

Effects of fertilization on raspberry growth and fruit production in the upper northern climate

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Abstract

Raspberry production in North Dakota and the upper northern climate is limited due to harsh winters and short growing seasons. This study investigated the effect of fertilization on plant growth, fruit production, and bud damage of four floricane-fruiting raspberry cultivars: 'Boyne', 'Nova', 'Encore', and 'Amethyst'. Field trials were conducted in Fargo, North Dakota (USA) throughout 2020 and 2021. Overwintered canes were thinned to 10 canes per hill prior to fertilization. Three levels of (0, 18, and 36 kg actual nitrogen/ha) of slow-release fertilizer (14-14-16) were applied in late May or early June. Fruit size, juice Brix, and yield were evaluated in the growing season, whereas the bud damage, cane height, and cane number were recorded the following spring. Results showed that fertilization rates had no significant effect on fruit size, Brix, and yield in the same year it was applied. Cane growth and bud damage were not significantly impacted by fertilization for all four cultivars. However, significance in fruit size, Brix, yield (except 'Encore'), and cane height and number (except Nova) were detected between the two years. Significant differences in bud damage between the two years were detected in 'Nova' and 'Amethyst'. The lack of response to fertilization in raspberry production in this study suggests that fertilization is only one piece of the overall nutritional puzzle. Fertilization programs should be developed based on soil and environmental conditions, and plant developmental stage, and fertilization must be integrated with other cultural practices, such as pruning, irrigation, and pest control, to validate its potential benefits.

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Introduction

Raspberry (*Rubus* spp.) is prevalently grown worldwide as a small fruit crop rich in various nutrients and soluble fiber^[1,2]. Raspberries are widely used for fresh consumption and processed products. Currently, large-scale commercial raspberry production in the US is focused in the pacific northwest region and several northeast states^[3,4]. However, raspberry production is gaining popularity elsewhere, particularly in local food production on family farms^[5]. In raspberry production, fertilization is one of the most important field management practices that can influence raspberry productivity and profitability. Fertilization plays an important role in the development of fruit quality, such as fruit size, Brix, color, firmness, yield, and cane growth. Poor fertilizer management may result in poor or excessive cane development, poor fruit quality, and reduced winter hardiness^[6–8]. In general, fertilizers, particularly nitrogen, are often applied at the early growing stage of raspberry plants. In the north-east and Midwest of the US and eastern Canada, raspberry fertilization is recommended in May, or split between May and June^[9]. The fertilization efficiency in raspberry production can be affected by many factors, including soil structure, fertility, soil pH, environmental conditions (moisture and temperature), application method, plant growth conditions (growth vigor and developmental stage), and differential responses of cultivars^[9]. Therefore, understanding how fertilization affects raspberry growth and development in different cultivars will help develop fertilizer management in raspberry production. Raspberry species have two main fruiting systems, primocane fruiting (ever- or fall-bearing), and floricane fruiting (summer-bearing). Primocane raspberry produces fruit on current year's growth (primocane) in the fall; while floricane raspberry produces fruit on the previous year's growth (floricane) in the summer. Certain raspberry cultivars can produce fruit twice a year (double

cropping), on floricanes in summer, and then on primocanes in the fall^[1,10]. Despite many raspberry cultivars that possess winter hardiness being available, a very limited number of raspberry cultivars can survive the harsh winter conditions in North Dakota (ND) and USDA hardiness zones 3–4^[11,12]. In addition, the short growing season in ND constrains the type of raspberry typically grown because early fall frost can destroy a considerable amount of fruit on primocane fruiting raspberries; therefore, winter-hardy floricane raspberries are generally recommended in ND. A few floricane raspberry cultivars, including Boyne, Nova, Encore, and Amethyst, showed no, or minor winter damage in ND^[13]; however, their overall response to fertilization, particularly in USDA zones 3–4a, has not been well documented. Therefore, the aim of this research was to evaluate the effect of fertilization on raspberry growth, fruit production, and bud damage of the four floricane-fruiting raspberry cultivars in ND. The resulting information will provide evidence-based strategies to manage raspberry fertilization in ND, and other cold climate regions.

Materials and methods

Experimental site and plant material

The experiment was carried out in the raspberry field at the North Dakota State University (NDSU) Experimental Research Station in Fargo, North Dakota, USA (46°53' N 96°48' W). The soil type is Fargo silty clay that is characterized as fine-textured, poor drainage, sticky, and plastic, with high organic matter. A soil test showed that the soil of 0–18 in deep in the raspberry field contains 25 kg/ha nitrate nitrogen (NO₃-N), 12.4 ppm ammonium nitrogen (NH₄-N), 7.5 ppm phosphorus (P), 430 ppm potassium (K), and 5.1% organic matter

(OM). The soil pH was 7.9. The climate in this region is a humid continental climate with cold winters and warm summers. Fargo is in USDA plant hardiness zone 4a with the lowest temperature at -31.7 to -34.7 °C^[14]. Three years of climate data (2020–2022) in Fargo, ND showed that extremely low temperatures are generally seen between January and February. The lowest air temperatures of 2020, 2021, and 2022 were -30.6 (January 16), -31.8 (February 14), and -33.4 °C (January 1), respectively. The final spring frost and first fall frost often occur in early May and early to mid-October, respectively^[15].

This experiment included three red raspberry cultivars, Boyne, Nova, and Encore, and one purple raspberry cultivar, Amethyst. In spring 2015, one-year-old bare-root raspberry plants (single cane) were planted with a spacing of 152 cm (in rows) × 274 cm (between rows). A V-shape trellis was installed in fall 2015 to support growth. The planting row was covered with landscape fabric for primary weed control. The area between rows was seeded with a mix of white and red clover (*Trifolium* spp.), and red tall fescue species (*Festuca* spp.) for soil management. In this 5-year old raspberry field, an average of 15 canes were grown in each planting site (known as a hill), and the distance between two hills is approximately 60–90 cm. In the fall, fruiting floricanes were removed after fruit harvest. Primocanes (current year growth) that overwintered in the field became fruiting floricanes the following year. Overwintered canes were generally thinned to 10 canes per hill, that equal to two canes per linear 60 cm planting row, and cut to 75–120 cm in height in late April to early May. Fertilization was regularly carried out in late May to early June, at a level of 18 kg actual nitrogen (N) per hectare (ha), once a year using slow-release Multicote 4 fertilizer (14-14-16).

Experimental design and statistical analysis

In this experiment, the Multicote 4 fertilizer (14-14-16) (Haifa North America, Savannah, GA, USA) was used. Fertilization was carried out on May 27, 2020 and June 4, 2021. Three fertilizer rates (treatments), 0, 7.56, and 15.12 g actual nitrogen (N)/planting hill, were used, which equals 0, 18, and 36 kg/ha (2,402 hills/ha). Fertilizer granules were spread in an area of ~0.2 m² around each planting hill. The experiment was arranged in a completely randomized block design (RCBD), with three replications (blocks). Each block consisted of three treatments (fertilizer rates) with two planting hill/cultivar in each treatment, except for cultivar 'Boyne', as limited 'Boyne' plants were originally planted in this field. Data from each cultivar were analyzed separately (i.e., no cultivar comparison) as cultivars have large genetic differences in growth habits and yield^[9].

All data were subjected to analysis of variance using PROC GLIMMIX, in which fertility treatment and year were the fixed effects, and block/replication was the random effect. Least squares means (LSMEANS) were separated using the pdiff option at the 0.05 probability level.

Evaluation of fruit size, Brix, and yield

The fruit was hand harvested every 2–3 d during the fruit harvest season in 2020 and 2021 (5–6-year-old plants). The fruit were sampled for fruit size and Brix evaluation at the early (early to mid-July), middle (mid-July to early-August), and late harvest times (late-July to mid-August). The fruit size was the average weight (g) of 25 berries each evaluation time. At each evaluation time, the fruit juice was pressed from 3–5 berries, with three replications, using a manual juice press. The juice Brix was then measured using a digital Brix refractometer (MA871, Milwaukee Instruments, Rocky Mount, NC, USA). The final Brix was the average Brix measurement of three harvest times because the juice Brix may slightly fluctuate during the harvest period. The raspberry yield was estimated as the average fruit weight per hill × the number of raspberry hills per hectare (2,402 hills/ha).

Evaluation of winter bud damage, cane number, and height

Winter bud damage was surveyed for all four cultivars. Primocanes were overwintering in the field without any winter protection, and these canes become floricanes that bear fruit in the next year. The bud damage was surveyed in late April to early May after the budbreak in the spring of 2021 and 2022. The winter bud damage was expressed using a bud damage index that was calculated based on a scale of 0 to 5; where 0: no visual damage, 1: < 20% buds died (no bud breaking), 2: 20%–50% buds died, 3: 51%–75% buds died, 4: 75% buds died, and 5: all above ground died. The cane height was measured in the spring of 2021 and 2022 before pruning. The cane height was the average cane height of each raspberry hill.

Results

Effects of fertilization on fruit size, juice Brix, and yield

In this study, the size and juice Brix of the raspberry fruit were compared among three fertilizer treatments in two years (Table 1).

Table 1. The effect of fertilization on fruit size and Brix of four floricane-fruiting raspberry cultivars in Fargo, ND, USA.

Fertilizer level (kg N/ha)	Boyne		Nova		Encore		Amethyst	
	Fruit size (g/fruit)	Brix	Fruit size (g/fruit)	Brix	Fruit size (g/fruit)	Brix	Fruit size (g/fruit)	Brix
0	1.60 ± 0.44	10.59 ± 0.65	1.75 ± 0.35	10.72 ± 0.78	1.57 ± 0.36	10.95 ± 1.42	1.44 ± 0.22	10.53 ± 0.56
17	1.53 ± 0.47	11.06 ± 1.15	1.72 ± 0.40	10.73 ± 0.94	1.68 ± 0.56	10.60 ± 1.23	1.55 ± 0.20	10.92 ± 0.61
34	1.62 ± 0.42	10.78 ± 0.76	1.76 ± 0.33	10.87 ± 0.50	1.61 ± 0.40	10.70 ± 0.99	1.49 ± 0.30	10.75 ± 0.99
Year								
2020	1.84 ± 0.30a	10.07 ± 0.30b	2.06 ± 0.12a	10.26 ± 0.34b	1.96 ± 0.34a	9.98 ± 0.54b	1.70 ± 0.10a	10.29 ± 0.62b
2021	1.33 ± 0.44b	11.55 ± 0.45a	1.43 ± 0.09b	11.29 ± 0.61a	1.28 ± 0.10b	11.52 ± 1.10a	1.28 ± 0.09b	11.18 ± 0.52a
Significance								
Fertilizer level	NS	NS	NS	NS	NS	NS	NS	NS
Year	< 0.001	< 0.001	< 0.001	0.0025	0.0003	0.0069	< 0.001	0.0041
Fertilizer level × year	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by the same letter within a column of each cultivar are not significantly different from each other at $p \leq 0.05$. NS means no significant differences at $p \leq 0.05$.

Raspberry fertilization in the cold region

Results showed that there are no significant differences among the fertilizer treatments. However, significant differences were observed in the years. Two years of observation showed that 'Nova' fruit was the largest with an average size of 1.74 g per fruit, followed by 'Encore' (1.62), 'Boyne' (1.50), and 'Amethyst' (1.49) (Table 1). Similarly, no significant differences were found for fruit juice Brix among the fertilizer treatments in the four cultivars. Results showed that the fruit of 2020 was significantly larger than that of 2021, while juice Brix was significantly higher in 2021 (11.40) than in 2020 (10.15) (Table 1). Results also showed that the fruit yield was not significantly affected by the fertilizer treatments. However, a significant interaction of fertilizer × year was observed in 'Amethyst'. Further analyses showed that a significant yield difference between fertilizer treatments in 2021 was observed, while no significant difference in yield existed among three fertilizer treatments in 2020 (Fig. 1). Such a yearly difference might be a result of worse bud damage of 'Amethyst' in 2020 than in 2021, causing a significant interaction between fertilizer and year (Table 2). A similar trend in yield difference was also observed in Nova as more buds were damaged in 2020 than in 2021 (Table 2).

Effect of fertilization on winter bud damage of raspberry plants

The effect of fertilization on winter damage of raspberry plants was determined by assessing bud damage on overwintered canes. Results showed no significant differences in winter damage among the fertilizer treatments, while both cultivar and year showed significant impact on winter bud damage for the four raspberry cultivars

(Table 2). 'Boyne' is the hardiest with no bud damage observed. 'Nova' and 'Encore' showed less than 20% bud damage, whereas 'Amethyst' is the least hardy cultivar, with more than 20% of buds damaged in 2020 (Table 2).

Effect of fertilization on cane height and number

The effect of fertilization on cane height and cane number of the four cultivars was recorded in the spring of 2021 and 2022. Results showed that three fertilizer treatments had no significant effect on both cane height and cane number (Table 3). However, a significant difference between the two years was observed in 'Boyne', 'Encore', and 'Amethyst'.

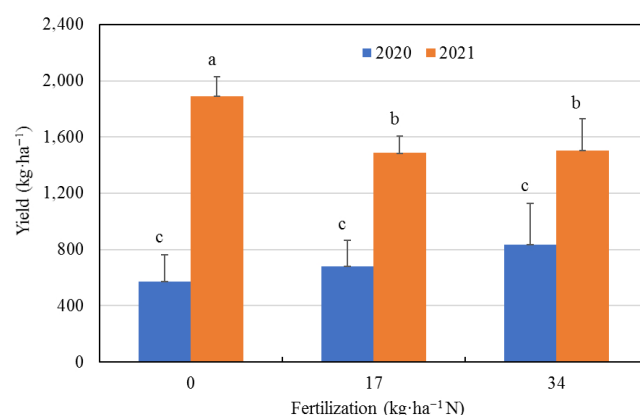


Fig. 1 Interaction of fertilizer × year in yield of cultivar 'Amethyst'.

Table 2. The effect of fertilization on yield and winter bud damage of four floricane-fruiting raspberry cultivars in Fargo, ND, USA.

Fertilizer level (kg N/ha)	Boyne		Nova		Encore		Amethyst	
	Yield (kg/ha)	Bud damage index	Yield (kg/ha)	Bud damage index	Yield (kg/ha)	Bud damage index	Yield (kg/ha)	Bud damage index
0	1030 ± 439	0	895 ± 419	0.40 ± 0.63	340 ± 204	0.58 ± 0.49	1232 ± 736	1.25 ± 0.61
18	728 ± 343	0	854 ± 530	0.50 ± 0.55	644 ± 515	0.42 ± 0.49	1084 ± 461	1.08 ± 0.38
36	1032 ± 409	0	903 ± 498	0.33 ± 0.41	498 ± 331	0.58 ± 0.58	1169 ± 435	0.83 ± 0.41
Year								
2020	847 ± 447b	0	502 ± 260b	0.77 ± 0.49a	585 ± 459	0.94 ± 0.30a	696 ± 226b	1.33 ± 0.50a
2021	1013 ± 348a	0	1266 ± 213a	0.06 ± 0.17b	406 ± 256	0.11 ± 0.22b	1626 ± 245a	0.78 ± 0.26b
Significance								
Fertilizer level	NS	NS	NS	NS	NS	NS	NS	NS
Year	< 0.001	NS	< 0.001	0.0025	NS	< 0.001	< 0.001	0.0155
Fertilizer level × year	NS	NS	NS	NS	NS	NS	0.0275	NS

Means followed by the same letter within a column of each cultivar are not significantly different from each other at p ≤ 0.05. NS means no significant differences at p ≤ 0.05.

Table 3. The effect of fertilization on cane height and cane number of four floricane-fruiting raspberry cultivars in Fargo, ND, USA.

Fertilizer level (kg N/ha)	Boyne		Nova		Encore		Amethyst	
	Cane height (cm)	Cane number	Cane height (cm)	Cane number	Cane height (cm)	Cane number	Cane height (cm)	Cane number
0	76.0 ± 8.4	19.1 ± 5.6	84.2 ± 11.6	19.7 ± 6.1	77.2 ± 5.5	17.2 ± 6.7	128.7 ± 8.1	13.8 ± 4.6
17	79.2 ± 9.7	20.7 ± 3.8	94.5 ± 10.2	23.2 ± 6.1	87.7 ± 12.4	19.7 ± 6.3	125.7 ± 5.3	13.8 ± 2.6
34	83.0 ± 16.5	22.0 ± 7.3	95.2 ± 11.6	23.2 ± 9.4	79.8 ± 19.7	17.7 ± 6.7	128.0 ± 7.3	14.3 ± 3.8
Year								
2020	85.7 ± 9.8a	24.8 ± 3.3a	96.4 ± 10.7	27.8 ± 5.0	91.3 ± 8.8a	22.2 ± 5.1a	124.1 ± 2.2b	16.0 ± 3.7a
2021	73.1 ± 10.3b	16.4 ± 3.8b	86.1 ± 10.7	16.2 ± 2.8	71.8 ± 15.0b	14.1 ± 3.4b	130.8 ± 8.1a	12.0 ± 2.1b
Significance								
Fertilizer level	NS	NS	NS	NS	NS	NS	NS	NS
Year	0.0076	0.0002	NS	NS	0.0004	0.0002	0.0546	0.0171
Fertilizer level × year	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by the same letter within a column of each cultivar are not significantly different from each other at p ≤ 0.05. NS means no significant differences at p ≤ 0.05.

Discussion

Commercial raspberry production in ND is limited because of the lack of winter-hardy raspberry cultivars. A previous study by Dai et al.^[13] in 2024 reported that a few floricane-fruiting raspberry cultivars, including four cultivars 'Boyne', 'Nova', 'Encore', and 'Amethyst' that were used in this study, are hardy in ND. There is no report on fertilization of field production of raspberries in ND. This study was developed to evaluate if fertilizer application at different levels can improve raspberry growth and development across the years 2020 and 2021. The results showed no significant differences in fruit size, Brix, yield, bud damage, cane height, and cane number among the three levels of fertilizer treatments in all four cultivars. However, the statistical analysis determined significant differences in fruit size, Brix, yield (except 'Encore'), bud damage (except 'Boyne'), and cane height and number (except 'Nova'), with very few exceptions between the two years. Fertilization is an important field management tool in fruit production. Research showed that mineral nutrition had a significant impact on raspberry fruit quality, yield, resistance to biotic and abiotic stresses, fruit shelf life, and growth and development^[16]. Research also indicated that fertilization, particularly nitrogen, showed no positive effects on plant growth, fruit quality development, and yield in raspberry production. Lu et al.^[17] recently reported that nitrogen fertilization showed no increase in yield, fruit quality, or plant growth of floricane red raspberry 'Meeker'. It is not uncommon that fertilization fails to improve yield and fruit quality in fruit crop production. There are many factors affecting fertilization efficiency in improving raspberry fruit quality and yield, such as environmental conditions, nutrient balance, application timing, and plant physiological conditions. Bushway et al.^[9] recommended that 45–90 kg actual N/ha is needed for summer-bearing raspberries annually, which is much higher than the fertilizer rate used in this study (18–36 kg/ha). In this study, the hill production system was used, where the average area of each planting hill was approximately 0.5–1 m², and fertilizer granules were spread in an area of 0.2 m² around each plant hill; therefore, individual raspberry plants received a higher fertilizer rate compared to raspberry plants in the hedge production system. In this study, a controlled released fertilizer, Multicote 4, was used. Multicote 4 fertilizer slowly releases nutrients continuously over four months, which minimizes nutrient losses caused by leaching and fixation and can considerably reduce the application rate up to 30% compared to conventional fertilizers (www.haifa-group.com/controlled-release-fertilizer). A single application of Multicote 4 fertilizer can cover the nutritional requirements of raspberry growth throughout its critical growing period (June–September). It has been reported that raspberry plants grown in heavy soils with high organic matter content require less nitrogen than in the soils with low organic matter content because a significant amount of nitrogen can be released from organic matter^[9]. The soil in the raspberry field is Fargo silty clay that is truly a heavy soil with a high organic matter of 5.6% in the upper 6-inch layer of the soil. Moreover, red and white clover plants grown in the field would supplement nitrogen for raspberry growth every year. Similar results were also reported by Stirk & Bryla^[18] and Lu et al.^[17] that the lack of plant response to fertilization may be due to good organic matter (3.8%–4.0%) in the soil, and reserved nutrients in plants. The aforementioned findings can explain why no nitrogen (and other minerals) deficiency symptoms were observed on raspberry plants in this study. The environmental conditions in the region may play a role in the lack of response to fertilization. Extreme low temperatures may partially injure root systems and overwintering canes, leading to impaired nutrient uptake and

translocation in plants. Short growing seasons (May to October) limit the overall raspberry growth, which is evidenced by short canes, few canes, and low fruit yield compared to other raspberry regions^[13]. Less vegetative and reproductive growth generally requires fewer nutrients that can be supplied from the soil organic matter and the legumes grown in the field. Three red raspberry cultivars 'Boyne', 'Nova', and 'Encore', and one purple raspberry cultivar 'Amethyst' were included in this study. 'Boyne' and 'Nova' are early to mid-season ripening raspberries, while 'Encore' and 'Amethyst' are late-season ripening cultivars. All four cultivars are floricane-fruiting, and fertilization can influence current and next year's growth, which involves both vegetative and reproductive growth. However, the lack of response of all four cultivars to fertilization indicates that cultivars might not be the main factor affecting the fertilization efficiency in the field production of raspberry. Other factors, such as soil and environmental conditions, fertilizer type, fertilization time and method, and plant physiological conditions may have more influence on raspberry growth and development.

It is understood that the low levels of vegetative (cane height and number), and reproductive (fruit yield) growth identified in this research certainly reduced the overall need for nutrients that can otherwise be supplemented from the organic matter in the soil, supplied by red/white clover, and those reserved in plants. A single application of the controlled release Multicote 4 fertilizer certainly benefits the environment and sustainable raspberry production by reducing fertilizer rates and saving labor and costs associated with fertilization in raspberry production. When considering using cultural strategies to enhance plant growth and yield development of raspberry, fertilization management should still be one of the most important factors that warrant further research.

In conclusion, the impact of fertilization on raspberry growth and fruit production is not always straightforward. The efficiency of fertilization can be affected by many factors, including plant type, soil fertility, application time, environmental conditions, and fertilizer type. Therefore, fertilizer management in raspberry production should only be considered as one piece of the puzzle and needs to be integrated into other cultural practices, such as proper pruning, irrigation, and pest management, to truly enhance raspberry productivity.

Author contributions

The authors confirm their contributions to the paper as follows: study conception and design: Dai W, Hermanson AL; data collection: Hermanson AL, Dai W, Zhang Q; analysis and interpretation of results, draft manuscript preparation: Dai W, Zhang Q. All authors reviewed the results and approved the final version of the manuscript.

Data availability

All data generated or analyzed during this study are included in this published article.

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Conflict of interest

The authors declare that they have no conflict of interest.

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