A Review of Nitrogen Nutrition of *Rubus*

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Abstract

Many fertilization trials have been conducted to determine optimum nitrogen (N) application rates for red raspberry and blackberry. Results from these studies have been highly variable, likely because of differences in soil fertility, planting age, and cultivar, for example. Total N in an alternate year trailing blackberry field was 46 to 49 kg/ha, not including roots, before pruning in the off- or on-year. In red raspberry, total above-ground N was 44 kg/ha after pruning. Annual total N accumulation (excluding roots) from all N sources has ranged from 69 to 122 kg/ha in red raspberry. In 'Kotata' trailing blackberry, 83 kg/ha of N was accumulated over a two-year alternate year production system. Research that determined the fate of applied 15-N in the plant or soil has helped clarify plant uptake and partitioning of fertilizer N. Matching fertilizer application to plant N requirement, is important for both improved production and decreased environmental risk. Plant N requirements depend on the time of year; therefore, N-partitioning within the plant varies throughout the growing season. Early in the season, blackberry plants partitioned fertilizer N to new growth such as primocanes and fruit. At the end of the growing season, the fertilizer N was stored in roots, crown, and over-wintering primocanes. Much of the stored 15-N was recovered in the floricanes (previous year primocanes) and fruit the following season. Time of fertilizer application also affects within-plant N partitioning. In red raspberry, fertilizer N applied at budbreak was found primarily in the fruit, fruiting laterals, and primocanes whereas the majority of the fertilizer N applied two months later was found in the primocanes. The average total N removed from a summer-bearing red raspberry field was 14 kg/ha in harvested fruit; 13 kg/ha in floricane prunings in September, and 15 kg/ha in senescing primocane leaves, for a total of 42 kg/ha per year of N. In field-grown trailing blackberry, the N removed from the field was 33 kg/ha in harvested fruit, 14 kg/ha in floricane prunings in October, and 5 kg/ha in senescing primocane leaves, for a total of 52 kg/ha per year of N. Delaying pruning, allowed for more time for N to be remobilized to primocanes, crown, and roots. The nitrogen concentration of ripe fruit of fertilized plants has ranged from 1.4 to 1.7% in red raspberry and 1.4 to 1.6% in blackberry.

NITROGEN FERTILIZATION RATE STUDIES

Raspberry

During the last century, many fertilization trials were conducted to determine optimum nitrogen (N) application rates for red raspberry (*Rubus* sp.); many have been reviewed by Dale (1989) and will not all be repeated here. Variability in results may partially be explained by differences in soil fertility. In British Columbia, Dean et al. (2000) and Kowalenko (1994b) reported 99 to 120 kg/ha of N was available in a non-fertilized, irrigated red raspberry field, primarily from soil N mineralization. Mohadjer et al. (2001) and Rempel et al. (2004) reported 70 and 20 kg N/ha available in bare soil plots adjacent to irrigated blackberry or non-irrigated raspberry fields, respectively.

Primocanes growing under high N fertilization were found to have greater cold injury the following winter in some studies (Jennings et al., 1964; Lawson and Waister, 1972; Strong, 1936), but not in others (Smolarz and Mercik, 1983). Nitrogen application in one season may affect current yield of the floricanes, mainly through increased fruit size, and next season's yield through impact on primocane growth and flower bud initiation or differentiation (e.g., Lawson and Waister, 1972). Lawson and Waister (1972) in Scotland found higher rates of N fertilization increased yield in the first and second cropping year of raspberry production, but had no effect or decreased yield in later cropping years, suggesting that crop response varies with age of the stand. Ljones and Sakshaug (1967; in Dale, 1989) suggested that a consistent supply of N will condition plants to that level and if N fertilization is later reduced, yields will decline. They showed, in a two year study, that in a program of high N (217 kg/ha) in one year followed by no fertilizer in the second (and the reverse, low followed by high) that yield was only reduced in the high followed by no fertilizer treatment due to fewer fruits per cane and small fruit size. In Hungary, N fertilizer rate studies (0, 50, 100, 200, and 400 kg/ha) in red raspberry resulted in yield and cane length increasing from 0 to 50 kg/ha, but no increases above 50 kg/ha were found (Papp et al., 1984). Spiers (1993) found that N fertilization increased growth of 'Dormanred' up to the mid-level of applied N, but additional N reduced plant growth. Smolarz et al. (1982) observed the best yield in red raspberry plants fertilized with 60 kg N/ha in an eight year study on soil of low fertility. Increased nitrogen fertilization rate (40, 133, 178 kg/ha) did not affect yield of 'Veten' red raspberry in Norway, but did increase berry weight in plantings without cover crops between the row (Heiberg, 2002).

'Heritage' produced the most flowering nodes per primocane at the highest N rate and growing temperature studied (Lockshin and Elfving, 1981). They also found that increased N rate shortened the time for flowering to occur in 'Heritage'. However, this was not observed in 'Amity' primocane fruiting red raspberry (DeGomez et al., 1986).

In the northwestern region of North America, a yield response to N fertilizer rate has not been observed in most red raspberry research (Chaplin and Martin, 1980; Kowalenko, 1994b; Rempel et al., 2004). Kowalenko (1981) found an increased yield with higher N fertilizer rate due to an increase in berry weight. In a four year study, Kowalenko et al. (2000) measured very little effect of N fertilization rate on yield; however, in their study floricanes were topped in winter and thus increased cane length as a result of N fertilization may have been removed. Strik and Cahn (1999) showed that topping canes reduced yield compared to arc-cane training. Rempel et al. (2004) found that plants fertilized with N had increased berry weight and longer primocanes than unfertilized plants and thus would likely have had increased yield if the study had lasted longer than two years. In contrast, higher N fertilization rates in red raspberry in Scotland increased primocane number but not length (Lawson and Waister, 1972).

Between row management in raspberry may affect N fertilization requirements. In Norway, 'Veten' red raspberry grown with a between row permanent cover (60% *Festuca rubra*, 30% *Poa pratensis*, and 10% *Agrostis tenuis*), but kept free of weeds in the row, had a lower yield and lower primocane leaf tissue N concentration than plants grown in clean cultivated fields (Heiberg, 2002). Zebarth et al. (1993) when comparing between row management systems in red raspberry over six years, found that white clover (*Trifolium repens* L.) increased soil organic matter, had a greater amount of total and mineralizable N than clean, tilled inter-row management and did not reduce raspberry plant vigor or yield compared to more competitive grasses such as perennial rye grass (*Lolium perenne* L.).

Current fertilizer N recommendations for floricane-fruiting ("summer-bearing") red raspberries in the USA are 25 to 45 kg·ha^{-1} in the establishment year and 45 to 85 kg/ha in subsequent years. In primocane-fruiting ("fall-bearing") raspberries, an additional 20 kg/ha of N at bloom is recommended (Hart et al*.*, 2000; Pritts and Handley, 1982). In black raspberries (*R. occidentalis* L., e.g., 'Munger'), 20 to 35 kg/ha of N in the establishment year and 35 to 50 kg/ha in subsequent years is recommended (Hart et al., 2000).

Blackberry

In blackberry, yield was highest at 67 kg/ha of N for 'Thornless Evergreen' trailing blackberries in every year production in Oregon (Nelson and Martin, 1986), was not affected by N fertilization for 'Arapaho' erect blackberry in Arkansas (Naraguma and Clark, 1998), but increased with increasing N rate to 123 kg/ha for 'Hull Thornless' semi-erect blackberries in Kentucky, USA (Archbold et al., 1989). Yield of *Rubus glaucus* Benth. was higher with 50 and 100 kg/ha of N than with no N fertilization in Venezuela, due to increased fruit number (Rincon and Salas, 1987). Current fertilizer recommendations for N fertilization of trailing blackberry, range from 25 to 45 kg/ha in the establishment year and 45 to 60 kg/ha in subsequent years. In 'Thornless Evergreen', experience in Oregon, USA has shown that mature plants can be fertilized with 55 to 70 kg/ha of N with good response. In erect (e.g., 'Navaho', 'Kiowa') or semi-erect (e.g., 'Chester Thornless', 'Triple Crown') blackberries, 25 to 45 kg/ha in the establishment year and 45 to 70 kg/ha in subsequent years is recommended in the USA (Hart et al., 2000; Pritts and Handley, 1982).

Growers typically base N fertilization decisions on results of tissue analysis of primocane leaves taken in late July to early August (northern hemisphere), soil tests every few years, and observations of annual growth (cane number, diameter, and height and fruiting lateral length), yield, color of leaves, and fruit quality (amount of rot and drupelet set). Primocane leaf N concentration from a late July - early August sampling should be between 2.3 and 3.0% (Hart et al., 2000). However, interpretations of N status can be misleading without observations of plant growth and yield. Ammonium nitrate, calcium nitrate, and urea are the most common products used and are most commonly broadcast as a granular in the row. However, N fertilizer may also be applied using drip irrigation systems or supplemented with foliar applications.

There has been very little research comparing N fertilization methods in raspberry or blackberry. Kowalenko et al. (2000) showed that N fertilization through the drip irrigation system resulted in more leaching of N than comparable granular rates applied in the spring. In their study, granular applications resulted in better plant performance than did fertigation.

Norton (1976) showed no effect of foliar N fertilizer applications (pre-bloom and two times pre-harvest with 5 kg N/ha as urea) on primocane tissue concentrations of N or yield in red raspberry in Wash., USA. From 26 to 46% of foliar applied urea (15-N) was absorbed by 'Heritage' red raspberry leaves within 32 h and transported throughout the plant within 7 days (Reickenberg and Pritts, 1996). They measured a slightly higher absorption rate on the lower leaf surface than the upper, but found no effect of leaf age or time of day of application. The addition of a surfactant (0.1% v/v Tween 80) reduced uptake of foliar applied N (Reickenberg and Pritts, 1996). A single application of foliar urea (5 kg/ha of N) had no effect on growth and accounted for 2.7% of the total N in the plant at the end of the season. When the soil surface was covered with black plastic to prevent root absorption, less foliar applied N was absorbed by red raspberry plants (Reikenberg and Pritts, 1996).

Assuming that a mature red raspberry planting would consist of about 100 kg/ha of N at the end of the growing season and that 80% of a foliar application containing 5 kg/ha of urea is intercepted by the leaves, and 50% is absorbed by the leaves, then one foliar application would supply about 1% of the total N contained in the plant. No evidence exists that the small increases in N supplied by foliar feeding are physiologically significant when soil nutrient supply is adequate. There are no reports in the literature of positive benefits of foliar macronutrient applications in raspberry or blackberry.

PLANT NITROGEN STATUS

Raspberries and blackberries have relatively low dry weight and N accumulation per hectare compared to other perennial crops (Dean et al., 2000; Mohadjer et al., 2001; Rempel et al., 2004). This is attributed to the 3 m row spacing required for machine harvest or use of tractor driven equipment. In addition, plant size is small and fruit yield is relatively low. For example, the cumulative total yield of 'Kotata' trailing blackberry fruit was 1.6 kg of dry matter per plant (2.2 t/ha; Mohadjer et al., 2001), whereas the average cumulative dry-matter fruit yield of 'Meeker' or 'Willamette' red raspberry fruit was 0.3 kg/plant or 1.3 t/ha (Kowalenko, 1994b; Rempel et al., 2004).

Accumulation of dry matter was very highly correlated with accumulation of nitrogen (e.g. Rempel et al., 2004). Dry weight of mature *Rubus* plantings have been documented as 7.5 t/ha, 6.5 t/ha, and 4.6 t/ha in above-ground summer-bearing red raspberry (Dean et al., 2000; Rempel et al., 2004), whole plant primocane-fruiting 'Heritage' (Bañados and Marchant, 2001), and above-ground 'Kotata' trailing blackberry (Mohadjer et al., 2001) in late autumn, respectively. Roots accounted for 36% of the dry weight of field-grown 'Heritage' (Bañados and Marchant, 2001), 41% of potted 'Chester Thornless' (Malik et al., 1991), and 26% of the total dry weight (excluding fruit) of 'Arapaho' (Naraguma et al., 1999).

Total N in an alternate year trailing blackberry field was 46 to 49 kg/ha, not including roots, before pruning in the off- or on-year (Mohadjer et al., 2001). In red raspberry, total above-ground N was 10 g/plant (44 kg/ha) after pruning (Rempel et al., 2004).

Annual total N accumulation (excluding roots) from all N sources has ranged from 16 to 28 g/plant (69 to 122 kg/ha) in red raspberry (Kowalenko, 1994b; Rempel et al., 2004; Wright and Waister, 1980). In 'Kotata' trailing blackberry, 64 g/plant (83 kg/ha) of N was accumulated over a two-year alternate year production system (Mohadjer et al., 2001). In pot culture, N accumulation of 'Chester Thornless' blackberry was 0.9 and 2.1 g/plant, including roots, after one and two years of growth, respectively (Malik et al., 1991).

Of the total N present in summer-bearing red raspberry, 17% was removed when pruning out spent floricanes in September, 12% fell to the ground due to primocane leaf senescence, 13% was in harvested fruit, and the remaining was in the over-wintering plant (Rempel et al., 2004). The average total N removed from a summer-bearing red raspberry field was 14 kg/ha in harvested fruit; 13 kg/ha in floricane prunings in September, and 15 kg/ha in senescing primocane leaves, for a total of 42 kg/ha per year of N (Kowalenko, 1994b; Rempel et al., 2004). Rempel et al. (2004) found no effect of fertilization treatments (0 to 80 kg/ha N) on the percentage of total N present in a given tissue or N partitioning.

Floricane pruning, in a commercial red raspberry field typically occurs any time after harvest throughout the autumn. Rempel et al. (2004) found that if floricanes were pruned in mid-August, 24 kg/ha of N was removed; however, pruning in mid-September removed 13 kg/ha thus increasing plant recovery through remobilization by 11 kg/ha. As floricanes senesced through September, primocanes and primocane leaves received remobilized N. Nitrogen in floricane prunings that are flailed (chopped) and left in the field would ultimately return to the system. Strik et al. (2006) showed than from 3 to 8% of the N in floricane prunings was taken up by red raspberry plants in the field after one-and-a-half years. The N in senescing primocane leaves would also likely return to the plant system, provided the leaves did not blow out of the field.

In field-grown trailing blackberry, Mohadjer et al. (2001) reported the N removed from the field was 33 kg/ha in harvested fruit, 14 kg/ha in floricane prunings in October, and 5 kg/ha in senescing primocane leaves, for a total of 52 kg/ha per year of N. Pruning floricanes in August instead of October reduced plant recovery of N by 27 kg/ha, as previously reported in red raspberry.

The nitrogen concentration of ripe fruit of fertilized plants has ranged from 1.4 to 1.7% in red raspberry (Rempel et al., 2004), 1.4 to 1.6% in 'Kotata' trailing blackberry (Mohadjer et al., 2001), and 1.5 to 1.6% in 'Arapaho' erect blackberry (Alleyne and Clark, 1997). Nitrogen fertilization rate had little effect on fruit pH, titratable acidity, and soluble solids in 'Thornless Evergreen' blackberry and had no consistent effect on fruit firmness (Nelson and Martin, 1986). In 'Arapaho' blackberry, increasing N fertilization rates increased fruit N concentration and pH, but had no effect on percent soluble solids, titratable acidity, and sugar-acid ratio (Alleyne and Clark, 1997). In a five-year study, Papp et al. (1984) found that N fertilization decreased total soluble solids of red raspberry fruit and increased leaf %N.

Nitrogen concentration in roots of red raspberry was low during fruiting (0.8% N), then increased after harvest to a high of 1.5% N in December (Rempel et al., 2004). Roots of 'Heritage' had 1.3 to 2.2% N and crowns 0.6% N (Bañados and Marchant, 2001).

In 'Thornless Evergreen', N concentration of primocane leaves was not significantly ($P < 0.05$) affected by N fertilization rate (0, 67, 135 kg/ha) in a four year study, and leaf %N was not correlated with yield of the current or following season (Nelson and Martin, 1986). Primocane leaves of red raspberry sampled in August had 2.2% N in un-fertilized plants, below recommended standards (Hart et al., 2000), and 3.0% in fertilized plants (Rempel et al., 2001). Increasing N fertilization rate (40, 133, 178 kg/ha) increased primocane leaf N concentration in August from 2.9 to 3.3% in 'Veten' red raspberry in Norway (Heiberg, 2002). John and Daubeny (1972) showed that leaf N concentration varied with cultivar and 'Meeker' had 2.29% N in late Aug. and 'Willamette' 2.89% N in late July. Kowalenko (1994a) found that primocane leaf N concentration of 'Willamette' was too variable during the season in British Columbia, Canada and thus did not recommend development of a fertilizer program on leaf analysis. In contrast, Hughes et al. (1979) found that the period of least change in N concentration of primocane leaves occurred the last two weeks of August on the 5^{th} to 12^{th} leaves from the terminal portion of the primocane of 'Meeker' red raspberry in Oregon, USA.

FERTILIZER UPTAKE AND PARTITIONING

Nitrogen fertilizer uptake studies, using 15-N, have been done in potted blackberry (Malik et al., 1991; Naraguma et al., 1999), field-grown blackberry (Mohadjer et al., 2001) and summer-bearing red raspberry using soil-applied (Rempel et al., 2004) or foliar-applied N (Reickenberg and Pritts, 1996).

Raspberry

Twenty-four to 37% of the applied granular fertilizer was taken up by the above-ground red raspberry plant (Rempel et al., 2004), depending on the timing and rate of fertilizer N applied. Fertilizer N accounted for 13 to 36% of the total N in the plant depending on time of year. In summer-bearing red raspberry, fertilizer N applied early (before new primocane emergence or when primocanes were less than 15 cm tall) was taken up by the new primocanes and the fruiting laterals and fruit on the floricanes. However, when fertilizer N was applied later (when green fruit were present, approximately one month before first harvest), most of the fertilizer N was taken up by the primocanes and little went to the fruit. Research has suggested that a split application of fertilizer N (first ½ about a week before primocane emergence and the second ½ about a month before first harvest) is best for maintaining current season yield and good primocane growth for next season's yield (Rempel et al., 2004).

Plants fertilized with relatively high rates of N (80 kg/ha compared to 40 kg/ha) had a higher fruit N concentration (1.4 vs. 1.0%) and a larger proportion of fertilizer N (29 vs. 9%; Rempel et al., 2004).

Research suggests that plants fertilized with high rates of N may exhibit "luxury" uptake in a N saturated system. Uptake of fertilizer N simply replaced soil N that would have been taken up otherwise (Rempel et al., 2004). This plant strategy has also been observed in kiwifruit; when additional fertilizer N was added, soil N-uptake was reduced (Ledgard and Smith, 1992).

Blackberry

In 'Chester Thornless' and 'Arapaho' blackberry, new fertilizer N was allocated primarily to new growth (primocanes, primocane leaves, and fruit), and fertilizer N accumulation continued in these tissues until late in the growing season (Malik et al., 1991; Naraguma et al., 1999).

In field-grown trailing blackberry, 45% of the applied fertilizer could be accounted for in the above-ground portion of the plant with maximum percent N derived from the fertilizer occurring in August (Mohadjer et al., 2001). In late June, just before fruit harvest, fertilizer N was partitioned with 39, 37, 19, 3, and 2% in the fruit, laterals, primocanes, floricanes, and crowns, respectively.

Malik et al. (1991) demonstrated that the fruit of ‘Chester Thornless’ blackberry was the strongest sink for newly acquired fertilizer N. In ‘Kotata’ trailing blackberry, harvested fruit averaged 30.5% N derived from the fertilizer (Mohadjer et al., 2001).

USE OF NITROGEN RESERVES

Stored plant N is an important resource for perennial plant growth in the spring. In red raspberry, Rempel et al. (2004) found that 24 to 37% of the N in the new growth came from the fertilizer applied that spring; therefore the remaining N came from reserves or new N from other sources such as soil mineralization. They found that percent nitrogen derived from the fertilizer (NDFF) declined at approximately 40% per year implying that plant reserves are a very important long term N source. This level of available stored N is much higher than the 10% estimated for red raspberry by Dean et al. (2000).

Little loss was seen in NDFF content between dormancy and budbreak in the above-ground red raspberry plant and percent NDFF in the roots did not change over the dormant season, suggesting that little fertilizer N (applied the previous year) was reallocated from the roots to the crown and floricanes during this time (Rempel et al., 2004).

A pot study using ‘Chester Thornless’ blackberry concluded that primocanes were a large reserve of fertilizer N; however, this N was not remobilized to other plant parts the following season (Malik et al., 1991). The same pattern was observed in red raspberry (Rempel et al., 2004) where primocanes ended the season with approximately 75% of the NDFF content present in the plant (excluding roots) and this N was not remobilized the following spring. This partitioning strategy ensures reproduction is supported with stored N while vegetative growth is more dependent on exogenous N. The decline in stored fertilizer N throughout the season was primarily attributed to removal through fruit harvest and leaf senescence.

Mohadjer et al. (2001) found that very little stored N was allocated to the primocanes and primocane leaves of on-year plants in alternate year production. There was a relatively high percentage of 15-N from the off-year application found in the following on-year fruit (20%) suggesting that reserves accumulated in the off-year are an important source for on-year growth. In the on-year, remobilization of crown and root N to fruiting laterals and fruit occurred. They concluded that N fertilizer is needed in both the on-year, for fruiting lateral and fruit growth, and in the off-year for new primocane growth, for sustainable production.

SUMMARY

Nitrogen fertilizer rate studies have been inconclusive to date. This may be due to variability in soil fertility, the rates of N fertilizer used, planting age, cultivar, length of study etc. Foliar N applications have not resulted in measurable yield or physiological responses in raspberry or blackberry. An average of 42 and 52 kg N/ha/year is removed in red raspberry and blackberry, respectively. A delay in pruning senescing floricanes post-harvest results in lower losses of N to the plant system. There are no conclusive data on the impact of N rate on fruit N concentration and any related impacts on fruit quality. Fertilizer N is partitioned to the primocanes and the floricanes, including fruit, whereas reserve N is partitioned mainly to the floricanes.

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