ABSTRACT

Title: SUSTAINABILITY OF COLD-CLIMATE STRAWBERRY PRODUCTION SYSTEMS

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Three cold-climate strawberry (*Fragaria xananassa* Duch.) production systems, conventional matted row (CMR), advanced matted row (AMR), and cold-climate plasticulture (CCP) were compared for aspects of sustainability including environmental impacts, economic viability and public acceptance over a three year production cycle. As a result of higher total yields, CMR had the highest overall revenue and estimated net profit of any system. The CCP had the lowest observed yield but the largest fruit in year one. Reduced fruit size and yield in the second harvest season indicate the CCP system may not be suitable for perennial production. Both the CCP and AMR production systems were better than CMR in preventing soil, nitrogen and pesticide loss due to rain-induced runoff, and had higher N uptake than CMR. The CCP and AMR systems were preferred over CMR in a pick-your-own consumer preference evaluation. AMR and CCP represent potential sustainable alternatives to the CMR system.

SUSTAINABILITY OF COLD-CLIMATE STRAWBERRY PRODUCTION SYSTEMS

By

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Chapter 1: Introduction

Strawberry (*Fragaria xananassa* Duch.) is a labor-intensive crop where production of marketable fruit depends on the ability of the grower to minimize weed, insect and disease pressure through pesticide usage and/or cultural practices (Chandler et al., 2001; Hancock et al., 2001; Rhainds et al., 2002). Weeds, the primary pest of strawberry, can severely limit the development of runners in matted row systems (Pritts and Kelly, 2001). Controlling weeds is especially vital during the establishment year (planting to first harvest), and following renovation between harvests in perennial systems. Additionally pathogens can cause substantial losses when outbreaks occur. In years when the weather is cool and there is heavy rainfall, fruit rots can render much of the crop unmarketable. In other instances, virus and soil-borne diseases can lead to crown rot and plant decline.

Ninety-six percent of the reported 1,041,000 tons of strawberries produced annually in the U.S. are grown in California and Florida (NASS, 2004). Growers in Midwestern and Northeastern states account for approximately 2.2% of total U.S. production and 18% of the total commercial acreage , but receive an average price nearly double that of southern states (NASS, 2004). This price difference is due to different nature of fruit production in these regions. Growers in the Midwest and Northeast are generally small-scale producers diversified in various fruit and vegetable crops and are direct market-oriented. This study is designed to reflect the production practices of these growers.

Growers in the Midwest and Northeast have typically relied on the Conventional Matted Row (CMR) system of strawberry production. Weed control in the CMR system is accomplished through periodic mechanical cultivation, with some hand weeding. Some growers have begun using a cold-climate plasticulture (CCP) system, in which plastic mulch provides most of the weed control, with some application of herbicide between rows as necessary. Typically, growers rely on an intense fungicide spray regime, regardless of production system, from the bud show stage through fruit set to limit potential diseases such as anthracnose, Botrytis rot, and other foliar diseases. In addition, the strawberry industry has previously relied on methyl bromide fumigation prior to planting to eliminate weeds, nematodes, and soil-borne pathogens. Methyl bromide has been identified as an ozone-depleting chemical and is being phased out of production. Because the absence of methyl bromide is a reality for future strawberry production, methyl bromide will not be used in this experiment.

The elimination of methyl bromide from strawberry production systems will result in increased need for other methods to control weeds and diseases. There is little information available in the literature to estimate the added costs, both economic and environmental, of these increased pesticide needs. This study was conducted without methyl bromide in order to determine crop budgets for each system in non-methyl bromide fumigated production. In terms of environmental impact, insecticides and fungicides are more likely to be lost in runoff than herbicides, due to timing of application. Nearly all of the insecticide and fungicide use in cold-climate strawberry production occurs in the spring, when the probability for surface runoff is highest due to rainfall frequency and the use of overhead irrigation for frost protection. Herbicide use is more evenly distributed throughout the growing season, and therefore not as likely to be applied in a time where the risk of runoff is high.

Much emphasis has been placed on advancing strawberry production systems in a more sustainable direction (Black et al., 2002a; Merwin and Pritts, 1993; Nonnecke and Dewitt, 1996;

Pritts, 2000). Sustainable systems have been defined as systems that provide adequate quantity to meet demand, optimize crop output per unit of input, conserve and protect the essential agro-ecosystem resource base, and provide profits which are sufficient to support farmers and viable rural communities (Merwin and Pritts, 1993). Based on this definition, this experiment compares sustainability among production systems in three logical components: economic viability, environmental impacts, and public acceptance. The efficiency section of the Merwin and Pritts definition includes factors in both the environmental and economic components of this study. Because yields and pest management are closely tied together in strawberry production, it is important to consider production systems with respect to both economic and environmental variables. Public acceptance is a major concern due to the prevalence of Pick-Your-Own (PYO) farms in the colder regions of the United States (including the mid-Atlantic, Northeast and Midwestern states). Providing an enjoyable PYO experience, in terms of setting, fruit quality, and ease of harvest, has a large effect on the level of consumer acceptance in high population areas, especially consumers with higher levels of disposable income. There is also a social aspect to the public acceptance factor. Typically, strawberry production relies on low wage labor for the majority of its labor requirement. Because labor requirements for strawberry production are typically very high, use of low wage labor keeps prices relatively low. While consumers may be unwilling to pay higher prices for fruit, most also believe that fair wages should be paid.

Each of the three main components of sustainability mentioned above are closely related and affect each other. As such, it is necessary to look at how each component is affected in current production systems. By doing so, each system can be more effectively evaluated as a sustainable system. Positive and negative aspects of each system can therefore be identified and changes to current production practices can be made to increase sustainability.

The goal of this research is to compare three methods of strawberry production for cold-climates in order to identify which system is most sustainable, as well as identify areas within each production system in which sustainability can be improved. It is hypothesized that the advanced matted row system of production will be more sustainable than either the conventional matted row or cold-climate plasticulture systems. Moreover, it is hypothesized that factors will be identified in each system that limit sustainability in current production. By identifying these limiting factors, and identifying the most sustainable production system, best management practices can be recommended.

Chapter 2: Economic and Horticultural Impacts

Introduction

For nearly 100 years, conventional matted row production (CMR) has been the standard method of strawberry production in colder areas of the United States. CMR plantings are maintained for 3 to 7 years depending on disease pressure and other site-specific considerations, which includes a non-fruiting establishment year. Growers in northeastern North America have long recognized the inefficiencies of the CMR system and have explored other production practices to improve efficiency, and reduce labor requirements (Hancock and Roueche, 1983; Rotthoff, 1980). One system currently being explored is an adaptation of the annual hill or plasticulture system patterned after the production practices of California and Florida (Poling, 1996). The northern adaptation of this system, (i.e. Cold Climate Plasticulture, CCP) may offer some benefits in improved yields and fruit quality (Fiola et al., 1995; Fiola et al., 1997; O'Dell and Williams, 2000). However, the trade-off costs of this system include increased financial risk, due to increased establishment costs with only marginal increases in returns, and historically a greater reliance on methyl bromide as a soil fumigant (Larson, 1996; Pritts and Handley, 1998). With the use of methyl bromide being phased out (except for critical use permits), the potential yield benefits of this annual hill system are now questionable (Chandler et al., 2001; Hancock et al., 2001). Although exceptional weed control is achieved by the use of plastic mulch in the plasticulture system, herbicide application is necessary to control weeds between rows. Since this system is also replanted more frequently (every 1 or 2 years) than the perennial matted row system, material costs are much greater over both the short and long term.

The advanced matted row (AMR) system has been proposed as a more sustainable alternative for growers in colder regions (Black et al., 2002; Black et al., 2002). The AMR system employs raised beds and drip irrigation similar to the plasticulture system, but plants are managed as in conventional matted row production with a cover crop residue mulch.

The goal of this study was to compare the production cost variables between these three systems, including labor inputs, material costs, and compare the marketable yields and potential returns from each system. From the data collected from these comparisons, a sample crop budget was developed for each production system, to compare relative costs and returns over a three-year planting cycle.

Materials and Methods

Production Systems

Three replicate plots of each of the three production systems, conventional matted row (CMR), advanced matted row (AMR) and cold-climate plasticulture (CCP) were established in 2001-2002 in a randomized complete block design at the South Farm of the U.S. Department of Agriculture, Henry A. Wallace Beltsville Agricultural Research Center (BARC) in Beltsville, Maryland. Each plot was prepared in a north-south direction measuring 13.7 meters long and 6.1 meters wide (four rows), and was planted in 2002 and cropped in the 2003 and 2004 seasons. Each cropping system was managed according to typical best management practices for the three different production systems in the mid-western and north-eastern regions of the United States.

The variety 'Allstar' was used in all systems because of a favorable disease resistance profile, and adaptability to different production systems. 'Allstar' was originally selected for CMR production (Galletta et al., 1981), but has shown superior performance in both the CCP and AMR systems (Black et al., 2002). Though growers would likely choose to grow a different cultivar that is particularly well adapted to the production system of choice, using 'Allstar' for this experiment limited potential treatment x cultivar interaction.

Individual irrigation systems including water meters (Hersey Meters model 430IIs, Cleveland, NC) and electronic valves (Irritrol Systems model 700B-.75, Riverside, CA) were installed for each plot according to the requirements for each production system: drip irrigation for AMR and CCP, overhead irrigation for conventional matted row. On 3-June 2002, a soil moisture indicator (Irrometer model RA, Riverside, CA) was installed in each CMR and AMR plot at 30 cm depth to measure soil moisture. Each soil moisture indicator was wired through the electronic shut off valve for the respective plot, and each valve was wired back to a single total control system (Irritrol Systems model TC-9 EX-B, Riverside, CA), which controlled irrigation for all nine plots. The control system was set to allow automatic irrigation to each plot independently as needed, based on the Irrometer soil moisture reading. Maximum daily irrigation time was one hour, and each plot was allotted a different hour of the day for irrigation to prevent water pressure differentials between plots. Irrometers were installed in the cold-climate plasticulture plots on 21-Aug 2002 following planting, using the methods described above. The soil moisture indicators were set at 20 centibars pressure for AMR and CCP plots and 30 centibars for CMR.

Conventional Matted Row

Following a winter cover crop of hairy vetch (*Vicia villosa* Roth), crimson clover (*Secale cereale* L.), and grain rye (*Trifolium incarnatum* L.), CMR plots were prepared in March of 2002. Dormant bare-root 'Allstar' strawberry plants were set at a spacing of 45 cm within row, and 1.5 m between row centers. Ammonium nitrate (NH_4NO_3) was broadcast applied at a rate of 64 kg N/ha on 10-May 2002. Overhead irrigation was delivered using gear-driven lawn sprinklers placed along the edges of each plot. Plots were cultivated periodically to control weeds, with hand weeding around mother plants, and hand placement of runners. Clean wheat straw was spread in December for winter protection, and overhead irrigation was used to protect flower buds from spring frosts. An additional 33.6 kg N/ha NH_4NO_3 was applied in spring 2003. Fruit was then harvested from late May to mid-June, 2003. Post harvest renovation was accomplished by mowing to remove leaves, cultivation, 2,4-D application, and a broadcast application of NH_4NO_3 at 56 kg N/ha. Fall and winter management was as described for the establishment year. An additional application of NH_4NO_3 at 16.8 kg N/ha was applied in spring 2004. Fruit was harvested from mid-May to early June, 2004.

Cold-climate Plasticulture

In August of 2002, CCP plots were prepared with raised beds, sub-surface drip irrigation lines placed at a depth 5-8 cm, and covered with 1.25 mil black plastic mulch. 'Allstar' plug plants were planted through the plastic mulch in offset double rows at a 30-cm within-row and between-row spacing. NH_4NO_3 was applied through the drip system in weekly applications of 11.2 kg N/ha for 7 weeks, beginning 26-August, for a total of 78.4 kg N/ha. Weeds between beds were controlled by directed application of paraquat (Gramoxone Max, Syngenta). Straw mulch was applied in December for winter protection, and overhead irrigation was used for frost protection. Ammonium nitrate at 16.8 kg N/ha of was applied in spring 2003 split over two weeks, prior to harvest.

Post harvest renovation was accomplished by mowing, followed by hand removal of excess crowns, with a fall fertigation that applied 56 kg N/ha of NH_4NO_3 over 4 weeks beginning 22-August, 2003. Winter management was the same as described for the establishment year. An additional 22.4 kg N/ha of NH_4NO_3 was applied over 3 fertigations in spring 2004, prior to harvest.

Advanced Matted Row

In September 2001, raised beds were formed in the AMR plots with sub-surface drip irrigation lines placed at a depth of 5-8 cm. A winter cover crop of hairy vetch, grain rye and crimson clover was seeded over the beds at seeding rates of 45, 78 and 34 kg/ha, respectively. The cover crop was killed using glyphosate (Roundup Original, Monsanto) approximately 3 weeks before planting and then cut down one week later. On 12-May, dormant bare-root 'Allstar' strawberry plants were hand-planted through the resulting cover crop residue layer. Plants were spaced 30 cm apart in a single row down the center of each raised bed and allowed to runner and form matted rows. The cover crop residue provided some weed suppression during strawberry establishment, and some hand weeding and spot applications of paraquat were used to control remaining weeds. Weekly NH_4NO_3 applications of 11.2 kg N/ha were supplied through the drip system for 10 weeks. In the fall, beds were narrowed with directed application of paraquat. Straw mulch was applied for winter frost protection, and overhead irrigation was used to prevent blossom damage during spring frosts. A pre-harvest NH_4NO_3 application of

16.8 kg N/ha over 3 weeks was made. Following fruit harvest, the AMR system was renovated by mowing for leaf removal, 2,4-D application for weed control, and NH_4NO_3 application through the drip system at a rate of 78.5 kg N/ha over 5 weeks. Fall and winter management were as described for the establishment year. An additional 22.4 kg N/ha NH_4NO_3 was applied over 3 weeks in spring 2004, prior to harvest.

Fruit Harvest

Yield data were collected from the two center rows of each four-row plot; the center rows were divided into three 3.7 meter-long harvest plots, with a minimum of 1 m of row remaining at each end to act as guard plots. This resulted in a total of 54 harvest plots (3 treatments x 3 reps x 6 plots per replicate). One harvest plot per research plot was randomly designated for measuring total biological yield and both marketable and unmarketable fruit was harvested and weighed. For the remaining harvest plots, only marketable fruit was harvested. Harvest plots were harvested by volunteers simulating PYO customers (see Chapter 4), who picked some fruit that typically would not be marketable as pre-picked fruit, but were considered marketable in this setting. Fruit was considered unmarketable if it had noticeable blemishes such as rot, insect damage, or other disease, or if the fruit weight was less than approximately 8 g. In 2003, fruit harvests were carried out twice weekly from May 27 through June 19 for all systems, for a total of eight harvests. There were 6 twice-weekly harvests in 2004, from May 17 through June 3.

Pesticides

Each production system was treated with an identical bloom-time fungicide spray regime, following the recommendations of the Maryland Commercial Small Fruit Production Guide

(Steiner et al., 1999). All fungicides were applied using an experimental plot sprayer equipped with a single row boom with three nozzles directing spray from above and both sides of the row. In 2003, benomyl (Benlate, DuPont Agricultural Products) was applied on April 22, at approximately 10% bloom, to control Botrytis rot (*Botrytis cinerea* Pers.:Fr). Azoxystrobin (Quadris Flowable, Syngenta) was applied 5-May as a management of anthracnose (*Colletotrichum acutatum* J.H. Simmonds). Thiophanate-methyl (Topsin-M WSB, Cerexagri) and captan (Captan 50-WP, Micro Flo) were applied together as a tank mix on 13-May. Thiophanate-methyl was applied for management of Botrytis rot, and captan was applied to manage common leaf spot (*Mycosphaerella fragariae* {Tul.} Lindau), Phomopsis leaf blight (*Phomopsis obscurans* {Ellis & Everh.} Sutton), and leaf blotch (*Gnomonia comari* P. Karst. and *Gnomonia*. *fragariae* Kleb.). Captan and thiophanate-methyl were applied together as a tank mix, because thiophanate-methyl has a similar mode of action to benomyl. A second azoxystrobin application was made 19-May. In 2004 benomyl was not applied because it was no longer available for commercial use. Except for the elimination of benomyl, a similar spray regime was used in 2004. Two applications of azoxystrobin were made, 12-April at approximately 25% bloom and 26-April at full bloom, with a single application of the captan/thiophanate-methyl tank mix applied on 19-April at approximately 50% bloom. Herbicides were applied to each plot as needed and in concert with other weed management practices appropriate for that system. A group of insecticides were identified for potential use and plots were scouted on a regular basis, but there was minimal insect infestation and no insecticide applications were necessary during the course of the experiment.

While between-row weed control in the CMR system was primarily through mechanical cultivation, the CCP and AMR systems were treated when necessary with gramoxone. On one occasion, the CMR treatment also received an application of gramoxone. Additionally, the CMR and AMR treatments each had one application of 2,4-D (2,4-D 6 Amine, NuFarm Turf & Specialty) during renovation following the 2003 harvest season. The advanced matted row had one application of glyphosate to kill the cover crop prior to planting. Gramoxone and 2,4-D were applied using a backpack sprayer. Glyphosate was applied via a boom sprayer**.** Fungicide and herbicide application volumes are shown in Table 1.

Data Analysis

Results of fruit harvest for 2003 and 2004 and measured labor inputs were analyzed as a completely randomized design, using the Proc Mixed routine of the SAS program package (version 8.2; SAS Institute, Cary, NC), with treatment means separation using the PDIFF option of the LSMEANS statement. Crop budgets for each system were constructed based on measured variables and approximations appropriate to the project scale. Costs for machine operations were determined based on those used by O'Dell et al., 2001, with a single 2% adjustment for inflation. As the crop budgets are intended to show relative profitability only among treatments, the cost of land and buildings, pick-your-own (PYO) harvest costs, and other costs were assumed to be equal among treatments, and were not included in the calculation of net returns. These costs would need to be included in a grower's assessment of the net profit from each system, though the presented costs constitute an adequate economic comparison between treatments.

Results

Hand Labor

Total hand labor for the duration of the production cycle was greatest for the AMR system and CMR, followed by CCP respectively (Table 2). The AMR system did not reduce need for weed control compared to the CMR and in fact, weed control costs were significantly higher. Although the AMR weed control requirement tended to be slightly higher than the CMR throughout the experiment, it was only significantly greater during the period of September to November 2002. This is likely the period when the cover crop residue began to break down. Both the CMR and AMR systems had substantially higher labor requirements for weed control than the CCP system. The CMR system had significantly higher labor requirements for runner and crown management due to frequent cultivation that tended to cause crowns to be partially covered with soil. This was also a function of the earlier planting date for the CMR compared to the other two systems, resulting in greater runner production during the establishment year. There was no significant difference in labor required for runner and crown management between the AMR and CCP systems. Fruit and flower removal were greatest in the CMR system, followed by AMR and CCP. Again, this can be attributed to the planting dates of each system. However, the minimal time requirement for fruit and flower removal compared to other management practices indicate that these differences are not economically significant.

Input and Operational Costs

Input costs were highest for the CCP system (Table 3), primarily due to the higher cost of plug plants, $0.17 **(**Davencrest Farms, Hurlock, MD) each compared to $0.09 (Nourse Farms, Whately, MA) for bare-root plants, and the higher planting density of the CCP system of 44,000 plants per hectare (based on 1.5 m row spacing) compared to 22,000 for AMR and 14,347 for CMR. The cost of the plastic mulch also contributes to the higher overall cost of materials for the CCP system. The overhead irrigation system used by the CMR system is initially more expensive than the drip irrigation system, but can be reused for typically 15 years, whereas the drip tape is generally only used for the life of the planting, which in this case was 3 years. Therefore the annualized cost of irrigation equipment is $521 for overhead and $71.04 for drip, assuming planting life of three years. Both the CCP and AMR systems also require overhead irrigation for spring frost protection and the yearly cost of this system is pro-rated for a two month period for these systems, at a total cost of $173.67 for the months of frost protection over the two production years. Also of importance is the higher pesticide expenditure for AMR compared to the other two systems.

The amount of hand labor required was largely responsible for the differences in operational costs between systems (Table 4). Management operations initially described in Table 2 were designated as minimum wage operations, while operating machinery, mixing and application of pesticides and fertilizers, and frost protection were considered semi-skilled, with an appropriately higher labor cost. Estimates of labor necessary per machine operation were made based on the number of operations performed by the approximate length of each operation as given by O'Dell, et al. 2001. Frost protection labor and hand labor were based on measured observations during the course of the experiment. AMR had the highest total cost of hand labor, followed by CMR and CCP. As a result, total operational costs were highest in the AMR system, followed by CMR and CCP. Custom hire operations were similar among systems, although CMR had a higher cost for cultivation, as expected, while AMR had higher cost of pesticide application. CCP had the highest labor cost for planting; per hour rates for each operation are shown in Table 4.

Yields

The CMR system had the highest yield in 2003 at 17,381 kg/ha; there was no significant difference between AMR and CCP yields (Table 5). CCP had larger fruit on average than either AMR or CMR treatments with 21.9 g / fruit compared to 16.1 g and 15.6 g respectively. Treatment differences in fruit size were most pronounced in the early season where CCP had peak size of 35.6g compared to 19.6 g for the AMR and 19.0 g for CMR (Table 5). In 2004, the AMR and CMR systems were the highest yielding treatments, with 10,021 and 8,971 kg/ha respectively, and were not significantly different from one another; the CCP system had a significantly lower marketable yield at 6,049 kg/ha. AMR had the largest weighted mean fruit size. Although AMR fruit was statistically larger than the other systems, the difference (less than one gram per fruit) was not large enough to have an effect on marketability. There was no difference in peak fruit size for 2004. The CCP system had a significantly higher percentage of unmarketable fruit than either the CMR or AMR systems at 32.5 %, compared to 25.9 % and 23.9 % for AMR and CMR, respectively.

Marketable yields in both 2003 and 2004 were lower than anticipated for all systems due to adverse weather conditions. The pre-harvest and harvest period in 2003 was unseasonably wet and cold. Rainfall was well above average for the months of April, May, and June 2003 (Figure 1a), and temperatures were below the recorded 30-year normal for 29 consecutive days during the harvest period (Figure 2a). As a result a large amount of the fruit was lost to water damage and fruit rot, despite the scheduled fungicide applications. In 2004, the weather during the pre-harvest and harvest period was much hotter than normal (Figure 2b), causing the harvest season to be very short. Much of the fruit ripened quickly and became overripe and unmarketable before it could be harvested. Although yields in both years were low, the marketable fruit percentages are likely higher than what would be expected from a typical pre-picked strawberry operation under the same weather conditions. Marketable yields were based on harvests by volunteers that were allowed to keep the harvested fruit at no charge. Although the volunteers were recruited to simulate PYO-consumers, they tended to harvest and keep smaller fruit that may have been unpicked if they were asked to pay for it, resulting in an overestimate of fruit marketability for the two years of this study.

Net Returns

Estimated returns were calculated for each of the treatments using a range of prices ($1.10/kg-$3.30/kg) and yields. Because experimental yields represent the theoretical high end of the production spectrum, a conservative estimate of yields (80% of observed) were calculated. However, the yields in this experiment are lower than expected for this location across all treatments as a result of poor weather in both harvest years. Black et al. (2002b) reported average yearly yields of 21,850 and 27,660 kg/ha for 'Allstar' in AMR and CCP systems, respectively for the Beltsville location 1997-2001. For that reason, an optimistic yield (120% of observed yield) was calculated for each system. Estimated net returns were determined for each combination of yield and price and are shown in Table 6. The CMR system had the highest net return of the three systems in this comparison under all scenarios; CMR also had the highest net profitability, calculated on a mid-price and conservative yield basis (Table 7). Even though the

CCP system had the lowest returns of any system in this scenario, the larger fruit size of the CCP system in early 2003 (Figure 3), indicated a likelihood that fruit from the CCP plots could be sold at a higher price in the first year. However, there was no size advantage for CCP fruit in 2004 (Figure 4), which likely negates the use of this system on anything but an annual basis.

Discussion and Conclusions

As a result of being the highest yielding system, CMR had the highest revenue of any system in the comparison, and was also the most profitable. Although CCP fruit in the first harvest season were large enough to likely receive a larger market price, overall yield was low enough to indicate that the CCP system could not earn comparable revenue to the CMR system. Further, the low yields and small fruit size of the CCP system in the second harvest year confirm the belief that CCP is strictly an annual production system. In order for growers to reap the benefits of large fruit size from CCP production, they will have to continuously replant their fields each season at great expense. Though in this experiment a single cultivar, ‘AllStar’ was used in order to minimize cultivar X treatment interaction, in reality growers would likely use separate cultivar(s) for each of these systems. While ‘AllStar’ might remain the choice of growers for CMR or AMR, ‘Earliglow’ is as likely an option. ‘Chandler’ is perhaps the most popular cultivar for the CCP system. As such, the differing yields among these cultivars would have an effect on net revenue for each system in a commercial setting.

While both the CMR and AMR systems were more profitable than the CCP system in this comparison, each systems profits are limited to some degree by the high labor requirement. Most of this labor expense is tied to hand weeding. The AMR system was not able to reduce the weeding requirement compared to the CMR system. A more cost effective method of weed control could improve profits for both of these systems. Similarly, the high cost of plug plants remains a limitation on the achievable profits for the CCP system. Plug plants tend to cost about twice as much as freshly dug bare root plants, and the CCP system is planted at twice the density of the AMR system. Although some growers may have experimented with using bare root plants in CCP systems, that practice is not currently recommended due to a poorer establishment rate. As long as the price of plug plants remains high and alternative planting strategies are not presented, the material costs of the CCP system will remain high.

Chapter 3: Environmental Impacts

Introduction

A major consideration for any agricultural production system is the conservation of soil and water, and the reduction of soil, nutrient and agrochemical movement from the land to adjacent surface water resources. Many states in the Northeast region of the U.S. have, or are considering enacting, nutrient management legislation for all sectors of agriculture, to reduce nutrient run off and leaching (Lea-Cox and Ross, 2001). In 1972, the Federal Clean Water Act was the first major legislation to deal with water pollution. This law has led to important reductions in point-source pollution, but not from non-point sources (e.g. agriculture) in many areas. Thus, the impact of irrigation and cultural practices on the movement of soil and agrochemicals from fields needs to be quantified when cultural management systems are considered, and alterations to current production practices should be made to increase environmental stewardship. In addition, nitrogen (N) applications and the subsequent plant uptake and use-efficiency of N are important components of any comprehensive nutrient management plan, when identifying best management practices for the production of strawberry.

Approximately 1 to 6% of applied agrochemicals may be transported off-site by runoff and drainage, depending on the slope of the field, management practices, presence or absence of subsurface drains, and the quantity and timing of rainfall after application (Bengston et al., 1990; Leonard et al., 1979; Triplett Jr. et al., 1978). Several studies have demonstrated significant negative effects of pesticides on aquatic plants (Forney and Davis, 1981; Jones and Winchell, 1984) and estuarine organisms (Clark et al., 1993; Savitz et al., 1994; Scott, 1994). Bacteriacides, insecticides and fungicides which are required to protect these crops are known to have adverse effects on finfish, shellfish and other aquatic organisms at environmentally relevant concentrations, compared to pesticides used on grain crops which are mainly herbicides (Pait et al., 1992).

Thus as strawberry production practices are evaluated in light of the loss of methyl bromide, proposed alternatives will need to be evaluated for their impacts on the environment. Best management practices should focus, in part, on soil and water conservation and on minimizing agrochemical and nutrient loss from the fields, while IPM techniques (such as regular scouting and selection of narrow spectrum chemicals) will reduce the application and toxicity of pesticides and herbicides.

Materials and Methods

Site Description

The research site at the South Farm of the USDA-BARC in Beltsville, Maryland was chosen in part for its slope (5.2 to 7.1% north-south), which facilitated the collection of runoff water. The site is comprised of Mattapex silt loam (fine-silty, mixed, active, mesic Aquic Hapludult with 1.3 to 1.6% organic carbon content). Each of the nine 13.7 m long by 6.1 m wide research plots was equipped with a fiberglass H-flume to capture runoff water at the southern end, using an automated runoff sampler (ISCO model 6700, Lincoln, NE) which contained twenty-four 300 ml glass collection bottles. Earthen berms bordered each plot to prevent surface water movement into the plot and to facilitate collection of runoff from within each plot. Runoff was collected from the three row middles between the four-bed plots. During each rain event that generated runoff water, the volume of flow through the flume was measured and periodic samples of the runoff water were collected and stored by the sampler until the end of the rain event. The exact procedure is given in more detail below. Following each rain event, the samples were removed from the samplers by hand, subsampled and frozen until later analyzed for sediment, nitrogen, and pesticide concentrations. Two suction lysimeters (Earth Systems Solutions model SPS210031, Lompoc, CA) were placed in each the lower (southern) half of each plot, at a depth of 50 cm; periodic soil water samples were collected from below the rooting zone, using a vacuum collection device to evacuate each lysimeter.

In winter of 2002, straw was applied to cover plants in all plots to protect them from low winter temperatures. In the following spring the straw cover was removed from the plants and placed between the rows. This process was repeated in winter of 2003.

Pesticides

Each production system was treated with an identical bloom-time fungicide spray regimen, following the recommendations of the Maryland Commercial Small Fruit Production Guide (Steiner et al., 1999). In 2003, benomyl was applied on 22-April, at approximately 10% bloom, to control Botrytis rot (*Botrytis cinerea* Pers.:Fr). Azoxystrobin was applied on 5-May, and 19-May to manage anthracnose (*Colletotrichum acutatum* J.H. Simmonds). Thiophanate-methyl and captan were applied together as a tank mix on 12-May. Thiophanate-methyl was used as to manage Botrytis rot, and captan was applied to manage common leaf spot (*Mycosphaerella fragariae* {Tul.} Lindau), Phomopsis leaf blight (*Phomopsis obscurans* {Ellis & Everh.} Sutton), and leaf blotch (*Gnomonia comari* P. Karst. and *Gnomonia*. *fragariae* Kleb.). Captan and thiophanate-methyl were applied together as a tank mix, because thiophanate-methyl has a similar mode of action to benomyl. In 2004 benomyl was not used because it was no longer available for commercial use. Except for the elimination of benomyl, a similar spray regime was used in 2004. Dates of application were 12-April and 26-April for azoxystrobin, and 19-April for captan and thiophanate-methyl. Herbicides were applied to each treatment as needed and in concert with other weed management practices appropriate for that production system. A group of insecticides were identified for potential use, but due to minimal insect infestation, none were used during the comparison.

Pesticide and Fertilizer Application

While weeds in the CMR system were managed primarily through mechanical cultivation, the CCP and AMR systems were treated, when necessary, with gramoxone. On one occasion the CMR treatment also received an application of gramoxone. Additionally, the CMR and AMR treatments each had one application of 2,4-D during renovation following the 2003 harvest season. The advanced matted row had one application of glyphosate to kill the cover crop prior to planting. All treatments received identical applications of fungicides. Total fungicide and herbicide applications for each production system are shown in Table 1.

According to the characteristics of the production systems, the CMR treatment received fertilizer by broadcast applications, while the AMR and CCP had weekly fertilizer applications through the drip irrigation for several periods during the comparison. Fertilizer application for each system is described in Table 8.

Rain Events

With the exception of 24-April 2003, 10-April 2004, and 16-April 2004, all runoff data were from natural rain events (Table 9). These three additional runoff events were a result of frost protection of strawberry flower buds prior to fruit set. During frost protection, overhead irrigation was applied equally to all treatments for a temperature-dependent time interval. A weather station located within 500 meters of the research plots measured rainfall, temperature, solar radiation, wind speed and direction, at 15-min, hourly, and daily intervals.

Runoff Sample Collection and Processing

The ISCO automated samplers (Model 6700) were each equipped with a bubbler flow module (Model 730) that contains a small microprocessor, a compressor, and a bubbler-type differential pressure transducer to measure the water level in the H-flume. The 6700 controller uses the known level-to-flow relationship of the H-flume to calculate the flow rate and total flow from the level measurement. Level-to-flow data were recorded every 5 min for as long as the flow module detected water in the flume. Time and intensity of each rain event were calculated using the data collected by the nearby weather station. The level-to-flow data and the weather station data provided sufficient information to determine the time to runoff, time of the total runoff event, total runoff volume, and runoff hydrograph (the profile of the water flux density over the course of an event) for each plot as well as the total rainfall. The date and time were recorded as the peristaltic pump and distributor arm delivered 300 mL of runoff to each sample bottle. A total of twenty-four 300 mL samples potentially could be collected from each event.

Water samples were removed from the samplers following each rain event and transported to the laboratory for sub-sampling and processing. A portion of each bottle collected was used to create a 1 L composite sample representing each plot for each event. The volume taken from each individual sample was dependent on the number of bottles filled during the rain event. Each composite water sample was immediately characterized for quantity of sediment (total suspended solids) and then frozen. Nitrogen concentration and dissolved-phase pesticide concentration were determined later from the composite sub-samples. Sample collection and processing methods were as previously described (McConnell et al., 1998; Rice et al., 2001).

Nitrogen Analysis

The amount of nitrogen in the water phase of the runoff samples was determined by colorimetric methods using automated flow through analysis. A LACHAT Quick Chem Automatic Flow Injection Ion Analyzer (#8000, Loveland, CO) was used for the simultaneous analysis of nitrate, ammonium and phosphorus. The amount of nitrate present in the runoff-water was analyzed by passing the sample through a copperized cadmium column, where the nitrate was quantitatively reduced to nitrite. The nitrite was then determined by diazotizing with sulfanilamide followed by coupling with N-(1 naphthyl)ethylenediamine dihydrochloride. The resulting water-soluble dye had a magenta color that was read at 520 nm, which was correlated to the nitrate concentration in a range of nitrate standards which were made up every day.

The amount of ammonium in the water was determined similarly, using the principle that when ammonia was heated with salicylate and hypochlorite in an alkaline phosphate buffer, an emerald green color is produced which is proportional to the ammonia concentration. The color was intensified by the addition of sodium nitroprusside and was read at 660 nm, and correlated to the ammonia concentration in a range of standards that were made up every day

Pesticide Analysis

The filtered runoff water samples were analyzed for pesticide concentration using high performance liquid chromatography with multiple reaction monitoring (MRM) dual mass spectral analysis. The chromatographic instrumentation and conditions were as follows: a Waters Alliance 2690 quaternary pumping / automatic liquid sampler system with a YMC ODS-

AQ column, 2 x 100 mm x 53µm x 120Å, held at 40 ^{o}C was set for isocratic (azoxystrobin, benomyl, thiophanate-methyl) and for gradient program (captan, 2,4-D & paraquat) chromatography. For the isocratic analyses, the mobile phase composition was 65:25:10 methanol:aqueous formic acid (0.1%):acetonitrile. In the gradient program analyses the mobile phase composition was 50:30:15:5 to 80:0:15:5 methanol:water:aqueous formic acid (0.1%):acetonitrile (polynomial curve 9) over 8 minutes with a 7 min. final hold. In all analyses the column flow rate was 0.2 mL/min.

A Micromass Quattro Ultima triple quadrupole mass spectrometer system with positive ion atmospheric pressure chemical ionization (APCI+) was set to run in MRM mode using argon collision gas. The ionization source and desolvation zone temperatures were set to 120 ^{o}C and 500 ^{o}C, respectively. Nitrogen desolvation and cone gas flows were set to 275 L/hr and 100 L/hr, respectively. The MRM transitions and detector voltages were as noted below:

			MS/MS voltages		
Analyte	MS1 ion	MS2 ion	Corona (µA)	Cone (V)	Collision (V)
Azoxystrobin	404.30	372.10	0.2	35	15
Benomyl	192.20	160.10	0.2	35	15
Thiophanate-methyl	343.23	151.14	0.2	35	15
Captan	302.12	266.04	4.0	35	9
2,4-D	217.25	171.18	0.2	35	15
Paraquat	186.31	171.19	0.2	35	15

Combined standards were prepared at 0.0011, 0.0111, 0.1110, 1.1100 ng/µL and 1, 3, 5 7 and 10 µL injections of each stock were made to generate four external calibration standard curves for each analyte. The limit of detection (LOD) for benomyl, azoxystrobin, and thiophanate-methyl was 0.0001 ppm. The LOD for captan and paraquat was 0.012 ppm and was 0.170 ppm for 2,4-D. All test samples were injected at 10 µL. Quantification was achieved by using a least squares linear regression analysis of the peak area versus amount (ng) injected on-column. The calculation of the residue amount for each test samples was determined by comparison of the peak area to the regression curve bracketing the peak area and then dividing by the injection volume.

Plant C/N Analysis.

Following fruit harvest in both 2003 and 2004, the plants within four one-foot square sections of each plot were destructively harvested. One-foot squares were used as representative sample areas due to the differences in plant spacing and growth habit among treatments. For the CCP system, one mother plant was present in each harvested square, while the CMR and AMR squares contained one mother plant along with several daughter plants. Plant tissue from each harvested square was then separated into leaf, crown, runner, root, and fruit truss. Fresh weights were taken for each tissue type. Number of leaves, crowns, trusses, and runners were recorded. Runners and trusses were then further separated to isolate leaves associated with each, thus designated as runner leaves and truss leaves, with all other leaves designated as crown leaves. Leaf area was then taken on runner leaves, truss leaves, and crown leaves. A ten-leaf subsample was taken from all crown leaf samples (with the exception of one sample which only had 13 total leaves), and a subsample was taken for any other tissue sample exceeding 40 g fresh weight. Tissue subsamples were stored in -86^{o}C freezer; excess plant samples were dried at 60^{o}C for 72 hours. All frozen samples were subsequently lyophilized using a LabConco Model 77550 Lyophilizer (LabConco Corporation, Kansas City, MO); the dry weights of all samples and sub-samples were recorded after drying. Dried samples were then milled with a high speed mill equipped with a 1.0 mm screen (Tecator Cyclotec 1093 sample mill, Rose Scientific Ltd., Edmonton, Alberta), and analyzed for total Carbon and Nitrogen content using an ECS 4010

Elemental Combustion System (Costech Analytical Technologies Inc., Valencia, CA), that was calibrated using a peach leaf standard (Standard Reference Material 1547, National Institute of Standards and Technology, Gaithersburg, MD).

Tissue N contents (g) were calculated by multiplying total sample weight (g) by N concentration (mg/g). A sample calculation is presented in Appendix A. Similarly the results of individual N runoff sampling events were calculated from N concentration x total liters runoff. Plant tissue C/N and N runoff samples from all treatments were analyzed as a completely randomized design, using the Proc Mixed routine of the SAS program package (version 8.2; SAS Institute, Cary, NC); treatment means were separated using the PDIFF option of the LSMEANS statement. A sample calculation of plant N uptake is included as Appendix A.

Results

Precipitation and Water Runoff Volume

A total of 40 precipitation events were measured during the 3-year experiment, with 17 events in 2002, 18 in 2003, and 5 in 2004. The duration, rainfall intensity, and total rainfall from each rainfall event were calculated from weather station data (Table 9). Three rain events on 22-July, 11-August, and 18-September, 2003 were of exceptional size, length, or intensity and resulted in high runoff volume and soil erosion. The rain event on 18-September was the result of Tropical Storm Isabel. Although the total volume of rain received as a result of Isabel was only 29 mm, and the intensity was much less than the other two highlighted events, the duration of the event, its high wind speeds, and two earlier rain events that week which saturated the soil contributed to making this Isabel event very substantial.

Runoff volume in 2002 (Figure 5), was not statistically greater than zero for most rain events. Eight out of the 17 rain events were significantly greater than zero in the CMR, seven out of 17 for AMR, and four out of seven for CCP in 2002. In 2003, a total of 15 of 18 total rain events for AMR had water runoff volumes significantly greater than zero. Both the CMR and CCP systems had 13 events that were significantly greater than zero in 2003 (Figure 6). For 2004, both the CMR and CCP had four events in which runoff volume was significantly greater than zero out of a total of five, compared to only two for AMR (Figure 7). The low amount of rain events that were significantly greater than zero in 2002 compared to 2003 and 2004 can be attributed to fewer intense rain events during this year. Most importantly, no significant differences were present in the yearly runoff volumes in 2002 and 2004 among any of the systems. In 2003, however, the CCP system had less total runoff than either the AMR or CMR. The CCP was relatively undisturbed by renovation practices. As a result of soil disturbances and several very heavy rain events late in 2003, significant runoff volumes were seen in late 2003 from both the CMR and AMR treatments. Because the CCP plots were not disturbed by machine operations, and had less foot traffic due to less need for hand weeding, the straw retained better mulch qualities. For these reasons, runoff volume was significantly lower in the CCP system for 2003.

Soil Erosion

In 2002, seven rain events resulted in soil loss significantly larger than zero from the CMR system, compared to only one for AMR and three for CCP (Figure 8). There were 17 total rain events in 2002, although only seven during the period after the CCP was established. When the CMR plots were cultivated, the soil was substantially disturbed, and in cases when a heavy rain event occurred closely following the cultivation event, large amounts of soil were lost from the CMR system. On 5-August, CMR plots lost ten times more soil than the AMR plots, and again, the CMR plots lost significantly more soil on 6-August and 29-August, as cultivation was performed prior to these events. Although cultivation was performed prior to the 19-June, 2003 rain event, no difference in soil loss was seen between CMR and AMR due to the low intensity of this rainfall event, and the 27- day interval between cultivation and the rain event in this instance.

In 2003, a total of twelve events resulted in significant soil loss for the AMR system, compared to nine for CMR, and five for CCP (Figure 9). In general soil losses were lower than in 2002 despite a higher number of significant loss events. This is because there were few events of very large losses, such as the 5-August 2002 event. However, following renovation practices, large amounts of soil loss were observed in several heavy rain events, in particular, the three previously identified rain events of 22-July, 11-August, and 18-September resulted in high soil loss. CMR had significant soil loss in each of these events, while AMR had significant soil loss on 22-July and 11-August, but not 18-September. CCP did not have significant soil loss on any of these dates. 11-August represented the first time that there was a substantially higher amount of soil loss in the AMR system than in CMR. The likely reason for this is that the AMR was first disturbed by machinery on 29-July when the rows were narrowed by discs. Therefore, when heavy rainfall followed, a spike in soil loss occurred, similar to what was consistently observed in CMR plots following cultivation.

Soil loss in 2004 was minimal, again due to the straw mulch in between rows, and resulted in significant loss in three events for CMR, two for AMR and only one for CCP. There were no significant differences in soil loss among treatments in 2004 (Figure 10). Cumulative totals for each year show a significantly higher soil loss in CMR compared to AMR and CCP for 2002. Both AMR and CMR were significantly higher than CCP for 2003, although AMR and CMR were not significantly different from each other (Figure 11).

Pesticide Runoff

Four fungicides were used to control disease (Table 1). Captan was not detected in any runoff samples for any treatment at any time. Benomyl was applied only in 2003. Benomyl was detected in 4 runoff events following application. In 3 of these events, loss was significant from the CMR system, compared to one event each for AMR and CCP (Figure 12). Total loss for the year was only significant from the CMR system (p>.0051). Thiophanate-methyl loss was significant in one event from CMR plots in 2003 (Figure 13) but no significant thiophanate-methyl loss was measured from any treatment in 2004. Total thiophanate-methyl loss for 2003 was significant for CMR only (p>.0142), and there was no significant total loss for any system in 2004. Azoxystrobin was applied, twice each in 2003 and 2004. The CMR plots had 5 significant runoff events of azoxystrobin in 2003 compared to 4 events for CCP and 3 for AMR (Figure 14). In 2004, there were 2 events each for CMR and CCP in which significant amounts of azoxystrobin were lost, but none occurred for AMR (Figure 15).

Three herbicides were used during the study, 2,4-D, paraquat, and glyphosate (Table 1). Glyphosate was used only on the AMR plots and was applied prior to activation of runoff samplers; therefore no data exists for glyphosate loss via runoff. 2,4-D was applied once to CMR and AMR plots during renovation, but was not detected in any runoff samples. Paraquat was applied once to CMR, and multiple times to both AMR and CCP, but was only detected in one runoff event. There was no significant difference in paraquat loss between systems for this event (data not shown).

Nitrogen Runoff and Plant Uptake

Because method of application, timing, and rate of application was different for each treatment, the results for ammonia and nitrate/nitrite runoff from individual events are not particularly meaningful. Total losses during the study, shown in Table 10, are more informative. Both CMR and AMR had significantly higher losses of nitrogen than CCP. CMR had the highest amount of N loss through runoff. Plant uptake efficiency was highest in the CCP system due to the N application method and significantly lower total N applied for this system; CMR was the least efficient treatment. In addition, the high density of the CCP planting ensured that more of the applied nitrogen was taken up by the plants prior to runoff. As evidenced by both the relatively low N uptake efficiencies and higher amounts of N runoff, timing and placement of fertilizer N was critical in the CMR system, which was the least efficient of all treatments. The two systems which used drip fertigation, AMR and CCP, each had higher N uptake efficiency and lower N runoff.

In all systems, a certain amount of N was unaccounted for at the end of the study. The majority of this amount likely was lost through volatilization of ammonium and denitrification of nitrate, in addition to the runoff losses. A portion was likely lost by leaching through the soil profile. Although a lysimeter system was in place to collect groundwater samples to determine this amount, the majority of rain events throughout the experiment were not of high enough volume to provide an adequate sample extraction volume from the soil below the rootzone. In addition, the later planting date of the CCP system eliminated a substantial number of events from potential sampling for this system. Based on the relatively low amounts of nitrogen applied to all systems compared to other horticultural crops, it can be assumed that the amount of leaching was relatively low in comparison to runoff and denitrification. Additionally some amount of N in each system was taken up by the fruit. Black et al. (2005) reported 0.666 mg N/g fruit (fresh weight) for 'Allstar' in the AMR system. This amount was not accounted for in this study due to the timing of destructive tissue harvest.

Discussion and Conclusions

Results of this study indicate that severe soil loss can occur in the CMR treatments when cultivation is followed closely by moderate or heavy rainfall. Soil loss for the AMR system was far lower until the cover crop residue and straw mulch began to break down in 2003. CCP soil losses were higher than AMR in 2002 but much lower in 2003. These results are different than similar previous studies. Comparisons of environmental impacts in tomato production were made between the use of plastic mulch, and a hairy vetch (*Vicia villosa*) cover crop residue mulch (Rice et al., 2002; Rice et al., 2001). In these studies, seasonal runoff from plastic mulch was two to four times greater than that from the cover crop treatment, and total soil loss loads, eroded primarily from the furrows, in the plastic mulch treatment were three times greater. Pesticide loads from plastic mulch were approximately an order of magnitude greater. As expected, for soil loss in this study, the plastic mulched CCP treatment was higher in 2002 than from the cover crop AMR, despite the difference in planting date. Had the intensity of rain events in the fall of 2002 been greater, we likely would have seen more soil loss in the CCP than what was observed. However, this study also differs from previous studies in that the strawberry systems in this study are perennial rather than annual systems. As such, the dynamics of these systems change over the years. The cover crop residue in the AMR treatment was effective through the first season, but as it began to break down and be carried off the plots through wind, runoff, or foot traffic, it was no longer an effective tool to limit erosion. While adding straw was a good management practice for limiting soil erosion for all systems, the straw had a greater effect in the CCP system, where it lasted longer. With less hand weeding, no cultivation or machine traffic of any kind in the CCP system, the straw was simply not disturbed. As a result, the low soil loss seen in all systems early in 2003 continued in late 2003 for the CCP system, while the other systems had high soil loss in the later part of 2003.

Pesticide loss was generally limited in the AMR treatment compared to CMR and CCP. CMR plots had a greater number of events with significant pesticide loss than AMR for benomyl, thiophanate-methyl, and azoxystrobin. CMR had a greater number of events with significant loss than CCP for benomyl and azoxystrobin. While in most cases the treatments did not show losses that were significantly different from one another, the fact that CMR had several events that were significant from zero, and AMR had few shows a greater likelihood for pesticide loss in CMR plots.

It is clear from the results that the CCP system was most efficient in terms of fertilizer application. Although the amount applied on a per hectare basis are somewhat similar, the difference in planting densities, particularly in regards to the CCP system, is an additional factor in decreasing the amount applied on a per plant basis, and increasing the efficiency of uptake. Drip fertigation, which places a small amount of fertilizer directly onto the rootzone also contributes to N uptake efficiency, as evidenced by comparing the AMR and CCP results to those of the CMR system. Additionally, the plastic mulch in the CCP system likely has some benefit in reducing runoff and leaching. As such, looking at both plant uptake efficiency and amount of runoff as shown in Table 10, CCP represents a significant improvement over the other systems. It is important to note however, that AMR N uptake efficiency is similar to that reported in other types of horticultural production (Ristvey 2004), and an improvement over the more commonly used CMR system.

Improvements can be made to each of these production systems to offset their negative environmental impacts. The AMR system performed very well in 2002 but was less effective in 2003 when the straw mulch and cover crop residue began to break down. Replenishing straw mulch earlier in the season could maintain the effectiveness of the AMR system throughout its intended production cycle. Cultivation could be abandoned in the CMR system, and a cover crop residue could be used similar to that in the AMR. When the residue begins to break down, straw can be added as a replacement, although this would add to production costs slightly. The CCP system performed surprisingly well in this comparison, particularly in regards to soil and N loss. Still, the time immediately after planting has high risk for soil loss and nutrient runoff depending on weather conditions, as evidenced by previous studies involving horticultural crops grown on plastic (Rice et al. 2001, Rice et al. 2002). A good management practice to improve the CCP might be to lay straw between the rows earlier, rather than in the spring. If straw were added at planting, by the following spring the previous layer of straw would have partially broken down, and straw that was covering the plants during the winter could replenish that supply to maintain its effectiveness.

Chapter 4: Public Acceptance

Introduction

In the mid-Atlantic region of the United States, many growers produce multiple crops for the pick-your-own (PYO) market. In PYO, or U-Pick markets the consumer harvests the crop themselves directly from the field. A number of fruit and vegetable crops work well as pick-your-own crops, and most farmers involved with pick-your-own offer a variety of crops to customers. By doing so, growers are able to offer fresh produce items for pick-your-own through much of the year. Strawberries tend to have the earliest harvest period, and are important to begin the flow of customers to the farm in early spring. Pick-your-own harvesting has become a fun, family-friendly alternative to buying strawberries at the grocery store for the consumer and a relatively low-cost harvesting practice for growers. In addition, growers often are able to entice pick-your-own customers to shop in a farm stand on site for jams, jellies and other value-added items.

Although each pick-your-own customer is unique, certain characteristics are important to customers when they choose to pick strawberries from a pick-your-own operation. In a study of direct marketing of strawberries for North Carolina, Safley et al. (2004) found that reasons cited by harvesters for picking less fruit than they expected included: poor fruit quality (31.1%), fields were picked over/not enough fruit (17.6%), too hot to pick (6.8%), small fruit size (4.0%), too hard to pick berries (4.0%), and that the fields were too muddy (1.4%). Other answers not listed constituted 35.1% of the responses. The same study cited reasons customers picked more fruit than expected: good fruit quality (57.7%), easier to pick than expected (25.3%), good fruit size (7.8%), and low prices (4.6%), with 4.6% listing other reasons (Safley et al., 2004).

Previously, much of the work done to increase public acceptance with strawberries has been through breeding. Strawberry breeders have continually released varieties with more flavor, better color, larger size, or firmer fruit for shipping. How the method of production affects consumer preference has been overlooked to some degree, particularly in regions that rely on pick-your-own marketing where the consumer experience is directly related to the way the fruit are grown. To that end, growers who wish to maximize pick-your-own sales should consider using a system that enhances characteristics that consumers value, such as quality and quantity of fruit produced, fruit size, and ease of harvest. Ease of harvest in particular is an area where the production system could have a substantial impact on the picking experience. Strawberry picking is notoriously hard on the back of the harvester. A system that provides a less painful picking experience would likely entice customers to pick more fruit, and enjoy their picking experience more. Field conditions were also cited by Safley et al. (2004) as playing a role in how long PYO customers chose to pick. While weather conditions primarily dictate customer comfort, one system may enhance or lessen the effects of weather conditions. Many growers offer anecdotal evidence that their customers prefer picking fruit from the plasticulture system, although this has yet to be directly addressed by any research.

While it is important for growers to consider the desires of the public when designing their production practices, economics primarily dictate which practices are implemented. Some studies have shown consumers are willing to pay a premium for products that are pesticide-free (Boccaletti and Nardella, 2000), environmentally certified (Jensen et al., 2003), or non-genetically modified (Chern et al., 2002). If pick-your-own strawberry customers were willing to pay a higher price for the convenience and increased enjoyment of picking strawberries from a system they prefer, it could conceivably make that system more economically viable than those under constant price (market-based) conditions.

For pick-your-own harvesting to be a continued success, changes to current production practices must not only meet the economic and environmental concerns of the growers, but also satisfy the needs of the consumers. Most importantly, the quality of the fruit must not suffer as a result of production practices. Fruit quality was another issue previously addressed only by breeding, but there is some evidence that certain attributes may be influenced by production system. Some cultivars have been shown to have increased soluble solids content, total sugar, fructose, glucose, ascorbic acid, titratable acid, and citric acid in the plasticulture system compared to the conventional matted row (Wang et al., 2002) in addition to earlier and larger-sized fruit (as noted in Chapter 2). It remains to be seen how these factors are influenced by the advanced matted row system, as well as how closely related these measurable factors of fruit quality are to fruit quality perceptions of the consumer.

Materials and Methods

Plot Layout

During the 2003 and 2004 harvest seasons, volunteers were recruited to harvest plots, as a pick-your-own simulation. Three production systems were maintained in three replicate plots, consisting of four 13.7 m long rows. Data were only collected from the two center rows, which were divided into three 3.7 m long plots, with a minimum of 1 m of row remaining at each end to act as guard plots. This resulted in a total of fifty-four harvest plots (3 treatments, 3 reps, 6 harvest plots per rep). Each of the 9 replicate plots and 54 harvest plots were randomly assigned three digit number designations. Number combinations of repeating digits, such as 111, or ascending or descending sequential combinations, such as 123 or 987, were eliminated, as were combinations of potential bias due to known connotations, such as 666. Once numbers were assigned to all harvest plots, the harvest plot within each replicate plot with the highest numerical value was designated as a 'biological harvest' plot. The biological harvest plot was harvested by research staff at each harvest date to determine total biological yield (biological yield= total harvestable fruit + diseased/damaged fruit), while the remaining five were harvested by the pick-your-own volunteers.

Volunteer recruiting and questionnaire administering

Prior to the spring 2003 harvest, pick-your-own volunteers were recruited via an email sent to a listserv of approximately 1300 clerical, administrative, technical, and scientific staff at Beltsville Agricultural Research Center, and via word of mouth. Seventy-five volunteers were assigned to one of five scheduled harvest dates, at one of three times per day (8:00-10:00 AM, 10:00AM-12:00 PM, or 12:00 PM-2:00PM). All volunteers were told they would be participating in experimental research and would be able to keep all fruit that they had harvested following data collection. Volunteers met at a centralized site on the research station and were then driven by van to the research field. Portable restrooms, drinking water and cups, a hand washing station, and plastic gloves were provided at the site for comfort.

A questionnaire was developed to assess the preferences of volunteers before, during, and after their harvesting experience (Appendix B1). The survey consisted of five pages, and each survey was anonymously labeled with a randomly assigned harvest plot from each treatment, with treatments assigned in random order. The first page of the questionnaire consisted of background demographic information, and a pre-assessment of prior experience at pick-your-own farms, plans for use of the harvested fruit, and initial visual impressions of each of the systems; this pre-assessment survey was completed by volunteers prior to harvesting. The second, third, and fourth pages corresponded to each of the three plots the volunteer was to harvest, and were identical except for the designation. Questions on these pages were designed to give quantitative answers concerning the aspects of fruit quality, visual appearance of the plot and the fruit, ease of harvest, and overall enjoyment of picking. Research staff was present at the time of harvest to help volunteers locate their assigned subplots and provide brief instructions for picking. Volunteers were instructed to pick any and all fruit that they wished within their assigned harvest plot, and complete the corresponding post-assessment survey page before moving on to the next harvest plot and repeating the process. After harvesting each of their assigned harvest plots and completing the corresponding page for each, the volunteers completed the final post-assessment survey page, which asked the volunteers to rank the three harvest plots in regard to their overall enjoyment of the picking experience and the overall quality of fruit. Volunteers were instructed to indicate which harvest plot they would most like to pick from again, and whether they would be willing to pay more to pick from this specific harvest plot. This page also allowed the volunteers to describe the picking conditions on that particular day, and make any additional comments. At no point were the harvesters told any relevant information about the systems by the researchers.

For the spring 2004 harvest, a new series of volunteers were recruited via an email sent to the USDA-BARC employee listserv, and via another sent to the graduate student, faculty, and staff email distribution lists of the University of Maryland Department of Natural Resources and Landscape Architecture, and by word of mouth. Because of the shorter harvest season caused by unusually hot weather at harvest time, only three harvests were completed using volunteers. There were a total of forty-five volunteers who participated in the 2004 harvest. Slight modifications to the survey were made for 2004 (Appendix B2). None of the forty-five volunteers in 2004 were previous participants in 2003.

Fruit Quality Assessment

In 2004, 20 fruit from each research plot were sampled to assess factors of fruit quality. Each fruit was cut in half vertically, and each half was compressed to determine firmness using a Magness-Taylor probe. The values for each half were averaged, giving a total of 20 observations. The berries were then blended using a household juicer, and the juice was filtered through cheese cloth. The soluble solids content of the filtered juice was measured by placing 4 drops on a handheld refractometer. Ten ml of the juice from each research plot was saved and stored in a -30^{o}C freezer. The juice was then thawed and diluted in 5% samples (5 ml juice + 95 ml dH20) to measure titratable acidity. The juice samples were titrated with 0.1 N NaOH until a pH of 8.2 was reached. Acidity was expressed as milligrams of citric acid per 100 ml of juice.

Data Analysis

Survey data were analyzed using a repeated measures subroutine in the Proc Mixed routine of SAS version 8.2, with treatment and harvest date as factors. When significant interactions were found, treatment means separation was performed using the PDIFF option of the LSMEANS statement. Correlations between attributes and overall enjoyment were performed by stepwise regression using the Proc Reg routine in SAS. Fruit quality measurement data were analyzed using the Proc Mixed routine, with treatment means separation using the PDIFF option of the LSMEANS statement.

Results

Demographics and Background Information

In considering consumer acceptance, it is important to characterize exactly who the 'consumer' is. In 2003, the majority (74.4%) of participants in our study were female. The largest age group represented in our survey was 21-30, at 50% of the total participants. There were also a large percentage of participants in the age 31-40, and 41-50 groups. The typical household income was $60,000-80,000 with 20,000-40,000 a close second. Nearly 95% of the participants lived in Maryland and 80.8% were born in the United States (Table 11).

In 2004, there were a greater percentage of women participants, and again the most common age was 21-30, with 31-40, and 41-50 second and third, respectively. The highest percentage of participants had a household income of $40,000-60,000, with $20,000-40,000, and over $100,000 being the next most populated groups. The $60,000-80,000 range, which had the highest percentage among 2003 participants, was fourth. Again a majority of the participants lived in Maryland, but with higher percentages of both District of Columbia and Virginia residents than in the previous year. 86.9% of participants were born in the United States. Overall, the typical consumer in this study was a 21-30 year old woman, from Maryland, native to the United States, with an annual household income of $60,000-80,000 (Table 11).

About 72% of participants in both 2003 and 2004 had picked some crop at a pick-your-own farm in the past. The most commonly picked crops were strawberries, followed by apples, pumpkins, blueberries, peaches, blackberries, and raspberries. Over a quarter (28.8%) of respondents in 2003 had picked strawberries at a PYO farm in the past 3 years, compared to 18.6% in 2004. Nearly half of the respondents in 2003 had never picked strawberries at a PYO farm, compared to about a third in 2004. In each year, more than 60% of the respondents indicated that they did not pick strawberries in an average year, with the remainder indicating somewhere between 1 and 3 pickings per year (Table 12).

Consumers were asked to indicate what they had used their strawberries for in the past if they had visited a PYO farm, and what they planned to do with them on this occasion. For both years, more than 70% indicated they had eaten or would eat at least some of the berries fresh. Freezing was the next most common response, followed by processing. Many of the applicants had in the past, or intended on this occasion to divide their fruit into two or more of these uses (Table 13).

Attributes of Production Systems

Consumer volunteers scored each production system for a number of attributes. Attributes ranked by consumers for each system as well as the high and low values for each system are shown in Table 14. In 2003, consumers rated the AMR and CCP systems highest for overall appearance of the plots, with the CMR system receiving the lowest rating. Probabilities of harvest and harvest by treatment interaction were not significant (p=0.505 and p=0.487 respectively). The CCP system was rated highest for ease of harvest, followed by AMR, with CMR receiving the lowest rating. There was again no significant interaction for harvest or harvest by treatment (p=0.052 and p=0.723 respectively). The CCP system was rated highest for appearance of fruit, with no significant difference between the AMR and CMR systems. There was no significant harvest or harvest by treatment interactions (*p*=0.618 and *p*=0.106). There was no significant difference between the amount of fruit not fit for harvest rating among systems, however the harvest interaction was significant (*p*<0.0001). Means comparison of harvests showed significant differences between harvests, though these did not follow and noticeable pattern. Harvest by treatment interaction was not significant (*p*=0.872). AMR and CCP ranked highest in overall enjoyment, with CMR rating significantly below the other systems (Table 15). Harvest and harvest by treatment interactions were not significant (*p*=0.203 and *p*=0.319).

In 2004, significant differences between treatments were only detected for two attributes, ease of harvest and fruit appearance. AMR and CCP ranked highest in ease of harvest, above CMR. For fruit appearance, AMR and CMR were the highest rated, with CCP the lowest. The overall appearance, amount of fruit not fit for harvest, and overall enjoyment were not statistically different among treatments (Table 15). Harvest and harvest by treatment interactions were not significant for any attribute in 2004.

Correlation analysis using stepwise regression found that overall enjoyment was positively correlated to fruit appearance (R^2=0.45), the ease of harvest (R^2=0.60) and negatively correlated to the amount of fruit not fit for harvest (R^2=0.62), *p*<0.0001, 0.0001, and 0.0011 respectively. There were no significant correlations between amount of fruit not fit for harvest and size or marketable yields.

Fruit Quality Measurements

No differences were found among treatments in either titratable acidity or soluble solids content (Table 16). However, fruit firmness differed between systems. Fruit from both the CMR and AMR systems were firmer than fruit from the CCP system. CCP fruit had an average F_{max} value of below 2 on a standard compression test. CMR and AMR were not significantly different for firmness (Table 15).

Discussion and Conclusions

The results of this study confirmed that CCP was preferred by PYO customers in the first year. However, this was not true in the second year, indicating the CCP system will likely not be successful as a perennial system. Although fruit yield and size dropped, these factors were not directly correlated to the drop in overall enjoyment cited by consumers. Fruit appearance (which likely is judged in relation to fruit size), ease of harvest, and amount of fruit not fit to harvest were found to be most correlated to overall enjoyment by the PYO consumer. In addition, by the second year of fruit production and the third year of the experiment, the plastic mulch in the CCP system had begun to break down. Some holes in the mulch had appeared due to weed pressure and some minor animal traffic within the plots. Though this was not directly measured, this may have had some role in the decrease in satisfaction with the CCP system.

In both years, AMR and CCP plots were favored over CMR plots, an indication that raised beds were a factor in harvesting enjoyment. This is likely a reason for the higher ratings in ease of harvest for AMR and CCP in each year, compared to CMR. Growers have often related that the consumers' major complaints with the CMR system were the fact that fruit clusters sat in the dirt due to the flat beds, and that picking was hard on the back. Raised bed systems seem to lessen these concerns, although picking strawberries for a long period of time remains a relatively difficult task.

The AMR system, or one sharing some of its characteristics may be the best suited for PYO customers in the area. Though the CCP is preferred when used as an annual system, the high cost of yearly replanting makes the CCP system uneconomic. The AMR system is preferred by PYO customers compared to the CMR and is suitable as a perennial system over a period of at least 2 years.

Chapter 5: Overall Discussion and Conclusions

Several changes to current strawberry production practices are necessary in order to create truly sustainable production systems. As they are commonly employed, each production system used in this study has limitations to its sustainability. Conventional matted row is a high labor input system, with inefficient irrigation, high risk of soil loss, potential vulnerability to nutrient and pesticide loss depending on proximity of application to a large rain event, and is generally disliked by consumers. The advanced matted row also requires high amounts of labor, and is susceptible to high levels of erosion following renovation and/or disintegration or loss of cover crop residue. The cold-climate plasticulture system has high startup costs, can have high erosion during establishment, does not perform well as a perennial system, and has a high percentage of unmarketable fruit in hot weather, although surprisingly, it showed excellent qualities in terms of overall soil and nutrient loss.

Although some of these problems are more difficult to address then others, each system can be modified to create improved sustainability. Overhead irrigation for CMR should be eliminated in place of above ground or buried drip irrigation. Though damage to a drip irrigation system from cultivation could be a concern, another recommendation is the elimination of cultivation as a weed control practice. Planting a low growing cover crop between rows in the CMR system and either mowing it occasionally or killing it to create a residue mulch are potential alternatives. This would help to control weeds and also reduce runoff and erosion. Similar results might be achieved by adding straw mulch between the rows earlier in the production cycle. The main complaint of consumers regarding CMR plots for pick-your-own is the flat beds and the fact that the fruit can sit in dirt and become dirty and unappealing.

Incorporating raised beds would ease the strain on harvesters somewhat, and allow the fruit to hang over the edge of the beds.

AMR production is hindered by loss of the cover crop residue over time, either by erosion, disintegration, or being carried away inadvertently via foot traffic. Replenishing the residue with straw mulch once it is no longer effective could help to maintain the positive environmental effects the cover crop residue showed in the first year of the study. However, reduction of labor requirements for both conventional matted row and advanced matted row, particularly in regards to weed control, are necessary to keep input costs as low as possible. Most of this labor requirement comes in the form of hand weeding between the plants within a row. Currently, most herbicides are not viable options for control of within row weeds during active growing periods. 2,4-D is one pesticide that is safe for use on strawberry, but is only recommended during renovation. Terbacil may also be effective for within-row weed control. Polter et al (2004) reported that terbacil was effective in controlling weeds in newly established plantings without lowering yields, but that best results occurred when the leaves were rinsed following application. The current label for Sinbar (terbacil) advises rinsing of leaves by rainfall or irrigation immediately following application to prevent unacceptable damage. While this practice appears to offer benefits for weed control, this practice will need to be evaluated for runoff potential.

CCP appears best suited as an annual production system, mainly due to the poor fruit size in the second year. Although the idea of replacing an entire planting every year does not generally follow the principles of sustainability, the large fruit size typical of CCP production early in its life cycle may allow CCP production to be economically viable in colder areas, even as an annual system, if returns were high enough, i.e. if PYO consumers were willing to pay a premium price for larger fruit. Startup costs will always be high, unless alternative plug plant production methods are found. This is currently the major portion of the startup costs. Although high soil loss in CCP plots was not seen in this study, there was some concern particularly in the establishment year that CCP could lose large amounts of soil under the right conditions. Other studies have shown plasticulture production systems to be highly erodable (Rice, et al. 2001). In this case, there were few rain events of particularly high intensity following establishment in 2002, and by 2003 straw mulch had been added, limiting potential erosion for the duration of the study. Placing straw mulch between rows earlier on, or using a living cover crop or cover crop residue between rows could be an effective way to manage potential runoff and erosion problems. Another problem with the CCP system is fruit quality in hot weather conditions. Although the 2004 harvest season was much hotter than normal, the CCP system lost a high percentage of fruit due to being overripe. PYO operations may be able to avoid this fruit quality problem by having more frequent pickings,

To some degree, the validity of the observations in this study was hindered by its small scale. Because the plots measured on 13.7 m x 6.1 m, it was not possible for some of the management operations to be performed exactly as they would be on commercial farms. Pesticide sprays often were performed using a backpack sprayer or an experimental plot sprayer equipped with a single row boom with three nozzles directing spray from above and both sides of the row, where typically these would be applied by a tractor trailing a boom attachment. Because the soil in these plots was not being disturbed as much as in a true farm setting, runoff and erosion might be understated. Despite this, the effects of cultivation on soil loss remain clear, and each system would experience an increase in machine traffic in a farm setting due to the homogeneity of fungicide treatments.

In conclusion, this study showed that each strawberry production system performed well in certain areas of sustainability and lacked in others. In particular the AMR system, which had been expected to be the most sustainable in the comparison, suffered from a higher than expected amount of hand labor for weed control, which raised production costs and limited net profit. However this system performed better than the standard CMR system in both environmental impacts and public acceptance, indicating that while not more economically viable, the AMR system may be more sustainable. In addition, the CCP system, while not suitable for perennial production, thus limiting its sustainability and economic viability, was surprisingly effective at limiting environmental impacts and was popular among consumers, as expected. The CMR system was the most profitable, but suffered in other aspects of the comparison. While ultimately economics will drive the decision process for many growers, the poor performance in other aspects of sustainability will continue to inspire researchers and forward-thinking growers to experiment with and incorporate new management practices and production systems for future strawberry production.

Appendix A: Sample Calculation of Plant Nitrogen Uptake

Nitrogen concentrations for plant tissue samples which were analyzed by an Elemental Combustion System were converted to grams N per plant (N content) based on the following sample calculation:

Sample weight (mg)	x	% N (mg/g)	/1000	=	Sample N	x	Total Tissue Mass (g)	= Tissue N (g)
12.0	x	1.35	/1000	=	0.162	x	40.0	= 0.648

This calculation was done for each of the 5 tissue types in each of the 2 seasons in which destructive harvests were performed. The values for the 5 tissue types in each year were added together, and the subsequent sums for each year where then added together to give total plant N uptake.

Appendix B1: 2003 Survey

PLEASE ANSWER THE FOLLOWING QUESTIONS BEFORE PICKING ANY FRUIT.

I. DEMOGRAPHICS

1. Age (circle one)
   under 20   20 to 35   36 to 50   51 to 65   over 65

2.Gender (circle one)   Male   Female

3. Where do you live?
   State____________   City_________________

4. What is your country of origin? ____________
5. How long have you lived in the United States?___________

6. What is your total household income?(choose one)
   <$20,000 $20,000-$40,000 $40,000-$60,000 $60,000-$80,000 $80,000-$100,000
>$100,000

II. PRE- PICK SURVEY

7. Have you ever picked fruit or vegetables from a pick- your- own farm?

   7a. If so, which crops have you picked (pumpkins, strawberries, apples, etc.)?

   7b. How recently have you picked strawberries at a pick-your-own farm?
      Last Year   Within 2-3 Years   More than 3 years   Never
      7c. How many times in an average year do you pick strawberries? ________

8. When you have picked strawberries in the past, what have you done with the fruit you've picked (check all that apply)? What do you plan to do with the fruit you pick today?

	Before	This time
Eat fresh	_____	_____
Freeze	_____	_____
Process	_____	_____

9. Look at fields _____ ______ ______ now, before you begin picking.
   9a. Which looks the most appealing and why?

   9b.. Which looks the least appealing and why?

III. INDIVIDUAL PLOT SURVEY

ANSWER THE FOLLOWING QUESTIONS BY PLACING A MARK ON THE SCALE THAT ACCOMPANIES IT, OR BY ANSWERING IN YOUR OWN WORDS WHERE APPROPRIATE.

PLOT #___________

1. Rate the overall appearance of this plot

|--|

Poor Excellent

2. What do you like/dislike about the appearance of this plot?

3. Rate the ease of harvest for this plot as a whole.

|--|

Difficult Easy

4. Rate the appearance of the fruit from this plot

|--|

Poor Excellent

5. Estimate the amount of fruit in the plot that was not fit for harvest

|--|

None 100%

5a. Describe why this fruit was not fit to harvest(ripeness, size, rot, etc.)

6. How enjoyable was it overall to pick from this plot?

|--|

Did Not Enjoy Very Enjoyable

III. INDIVIDUAL PLOT SURVEY

ANSWER THE FOLLOWING QUESTIONS BY PLACING A MARK ON THE SCALE THAT ACCOMPANIES IT, OR BY ANSWERING IN YOUR OWN WORDS WHERE APPROPRIATE.

PLOT #________

1. Rate the overall appearance of this plot

   |---|

   Poor   Excellent

2. What do you like/dislike about this plot?

3. Rate the ease of harvest for this plot as a whole.

   |---|

   Difficult   Easy

4. Rate the visual quality of the fruit from this plot

   |---|

   Poor   Excellent

5. Estimate the amount of fruit in the plot that was not fit for harvest?

   |---|

   None   100%

   5a. Describe why this fruit was not fit to harvest(ripeness, size, rot, etc.)

6. How enjoyable was it overall to pick from this plot?

   |---|

   Did Not Enjoy   Very Enjoyable

III. INDIVIDUAL PLOT SURVEY

ANSWER THE FOLLOWING QUESTIONS BY PLACING A MARK ON THE SCALE THAT ACCOMPANIES IT, OR BY ANSWERING IN YOUR OWN WORDS WHERE APPROPRIATE.

PLOT # __________

1. Rate the overall appearance of this plot

   |--|

   Poor   Excellent

2. What do you like/dislike visually about this plot?

3. Rate the ease of harvest for this plot as a whole.

   |--|

   Difficult   Easy

4. Rate the appearance of the fruit from this plot

   |--|

   Poor   Excellent

5. Estimate the amount of fruit in the plot that was not fit for harvest

   |--|

   None   100%

   5a. Describe why this fruit was not fit to harvest(ripeness, size, rot, etc.)

6. How enjoyable was it overall to pick from this plot?

   |---|

   Did Not Enjoy   Very Enjoyable

IV. POST- PICKING SURVEY

Name__________________________

ANSWER THE FOLLOWING QUESTIONS BY RANKING THE THREE PLOTS AS INSTRUCTED, OR BY ANSWERING IN YOUR OWN WORDS WHERE APPROPRIATE.

1. Rank each plot in terms of your overall enjoyment.
   Most Enjoyable________________
   ____
   Least Enjoyable________________

2. Rank each plot in terms of the overall fruit quality.
   Best quality____________________
   ____
   Lowest quality__________________

3. If given the choice, which of the three plots would you most like to pick from again?

4. How much more, if at all, would you be willing to pay for fruit grown in the system you liked best (what % more would you pay)?

5. Please describe the conditions while you were picking (weather, insects, etc.).

6. Please add any additional comments.

Appendix B2: 2004 Survey

PLEASE ANSWER THE FOLLOWING QUESTIONS BEFORE PICKING ANY FRUIT.

I. DEMOGRAPHICS

1. Age (circle one)
   under 20   20 to 35   36 to 50   51 to 65   over 65

2.Gender (circle one) Male Female

3. Where do you live?
   State____________ City_________________

4. What is your country of origin? ____________
5. How long have you lived in the United States?___________

6. What is your total household income?(choose one)
   <$20,000 $20,000-$40,000 $40,000-$60,000 $60,000-$80,000 $80,000-$100,000
>$100,000

II. PRE- PICK SURVEY

7. Have you ever picked fruit or vegetables from a pick- your- own farm?

   7a. If so, which crops have you picked (pumpkins, strawberries, apples, etc.)?

   7b. How recently have you picked strawberries at a pick-your-own farm?
      Last Year   Within 2-3 Years   More than 3 years   Never

   7c. How many times in an average year do you pick strawberries? ________

8. When you have picked strawberries in the past, what have you done with the fruit you've picked (check all that apply)? What do you plan to do with the fruit you pick today?

	Before	This time
Eat fresh	_____	_____
Freeze	_____	_____
Process	_____	_____

9. Look at fields _____ ______ ______ now, before you begin picking.

   9a. Which looks the most appealing and why?

   9b.. Which looks the least appealing and why?

III. INDIVIDUAL PLOT SURVEY

ANSWER THE FOLLOWING QUESTIONS BY PLACING A MARK ON THE SCALE THAT ACCOMPANIES IT, OR BY ANSWERING IN YOUR OWN WORDS WHERE APPROPRIATE.

PLOT #___________

1. Rate the overall appearance of this plot

|---|
Poor Excellent

2. What do you like/dislike about the appearance of this plot?

3. Rate the ease of harvest for this plot as a whole.

|---|
Difficult Easy

4. Rate the appearance of the fruit from this plot

|---|
Poor Excellent

5. Estimate the amount of fruit in the plot that was not fit for harvest

|---|
None 100%

5a. Describe why this fruit was not fit to harvest(ripeness, size, rot, etc.)

6. How enjoyable was it overall to pick from this plot?

|---|
Did Not Enjoy Very Enjoyable

III. INDIVIDUAL PLOT SURVEY

ANSWER THE FOLLOWING QUESTIONS BY PLACING A MARK ON THE SCALE THAT ACCOMPANIES IT, OR BY ANSWERING IN YOUR OWN WORDS WHERE APPROPRIATE.

PLOT #________

1. Rate the overall appearance of this plot

|--|

Poor Excellent

2. What do you like/dislike about this plot?

3. Rate the ease of harvest for this plot as a whole.

|--|

Difficult Easy

4. Rate the visual quality of the fruit from this plot

|--|

Poor Excellent

5. Estimate the amount of fruit in the plot that was not fit for harvest?

|--|

None 100%

5a. Describe why this fruit was not fit to harvest(ripeness, size, rot, etc.)

6. How enjoyable was it overall to pick from this plot?

|--|

Did Not Enjoy Very Enjoyable

III. INDIVIDUAL PLOT SURVEY

ANSWER THE FOLLOWING QUESTIONS BY PLACING A MARK ON THE SCALE THAT ACCOMPANIES IT, OR BY ANSWERING IN YOUR OWN WORDS WHERE APPROPRIATE.

PLOT # __________

1. Rate the overall appearance of this plot

   |--|

   Poor   Excellent

2. What do you like/dislike visually about this plot?

3. Rate the ease of harvest for this plot as a whole.

   |--|

   Difficult   Easy

4. Rate the appearance of the fruit from this plot

   |--|

   Poor   Excellent

5. Estimate the amount of fruit in the plot that was not fit for harvest

   |--|

   None   100%

   5a. Describe why this fruit was not fit to harvest(ripeness, size, rot, etc.)

6. How enjoyable was it overall to pick from this plot?

   |--|

   Did Not Enjoy   Very Enjoyable

IV. POST- PICKING SURVEY

ANSWER THE FOLLOWING QUESTIONS BY RANKING THE THREE PLOTS AS INSTRUCTED, OR BY ANSWERING IN YOUR OWN WORDS WHERE APPROPRIATE.

1. Rank each plot in terms of your overall enjoyment.
   Most Enjoyable_________________
   ____
   Least Enjoyable_________________

2. Rank each plot in terms of the overall fruit quality.
   Best quality ___________________
   ____
   Lowest quality___________________

3. If given the choice, which of the three plots would you most like to pick from again?

4. What factors most influenced your opinions about each plot?

5. Would you be willing to pay more to pick berries from your favorite plot? If so, how much more would you pay (Assume $1.00 per pound is standard price)? What would you be willing to pay for the other plots?

6. Please describe the conditions while you were picking (weather, insects, etc.).

7. Please add any additional comments.

Tables

Table 1. Total herbicide and fungicide use for duration of study. Glyphosate was used in AMR prior to planting to kill pre plant cover crop. Spot applications of paraquat were applied as needed to all systems. 2,4-D was applied to CMR and AMR treatments at an equal rate as part of renovation in July 2003. All fungicides were applied equally to all treatments. Benomyl used in 2003 only.

Pesticide	Conventional Matted Row (CMR)		Advanced Matted Row (AMR)		Cold-Climate Plasticulture (CCP)	
	Sprays	Amount	Sprays	Amount	Sprays	Amount
	(#)	(kg ai/acre)	(#)	(kg ai/acre)	(#)	(kg ai/acre)
Paraquat	1	0.3	4-5	4.1	3-4	2.0
Glyphosate	-	---	1	2.3	-	---
2,4-D	1	3.9	1	3.9	-	---
Azoxystrobin	4	0.5	4	0.5	4	0.5
Benomyl	1	0.1	1	0.1	1	0.1
Thiophanate-methyl	2	0.3	2	0.3	2	0.3
Captan	2	0.9	2	0.9	2	0.9

Pesticide formulations and toxicity ratings were: Paraquat (Gramoxone Max, Danger/Poison), Glyphosate (Roundup Original, Warning), 2,4-D (2,4-d 6 Amine, Danger), Azoxystrobin (Quadris Flowable, Caution), Benomyl (Benlate 50WP, Caution), Thiophanate-methyl (Topsin M 70WP, Caution), Captan (Captan 50WP, Danger)

Table 2. Hand labor among treatments from establishment through 2nd harvest. Fruit and flower were removed from all systems during establishment year to encourage vegetative growth. Runners in AMR and CMR treatments were placed within rows as they spread, and were removed in CCP. Hand weeding of within row area performed as necessary for all systems.

Management practice	CMR (hr/ha)	AMR (hr/ha)	CCP (hr/ha)
Fruit/Flower Removal	36 a [z]	15 b	0 c
Runner/Crown Management	165 a	66 b	70 b
Weed Removal	966 a	1294 b	148 c
May-June 2002	*295 a*	*370 a*	---
July-Aug 2002	*330 a*	*496 a*	---
Sep-Nov 2002	*91 b*	*152 a*	*9 c*
2003	*55 ab*	*87 a*	*29 b*
2004	*195 a*	*188 ab*	*110 b*
Total Labor	1166 a	1375 a	217 b

[z] Means followed by different letters are significantly different at α=.05

Table 3. Comparison of input costs among treatments over a three year production cycle.

Item	Unit	Price	Unit cost ($/ha) CMR	AMR	CCP
Cover crop seed					
Hairy Vetch [a]	Kg	2.76	--	49.18	--
Grain Rye [a]	Kg	0.49	--	15.14	--
Crimson Clover [a]	Kg	2.20	--	29.61	--
Strawberry plants					
'Allstar' Bareroot[b]	Plant	0.09	1291.23	1980.00	--
'Allstar' Plugs[c]	Plant	0.17	--	--	7480.00
Irrigation equipment					
Drip tape[d]	M	0.10	--	660.00	660.00
Blue-line poly[d]	M	0.36	--	39.60	39.60
4" Aluminum pipe[e]	M	2.20	1320.00	146.67	146.67
Plastic inserts[d]	Ea	1.72	--	113.52	113.52
Aluminum inserts[e]	Ea	9.72	243.00	27.00	27.00
Mulch					
1.25 mil embossed plastic[d] Mulch	M	0.10	--	--	660.00
Herbicides					
Gramoxone Max[a]	L	10.57	23.89	326.72	159.40
Roundup Original[a]	L	9.77	--	155.93	--
2,4-D 6 Amine[a]	L	3.58	50.51	50.51	--
Fungicides					
Quadris Flowable[f]	L	84.54	419.08	419.08	419.08
Benlate 50WP[g]	Kg	36.38	17.98	17.98	17.98
Topsin M 70WP[f]	Kg	45.17	47.84	47.84	47.84
Captan 50 WP[a]	Kg	6.64	29.53	29.53	29.53
Fertilizer					
Ammonium nitrate[a]	Kg	0.41	60.68	53.30	40.30
Total input costs			3503.74	4161.61	9840.92

Price estimates taken from the following sources: [a]Bowens Farm Supply, [b]Nourse Farms, [c]Davencrest Farms, [d]Trickle-Eez, [e]Mid-Atlantic Irrigation [f]Talbot Ag Supply, [g]Parvin and Wadden, 1997

Table 4. Operational costs among treatments over a three year production cycle.

Item	Rate ($/hr)	CMR ($/ha)	AMR ($/ha)	CCP ($/ha)
Custom Hire				
Fertilizer broadcast	7.95	39.75	--	--
Machine planting	15.40	77.00	96.25	192.50
Pesticide spraying	14.73	29.46	98.25	54.06
Cultivation/discing	7.72	61.76	15.44	7.72
Mowing	7.48	7.48	7.48	7.48
Bed formation	7.50	--	7.50	7.50
Labor				
Minimum wage	5.15	6005.42	7079.71	1119.10
Semi skilled	7.00	309.40	331.69	327.84
Total operational costs		6530.27	7636.32	1716.20

Custom hire rates based on O'Dell, 2001 with 2% appreciation

Table 5. Comparison of 2003 and 2004 harvest data among treatments. Marketable yield represents total amount of marketable fruit harvested in kg/ha. Weighted Mean Fruit Size is weight of fruit in grams averaged over the number of fruit for each treatment in each season. Peak fruit size is the largest average fruit size of any harvest date. Percentage of unmarketable fruit represents the percentage of fruit not suitable for harvest, averaged over harvest dates. There were a total of 8 harvests in 2003 and 6 in 2004.

Treatment	Marketable Yield (kg/ha)	Weighted Mean Fruit Size (g)	Peak Fruit Size (g)	Unmarketable Fruit (%)
2003				
Conventional Matted Row	17,381 a[z]	15.6 b	19.0 b	33.1 a
Advanced Matted Row	13,219 b	16.1 b	19.6 b	32.0 ab
Cold-climate Plasticulture	11,786 b	21.9 a	35.6 a	21.4 b
2004				
Conventional Matted Row	10,021 a	11.0 a	17.3 a	23.9 a
Advanced Matted Row	8,971 a	11.9 b	16.0 a	25.9 a
Cold-climate Plasticulture	6,049 b	11.0 a	16.2 a	32.5 b

[z] Means followed by different letters are significantly different at $\alpha = .05$

Table 6. Estimated net revenue per hectare for each system at varying prices based on observed yields (100%), conservative (80%) and optimistic (120%) estimates.

PYO Price ($/kg)	Marketable Yields								
	CMR			AMR			CCP		
	80% ($/ha)	100% ($/ha)	120% ($/ha)	80% ($/ha)	100% ($/ha)	120% ($/ha)	80% ($/ha)	100% ($/ha)	120% ($/ha)
1.10	24,114	30,142	36,170	19,527	24,409	29,291	15,695	19,619	23,542
2.20	48,228	60,284	72,340	39,054	48,818	58,582	31,390	39,237	47,084
3.30	72,343	90,427	108,510	58,581	73,227	87,873	47,085	58,856	70,626

Table 7 Estimated Net Profit per hectare for each system based on total input costs, total operational costs, and estimated net revenue (at a conservative mid-price and yield estimate).

Item	($/ha)		
	CMR	AMR	CCP
Total Input Costs	3,504	4,162	9,841
Total Operational costs	6,530	7,636	1,716
Total Costs	10,034	11,798	11,557
Net Revenue (80% @$2.20 / kg)	48,228	39,054	31,390
Net Profit	**38,194**	**27,256**	**19,833**

Table 8. Fertilizer applications, rates, and method for 3 strawberry production systems.

Treatment	Applications (#)	Application rate (kg N/ha)	Application method
CMR	5	170.4	Broadcast
AMR	20	229.8	Drip Fertigation
CCP	15	173.7	Drip Fertigation

Table 9. Description of sampled rain events for 2002-2004. Samplers were turned off between 18 Oct 2002- 25 Mar 2003, and 19 Sep 2003- 9 Apr 2004. Data recorded by weather station on the South Farm at Beltsville Agricultural Research Center in Beltsville, MD, approximately 500 m from research plots. Peak intensity is shown as the maximum rate of rainfall during any one-hour period of the event.

Date	Rain Event	Total Rainfall	Duration of Rain Event	Average Intensity	Peak Intensity
		mm	hr	mm/hr	mm/hr
28-Apr 2002	1	35.8	15.5	2.3	5.1
29-Apr 2002	2	1.8	1.5	1.2	1.5
14-May 2002	3	8.4	4.1	2.1	6.9
20-May 2002	4	14.5	13.8	1.1	4.3
19-Jun 2002	5	12.2	7.1	1.7	5.3
28-Jun 2002	6	6.1	0.8	9.3	9.3
14-Jul 2002	7	27.9	7.9	3.5	9.1
29-Jul 2002	8	12.2	11.3	1.1	8.1
5-Aug 2002	9	9.9	15.8	0.6	7.4
6-Aug 2002	10	7.4	7.9	0.9	6.6
29-Aug 2002	11	44.5	24	1.9	7.1
3-Sep 2002	12	35.1	10.4	3.4	9.7
16-Sep 2002	13	6.4	16.7	0.4	3.6
25-Sep 2002	14	26.7	15	1.8	4.3
30-Sep 2002	15	5.6	0.8	6.7	6.7
14-Oct 2002	16	40.6	32.3	1.3	4.3
17-Oct 2002	17	26.9	17	1.6	3.6
26-Mar 2003	18	7.1	4.1	1.7	3.6
28-Mar 2003	19	14.0	18.8	0.7	1.8
24-Apr 2003	20	15.2	2.0	7.6	7.6
28-Apr 2003	21	15.7	16.3	1.0	4.1
7-May 2003	22	5.1	4.9	1.0	4.6
9-May 2003	23	13.6	6.9	2.0	4.3
15-May 2003	24	28.7	10.2	2.8	6.9
21-May 2003	25	16.0	13.8	1.2	3.6
6-Jun 2003	26	34.5	16.9	2.0	9.7
12-Jun 2003	27	21.1	9.3	2.3	8.9
15-Jun 2003	28	12.4	2.3	5.5	6.9
22-Jul 2003	29	34.5	3.1	11.2	30.0
28-Jul 2003	30	17.0	13.3	1.3	10.2
11-Aug 2003	31	19.6	0.5	39.1	39.1
27-Aug 2003	32	12.2	5.9	2.1	11.4
12-Sep 2003	33	26.2	24.6	1.1	5.6
15-Sep 2003	34	8.6	0.8	10.4	10.4
18-Sep 2003	35	29.0	12.8	2.3	9.9
10-Apr 2004	36	59.1	7.8	7.6	7.6
16-Apr 2004	37	26.6	3.5	7.6	7.6
23-Apr 2004	38	14.5	2.8	5.2	7.1
5-June 2004	39	14.7	21.5	0.7	3.8
11- June 2004	40	12.4	12.3	1.0	3.3

Table 10. Nitrogen application, plant N uptake, N in runoff, N recovered, and N uptake efficiency for 3 strawberry production systems.

Treatment	Total N Applied (g/plant)	Total Plant N Uptake (g/plant)	Total N Runoff (g/plant)	Total N Recovered (%)	Plant N Uptake Efficiency (%)
CMR	10.77	1.73 a[z]	0.22 a	18.1 c	16.1 c
AMR	6.49	2.01 a	0.11 b	32.7 b	31.0 b
CCP	2.33	1.78 a	0.01 c	76.8 a	76.4 a

[z]Means followed by different letters are significant at α=0.05 LSD

Table 11. Demographic information for volunteer harvesters.

Parameter	2003 (%)	2004 (%)	2- Year Totals (%)
Sex			
Male	25.6	6.7	18.7
Female	74.4	93.3	81.3
Age (years)			
<20	7.7	2.2	5.7
21-30	50.0	53.3	51.2
31-40	23.1	22.2	22.8
41-50	15.4	20.0	17.1
51-65	3.8	2.2	3.3
>65	7.7	2.2	5.7
Household Income ($)			
<20,000	3.9	6.8	5.0
20,000-40,000	22.4	25.0	23.3
40,000-60,000	17.1	20.5	18.3
60,000-80,000	27.6	18.2	24.2
80,000-100,000	14.5	9.1	12.5
>100,000	14.5	20.5	16.7
State of Residence			
Maryland	94.9	75.6	87.8
Virginia	3.8	17.8	8.9
District of Columbia	1.3	6.7	3.3
Country of Origin			
United States	80.8	86.7	82.9
India	5.1	0.0	3.3
China	3.8	0.0	2.4
Venezuela	1.3	4.4	2.4
Other	9.0	8.9	8.9

Other countries listed included Germany, Lithuania, Brazil, Taiwan, Chile, Columbia, Korea, and Serbia and Montenegro

Table 12. Pick-your-own history of volunteer harvesters.

Question	2003	2004	Total
1.) Have you ever picked fruit or vegetables from a PYO farm?			
Yes	71.8	72.1	71.9
No	28.2	27.9	28.1
2.) If so, what crops have you picked			
Strawberries	50.0	67.4	56.2
Apple	25.6	37.2	29.8
Pumpkin	17.9	32.6	23.1
Blueberry	17.9	20.9	19.0
Peach	12.8	14.0	13.2
Raspberry	6.4	16.3	9.9
Blackberry	6.4	11.6	8.3
Other	39.7	20.9	33.1
3.) How recently have you picked strawberries from a PYO farm?			
Within the last year	17.8	11.6	14.7
Within 2-3 years	11.0	7.0	9.5
More than 3 years	28.8	48.8	36.2
Never	42.5	32.6	38.8
4.) How many times in an average year do you pick strawberries?			
0	64.2	60.9	62.9
1	17.9	29.3	22.2
2	9.0	2.4	6.5
3	1.5	0	0.9
Depends	7.5	7.3	7.4

Table 13. Previous and intended use(s) of strawberries picked by volunteer harvesters. Volunteers could list up to three uses for harvested fruit, if applicable.

Use	How have you previously used your PYO strawberries?			How do you intend to use the strawberries you pick today?		
	2003 (%)	2004 (%)	Total (%)	2003 (%)	2004 (%)	Total (%)
Eat Fresh	59.0	68.9	62.6	71.8	77.8	74.0
Freeze	32.1	51.1	39.0	33.3	48.9	39.0
Process	30.8	48.9	37.4	24.4	31.1	26.8

Table 14. Attributes scored for each production system by panel of volunteer harvesters.

Attribute	Left Label (Score=0)	Right Label (Score=100)
Overall appearance	Poor	Excellent
Ease of harvest	Difficult	Easy
Appearance of fruit	Poor	Excellent
Amount of fruit not fit for harvest	None	100%
Overall enjoyment	Did Not Enjoy	Very Enjoyable

Table 15. Consumer scores for attributes of production systems in 2003 and 2004.

	2003			2004		
Attribute	CMR	AMR	CCP	CMR	AMR	CCP
Overall appearance	54 b[z]	68 a	71 a	55 a	58 a	60 a
Ease of harvest	54 c	67 b	83 a	57 b	74 a	78 a
Appearance of fruit	59 b	61 b	70 a	64 a	67 a	54 b
Amount of fruit not fit for Harvest	50 a	53 a	48 a	37 a	38 a	43 a
Overall enjoyment	56 b	67 a	73 a	65 a	68 a	63 a

[z]Means followed by different letters are significant at α=0.05 LSD

Table 16. Titratable acidity, soluble solids, and firmness by compression of strawberry fruit harvested in 2004.

Treatment	Titratable Acidity (% Citric Acid)	Soluble Solids (%)	Compression (F_{max})
CMR	0.70 a[z]	6.95 a	2.21 a
AMR	0.74 a	7.02 a	2.23 a
CCP	0.69 a	7.71 a	1.87 b

[z]Means followed by different letters are significant at α=0.05 LSD

Figures

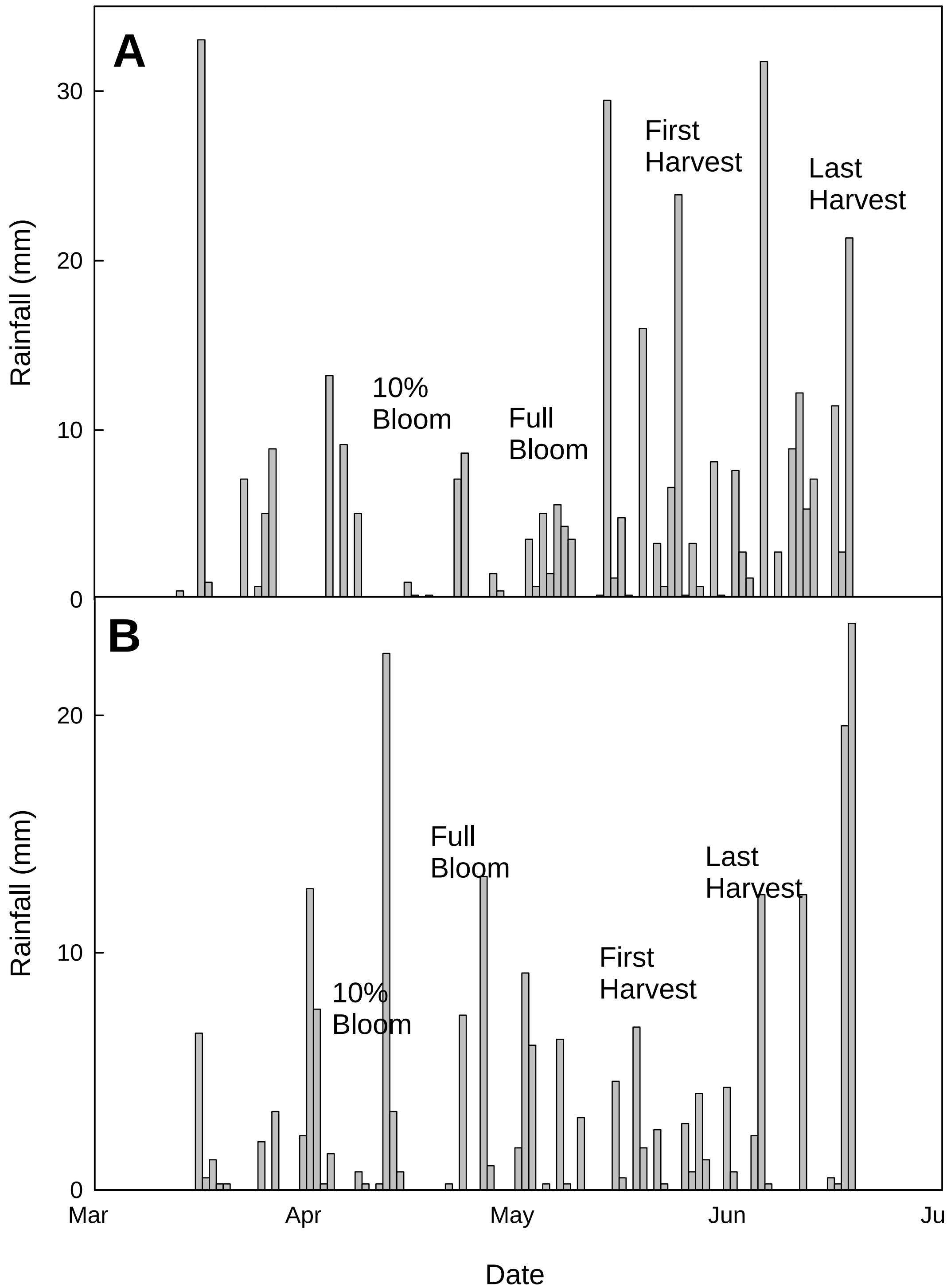

Figure 1. Total daily rainfall for period from bloom to harvest for 2003 (a) and 2004 (b)

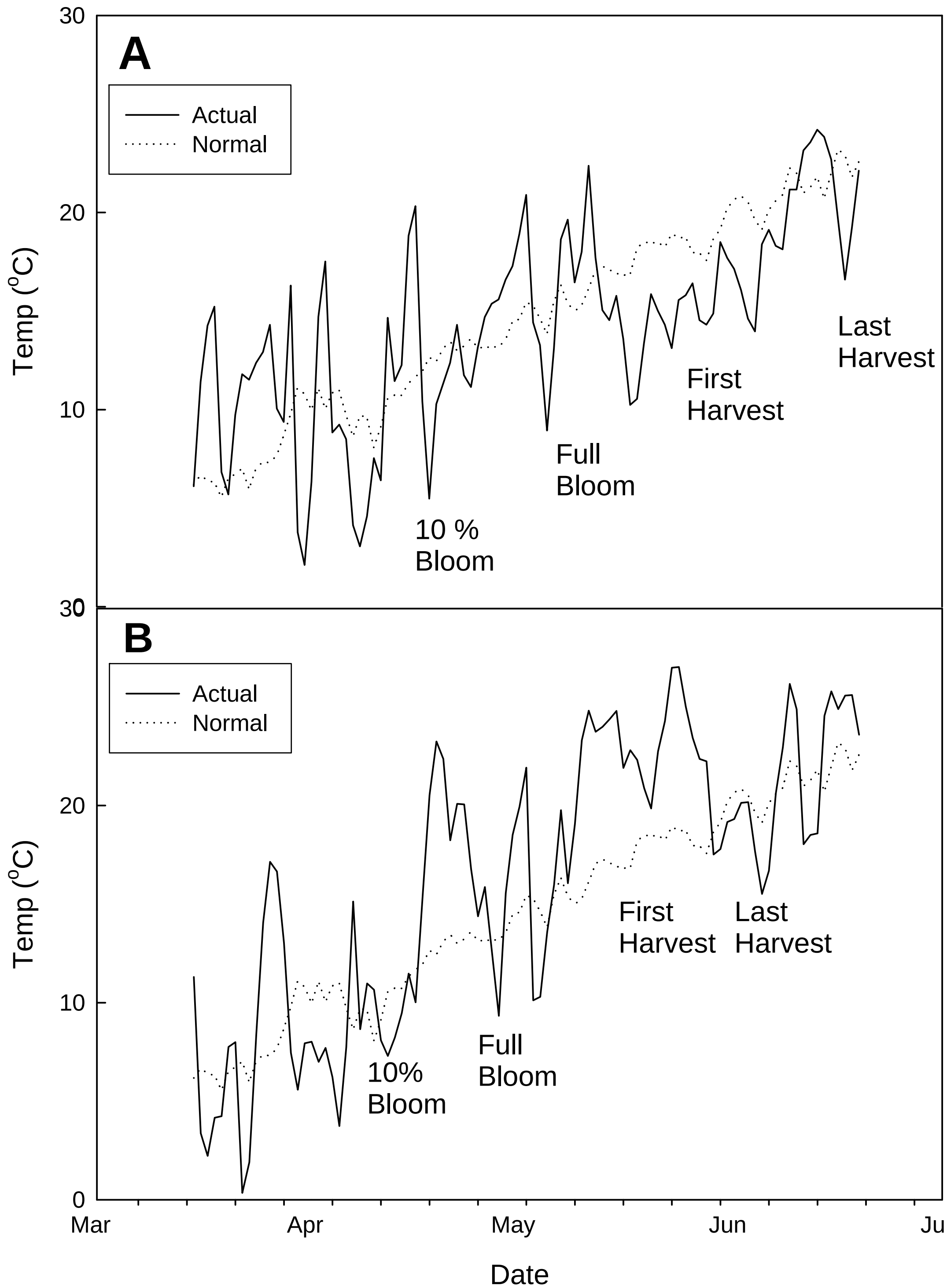

Figure 2. Daily average vs. 30-year normal temperature for period from bloom to harvest 2003(a) and 2004(b)

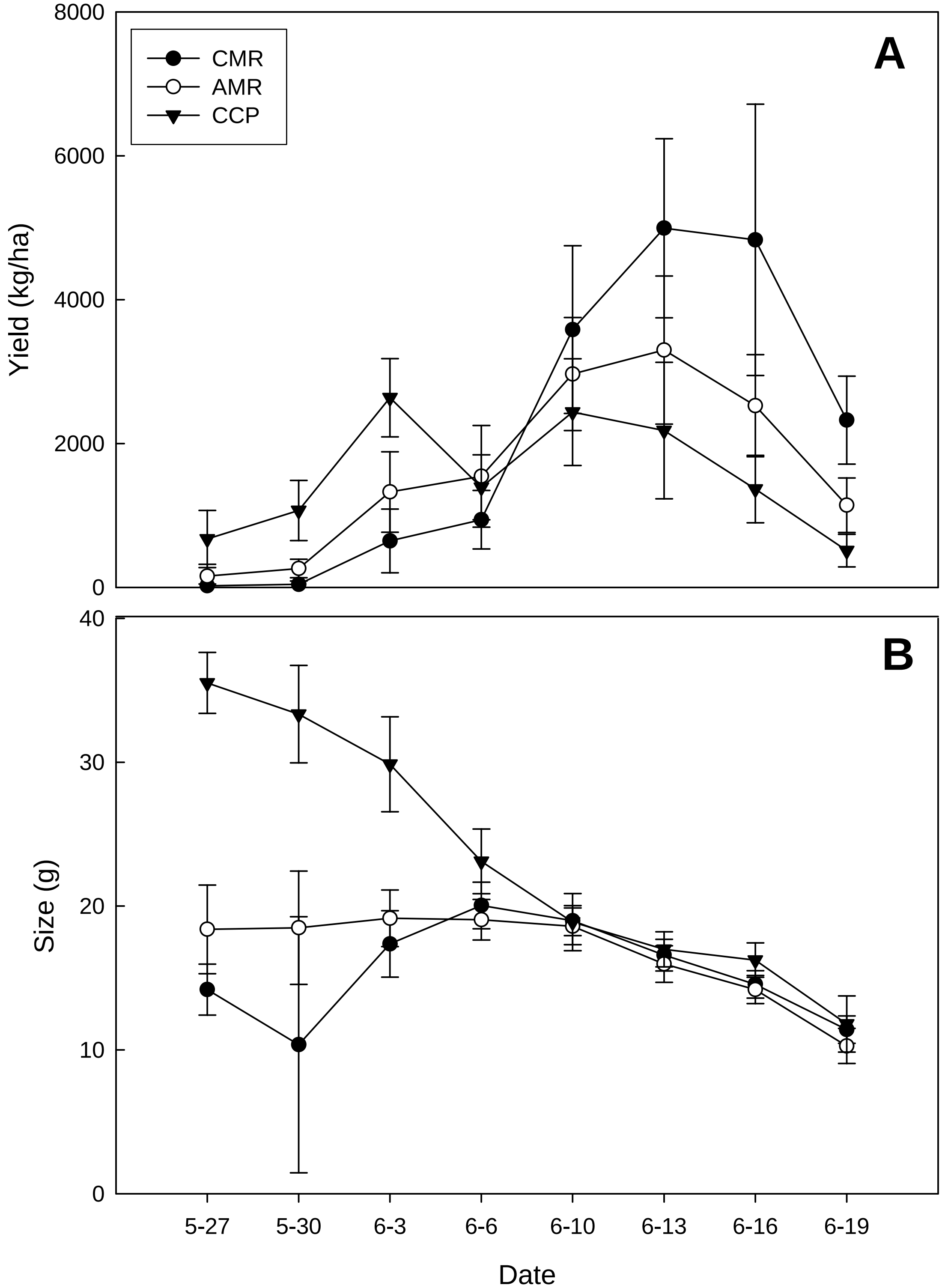

Figure 3. Fruit yield(a) and size(b) by harvest 2003

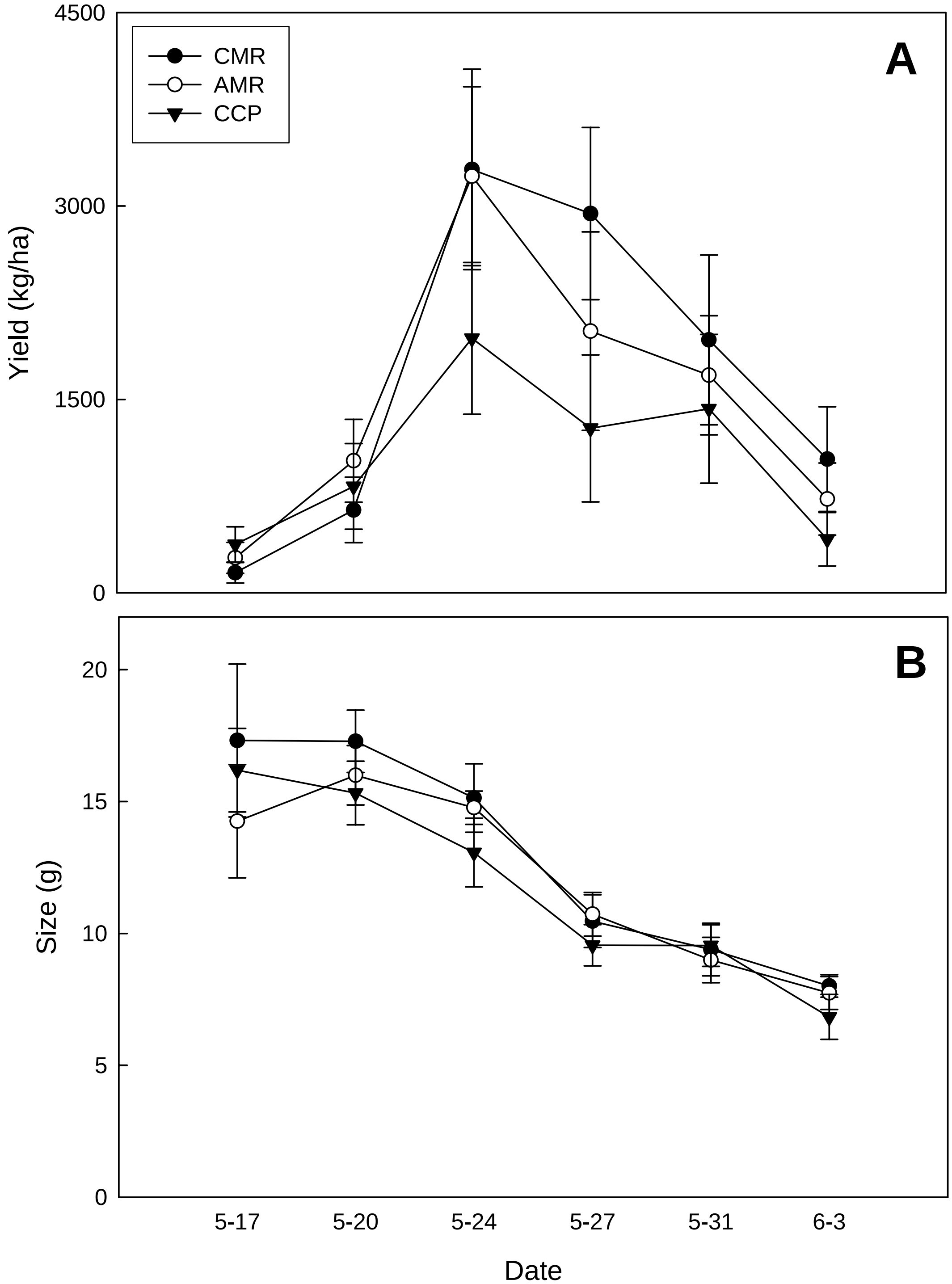

Figure 4. Fruit yield(a) and size(b) by harvest 2004

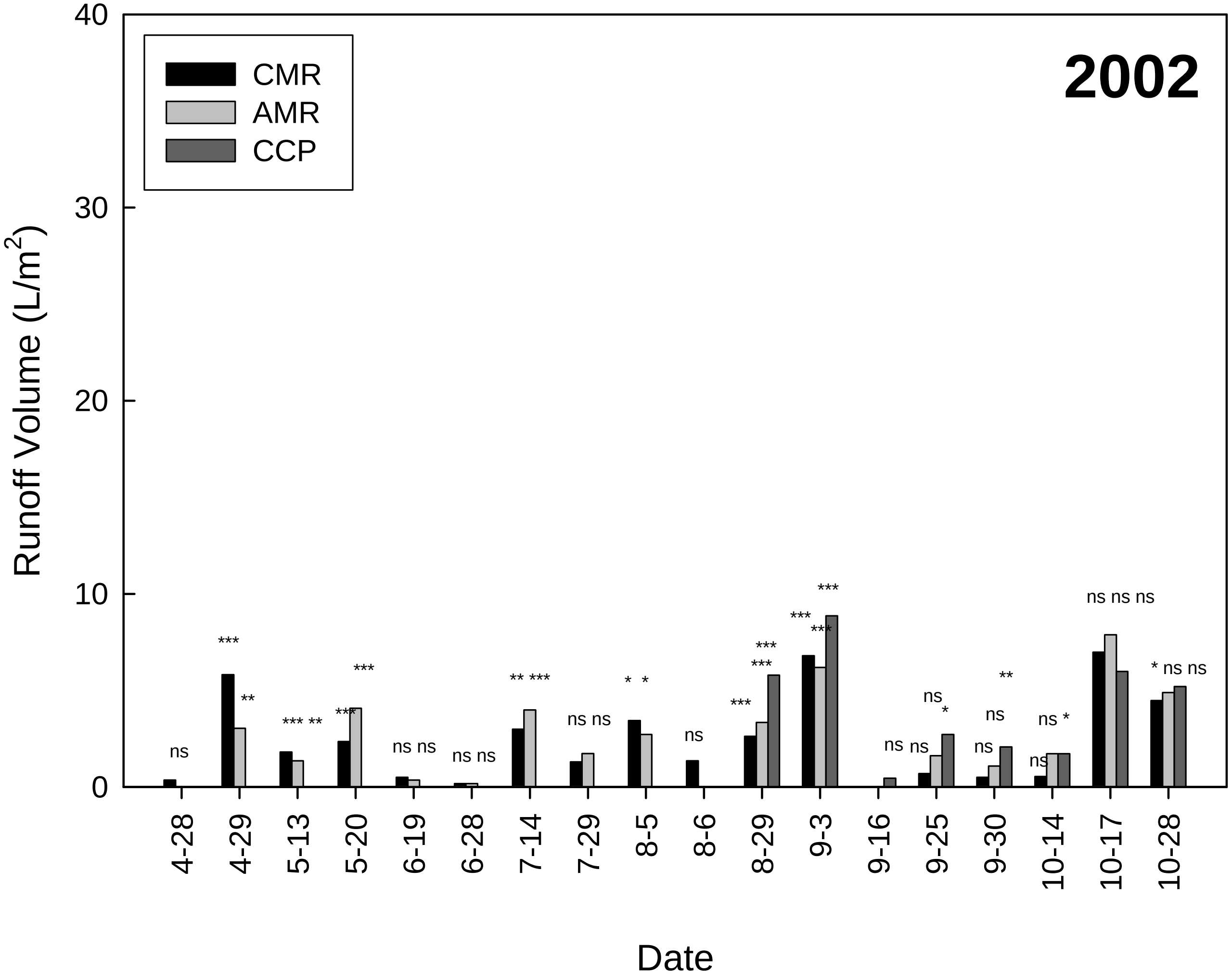

Figure 5. Water runoff volume in 2002

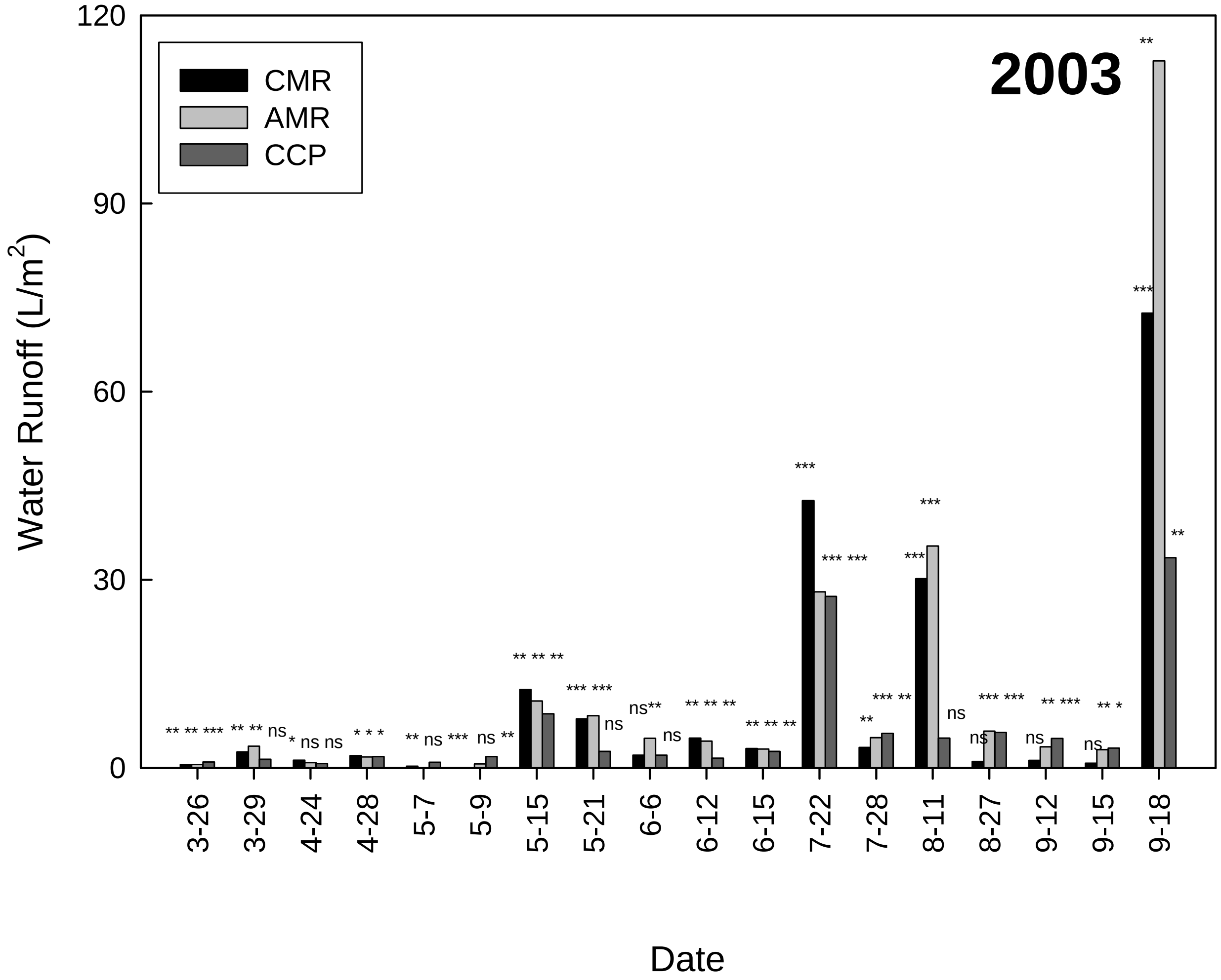

Figure 6. Water runoff volume in 2003

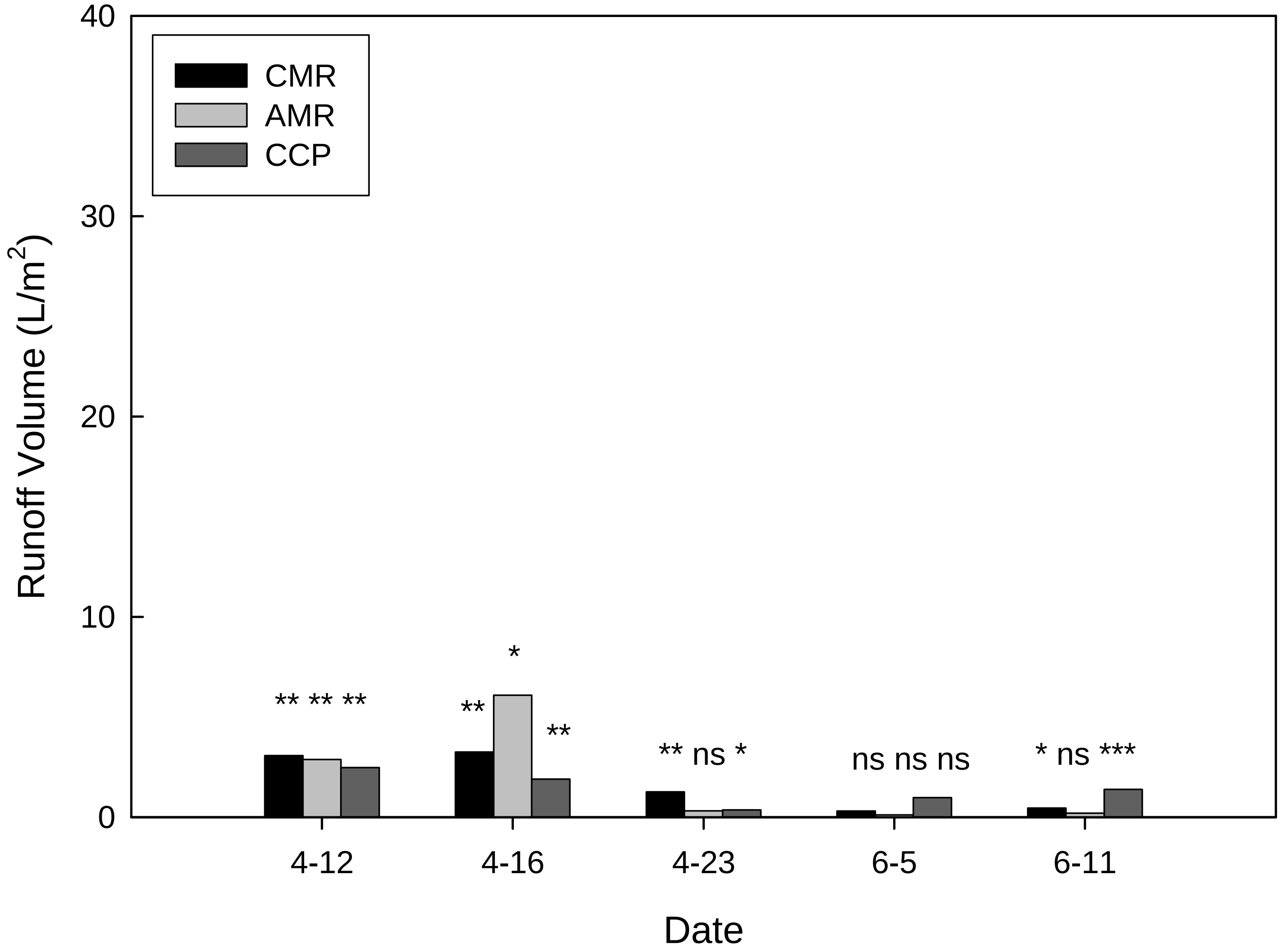

Figure 7. Water runoff volume in 2004

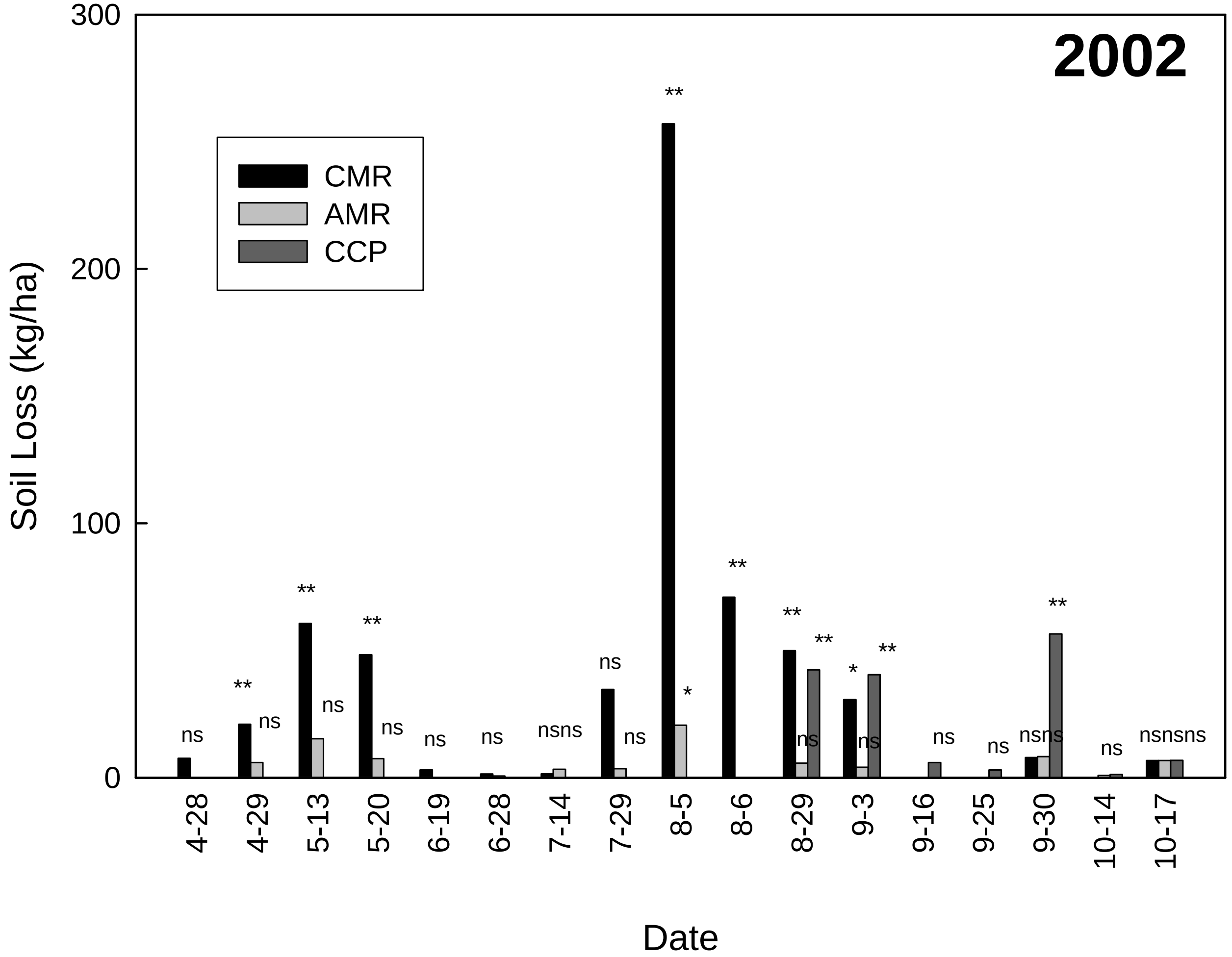

Figure 8. Soil erosion in 2002

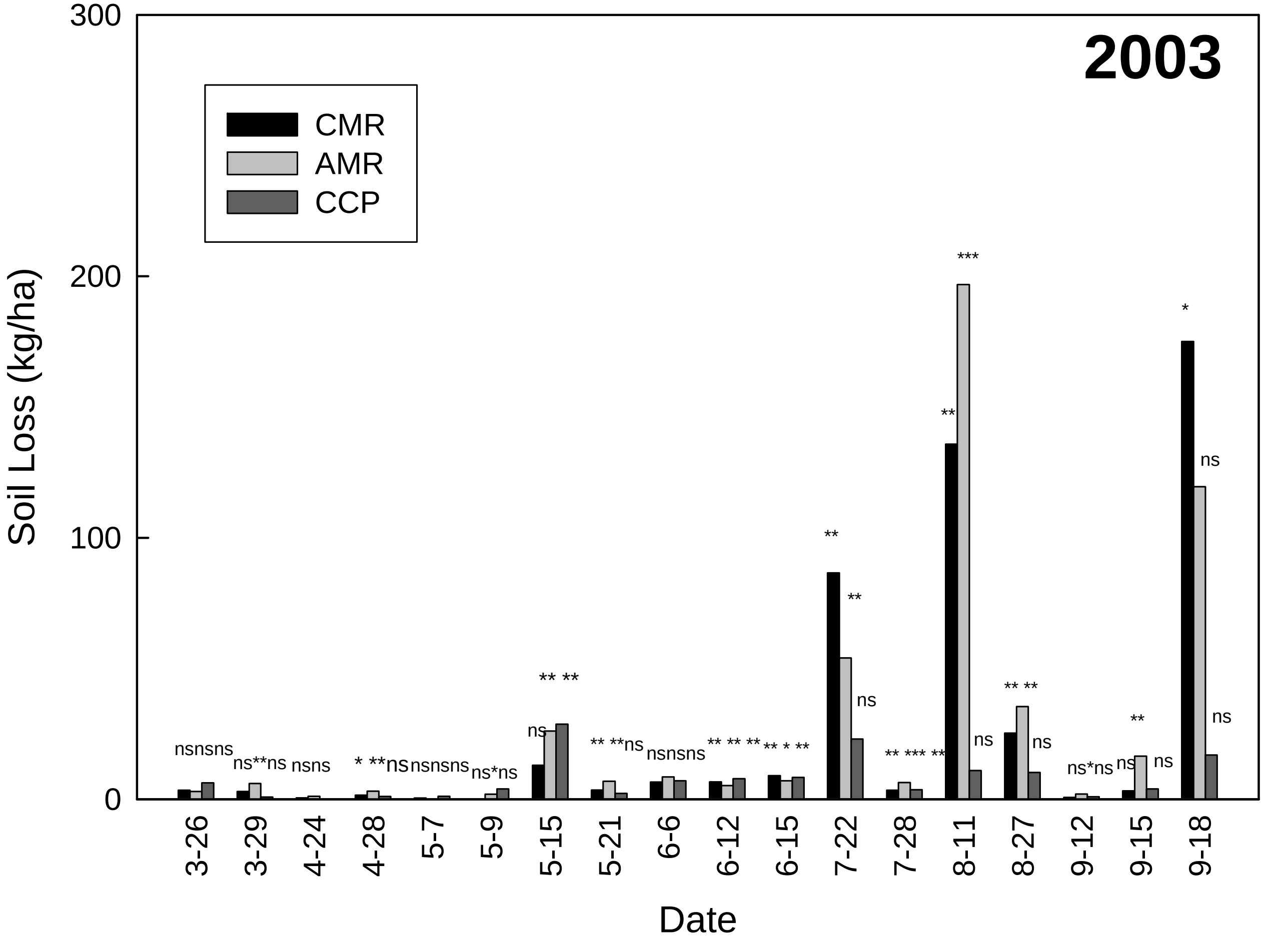

Figure 9. Soil erosion in 2003

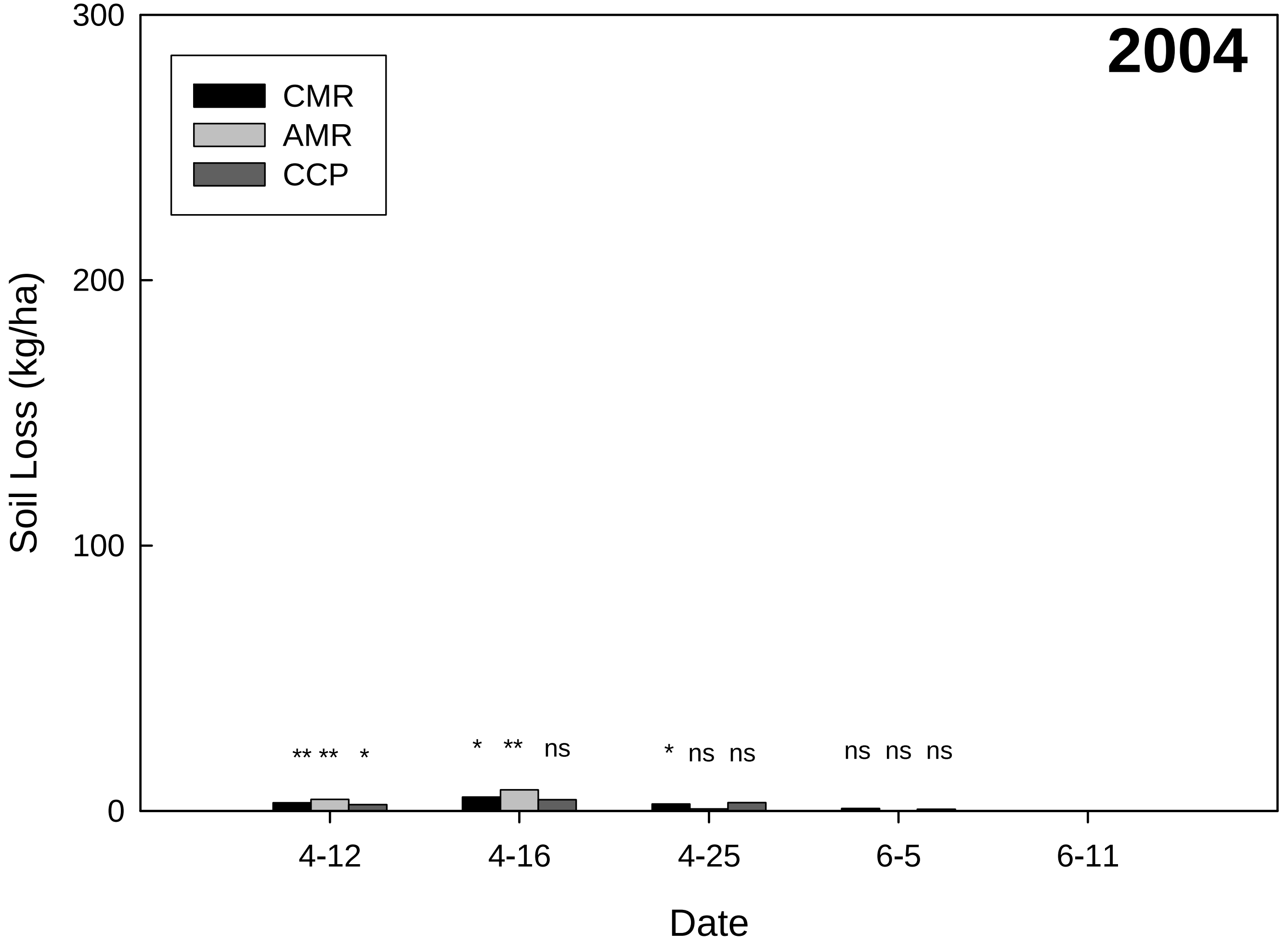

Figure 10. Soil erosion in 2004

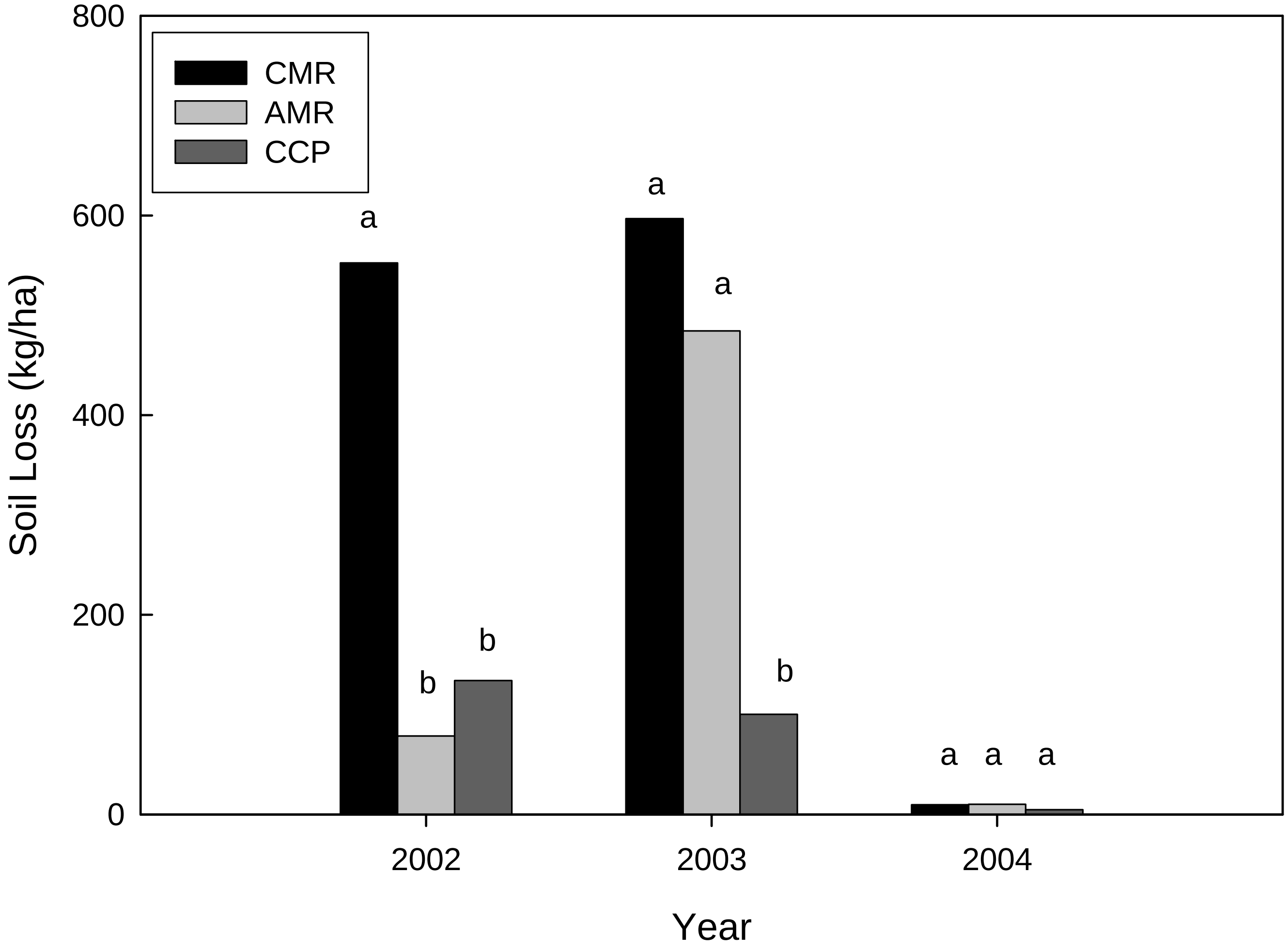

Figure 11. Soil erosion by year

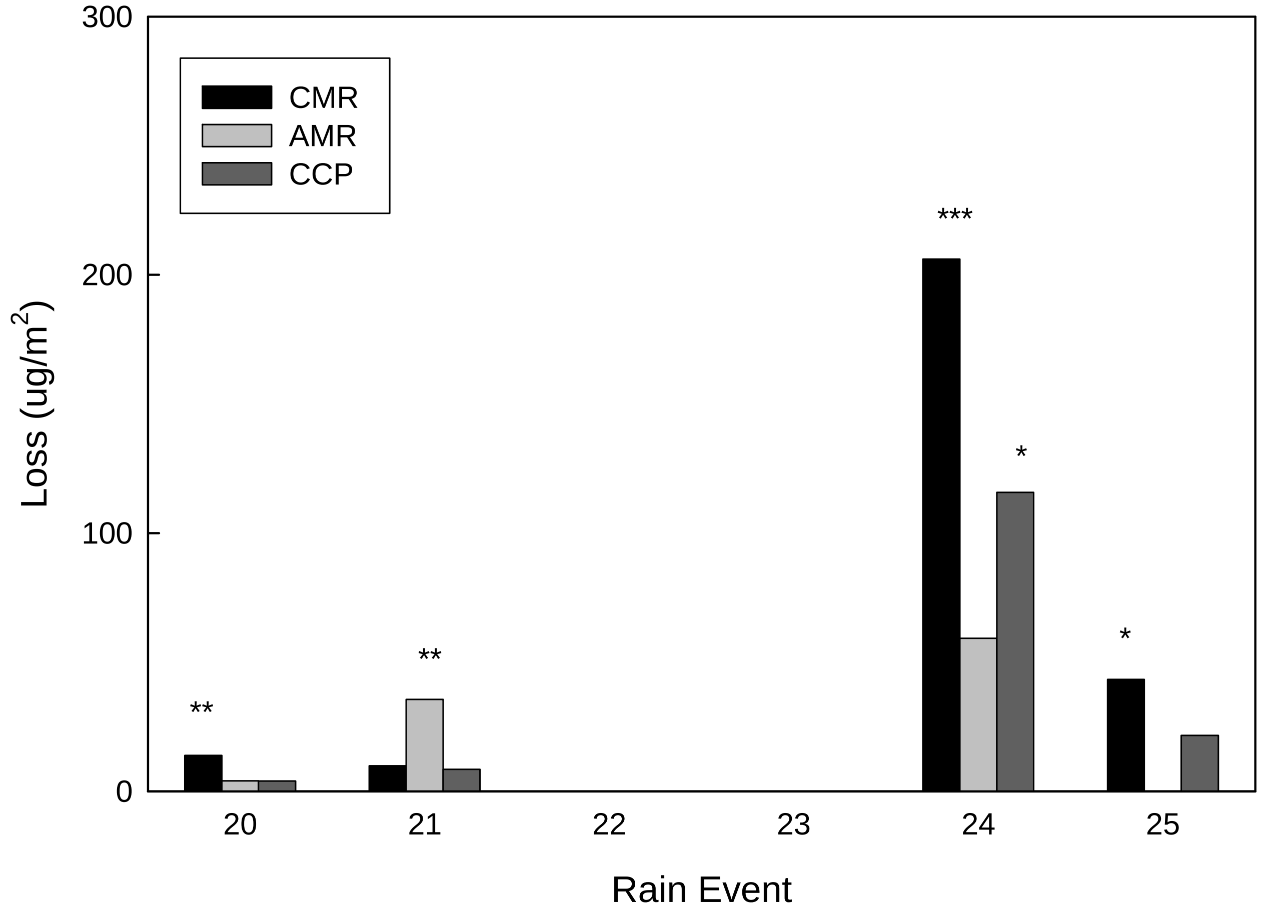

Figure 12. Benomyl loss following application in 2003

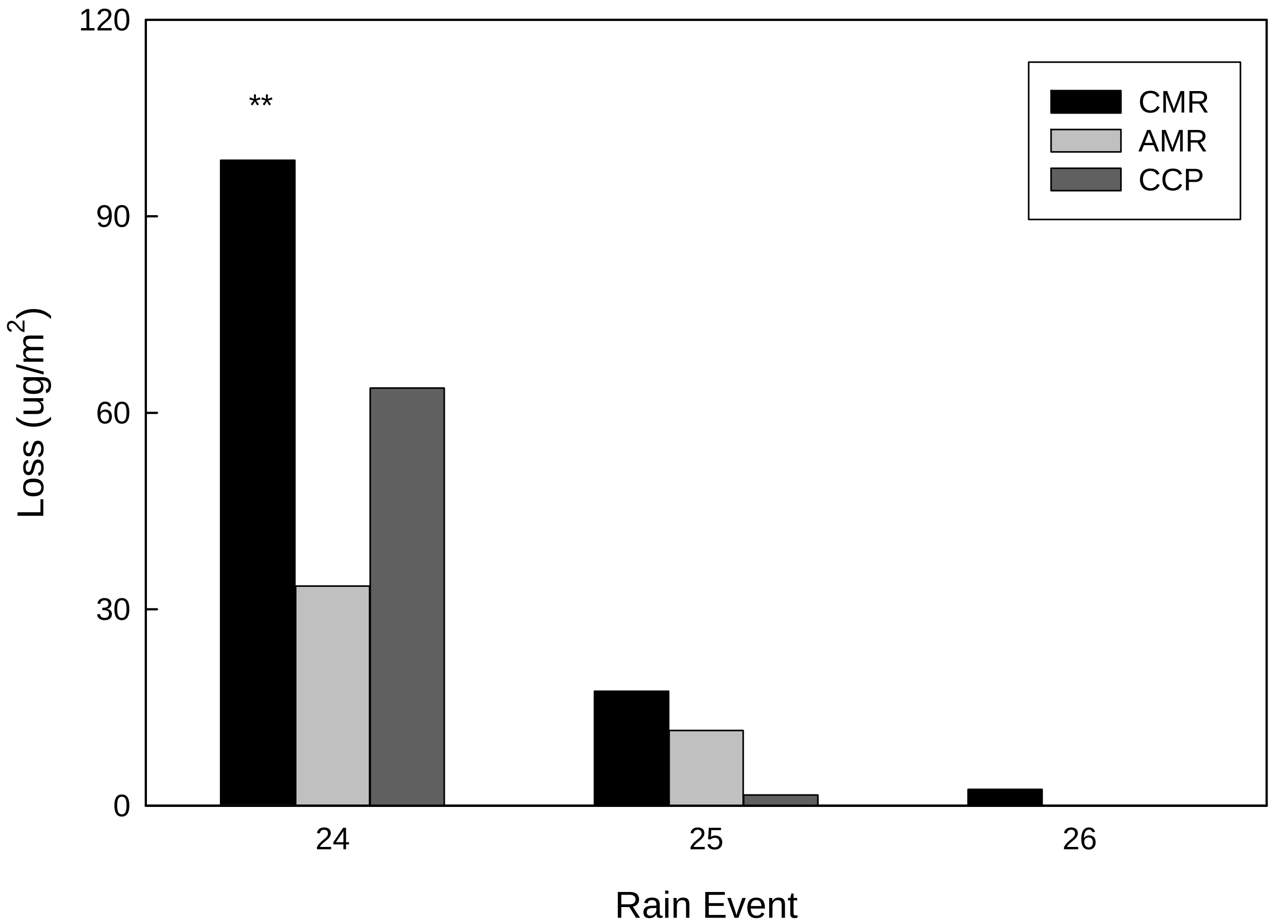

Figure 13. Thiophanate-methyl loss following application in 2003

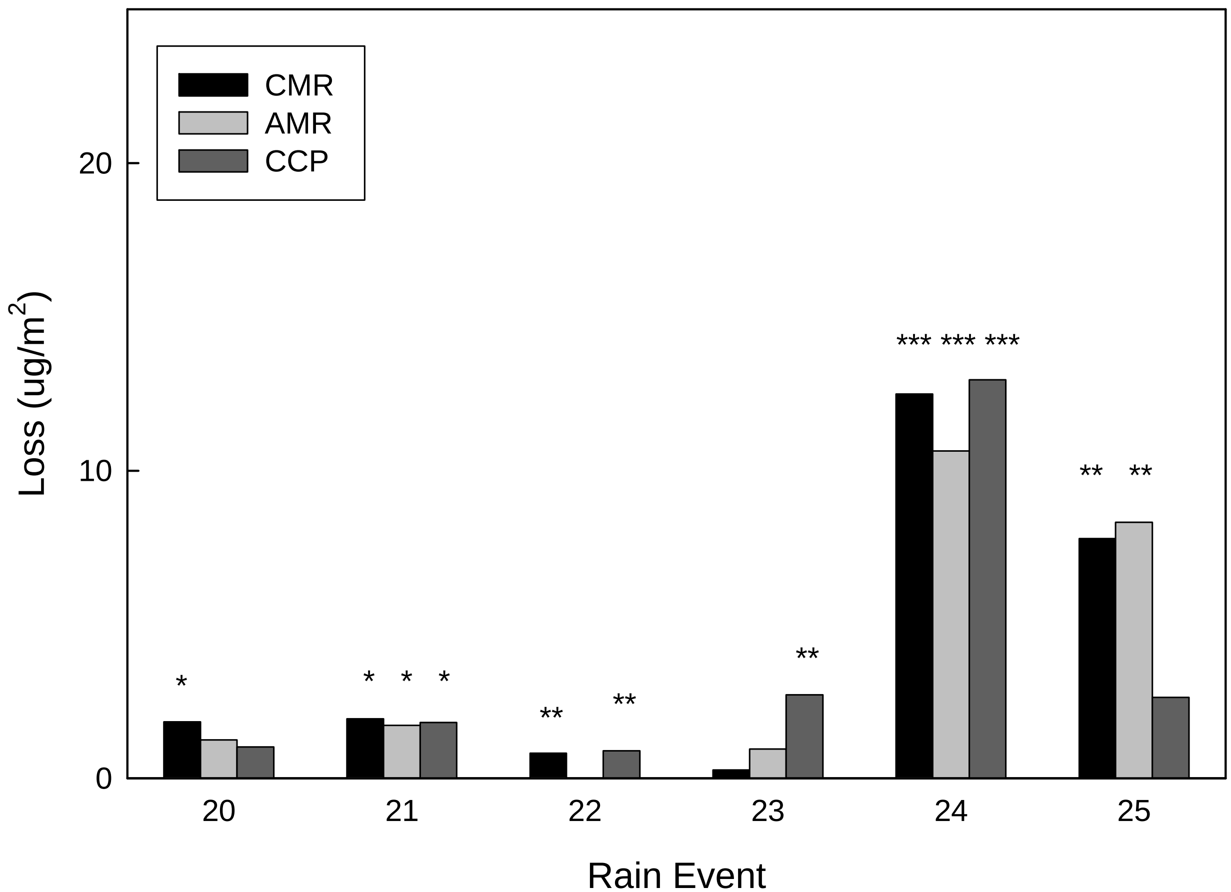

Figure 14. Azoxystrobin loss following application in 2003

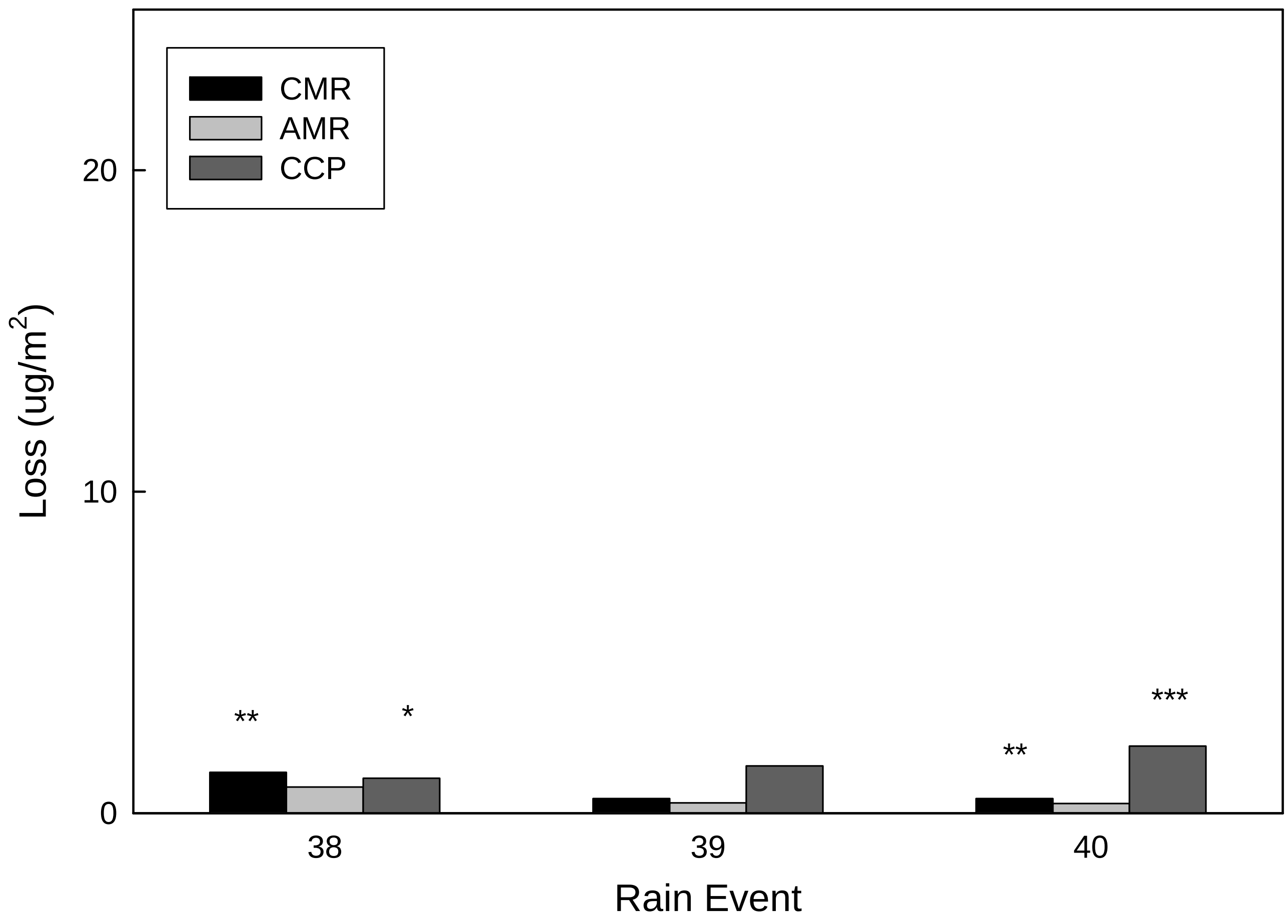

Figure 15. Azoxystrobin loss following application in 2004

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