment regimes in each orchard. BMP recommendations will be made and critical values reassessed respective to the current CVs and the trial results.

Subtask 4.2: A final report will be made to CDFA with revised recommendations.

Task 5: Monitor and quantify growers' irrigation practices in each trial site; cooperate with growers to follow recommended irrigation frequency as outlined by UC recommendations (see Pear Production and Handling Manual, UCANR Publication 3483, Mitcham and Elkins (eds), 2007) **Elliot 1 and 2, McCormack**

To be initiated: Jan, 2010 To be completed: Dec, 2012

Task product: Irrigation practices by growers at all sites will be monitored and water usage and frequency of irrigation recorded during Year 1 (2010). As appropriate, the irrigation practices (initial and changed to adhere to recommendations, if appropriate) will be included in the annual reports and final report with any appropriate recommended changes to irrigation practices described.

Subtask 5.1: Irrigation practices by growers at all sites will be monitored and water usage and frequency of irrigation recorded during Year 1 (2010). These records will be compared to the current UC recommendations as published and results discussed with each grower for each site to determine whether the current management of irrigation is within appropriate practices to reduce the likelihood of nitrate leaching. Should irrigation practices be well outside the recommendations, the grower will be asked whether he is willing to adjust his practices, and if not, his reasoning. Should the need for irrigation adjustments arise, these changes will be monitored as before and interpreted with respect to orchard productivity, vegetative vigor and the grower's records for soil analyses. As appropriate, the irrigation data will be included in the annual reports and final report with any appropriate recommended changes to irrigation practices described.

Experimental sites

This project will be conducted on commercial orchard trees of the standard industry variety 'Bartlett'. **Elliot Orchards 1 and 2** are adjacent to the Sacramento River, on Columbia series silty loam soils and Sutter Island (Elliot 2). The orchards have similar yields per acre of ~25 tons and tree ages (original trees ~100 yrs old and interplants or replants approximately one-third as old). Rootstocks are not clearly identifiable due to orchard age, which is typical for the Delta. **McCormack orchard**, however, is several miles east of the River Delta, on heavier, shallow soil (Twin Cities Rd). This orchard historically yielded moderate tonnage when flood-irrigated. In the last 4 years fertigation and soil applications of various forms of calcium, nitrogen and potassium at specific intervals and seasonal timings have increased production from 20-22 tons/acre to 30 tons/acre with significantly improved fruit quality. Soils, therefore, are more similar to those of the 'Late District' than in the Elliot Orchards. The rootstock is unusual in that it is *Pyrus ussuriensis*, an Asian pear rootstock.

F. Project Management, Evaluation, and Outreach

1. Project Management

Kitren Glozer: overall project and labor coordinator; experimental design implementation; data collection and analysis; publication authorship and educational outreach; extramural funding sourcing; primary communicator between project leaders, cooperators, and extramural/intramural funding supporters.

Chuck Ingels: local project and labor coordinator in Sacramento Delta Region (Early District); experimental treatment implementation; data and educational outreach; product sourcing; primary communicator between project leaders and cooperators. ocal project and labor coordinator; experimental treatment implementation; data and educational outreach; product sourcing; primary communicator between project leaders and cooperators.

Support labor: for project sampling and routine assistance, labor will be supplied by Sacramento County technical support staff.

Orchard maintenance: provided by cooperating growers (Richard Elliot, Fred Wheeler and Jeff McCormack)

2. Project Evaluation

The following evaluation criteria will be examined at the completion of the project:

1. Were one or more relationships established between N application variables, seasonal N tissue partitioning and fruit, yield and vigor indices?
2. Were one or more relationships established between N application variables, spring tissue N levels and fruit, yield and vigor indices that justify use of early sampling for early nutrient adjustment?
3. Were one or more relationships established between N and K application variables and tissue N, Ca and K levels, fruit, yield and vigor indices?
4. Were recommendations developed for nutrient management to affect with maximum yield, optimum fruit quality and controlled vigor while controlling potential for over-fertilization and excess cost?
5. Were irrigation practices by growers consistent with UC recommendations for pear?
6. Were project data and recommendations communicated to growers via publications, internet resources, and educational extension programs, and to peer scientists via journal articles?

No barriers to adoption of recommendations are foreseen, as all methodology being examined can be readily and quickly implemented by typical California pear producers, who are supportive of nutrient management research and outreach, as shown by their current support for the CPAB project.

3. Project Outreach

Outreach efforts associated with this project will include:

- 1) Project updates via UC Fruit & Nut Research Information Center and website (<http://fruitsandnuts.ucdavis.edu/>)
- 2) Presentation at annual CPAB grower meetings (Delta district and 'Late' district), attended by growers and PCAs
- 3) ANR Pear Workgroup Annual Tour: tour project sites and discuss results with UCCE and UC personnel
- 4) Progress report at annual FREP conference
- 5) Popular and scientific publications, such as Good Fruit Grower articles, Cal Ag, HortTechnology and other ASHS journals.

G. Budget Itemization -- specifics outlined in annual summaries below

Personnel -

Kitren Glozer, to be funded 25% of salary and benefits per year

Chuck Ingels, 'in-kind' Years 1 – 3 = 8% of salary and benefits

Support staff:

Lab Technician, Sacramento UCCE 15% salary in Years 1 and 2, increased to 22% salary in Year 3, with 30% benefits annually. Technician will aid in project implementation in-orchard, data collection and data management.

Other labor

- Equipment --None.
- Publications -- None to be charged to this project.
- Subcontracting -- None.
- Overhead -- UC has authorized an exemption for overhead (IDC) for FREP projects.