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Response of straw berry crop to runner removal: A review

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Abstract
Most of the commonly cultivated varieties of strawberry plants (*Fragaria* x *ananassa*) produce "runners" as a means of propagating themselves. However, production of more runners on strawberry plant means that plants are turning valuable buds to develop runners instead of extended crowns (new shoots) or flower clusters. Under optimum growing conditions, runner production should be minimum or none during fruit production. Removal of runners in strawberry is a key crop management practice to balance sink/source and vegetative/reproductive growth. Runners are also removed to prevent allocation of photoassimilates to these unwanted sink organs. Since it is a recommended but costly practice in strawberry production system, use of prohexadone-calcium for suppressing runner production or development of an automation system for the cutting of runners may be think of for large scale strawberry production.

Keywords: Strawberry, runner removal, source-sink, day-neutral

Introduction
Source–sink relations play a fundamental role in the regulation of vegetative growth and flower and fruit development in berry crops. In the plant, a "source" can be defined as a photosynthesizing tissue or organ with net export of carbon skeletons, typically comprising all kinds of green leaves, while a "sink" can be defined as a heterotrophic tissue or organ, which is dependent on net import of photosynthetic compounds for its development (Hansen, 1989 [14]; Blanke, 2009) [4]. Typical examples of sinks are fruits > flowers > roots > shoots > leaves, in that order of strength hierarchy. During ontogeny, some of these organs may change from sinks to sources over time (Blanke, 2009) [4]. This means that, in berry crops in general, the fruit growth regulatory source–sink relationship is mainly determined by the fruit/leaf ratio of the plant. Accordingly, plant manipulations to alter this ratio have the potential to be used as a means to modify plant and crop yield.

Plant reproduction often involves concentrated energy for seed production after flower fertilization,vegetative growth tends to slow or stop altogether because seed creation takes most of the plant's energy. However, other propagation methods exist so that plants can continue to spread throughout an area without losing energy to seed generation, including growing expansive plant runners. In botany a stolon, also called a runner, is a slender stem that grows horizontally along the ground, giving rise to roots and aerial (vertical) branches at specialized points called nodes (Figure 1). Although the term "runner" is used interchangeably with "stolon," runners are not the same appendage. In fact, runners do not have any substantial leaves for photosynthesis, which means they need to get their energy from the mother plant. Unlike stolons, an individual runner cannot survive unless it is still attached to the mother plant–stolons have leaves and photosynthesizing abilities. In essence, runners connect the mother plant to a newly formed daughter plant. Once established, the daughter plant photosynthesizes for fresh growth and possible new runner generation.

Avoiding high-energy seed production, runners allow plants to establish themselves quickly within a large growing space– they tend to crowd out other plants and some weeds. As daughter plants spread around the mother plant, the entire plant configuration takes advantage of all the soil nutrients and moisture available because the root system has a larger surface area in which to search for sustenance. If your runners produce crops, daughter plants generate fruits just like the mother plant for a high yield during the growing season (Caruana *et al.*, 2018 [5]; Li *et al.*, 2020) [20].

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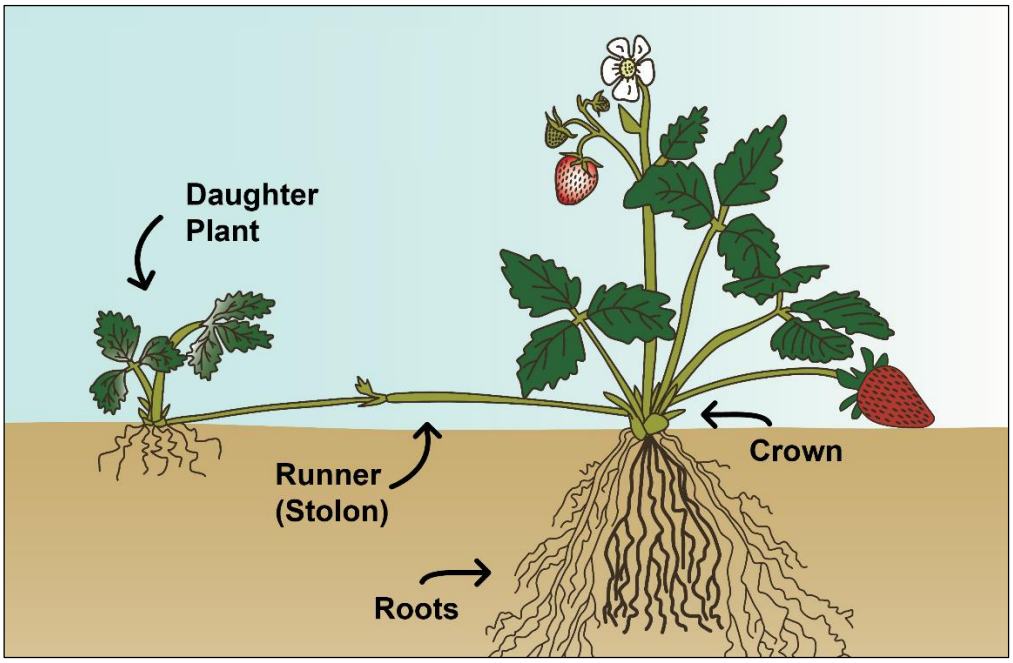

Fig 1: Depiction of runners in strawberry plants

However, daughter plants takes considerable energy away from the mother plant, it is possible that a potential fruit crop may be reduced because the plant is concentrating on vegetative spreading rather than fruiting. As a solution, you can remove the runners and plant the daughter plants in a separate area. Crowded plants tend to compete fiercely for natural soil resources, making it difficult for any crop production. Once removed, both the mother and individual daughter plants have a chance to grow larger fruits because they are not limited by their small growing space with scarce moisture and nutrients. As such, runner production in the strawberry is undesirable because of the possible negative effect on fruit yields, nevertheless, runners may become useful as transplants when the original transplants are lost to disease or stress Albregts and Howard, 1986) [3]. In strawberry, the relationship is complicated by the presence of runners, which are known as strong sinks for leaf assimilates, water, and nutrients in competition with developing flowers and fruits (Albregts and Howard, 1986 [3]; Handley *et al.*, 2009) [13]. In general, long-days (LD) and higher temperatures promote runner formation in the seasonal flowering strawberries (Hytonen *et al.*, 2004 [18]; Mouhu *et al.*, 2013) [23]. Much of the published research on strawberry runner removal (Figure 2) has used short-day or June-bearing cultivars that initiate flowers under short-day cooler conditions and produce runners under long days and warm temperatures (Heide *et al.*, 2013) [15].

Fig 2: Manual method of runner removal in strawberry plants

However, the yield effect of de-runnering and other leaf canopy manipulations have varied considerably between cultivars, production systems, and with varying time and duration of application, for example (Pritts and Worden, 1988 [27]; Chandler *et al.*, 1988 [6]; Lyu *et al.*, 2014) [21]. Portz and Nonnecke (2009) [26] reported that runner removal improved yields for only one of three day-neutral strawberry cultivars tested. Runner removal is a costly but recommended procedure in day-neutral strawberry production that is said to maximize fruit production. Runners are typically removed by hand which is labour intensive. Some growers remove flowers during the establishment period and runners over a season (Galic, 2015) [9]. Runner plants are a liability in a plasticulture system as they are a sink for assimilates which reduces resources that could support flower and fruit production (Handley *et al.*, 2009) [13]. The presence of runners also makes it more difficult for pickers to find berries during harvest (Duval and Golden, 2005), and may interfere with cultivation and pest control (Handley *et al.*, 2009) [13].

Effects of runner removal on vegetative growth of plant

Handley *et al.* (2009) [13] found that strawberry plant spraying with prohexadione-calcium (a chemical that blocks the biosynthesis of active gibberellins and strongly suppressed runner development) decreased the plant dry weights at higher concentration with increased frequency of spray. Handley *et al.* (2009) [13] found that strawberry plant spraying with prohexadione-calcium (a chemical that blocks the biosynthesis of active gibberellins and strongly suppressed runner development) increased fruit yield in summer-planted 'Honeoye' short day strawberry. Both runner suppression in the planting year and yield increase in the following season were strongly enhanced with increasing rates and application numbers and were in most cases more effective than removal of runners by hand. However, the plant dry weights were also reduced by prohexadione-calcium, but only at the two highest rates and frequencies of application.

Lyu *et al.* (2014) [21] studied the effects of partial defoliation and runner removal on plant growth, leaf photosynthesis (P^n) and yield in field-grown or potted strawberry plants ('Toyonoka'). The treatments were consisted of partial defoliation by removing leaves older than 45 days (PD), removing all runners (DR), PD + DR and the control (CK). Treatments were applied weekly from mid-November until early March. DR promoted yield and number of fruits for the first harvest cycle but not for the second harvest cycle. Multiple linear regressions indicated that leaf area had greater overall effects on runnering and fruit traits than the existence of runners. The leaf P^n was not responsive to DR but a transient increase in P^n was consistently detected on the remaining leaf after each PD treatment. The compensatory increase in P^n was only detectable within 1 day after each PD treatment, indicating that the actual compensation for partial loss of functioning leaf area may be negligible. Crown dry weight was less affected by canopy manipulation than growth and dry weight of roots. They concluded that yield of strawberry in Taiwan's subtropical climate can be improved by removing runners while maintaining a greater leaf area with less severe defoliation.

Lyu Yang *et al.* (2014) [21] reported that runner removal in short day strawberry (Toyonoka) decreased the crown and aboveground plant weight, and in particular growth and dry weight of roots. Hughes *et al.* (2017) [17] also communicated the similar type of results with varying severity of runner removal in the ever bearing cultivars 'Albion' and 'Seascape' cultivars of strawberry. Runner removal has been shown to stimulate runner production over the season (Greene and Schloemann, 2010; Lyu *et al.*, 2014; Hughes *et al.*, 2017) [17].

Ahmed *et al.* (2017 [2] indicated that foliar application of 25 ppm of gibberellic acid (GA_3) with removing all runners caused an increase in plant height. The study shows that it's better to use gibberellic acid (GA_3) with 25 ppm to spray the strawberry fruits with removing all the runners that exist beside the mother plant and that's to increase the vegetative growth and to improve the yield qualities.

Palonen *et al.* (2022) [24] investigated the impact of repeated runner removal after harvest on strawberry (Fragaria × ananassa) cvs. Polka and Wendy. The treatment effects on the crown carbohydrate reserves, flowering, and yield were recorded. Runner removal three times in three-week intervals after harvest decreased the crown starch reserves but increased the length of the apical inflorescence initials and the numbers of inflorescences and flowers in cv. Polka. Although the effects may depend on a cultivar and weather conditions during fall, repeated removal of runners after harvest has been recommended to increase strawberry yield potential.

Shi *et al.* (2021) [28] reported that stolan removal (every 7 days, nine times total; every 21 days, three times total; one-time stolon removal after 63 days) after 63 days resulted in more production of daughter plants compared to other runner removal treatments. However, mother plant organs (including roots, crown, and leaves) had less dry weight in the 63-day treatment compared with other treatments. The results of this study show daughter plant production of strawberry plants declines significantly with shorter stolon removal intervals, indicating the need to adjust stolon removal in strawberry nurseries for optimal daughter plant production.

Effects of runner removal on reproductive growth and yield

Albregts and Howard (1986) [3] reported that removal of strawberry runners once and twice in a month improved early marketable yields of Tufts' variety compared to the plants where runners remained attached to the fruiting plants. Yields were reduced because of fewer marketable-size fruit. However, yields of 'Dover' variety were unaffected by runner removal treatments. Klaas *et al.* (2009) [19] demonstrated that keeping the runners from plants has negative effect on strawberry where it decreases in berry weight and final yield. Also there is an increase in the amount of grade two berries. In order to obtain a high-quality yield, runners must be removed during harvest. Handley *et al.* (2009) [13] stated that runners are undesirable as they reduce marketable yield and are expensive to remove by hand. Prohexadione-calcium (Apogee®) is a gibberellic acid synthesis inhibitor that can reduce shoot growth in plants. Summer planted 'Honeoye' strawberries grown in a plasticulture system were treated with foliar sprays of prohexadione-calcium one, two or three times, approximately two weeks apart, at rates of 50 ppm, 100 ppm or 200 ppm, beginning when runner development was first noticed, or had runners removed by hand. The higher rates and doses of prohexadione-calcium in this trial provided the greatest inhibition of runner development and the highest marketable yield. Increasing rates and doses also tended to increase leaf number, reduce petiole and runner internode length, and reduce plant dry weights. Fruit size tended to be reduced under the

highest number of sprays. Foliar sprays of prohexadione-calcium at 100-200 ppm appears to provide an effective means to reduce runner plant production for summer-planted strawberries grown in plasticulture. Portz and Nonnecke (2010) [26] reported that practice of the removal of flowers and runners of day-neutral strawberries have marked influence on total fruit production, average berry size and plant biomass.

Lyu *et al.* (2014) [21] reported that runner removal in short day strawberry (Toyonoka) increased the fruit number and yield. Sonsteby and Heid (2015) [30] stated that it is not clear at what degree growth and fruit yield are source-limited in everbearing strawberry plants. They grew plants on a table-top system in an open plastic tunnel under natural light conditions and found that bi-weekly runner removal increased total and marketable yield and number and size of fruits, while increasing leaf thinning had the opposite effects. However, none of the treatments affected the fruit number and yield of the first fruiting flush.

Hughes *et al.* (2017) [17] also found that runner removal (once, three times, and weekly for two months) of two ever bearing strawberry varieties ('Albion' and 'Seascape') increased total and marketable yields in the planting year but not in the second year. They further clarified that weekly runner removal showed better response compared other removal practices.

Hughes *et al.* (2017) [17] reported that runner removal (once, three times and weekly for two months) increased total and marketable yields in the 'Albion' cultivar at both sites in the planting year, while few effects were observed in the second year. At the cooler climate site, both 'Albion' and 'Seascape' produced larger yields in the planting year with weekly runner removal, but not with less frequent removal. At the warmer site, total yield of 'Albion', but not 'Seascape', was reduced by 30% when runners were not removed. Plant dry weight and number of crowns increased with increasing frequency of runner removal.

Ahmed *et al.* (2017) [2] carried out an experiment during the two successive seasons of 2014-15 and 2015-16 to study the effect of runners' removal rates beside mothers full removal "no runners", five runners left, ten runners left and without runners' removal and foliar spray of gibberellic acid 0, 25 and 50 ppm and their interactions on vegetative growth, chemical properties, physiological traits, yield and quality of strawberry "Fortuna cv." planted under mixed planting system which fixed many runners beside mother plant with different density. Results indicated that foliar application of 25 ppm of gibberellic acid (GA_3) with removing all runners caused an increase in plant height, size, weight and shape index of the fruits. gibberellic acid (GA_3) at 25 ppm gave also the highest number of early fruits and early yield during both seasons, GA_3 also gave the highest value of TSS, vitamin C, number of leaves, number of fruits and the yield too. The study shows that it's better to use gibberellic acid (GA_3) with 25 ppm to spray the strawberry fruits with removing all the runners that exist beside the mother plant and that's to increase the vegetative growth and to improve the yield qualities.

Sonsteby *et al.* (2021) [29] determined the effect of runner removal on growth and yield performance of tunnel-grown 'Favori' ever bearing strawberry plants. Removal of runners and leaves was biweekly from 5th June until 25th September. Fruits were harvested from 5th July to 7th October. Bi-weekly runner removal increased total and marketable yield and number and size of fruits, while increasing leaf thinning had the opposite effects. However, none of the treatments affected the fruit number and yield of the first fruiting flush. The treatments did not affect realization of the yield potential of the plants at planting, whereas the continued floral initiation and fruit growth were enhanced by runner removal. Increasing leaf thinning had the opposite effects. Both floral initiation and fruit growth in heavily flowering and fruiting everbearing strawberry are source-limited owing to the high fruit/leaf ratio of such plants.

Hughes *et al.* (2022) [16] reported that removing runners from Albion strawberry resulted in significantly greater yield and yield attributes as well as marketable yield. Palonen *et al.* (2022) [24] investigated the impact of repeated runner removal after harvest and row cover during fall on strawberry (*Fragaria* × *ananassa*) cvs. Polka and Wendy cropping potential in the joint project of the University of Helsinki and the Rural Advisory Services Finland. Field trials were carried out in 2017 to 2019 on strawberry farms in Southern Ostrobothnia, Finland, at 62°49′N. The treatment effects on the crown carbohydrate reserves, flowering, and yield were recorded. Runner removal three times in three-week intervals after harvest decreased the crown starch reserves but increased the length of the apical inflorescence initials as observed through flower mapping in November, and the numbers of inflorescences and flowers in cv. Polka. Floating row cover after flower induction in September to October hastened floral development in the fall and increased the numbers of inflorescences, flowers, and fruit in cv. Wendy. Although the effects may depend on a cultivar and weather conditions during fall, repeated removal of runners after harvest and covering plants with a floating row cover after flower induction are recommended to increase strawberry yield potential in the Northern climate.

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