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Recovery of ^{15}N Fertilizer Applied at Different Stages of Pecan Kernel Fill

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Abstract. **Previous research on late-season N fertilization of pecans [*Carya illinoinensis* (Wangehn*)* K. Koch] has shown significant uptake and storage of N in perennial tissues (roots, trunk, and shoots) that was used in subsequent years. The objectives of this study were to follow the fate of ^{15}N applied at three different stages during pecan kernel fill in both the soil and tree components. In August and September 2002, ^{15}N-labeled ammonium sulfate (9.94% ^{15}N atom excess) was applied (56 kg N/ha) to nine pecan research trees during the early [3 days into kernel fill (DIK)], middle (25 DIK), and late (38 DIK) stages of pecan kernel fill near Las Cruces, N.M. In November 2002, about 67% of applied ^{15}N was recovered from the soil and 13% from tree components. More ^{15}N was recovered in nuts from the early treatment than middle or late treatments. Recoveries for May 2003 were 27% and 60% for tissues and soils, respectively. Leaf recovery increased an average of 14% in May 2003 over November 2002 leaves. More ^{15}N was recovered from the late treatment in all tree components for May 2003 than early or middle treatments. The primary source of N for spring growth was ^{15}N stored in perennial tissues. Fifteen months after ^{15}N fertilizer was applied during kernel fill in 2002 about 24% remained in the soil, 28% had been used by the tree, and 48% was lost to the environment.**

Many studies have attempted to understand the dynamics of N application, N uptake, and N storage in fruit and nut trees. Weinbaum et al. (1984) found that the later in the growing season $(^{15}NH_4)_2SO_4$ was applied to almonds (*Prunus dulcis* (Miller) D.A.Webb), the less ^{15}N was recovered in the fruit and leaves during the year of application and the greater was the ^{15}N contribution to these organs the following year. These results supported previous ideas (Weinbaum, 1978, 1979; Weinbaum et al., 1980) that N applied late in the growing season was preferentially stored for the following year's spring growth and not for current-year growth. Research in apple (*Malus domestica* Borkh) (Neilsen and Millard, 1989; Neilsen et al., 1997; Tromp and Ovaa, 1969), walnut (*Juglans regia* L.) (Deng et al., 1989), and peach trees (*Prunus persica* (L.) Batsch) (Tagliavini et al., 1999) also gave support to those ideas.

When compared to other tree crops, research on N use in pecan has been limited. Smith et al. (1995) compared March vs. October applications of N and found no effect of N application time on leaf N concentrations. They did not measure N recovery, or consider stored N or annual variations in N demand. A later study (Acuna-Maldonado et al., 2003) compared N applied to pecan trees in a single application in March and a split application of 60% in March and 40% in October. Application time had no effect on overall N absorption or yield. However, they reported that 30% of annual N uptake occurred during tree dormancy. They also found no increase in stored N after the fall application and did not find a dependence of N uptake on crop load.

Kraimer et al. (2001) applied $(^{15}NH_4)_2SO_4$ from late March to mid-June in six split applications to pecan trees. Tissue samples taken at catkin maturation during the year of application resulted in about 0.8% total ^{15}N enrichment in annual tissues (leaf, shoot, and catkins). Tissues sampled, at the same growth stage, the following year had a total enrichment increase of about 1.4%. The increase in ^{15}N enrichment the year following application demonstrated that some of the N applied in spring and summer was stored for the following year's growth.

Kraimer et al. (2004) published another study that followed the recovery of $(^{15}NH_4)_2SO_4$ applied during kernel fill in September. This study compared the previously reported recoveries from March-June N applications (Kraimer et al., 2001) and a single September application. In both studies, the trees were in the same orchard and the experiments were initiated in 1996. Differences in the partitioning of ^{15}N in perennial storage tissues (wood and roots) and annual tissues (leaves, nuts, and shucks) between the application times were observed. Twice as much ^{15}N was recovered from storage tissues (about 20%) with the fall applied ^{15}N than from the March to June applied ^{15}N (about 10%). Annual tissue ^{15}N recoveries from the March to June and September application were about 10% and about 1.7%, respectively. These results agree with the theory that pecan trees use N in the spring and early summer for vegetative growth of shoots, leaves, and early fruit development, and late in the season for replenishment of stored N levels, and to a lesser extent, for fruit growth (Weinbaum and Kessel, 1998).

Managing N inputs in pecan to maximize production and minimize N losses requires an understanding of pecan N uptake and how it varies throughout the growing season. Studies on other fruit and nut trees have shown seasonal variations of N uptake and a dependence on stored N, but the effects of late season N fertilization remain unclear.

No studies have considered the effects of N application during different stages of kernel fill. Investigating the fate of ^{15}N applied during kernel fill may reveal the proportion of endogenous/exogenous N used for kernel fill and if it changes through the fill period. Furthermore, recoveries from subsequent years may further improve our understanding of the seasonal fluctuation between endogenous and exogenous N usage. The objectives of this study were to follow the movement of N in both soil and tree tissues when applied at three different times during the kernel fill stage of pecan fruit development.

Materials and Methods

In June 2002, a study was initiated in a well-maintained commercial pecan orchard in the Mesilla Valley near Las Cruces, N.M. The soil was a well-drained Glendale clay loam (fine-silty, mixed, superactive, calcareous, thermic Typic Torrifluvent) that formed in alluvium. Soils were sampled at varying depths for analysis of texture and background ^{15}N levels in June 2002. Surface soil texture (0 to 30 cm) was a fairly homogenous clay loam. From the 30 to 90 cm depth, the soil was generally a silty clay or silty clay loam. Soil texture from the 80 to 270 cm depth was extremely heterogeneous from tree to tree and ranged from nearly pure clay to nearly pure sand.

The orchard contained 662 mature pecan trees on 5.7 ha. About 95% of the trees were 'Western Schley' and 5% were 'Wichita' pollinator trees. During the growing season about 152 cm of irrigation water were applied. Nitrogen fertilizer applications were split into four applications that began in April and ended in July and totaled about 340 kg·ha^{-1} of N in the $(NH_4)_2SO_4$ form. Twelve 'Western Schley' trees with similar trunk diameter and canopy were chosen for the study. Tree diameters, measured at a height of 1.1 m, ranged from 30.2 to 32.5 cm. Three of the trees had no treatment applied but were sampled to measure background ^{15}N levels. Trees were the center of 9.14 × 9.14 m research plots that delineated the midpoint between neighboring trees.

The three treatments were defined according to the number of days into kernel fill (DIK). The three treatments were early (3 DIK), middle (25 DIK), and late (38 DIK) ^{15}N application (Table 1). The pecan kernel fill stage was defined by

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Herrera (1988) as the period when the kernel develops and fills the fruit. Herrera (personal communication) further defined this stage as lasting 42 d. The inception of this stage is signaled by the hardening of the shell, and typically occurs during late August in the Mesilla Valley and continues until complete kernel fill in early October. The start of kernel fill was determined by daily observation of the nuts starting the second week in August and was determined to be 16 Aug. 2002. Dates for early, middle, and late application treatments were 19 Aug., 10 Sept., and 23 Sept. 2002. The timing of fertilizer application was somewhat dependent on irrigation scheduling.

Before application of ^{15}N, soil surrounding all research trees was rototilled to assure quick infiltration and to avoid spreading fertilizer outside the research plots. The area rototilled included the 9.14 × 9.14 m plots and a border approximately 1 m around each plot. ^{15}N-labeled ammonium sulfate (20.5% N and 9.94% ^{15}N atom excess, Icon Isotopes, Summit, NJ) was applied to three trees at each treatment date. The ^{15}N-labeled fertilizer was hand-spread and raked over the research plots at a rate of 56 kg·ha^{-1} of N (2231 g/tree). Flood irrigation occurred within 48 hours. No additional ^{15}N was applied during kernel fill in 2003 or 2004, and the split application of 340 kg·ha^{-1} of N during spring and summer was followed in subsequent years.

Soil and tissue samples were taken carefully to prevent contamination between depths and trees. Soil samples were collected with a 3.8-cm bucket auger at depths of 0 to 30, 30 to 60, 60 to 90, 90 to 180, and 180 to 270 cm. Three sample holes were augured within each research plot at random distances (ranging from 1 to 4 m) from each tree. Samples from the same depth from each of three holes were composited. Soil samples for background ^{15}N levels were taken in August, 2002.

Tissue samples included root, trunk, shoot, leaves, nuts, and shucks in the fall and root, trunk, shoot, leaves, and catkins in the spring. Leaf samples were collected from the middle pair of leaflets at the middle position of the compound leaf of current-year growth. Shoots were sampled at random from around the canopy and included only current-year growth. The trunk sample, which included the bark, was collected by coring to the center of each tree. Catkins were sampled in the spring just before catkin drop. Roots were removed from soil samples and brushed clean of soil particles before grinding. Root samples of varying sizes were collected at various depths (0 to 270) from each tree; no attempt was made to distinguish roots collected from different depths. Shucks and nuts were collected at random from around the canopy just before harvest. Background ^{15}N samples were additionally taken in November 2002 (root, trunk, shoot, leaves, nuts, and shuck) and May 2003 (catkins).

Soil samples were immediately air-dried for 72 h and tissues were oven dried at 65 °C for 48 h. Soil and tissue samples were ground to pass through a 150- and 250-µm sieve, respectively. All samples were analyzed for total N and ^{15}N by Isotope Labs Inc., Los Alamos, N.M., with a Tracermass, Stable Isotope Mass Spectrometer. A sample of the ^{15}N fertilizer used in the study was also sent to Isotope Labs for ^{15}N and total N analysis. The amount of ^{15}N relative to the total $^{14}N + {}^{15}N$ in samples is reported as % ^{15}N. Texture analysis (hydrometer method) and soil chemical analyses were performed by Soil, Water, and Air Testing Lab, New Mexico State University, Las Cruces.Soil bulk density was measured by weighing intact soil cores.

Calculating recovery from soil and tissue samples required ^{15}N and total N analysis of all samples, in addition to soil bulk density measurements and tree biomass estimates. Soil and tissue recovery were calculated with the following equations:

$$\%\,\text{Recovery}_{soil} = (\text{total N})(^{15}N_{sample} - {}^{15}N_{BG})(D_B)(\text{Volume})(100)(1/{}^{15}N_{applied})$$

$$\%\,\text{Recovery}_{tissue\ component} = (\text{total N})(^{15}N_{sample} - {}^{15}N_{BG})(\text{Biomass})(100)(1/{}^{15}N_{applied})$$

where total N = mean total N of three research trees (%); $^{15}N_{sample}$ = mean ^{15}N of three research trees (atom %); $^{15}N_{BG}$ = mean ^{15}N of background samples (atom %); D_B = soil bulk density (kg·m^{-3}); Volume = soil volume of research plot (m^3/plot); $^{15}N_{applied}$ = ^{15}N application rate (kg/plot); and Biomass = mean mass developed for each tissue component of three research trees (kg/plot).

Estimations of total, above ground, root and stump biomass were calculated with the following model of *Quercus velutina* Lam. (King and Schnell, 1972):

Total biomass: log (wt) = 1.00005 + 2.10621 LOG dbh

Root and stump biomass: log (wt) = 0.38000 + 2.12094 LOG dbh

where dbh = diameter of trunk at breast height (1.37 m above ground) in inches, wt = oven-dried weight in pounds. More detail on biomass estimations of each component were given in Kraimer et al. (2001).

The validity of these equations relative to *C. illinoinensis* was confirmed by Kraimer et al. (2001) and Acuna-Maldonado et al. (2003); the model biomass estimates agreed with actual biomass measurements within 8.6% and 2%, respectively. Kernel and shell weight were calculated using yield and percent shell mass measured by the pecan grower. Shuck weight was calculated using previously determined percent shuck mass by Kraimer et al. (2001).

The treatment structure was a one-way classification with time of ^{15}N application as the variable. Treatments were assigned completely at random to trees about equal distance from the water source forming three replicates. The experiment was designed to include watering time as a covariate to help explain variation in the response variables. A second covariate, trunk diameter, was added into the statistical analyses to further explain variation. The covariates were subsequently eliminated from the analyses when they provided no statistical advantage. The response variables measured were five soil depths (0 to 30, 30 to 60, 60 to 90, 90 to 180, and 180 to 270 cm) and seven plant tissues (roots, trunk, shoots, leaves, catkins, shucks, and nuts). To observe changes in response variables over time the pecan orchard was sampled in November 2002, May 2003, November 2003, May 2004, and November 2004. All soil and plant tissue statistical analyses were calculated in the same manner using the GLM procedure of SAS (1999). The significance level was 5% ($\alpha = 0.05$) and treatment comparisons were made with Fisher's protected LSD.

Results and Discussion

Soil analysis. At the end of the 2002 growing season (November 2002) the research trees had received ^{15}N-labeled ammonium sulfate (56 kg·ha^{-1}) at different times during kernel fill. Because fertilizer treatments were applied at different times, each treatment received varying amounts of irrigation water. The early treatment received the most water followed by middle and late treatments (Table 1).

The ^{15}N soil profile in November 2002 had elevated levels of ^{15}N in the soil profile (Fig. 1, Table 2). We anticipated the later the ^{15}N application, the greater the amount of ^{15}N that would remain in the soil because of less tree uptake and leaching. Despite differences in irrigation and number of days ^{15}N was available for uptake; few statistical differences of ^{15}N levels among treatments were detected. Soil ^{15}N levels were highly variable in most of the soil profile. Some of the variability was undoubtedly caused by differences in subsurface soil texture that may have caused uneven fluid percolation and consequently an uneven ^{15}N distribution.

Overall ^{15}N enrichment was clearly greatest in the top 30 cm followed by the second (30 to 60 cm) and third (60 to 90 cm) sample depths. Differences among treatments were only statistically significant ($p = <0.05$) at the 60 to 90 cm depth where ^{15}N levels were higher in the early treatment than the middle and late treatments (Fig. 1). Although not statistically significant at the 5% level, the trend continued through the lower soil depths and is attributed to the extra irrigations the treatment received. ^{15}Nitrogen levels from all treatments below the 60 to 90 cm depth indicated that ^{15}N had moved below the observed pecan rooting zone (0 to 90 cm) where it was susceptible to further leaching.

Orchard irrigation ceased mid October 2002 and commenced in late April 2003; precipitation for this period was 9.8 cm. The soil ^{15}N distribution in May 2003 (Fig. 1, Table 2) had changed little since November 2002. However, evidence of ^{15}N downward movement was shown by a slight ^{15}N decrease in the top 90 cm and a notice-

Table 1. Amount of water each treatment received after ^{15}N application.

Treatment application	Irrigations (no.)	Water applied (cm)
Early, 3 d into kernel fill	5	51
Middle, 25 d into kernel fill	3	30
Late, 38 d into kernel fill	2	20

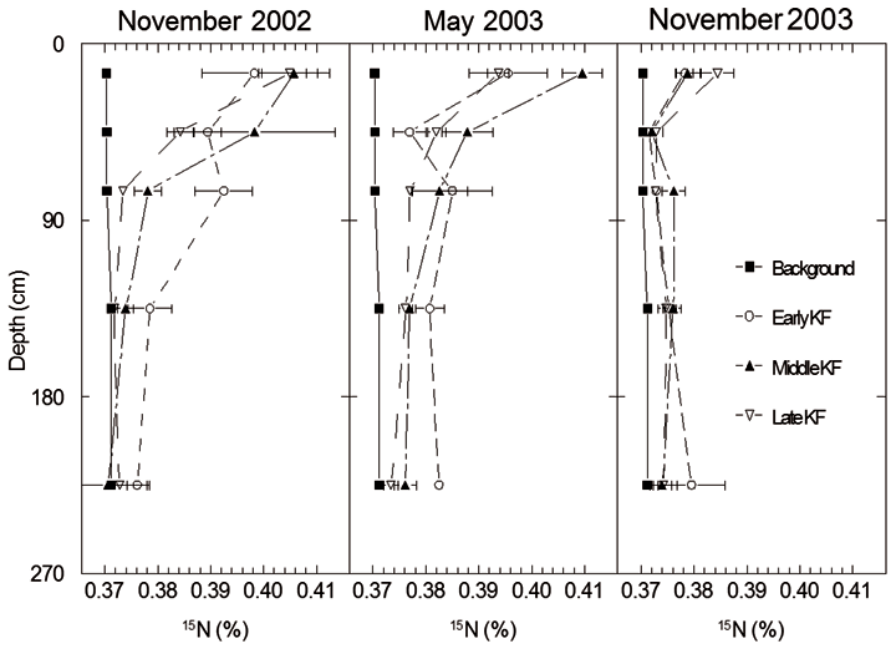

Fig. 1. Soil ^{15}N enrichment in November 2002, May 2003, and November 2003 after ^{15}N fertilizer was applied to pecans during early, middle, and late kernel fill (KF) in August and September 2002. Bars represent standard error of the mean (n = 3).

Table 2. Mean soil ^{15}N recovered (n = 9).

Soil depth	N recovered (%)		
(cm)	November 2002	May 2003	November 2003
0–30	31.2	28.4	9.4
30–60	18.7	10.2	1.6
60–90	10.8	10.5	3.4
90–180	5.1	10.0	7.4
180–270	1.5	1.4	1.8
Total	67.2	60.5	23.6

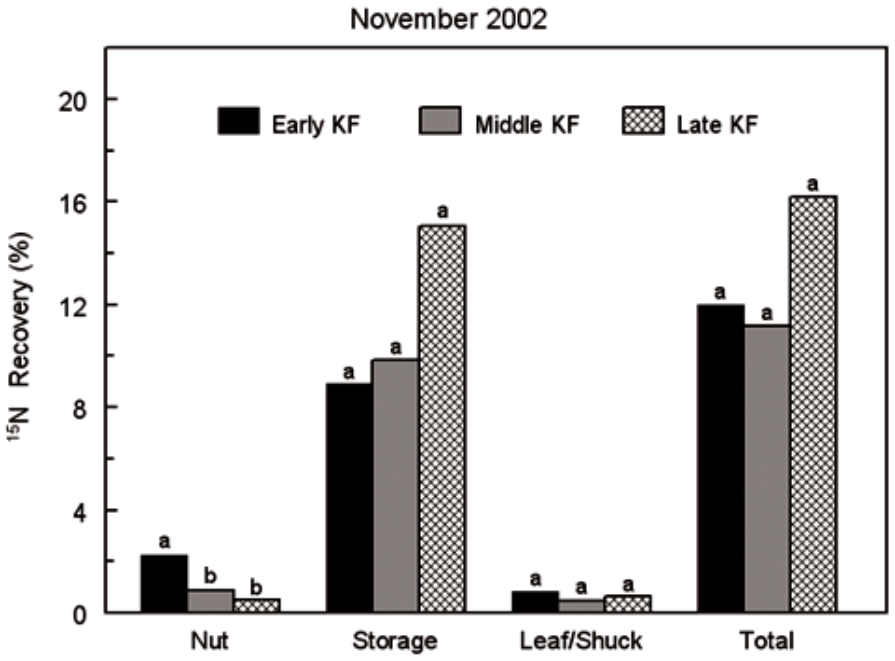

Fig. 2. Percentage of ^{15}N recovered from ^{15}N applied at early, middle, and late kernel fill (KF) at the end of the 2002 growing season. Bars within each tissue classification with the same letter are not significantly different by Fisher's protected LSD at $\alpha = 0.05$ (n = 3).

able increase in the lower soil profile. The ^{15}N changes in the rooting zone indicated little ^{15}N movement in the soil during the winter months when irrigation water was not applied and trees were dormant. Furthermore, we attributed the small changes to ^{15}N levels in the rooting zone to a combination of leaching and root uptake. Others (Weinbaum, 1978; Weinbaum, 1979, Weinbaum et al., 1980; Neilsen and Millard, 1989; Deng et al., 1989) have shown that N is primarily derived from perennial storage tissues during early spring growth. However, a study conducted by Acuna-Maldonado et al. (2003) reported that significant amounts (30%) of all N absorbed by pecans in their study occurred during dormancy and that little N was absorbed between the end of shoot expansion and leaf fall. No other fruit or nut studies have documented significant N uptake during tree dormancy.

In November 2003, after an entire season of irrigation, the addition of 340 kg·ha^{-1} of N by the farmer, and tree growth, ^{15}N levels at the end of the growing season dropped across all treatments and soil depths to near background levels (Fig. 1). The overall drop in ^{15}N levels were presumably caused by leaching, tree uptake, denitrification, and ammonia volatilization. The greatest ^{15}N levels were present in the top 30 cm, some of which was likely derived from recycled leaves or shucks that contained elevated ^{15}N levels.

No conclusions concerning soil ^{15}N recovery and treatment effects can be made because of the heterogeneous distribution of ^{15}N and the lack of statistically significant effects. We had expected more nitrogen to be recovered from the late treatment because it received less water and had less time for tree uptake of ^{15}N. However, the heavy textured soils reduced the expected effect from differences in irrigation between treatments and contributed to the lack of detectable treatment effects.

Treatment recoveries did not help understand the fate of ^{15}N-labeled ammonium sulfate in soil, but the mean ^{15}N recoveries did offer some insight (Table 2). The total mean soil ^{15}N recovered from November 2002 was 67%, considerably higher than the 43% recovered by Kraimer et al. (2004) after they applied similar amounts of ^{15}N during kernel fill. However, the orchard used by Kraimer et al. (2001 and 2004) was on a homogenous soil with a sandy texture below 60 cm and likely contributed to the lower recoveries in that study. Most (91%) of the ^{15}N recovered in November 2002 was from the upper 90 cm of the soil profile. In May 2003, 81% of the ^{15}N recovered was found in the top 90 cm. From the lower sample depths (90 to 270 cm) 9.1 and 19.5% were recovered in November 2002 and May 2003, respectively. The increase from November 2002 to May 2003 indicated once again the downward movement of ^{15}N from the upper profile. By November 2003 the total mean soil ^{15}N recovered had dropped to 23.6% and was more evenly distributed in the soil profile. ^{15}Nitrogen recovered continued to drop toward background levels through the 2004 growing season (data not presented). Similar ^{15}N movements and distributions were observed in previous pecan studies (Kraimer et. al, 2001, 2004).

Tissue analysis. The first tissue samples were taken at the end of the growing season in November 2002, just before leaf fall. Tissue results were separated into four N pools: nut (shell and kernel), storage (trunk, shoots, and roots), leaves (includes shucks in fall data), and total

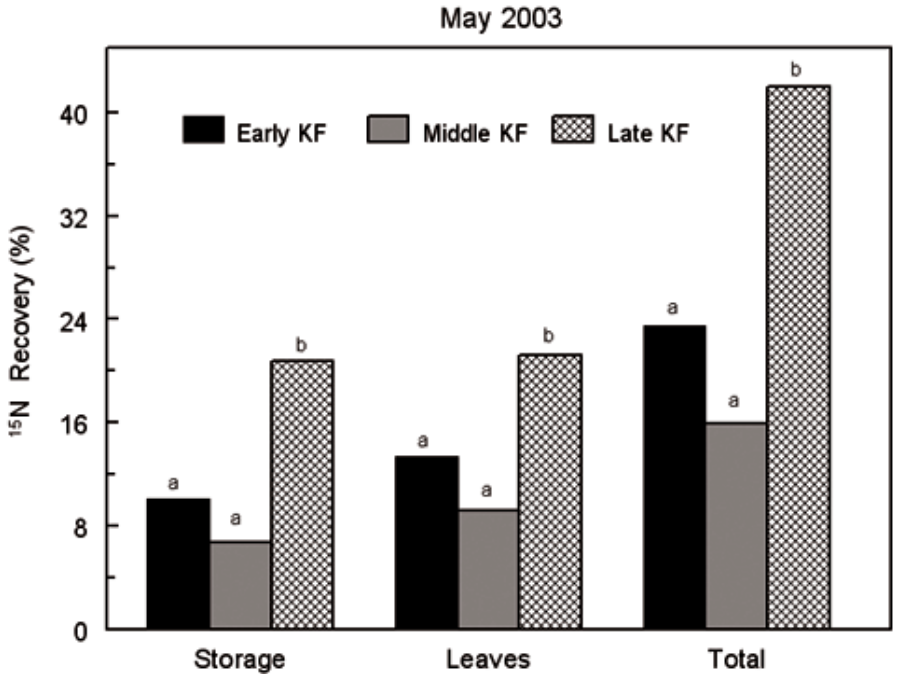

Fig. 3. Percentage of ^{15}N recovered from ^{15}N applied at early, middle, and late kernel fill (KF) in storage tissues (trunk, shoots, and roots) and leaves at the beginning of the 2003 growing season. Bars within each tissue classification with the same letter are not significantly different by Fisher's protected LSD at $\alpha = 0.05$ (n = 3).

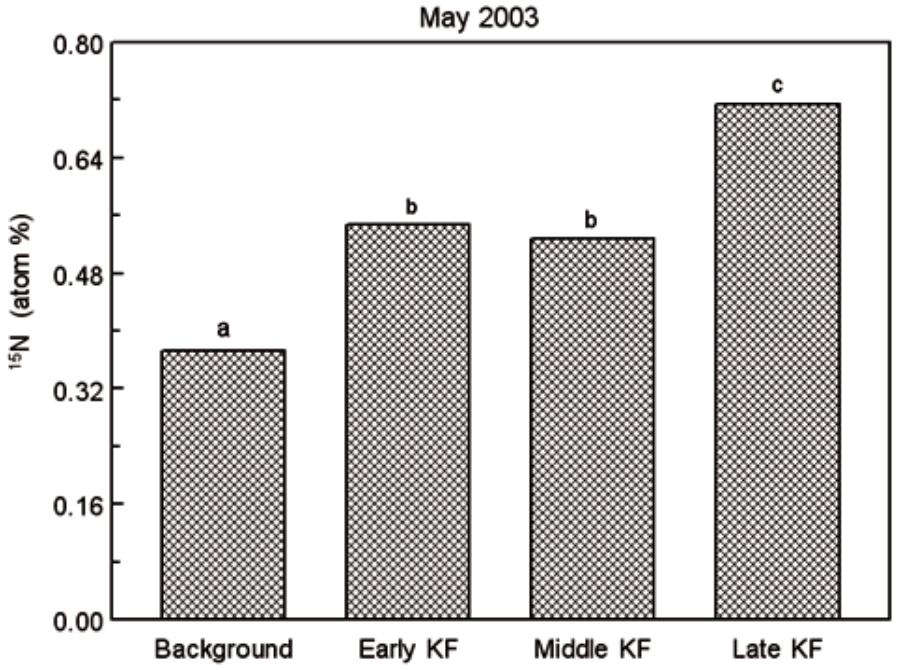

Fig. 4. Pecan catkin ^{15}N enrichment from May 2003 after ^{15}N was previously applied at early, middle, and late kernel fill (KF). Bars with the same letter are not significantly different by Fisher's Protected LSD at $\alpha = 0.05$ (n = 3).

Table 3. Mean soil and tissue ^{15}N recovered in November 2002, May 2003, and November 2003 (n = 9).

	Mean ^{15}N recovered (%)		
Component	November 2002	May 2003	November 2003
Soil	67.2	60.5	23.6
Tree	13.1	27.2	18.7
Nuts	1.2	NA	3.2
Leaves and shucks	0.6	14.6	6.5
Storage	11.3	12.6	9.0
Total	80.3	87.7	42.3
Unaccounted	19.7	12.3	57.7

[z]Catkin data are not included and would slightly increase the true recovery data.

(shell, kernel, trunk, shoots, roots, leaves, and shucks). Application time significantly affected the ^{15}N recovered from nuts but not for storage or leaves/shucks (Fig. 2). Nitrogen recovered from nuts was statistically higher in the early treatment ($p = 0.0311$) than the other treatments. About 2.2% of total ^{15}N applied was recovered in the nuts from the early treatment and 0.9% and 0.5% from the middle and late treatments, respectively. The higher recovery from the early treatment was attributed to the increased time trees had ^{15}N available for uptake and assimilation. However, the vast majority (87%) of the recovered tissue ^{15}N was not found in nuts or leaves in November 2002, but in perennial storage tissues. This supports the previous findings (Weinbaum, 1978, 1979; Weinbaum et al., 1980) that late season applications of N have little effect on current year tree production.

Treatment differences from soil ^{15}N levels in the root zone (0 to 90 cm) could not be detected in May 2003 (Fig. 1), but ^{15}N tissue recoveries were statistically different (Figs. 3 and 4). Moreover, the statistical differences revealed the same treatment effect for all response variables (storage, leaves, catkins, and total); more late applied ^{15}N was recovered from storage, leaves, and catkins than early or middle applications. The difference in partitioning of ^{15}N between treatments in soil and tissue indicate that recently applied soil N is not the source of N for pecans in spring growth. If recent root uptake were the source of ^{15}N at the start of the growing season, then spring leaves, shoots, and catkins should have had similar levels of ^{15}N, reflecting the relative proportions of ^{15}N among soil treatments. Therefore, the high recovery of ^{15}N from May 2003 leaves and catkins must have been a result of ^{15}N mobilized directly from storage rather than ^{15}N recently applied to soil (Table 3).

Because ^{15}N recovered from storage changed little (<2%) from November 2002 to May 2003, root uptake must have replenished storage ^{15}N while previously stored ^{15}N was remobilized for leaf, shoot, and flower expansion. Results from this and previous studies suggest that N reserves are the initial source of N in the spring, but root uptake becomes more and more critical when reserves begin to deplete. These results then suggest a pathway for N in pecan trees that is set into motion when there is a N demand: beginning with new growth (leaves, shoots, catkins, nuts, etc.), N is remobilized from perennial storage tissues, and the loss of N from storage compartments triggers absorption of inorganic soil N.

Results of another pecan study (Kraimer et al., 2001) also show the importance of stored N in spring. Researchers applied ^{15}N at a rate of 96 kg·ha^{-1} before tissue samples were taken at catkin maturation in May 1996. About 9.7% of the N was ^{15}N excess (^{15}N above background) in 1996 May growth (shoots, leaves, and catkins), that figure increased to about 28% in 1997 for the same new growth. If root uptake was the primary source of N during spring growth, 1996 ^{15}N levels would have been equal to or higher than 1997 ^{15}N levels, mirroring ^{15}N levels in soil. Other studies of prune, apricot, almond, and walnuts have also shown that the primary source of N used for spring growth is N stored in perennial tissues (Weinbaum, 1978, 1979;

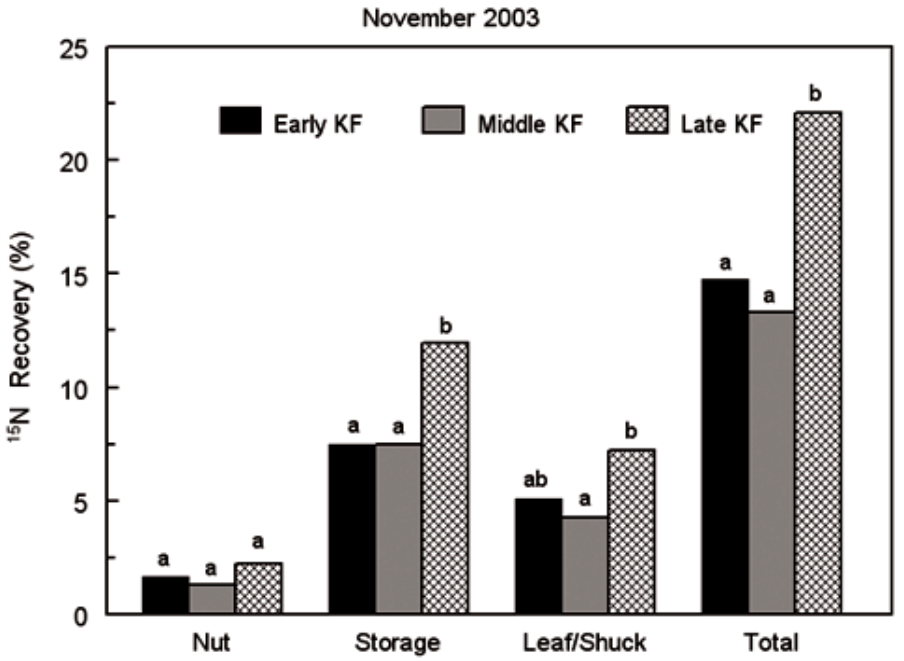

Fig. 5. Percentage of ^{15}N recovered from ^{15}N applied at early, middle, and late kernel fill (KF) at the end of the 2003 growing season. Bars within each tissue classification with the same letter are not significantly different by Fisher's protected LSD at $\alpha = 0.05$ (n = 3).

Weinbaum et al., 1980; Weinbaum and Kessel, 1998; Deng et al., 1989).

One year after ^{15}N fertilizer was applied, the mean total tissue ^{15}N recovered for November 2003 was 19%, compared to 13% from November 2002 (Table 3). Mean nut ^{15}N recovery increased from 1.2% to 3.2%. The 167% increase from November 2002 to November 2003 of ^{15}N recovered in nuts support Weinbaum's (1979) suggestion that N fertilizer applied late in the season was used for the following season's growth. However, fall applied N should directly impact growth in the early season the most and have less of an effect later in the season, including the kernel fill stage. Overall ^{15}N recovered from tissues dropped to 14% and 11% in May and November 2004, respectively (data not presented). Differences among treatments also decreased, and subsequently, statistical differences were no longer detected in May and November 2004.

The treatment effect detected from May 2003 tissue samples (more ^{15}N recovered from the late treatment) was detected once again in November 2003 (Fig. 5), and, although not statistically significant at the 5% level, the trend continued in May and November 2004. This further supports our conclusion that more N is absorbed by pecan trees late in the kernel fill period than early or middle. At this point, however, no yield effect from fall applied N in the Mesilla Valley has been found (Herrera, personal communication). In this study, we chose not to analyze treatment effects on yield because our sample size (nine trees) was too small to detect differences.

About 80% of the ^{15}N fertilizer applied late August and September 2002 was recovered at the end of the growing season in November 2002 from soil and tissue combined (Table 3). The recovery increased to 88% in May 2003, we expected a slight drop in total ^{15}N recovered because we assumed some N would be lost from the soil through leaching or gaseous mechanisms. We attributed the discrepancy to the variability of ^{15}N levels present in the soil. One year after ^{15}N was applied total recovery had dropped to 43%, most (about 36%) of the ^{15}N lost was from the soil. The percent ^{15}N lost through nut harvest, after two harvests, accounted for only 4.4% of the total ^{15}N applied. After the first harvest, most (about 67%) of the ^{15}N was still in the soil, but decreased to 24% in November 2003. The tree contained 13% of applied ^{15}N in November 2002, 27% in May 2003, and 19% in November 2003. The amount of ^{15}N unaccounted for increased from 20% in November 2002 to 57% in November 2003. Weinbaum (1979) stated that deciduous fruit trees obtain less than 50% of N fertilizer applied; that figure dropped to 29% for walnut trees (Weinbaum et al., 1998). In this study, approximately 28% of N applied during kernel fill stage had been used a little over a year after it was applied.

The yield benefits of late season N fertilization could not be ascertained with the small sample of pecan trees used in this study. Thus far, fall nitrogen application has not been observed to benefit pecan yield in the Mesilla Valley of New Mexico (Herrera, personal communication) or in Oklahoma (Acuna-Maldonado et al., 2003; Smith et al., 2004). The effects of the fall applied ^{15}N on yield may be masked by the split N applications, high rate of N applied by growers, and intensive management common in the Mesilla Valley. Fall applied N may produce measurable yield effects in N limited orchards more common in the southeast United States.

Conclusions

About 28% of ^{15}N-labeled fertilizer applied to pecans during the 2002 kernel fill stage was used by the trees 15 months after application. The rest of the ^{15}N either remained in the soil (24%) or was lost to the environment (48%) through leaching and gaseous mechanisms. Maximum tree use occurred during spring growth in 2003, following ^{15}N fertilization in August and September 2002. ^{15}Nitrogen absorbed by the trees during kernel fill was primarily allocated in perennial tissues, only a small percent (4%) of applied ^{15}N was used for nut production. Endogenous ^{15}N was stored through winter dormancy and was the primary source of N for spring growth. Of the three applications periods, more ^{15}N was absorbed and used by the trees when it was applied near the end of kernel fill (late application). Subsequently, spring growth from the late application had the greatest levels of ^{15}N.

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