

2018 Strawberry Twilight

University of Maryland

Wye Research and Education Center

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UNIVERSITY OF
MARYLAND
EXTENSION



COLLEGE OF
AGRICULTURE &
NATURAL RESOURCES

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EXPERIMENT STATION

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To access this booklet and program information online, go to:

<https://agresearch.umd.edu/wye>

Original cover photo of WREC berries courtesy of Danny Poet

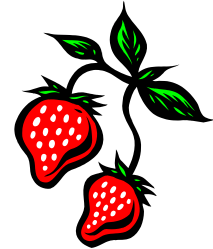


Table of Contents

2017/2018 Strawberry Plot Map.....	1
Developing Strategies for Fall Floating Row Cover Deployment and Their Effect on Spring Yields in the Annual Plasticulture Strawberry Production System.....	2
Spray Recommendations for Botrytis and Anthracnose Fruit Rot.....	7
Continuation of Strawberry Advisory System (SAS) Implementation in Maryland and Virginia.....	9
Importance of Botrytis Resistance Management and How to Test the Resistance.....	11
Managing Climate Risk to Strawberries (slides).....	14
Strawberry Clipper.....	15
Effect of Soil Moisture Regimes on Plant Growth, Yield and Fruit Quality of Strawberry..	17
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Mention of trade names and products is for information only and does not constitute an endorsement or recommendation of, or discrimination against, similar products not mentioned.

**2017/18 Sberry Plot Map
SAS Validation Trial**

RS	AS	EG	CH
AS	RS	CH	EG
FF	FF	FF	FF
CH	AS	CH	RS
RS	EG	AS	EG
FF	FF	FF	FF
AS	CH	EG	RS
EG	RS	CH	AS
FF	FF	FF	FF
15 foot gap between main plots			
FF	FF	FF	FF
RS	AS	EG	CH
AS	RS	CH	EG
FF	FF	FF	FF
CH	AS	CH	RS
RS	EG	AS	EG
FF	FF	FF	FF
AS	CH	EG	RS
EG	RS	CH	AS
1	2	3	4

KEY

- RS RUTGERS SCARLET
- AS ALLSTAR
- CH CHANDLER
- EG EARLIGLOW
- FF FLAVORFEST

"=Growers Spray

"= SAS sprays

GATE

Developing Strategies for Fall Floating Row Cover Deployment and Their Effect on Spring Yields in the Annual Plasticulture Strawberry Production System

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Background:

The annual plasticulture system of producing strawberries has been a productive system for growers throughout the Southeast and mid-Atlantic regions. The cost of establishment and maintenance of this system is high, but high yields of high quality fruit can be the result. The system has specific requirements for success. Planting bed preparation, variety selection, fertility practices and planting date. Depending on the location in Maryland, recommended planting dates can vary from August 25 to September 25th. However, weather conditions, plant supply and other factors may prevent planting during the desired planting window. Weather conditions after planting can also affect Spring yields. If it's too cool in the Fall or if we have to plant late, plants may not make acceptable Fall growth which is imperative for high Spring yields.

The strawberry is an amazing plant. Because flower initiation is governed by day-length (short-day varieties) and influenced by temperatures (lower temperatures promote flower initiation and high temperatures can limit flower initiation but promote vegetative growth), systems have been developed (Primarily greenhouse production), that can take advantage and alter these factors to produce fruit for specific targeted markets.

Out in the field, we do not have control of the day-length other than when we plant and plant source. We use formed, high beds covered tightly with black plastic to warm the soil later into the Fall and earlier in the Spring to promote plant growth. Another tool we use to alter temperatures are floating row covers (FRC).

FRC's have a place in the annual system already. They are used for over-wintering and for frost/freeze protection during flowering. They can be used to advance the crop when used in the Spring. Using a FRC in the Fall is used to advance growth in attempts to "catch-up" if the planting date was later than recommended, or if the weather had been cooler than normal. There are no hard and fast rules on optimal times for using FRC's in the Fall. Past research at the Wye Research Center (Ref 1 and 2) looking into the Fall deployment of FRC's in 2004/05 and in 2009/10 was inconclusive. Deployment of either a 1 oz. or 1.2 oz. FRC and various covering dates and durations were investigated. However at Wye, Fall deployments were usually long in duration (up to 60 days) and/or later in October and November.

Research by Fernandez, (Ref 3) showed that deployment of FRC's 3 weeks after planting and for only 2 weeks increased marketable yields by ¼ lb. per plant. This increase in yield occurred over multiple years with different planting dates. More recently Dr. Jeremy Pattison (REF 4), formerly with NCState, reported on research that indicates the optimal time to deploy FRC's in the Fall is before the daytime high temperatures fall below 64 f, and a 2 week duration was long enough to increase Spring yields by 14%. In

addition, although the correct planting date was the best indicator of high yields, the 2 week FRC deployment increased yields for all planting dates.

Reviewing the past 15 years of weather data for Queenstown MD, 21658, during the month of September, 30 days had daily high temperatures greater than 64 f. During October, 20 days and during November, only 6 days. Within Maryland, the various regions will have departures in temperatures then what we have in Queenstown. Available subscription weather services can pin point our locations and give us specific temperatures, but they can't tell us the temperature under a FRC.

Objective:

- 1) Trial, Fall applied FRC's on the annual strawberry plasticulture system in an attempt to boost Spring yields.

Procedures:

A cover crop of sudan grass was grown in July 2016. The cover crop was terminated on August 17th and the field was fertilized with 16-8-8 @ 383 lbs/a. Hills were shaped and black plastic applied with 2 drip lines (0.25 gpm/100ft) placed 8 inches apart. Plant holes were staggered spaced 12" x 12" with a water wheel on each planting date. Plants were hand set and watered-in. Plug plants were purchased from KubePak. Plug's were received on 2 dates (September 1 and September 20th) to accommodate the 4 planting dates. The September 1st plugs were used to plant on September 8th and 15th, the September 20th plugs were used to plant on September 22nd and 29th. Fall deployed FRC's used were a 1.2 oz., Dupont Tytar T-518.

Captan + Topsin-M + Kocide3000 were applied twice in October for management of leaf diseases and bacterial angular leaf spot (which was observed on leaves). Runners were counted and removed on December 1st. The 1.2 oz floating row cover (FRC) was deployed for over-wintering on January 6th 2017. The FRC's were removed and redeployed several times (for freeze/frost protection) and finally removed on April 9th 2017. The planting was cleaned of dead plant material in March and fungicides were applied as needed based on rainfall, temperatures and plant stage of growth. An additional 30 lbs. of nitrogen was split applied as KNO₃, CaNO₃ and urea. The first harvest was on May 1st and the final harvest was June 6th. Plants were harvested twice a week. Fruit was graded, counted and weighed. Fruit less than 10 grams were culled. No fruit botrytis or anthracnose was evident. Fruit quality was considered good.

Observations and Discussions:

2016 temperatures in the Fall were considered warmer than usual. Heat units generated (Table 1) with the 2 week FRC deployment resulted in greater than 100 more growing degree units (GDD) for the first 3 planting dates, but only 63 GDD for the last planted date. Interestingly, it is the last planting date, both with (450 heat units) and without (387 heat units) the Fall deployed FRC that had the numerically higher fruit yields (Table 3), although not statistically different. It has been stated by Barclay Poling at NCState that Chandlers need at least 600 GDD's in the fall to make adequate growth and that this is the driving factor in determining the optimal planting date.

Suggested planting dates for Chandler depend on location. To gain high spring fruit yields, adequate fall growth needs to occur. This is where the NCState recommendation that we need 600 GDD (baseline 50f) in the Fall. In the northern and western parts of Maryland, planting dates as early as the last week in August are suggested. But in the Southern and Eastern parts of Maryland, mid-September is the general recommended planting date. Planting date can also affect the number of runners produced in the Fall. The later we plant, the fewer runners are produced...usually. From a management standpoint, we prefer fewer runners. Runners will die over the winter. Dead leaves can harbor the botrytis fungus. Removal of runners either green (Fall) or dead (late Winter) is recommended to reduce disease inoculum. Ideally, growers would prefer to plant later to reduce runner production, but usually GDD accumulation is not enough if we plant too late. Some growers believe that you can plant late and deploy a FRC to generate the needed GDD's. In Table 2, the 3rd planting date produced significantly more number of runners contraire to what is usually observed. This, I cannot explain! I intentionally had plug plants come on 2 delivery dates, so I had plugs of nearly similar age when planted (4-5 week old plugs) over the 4 week planting period. The 4th plant date had the fewest runners as expected. The Fall deployed row covers for each planting date did not result in increased runner production (Table 2) when compared to no Fall row covers.

2017 Spring fruit yields (Table 3) were lower than the long time averages for the WyeREC site (1.2lbs/plant). Tumultuous weather conditions during the Winter and early-Spring, forced early flower development and we lost on average 5 flowers per plant (data not presented). Had we not lost these flowers, we would have had above average yields. The only significant yield differences were between the earliest planting date and the last planting date, and both when Fall row covers were not used!

Planting date for Chandler is still the number one factor in achieving high yields, assuming everything-else is managed correctly. It is the planting date that we have the most control of and it should always be the number one goal when planting in the annual system.

Here in the mid-Atlantic, we are on the northern limits of effectively using Chandler as a reliable variety in the annual plasticulture system. Over the years, yields at WyeREC have ranged from 0.6 lbs. to 2 lbs. per plant. Usually when Chandler does well, most other strawberry varieties grown at the location do well also. When Chandler under-preforms, most other varieties under-preform as well. Manipulating Fall applied FRC's has been attempted at Wye REC in the past, including this most recent trial which was based on research from NCState. Every season is different, obviously, attempting to use Fall applied row covers to advance plant development needs to be done with caution to avoid too much growth and to be sure the plant is cold acclimated enough before extreme cold temperatures arrive.

REF 1. 2006 Wye Research and Education Center Strawberry Twilight Book

REF 2. 2011 Wye Research and Education Strawberry Twilight Book

REF 3. 2001 Fernandez, G.E. Fall applied row covers enhance yields. Hort Technology 11:440-444

REF 4. 2013 Pattison et. al. Modeling Yield of Chandler and Camarosa as a function of accumulated Fall growing degree days and practical row cover intervention strategies. 2013 ASHS Annual Conference Abstract.

Table 1. Chandler Plant Date and Row Cover Deployment

Plant Date	Row Cover ?	Deploy row cover date	Remove row cover date	# heat units Generated (>50f) during row cover time period	Difference in heat unit accumulation during row cover deployment	Heat units generated from plant date to November 3
September 8	Yes	September 29	October 13	329	+109	1001
September 8	No	N/A	N/A	220		892
September 15	Yes	October 6	October 20	338	+138	853
September 15	No	N/A	N/A	200		675
September 22	Yes	October 13	October 27	278	+103	611
September 22	No	N/A	N/A	175		508
September 28	Yes	October 20	November 3	189	+63	450
September 28	No	N/A	N/A	126		387

Table 2. 2016/17 Chandler Fall Runner Counts

Plant date	Row cover?	# runners per 10 plants	Significance
September 8	Yes	35	ab
September 8	No	26	bc
September 15	Yes	23	bc
September 15	No	31	b
September 22	Yes	47	a
September 22	No	46	a
September 28	Yes	16	cd
September 28	No	9	d

Similar letters within the column are not significantly different at the 95% confidence level (Tukey Test).

Table 3. Chandler marketable yields x plant date x row cover usage at WyeREC

Plant date	Row cover?	Marketable yield (lbs. per plant)	Significance	Average Fruit size (oz)	Significance
September 8	Yes	0.84	ab	0.57	ab
September 8	No	0.82	b	0.56	ab
September 15	Yes	0.88	ab	0.57	ab
September 15	No	0.84	ab	0.54	b
September 22	Yes	0.90	ab	0.59	ab
September 22	No	0.89	ab	0.60	a
September 28	Yes	1.07	ab	0.56	ab
September 28	No	1.11	a	0.57	ab

Similar letters within the column are not significantly different at the 95% confidence level (Tukey Test).

SPRAY RECOMMENDATIONS FOR BOTRYTIS AND ANTHRACNOSE FRUIT ROT

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Gray mold (caused by *Botrytis* spp.) and anthracnose fruit rot (*Colletotrichum acutatum*) are very important diseases on strawberries, and the management of both diseases is largely rely on the use of chemicals. However, fungicide selection can be very perplexing due to the complication in FRAC codes, variation in efficacy, and the potential resistance issues in the fungal pathogens.

Three periods, “Prebloom”, “bloom”, and “fruit ripening”, are used to represent the different growth stages of strawberries (Figure 1). In principle, fungicide applications should always be made prior to significant rain events such as consecutive or heavy rains that could result in more than 1 inch of precipitation (Figure 1), if the field hasn’t been sprayed for at least 5 days. In mid-Atlantic region, anthracnose may not be of a concern during prebloom and bloom, thus, fungicide application during those periods may need to be focused on gray mold. Multi-sites fungicides Thiram or Captan are recommended before the use of row covers or straw for frost protection or for row covers used for growth enhancement. Rovral is only allowed once a season and can only be used before the first fruiting flower. It may therefore be important to spray Rovral before bloom for Botrytis crown rot. During bloom and fruit ripening, Thiram and Captan should be the backbone of the spray program, due to less risk of resistance issues. Single-site fungicides, including newer **Succinate Dehydrogenase Inhibitors** (SDHIs), Switch, Elevate and others are not recommended to be used alone if resistance is unknown, and only use them when disease pressure is high and / or during harvest for U-Pick farms. Captan has pretty good efficacy for anthracnose fruit rot control, which may be considered a primary fungicide during fruit ripening if anthracnose has been a concern historically (Figure 1).

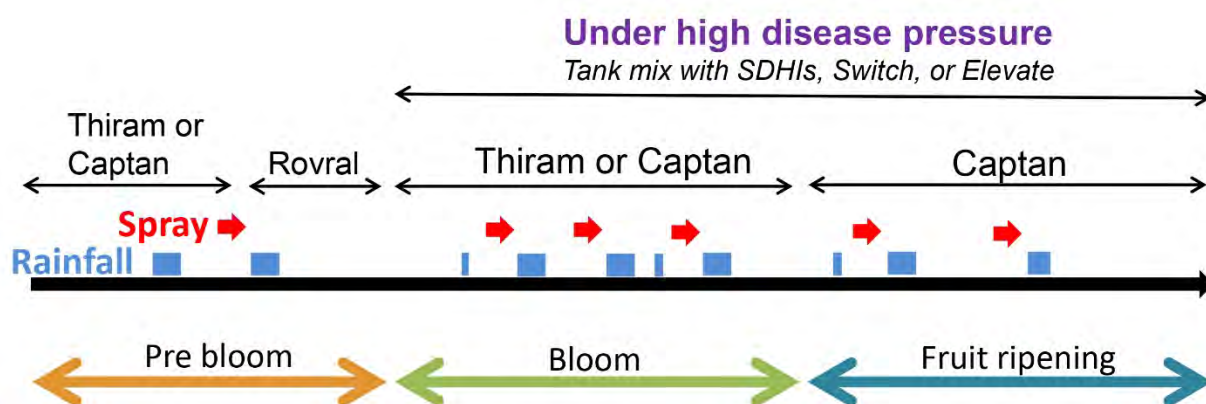


Figure 1. A schematic diagram of fungicide spray program for the management of gray mold and anthracnose on strawberries.

The Table below shows our current understanding of the efficacy (+++ = high efficacy) of fungicides for the Southeastern US (north of Florida). A large number of farms are experiencing problems with Botrytis strains that are resistant to one or more fungicide (Frank Louws, Guido Schnabel, and Chuck Johnson. “Fungicide Selection for Botrytis and Anthracnose Fruit Rot Management 2018”).

	FRAC	Botrytis	Botrytis Resistance	Anthracnose
Captan or Captec	M4	++	None	++
Captevate	M4+17	+++	Prevalent for ‘Elevate’	++
Thiram	M3	++	None	+
Fracture	M12	+	No Data	No Data
Topsin M	1	Not effective	Widespread	Not effective
Rovral	2	++	Prevalent	Not effective
Tilt and generics	3	Not Effective	Not applicable	+
Fontelis	7	+++	Prevalent	+
Kenja	7	+++	NOT Prevalent	Not effective
Scala	9	++	Prevalent	Not effective
Pristine	7+11	++	Prevalent	+++*
Merivon	7+11	+++	Prevalent	+++*
Luna Sensation	7+11	+++	NOT Prevalent	+++*
Cabrio	11	Not effective	Widespread	+++*
Abound or Azaka	11	Not effective	Widespread	+*
Switch	12+9	++	NOT Prevalent	++
Elevate	17	+++	Prevalent	Not effective
Ph-D, OSO	19	++	NOT Prevalent	No Data

*Resistance issues to FRAC 11 fungicides have been reported in FL, CA, VA, and NC in the last 3 yrs. Problems tend to be plant source related.

Use members of any FRAC code (except M3 or M4) no more than twice per season (For example, if you used Fontelis once and Merivon once you maxed out the 2 applications for FRAC 7 fungicides).

CONTINUATION OF STRAWBERRY ADVISORY SYSTEM (SAS) IMPLEMENTATION IN MARYLAND AND VIRGINIA.

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Bulger et al. (1987) and Wilson et al. (1990) developed models which predict the infection risks of Botrytis and anthracnose fruit rot on strawberries, based on the duration of leaf wetness and the average temperature during the wet period. Temperatures between 25 °C (77f) and 30 °C (86f), and 15 °C (59f) and 25°C (77f) were found to be most conducive for Botrytis and anthracnose development, respectively. Using this information, scientists at the University of Florida conducted multi-year field trials and launched the on-line Strawberry Advisory System (SAS; figure 1). Under this system, growers and researchers can virtualize the real-time infection risks for both diseases through AgroClimate (<http://agroclimate.org/tools/sas/>) or the smartphone app SAS. Free email and/or text-message service is also available for subscription to issue alerts for fungicide applications when environmental conditions are favorable for Botrytis and anthracnose infection (Pavan, 2011). SAS was designed to reduce fungicide applications by eliminating unnecessary sprays. Fungicide costs comprise approximately 7% of pre-harvest variable costs, which represents about \$690 per acre (IFAS 2010). According to three-season trials conducted in Florida, fungicide applications have been reduced, on average, by approximately 40%. To date, 27 SAS-specific iMeto weather stations have been installed in the strawberry fields on both the East- and West Coast, feeding the SAS with live data of leaf-wetness and temperature.

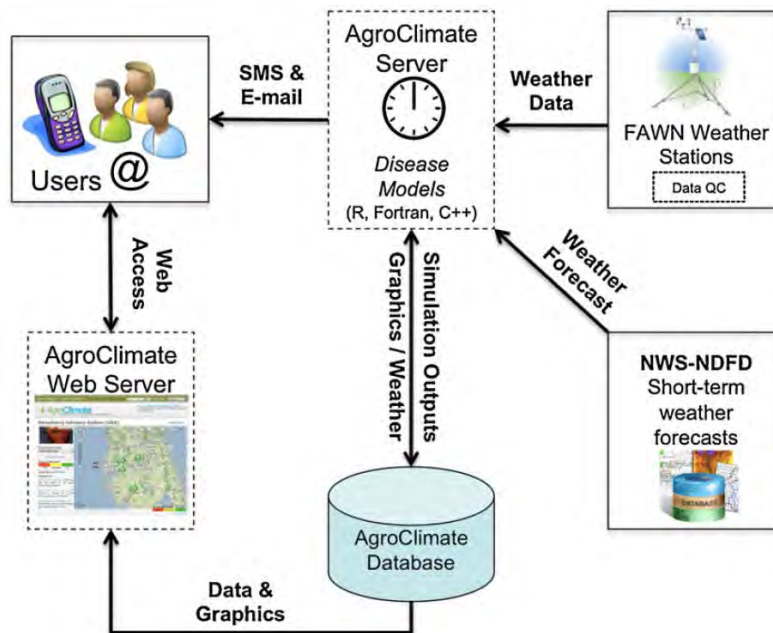


Fig. 1. The system infrastructure.

(Pavan et al. 2011)

Former UMD small fruit pathologist Dr. Cassandra Swett brought an NIFA-CARE grant to implement the SAS in the Mid-Atlantic region. Based on 2 year efficacy trials on plasticulture strawberries at Western MD Research and Education Center (WMREC), the SAS reduced fungicide applications by approximately 50% while yielding the equivalent amount of marketable berries compared to calendar-based sprays. However, the results were inconsistent with the one-year trial conducted in Virginia, where the SAS yielded less marketable berries at all the four partnering sites due to higher Botrytis or anthracnose incidence. Several hypotheses have been proposed for the negative results, including not accounting for the microclimate under row covers, fungicide resistance issues, and delayed SAS sprays due to inaccessible conditions (wet soil). This year, we continue conducting trials on plasticulture strawberries at the Western Maryland Research & Education Center (WMREC), WyeREC and in Virginia. In addition, we are also conducting SAS efficacy trials on matted-row system at two commercial farms in MD. With collecting more disease data from different systems (plasticulture and matted-row) and additional environmental variables under row covers, we hope we could further address the efficacy of the SAS in the Mid-Atlantic region.

IMPORTANCE OF BOTRYTIS RESISTANCE MANAGEMENT AND HOW TO TEST THE RESISTANCE.

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Botrytis cinerea, the causal agent of gray mold, has tremendous ability to develop fungicide resistance due to its short life cycle, highly diverse genotypes and large production of conidia. Single-site chemical classes of fungicides are known to be more effective and less toxic compared to old chemistry such as captan and thiram. However, single-site fungicides only attack a specific protein in fungal pathogens which could be easily overcome by mutation(s) in the gene (protein). The great ability combined with the weakness of single-site fungicides set a perfect stage for *B. cinerea* to develop fungicide resistance.

A variety of single-site fungicides have been developed for Botrytis control, including anilinopyrimidines (APs; cyprodinil and pyrimethanil), methyl benzimidazole carbamates (MBCs; thiophanate-methyl), dicarboximides (DCs; iprodione), hydroxylanilides (HAs; fenhexamid), quinone outside inhibitors (QoIs; pyraclostrobin), phenylpyrroles (PPs; fludioxonil), and succinate dehydrogenase inhibitors (SDHIs; boscalid, fluxapyroxad, fluopyram, penthiopyrad, and isofetamid). Based on our 5-year resistance monitoring, resistance has been found to all those chemical classes of single-site fungicides; moreover, a shift towards multiple chemical classes of resistance (CCR) was observed. In other words, more and more Botrytis isolates are found to be simultaneously resistant to multiple FRAC codes.

The Schnabel lab at Clemson University identifies potential fungicide resistance problems in commercial strawberry fields and provides location-specific disease and resistance management advice. Below are specific instructions on how to send your samples (adapted from <http://www.clemson.edu/extension/peach/commercial/diseases/index.html>).

1. Collection of Samples (Flowers/Leaves OR Fruit Swabs):

- Gray mold from **dead flowers (preferred)** in spring, leaves, and spores from fruit.
- Early in the season you may send dead flowers and leaves within a zip lock bag.
- Later in the season you may send cotton swabs with spores from fruit for analysis individually wrapped to avoid contamination (see instructions below).

Collection of gray mold from dead flowers or dead leaves (early season):

Obtain 20-40 dead strawberry flowers **OR** 150 healthy strawberry flowers from throughout the strawberry field you would like to have tested. Dead strawberry flowers are preferred (Fig. 1); it is much harder to get the fungus out of healthy flowers. Sometimes we can grow the fungus from dead leaves (Fig. 2). You may send as many dead leaves as you would like in addition to the flowers. These may be combined in one sandwich size zip lock bag.



Figure 1. Dead flowers next to a healthy flower (petals and sepals were removed). The dead flowers were asymptomatic upon collection, but revealed gray mold symptoms after 2 days in the laboratory.



Figure 2. Sometimes we can get the fungus from dead leaves. The dead leaves in this picture were asymptomatic upon collection but revealed gray mold after 2 days in the laboratory.

Collection of gray mold from fruit (late season):

- i. Obtain cotton swabs from a local pharmacy. Collect spores with swabs from 10 individual berries with **FRESH** gray mold lesions (Fig. 3). Make sure the 10 samples are spread out and represent the entire field. **Do not collect** from badly rotted fruit, old mummies, or discarded fruit on the ground!!!

- ii. Use a fresh cotton swab for **each** berry and carefully rub **one side** of the swab on the diseased portion of each berry **without touching the fruit itself**. The idea is to only use enough force to collect the fungal spores; there should be no strawberry juice on the cotton swab (Fig. 3). **The rubbed portion of the swab should look lightly gray**. A tiny bit of gray is sufficient for analysis. A minimum of 10 cotton swabs from 10 fruit should be submitted per location, put swabs individually in paper bags or envelopes and then all together in a zip lock bag.



Figure 3. Use cotton swabs to carefully collect spores from symptomatic fruit (upper left) without getting strawberry juice on the swab (lower left). The swab should look lightly gray, a tiny bit of gray color is sufficient for analysis. If the spores cannot readily be seen, mark the area with a sharpie (right).

2. Mailing your samples:

Attach your contact information (name and email address), and field location to the corresponding sample and send either by regular mail OR overnight to:

Dr. Guido Schnabel
 Clemson University
 105 Collings St./220 BRC
 Clemson, SC 29634
 Cell 864-643-7131

3. Waiting for your Results:

You will receive a notification email when your samples arrive to the laboratory. The results will be sent via email approximately 7 business days (flowers and leaves) and 4 business days (swabs) after the initial notification email.

**** The Maryland State Horticulture Society has provided grant money the past several years in support of this testing program. If you are a Maryland strawberry grower and would like to have your plants tested, please contact Mengjun Hu (mjhu@umd.edu) or Mike Newell (mnewell@umd.edu) about this program.

Managing climate risk to strawberries



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Climate Change's "New Normal"

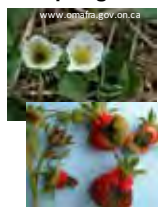
- More unpredictable and severe weather
- More extreme extremes
- More tidal flooding and storm surge

- Warmer winters, earlier springs, hotter summers
- More rainfall comes as downpours; flash flooding
- Rainier springs & falls (MD)

- Heat waves last longer
- Drier summers

Warmer winters and earlier springs

Plants may break dormancy early
Late spring cold snap → freezing, possible fruit loss



- irrigate to prevent freezing, can be tricky
- check for damage to crown— plant might recover
- use thick straw or row cover; be ready to remove/replace
- stagger planting dates to hedge bets
- diversify varieties to hedge bets

Heat stress in strawberries



scald



-varieties differ in damage from heat stress (86 day/77 night)
Ledesma et al 2008. doi:10.1016/j.scianta.2007.12.010

- black plastic mulch can increase heat stress
- healthier soil holds more water, reducing water stress
- diversify varieties to hedge bets
- try leafier varieties to reduce scald

More rain and heavier rainfalls



tieravegetableswaj.blogspot.com/

- Improve drainage
- Improve soil health for better infiltration (best plan)
- Stagger planting dates
- Diversify varieties for rain tolerance, disease resistance
- Watch out for food safety



Contact me anytime with questions or comments!

Dr. Sara Via
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Strawberry Clipper

Jerry Brust, IPM Vegetable Specialist

There have been a few reports of the strawberry clipper (or weevil) being more of a problem in some fields this spring than it usually is, so it may be a good time to go over some of the biology and management of this pest.

Strawberry clippers (*Anthonomus signatus*) are small (1/4 inch long), brown beetles with the characteristic weevil "snout" (fig.1). Known hosts include strawberry, blackberry, raspberry, dewberry, and red bud. The beetles leave their overwintering sites in fence rows and wooded areas in the spring as temperatures approach 60°F, usually around the end of April. They move into strawberry fields with early fruit bud development. They begin by feeding on pollen by puncturing the buds with their long snouts. Females deposit a single egg inside the nearly mature bud and then girdle the bud, so that it hangs by a thread or falls to the ground (fig. 2). In about one week, the egg hatches into a white, legless grub (fig. 1). The larva develops inside the bud and pupates in 3 or 4 weeks.

Adult weevils emerge from the buds sometime in June. After feeding on the pollen of various flowers for a short time, the new adults will seek hibernating sites by midsummer and remain inactive for the rest of the season. There is only one generation of strawberry clipper a year. Because beetles overwinter in wooded areas fields located near the woods or rows closest to the woods often experience the greatest clipper injury.

To determine if a pesticide treatment is necessary, walk the field and count the number of cut buds per linear foot of row. Detecting clipped buds is the only recommended form of sampling for strawberry clipper. Sample five separate 10-foot sections from throughout the field. Divide the total number of cut buds observed by the total number of linear row feet inspected. A conservative threshold is if more than one cut bud per linear row foot is found, a pesticide treatment may be justified. Treatment of field borders may be sufficient in some instances.

Research on the impact of clipper damage in **matted row** strawberries in New York found that all strawberry varieties tested compensated well for early season clipper damage, specifically damage to primary and secondary buds. Only damage in later season (tertiary) buds resulted in a significant yield loss because the plant was not able to mature additional fruit. In North Carolina (**annual production**) strawberry plants also compensated from clipper damage for fruit size and fruit timing to a significant degree. Therefore, it is unclear how important it is to prevent strawberry clipper damage. **Plant compensation may offset strawberry clipper damage.**

Mulches and full canopy beds can encourage newly emerged adults to remain in the planting, causing damage to occur in succeeding years. Cropping fields more than 3 years, plowing under old beds immediately after harvest, and removing the foliage and mulch to reduce the suitability of overwintering sites reduce the chances of clipper damage.

Little work on the impact of strawberry clipper weevils in annual plasticulture production systems has been conducted, further work is needed on key strawberry varieties along with strawberry clipper biology.



Fig. 1 Adult Strawberry clipper. Photo by Tom Murray

Larva of strawberry clipper. Photo by Hannah Burrack

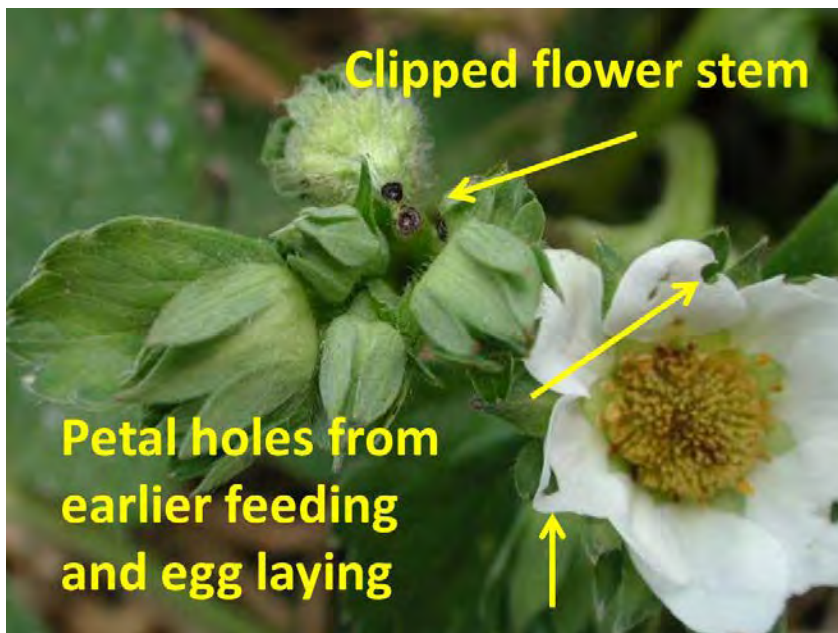


Fig. 2 Strawberry buds clipped by weevil adult. Ontario Strawberry IPM OMAFRA

Pollinator safety

Unfortunately, most insecticides recommended for strawberry clipper weevils are broad spectrum and should not be applied when bees are foraging (i.e., during the day). Necessary applications should be made in the evening, after bee foraging has stopped.

There are no organically acceptable insecticides effective against the strawberry clipper.

Effect of soil moisture regimes on plant growth, yield and fruit quality of strawberry

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Introduction

Since the 2014/15 growing season, we have been conducting research at the Wye Research and Education Center (WREC) aimed at studying the effect of varying soil moisture regimes on strawberry (*Fragaria X ananassa*) plant growth, yield and fruit quality. The experiments have been laid out in a randomized complete block design (RCBD) with four replications. Chandler, the strawberry cultivar that is widely grown in the mid-Atlantic region under plasticulture, is being used in this study.

Four soil moisture regimes - a control and three deficit irrigation levels - constitute the treatments in our study. The control and deficit irrigation treatments are chosen to apply progressively less water and are controlled at soil matric potential (SMP) thresholds of -30, -40, -50 and -60 kPa, respectively. Corresponding soil VWC levels for the matric potential thresholds were obtained by developing water retention curves for the soil at the study site using Hyprop (Decagon Devices, Inc., Pullman, WA). These VWC values were used to implement the control and deficit irrigation treatments.

A wireless sensor network has been established to independently control the 16 experimental units in the experiments. In each plot, two 10HS (soil moisture), MPS-6 (matric potential) and GS-3 (soil moisture, electrical conductivity and soil temperature) sensors (Decagon Devices, Inc., Pullman, WA) are installed in the root zone. Irrigation application for each plot is also measured by Badger flow meters. Data is recorded on a 15-min basis using nR5 control data loggers (Decagon Devices, Inc.,).

Microclimatic conditions at the study site are monitored by a weather station equipped with a PYR solar radiation sensor, QSO-S photosynthetically active radiation (PAR) sensor, VP-3 sensor (temperature, relative humidity and vapor pressure deficit), DS-2 sonic anemometer (wind speed and direction) and ECRN-100 rain gauge (Decagon Devices, Inc., Pullman, WA). The weather parameters are measured every minute and recorded on a 5-minute basis using Em50R data loggers.

The overall goal of this ongoing study is to identify deficit irrigation practices for use in the plasticulture production system to minimize environmental impact while maintaining productivity. The specific objectives are to implement increasing drought stress on strawberry plants to study the effect on:

- plant growth - leaf area, shoot and root fresh and dry masses
- yield and yield parameters - number of fruits per plant and average fruit weight
- fruit quality - pH, titrable acidity and total soluble solids

Irrigation Treatments

2014/15 Growing Season: All plots were irrigated at the same rate using a timed irrigation controller during establishment phase of the strawberry plants and throughout the fall. Irrigation treatments were imposed during the spring growing season when plants reached full flowering. To implement the treatments, whenever the average volumetric water content (VWC) of the two 10HS soil moisture sensors in each plot dropped below the corresponding VWC set-point, irrigation was applied for 4 minutes. This was repeated until the average VWC was above the set-point; thus, the soil VWC for

each treatment was continuously maintained above the minimum threshold. Figure 1 shows a comparison of the irrigation frequency and soil VWC levels for the control and three DI treatments. Irrigation events were triggered with the highest frequency for the control treatment and decreased with increasing deficit irrigation levels. Irrigations were also interrupted after rain events that significantly raised soil VWC levels due to capillary rise of water from rain accumulating between the rows.

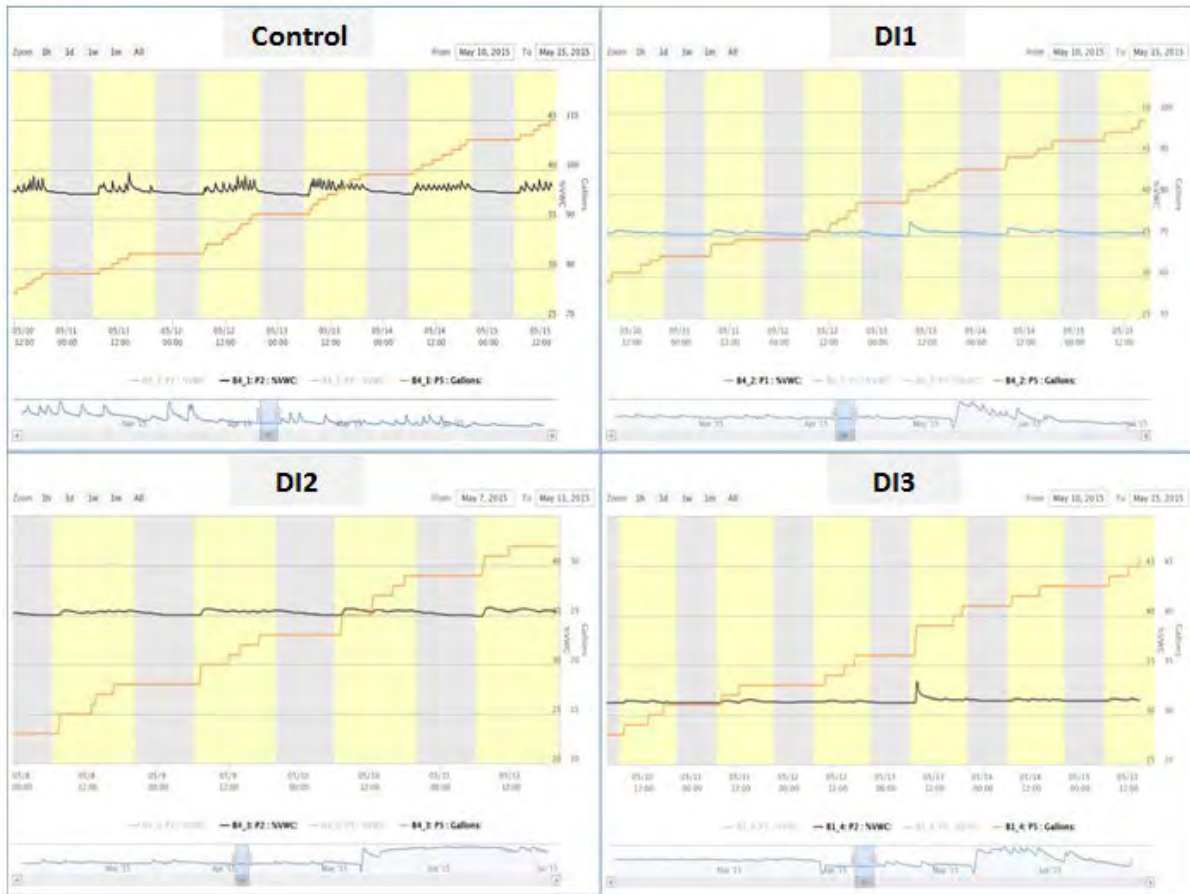


Figure 1. Soil volumetric water content variation for the control irrigation compared to the three deficit irrigation treatments

2015/16 Growing Season: Plants were carried-over from the previous year following standard protocols established for renovating plots. The experiment carried out was a repeat of the previous year with the same soil matric potential and corresponding VWC levels. To validate actual soil matric water potential levels implemented in the control and deficit irrigation treatments, T8 field tensiometers were installed in two plots per treatment. The soil matric potential measurements obtained using the T8 field tensiometers showed that the control and deficit irrigation treatments imposed through VWC thresholds maintained the SMP levels above the required thresholds. Frequent rain events during May 2016 however prevented the maintenance of threshold SMP values for a longer period of time (Figure 2).

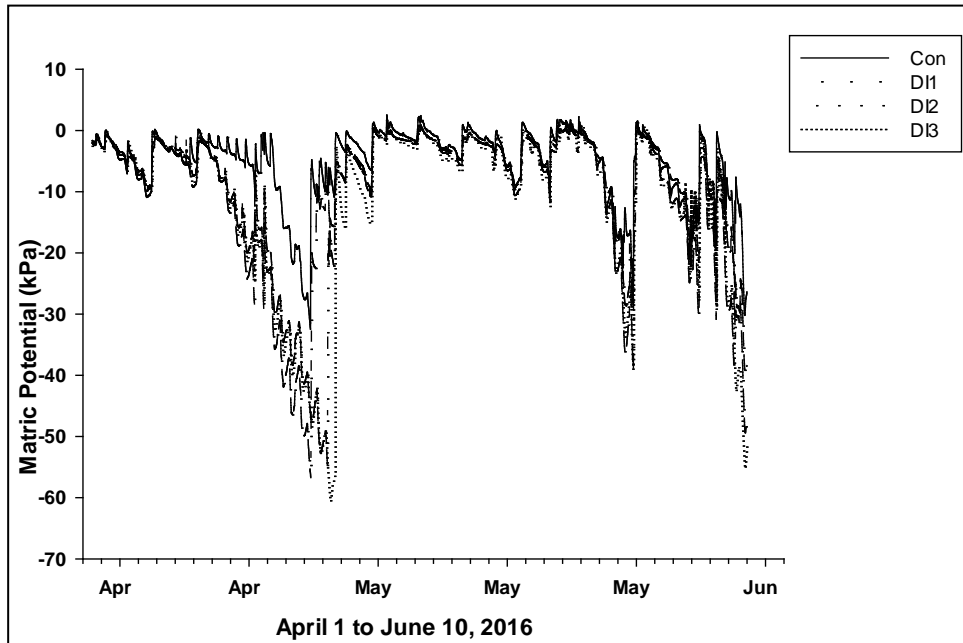


Figure 2. T8 tensiometer soil matric potential values for the control and deficit irrigation treatments during the treatment period

2016/17 Growing Season: The experimental design remained the same and the irrigation treatments were maintained at the same soil matric potential thresholds, i.e., Cont. = -30 kPa, D11 = -40 kPa, D12 = -50 kPa, and D13 = -60 kPa. However, treatments were implemented based on real-time measurements of soil matric potential using MPS-6 sensors instead of the VWC measurement of the 10HS sensors. The MPS-6 sensors were installed at a depth of 30 cm (12 inch) and with proper installation gave comparable soil matric potential data to the more accurate T8-field tensiometer. The variation in soil matric potential during treatment period recorded using the MPS-6 sensors (4 per treatment) for the control and three deficit irrigation treatments is shown in Figure 3.

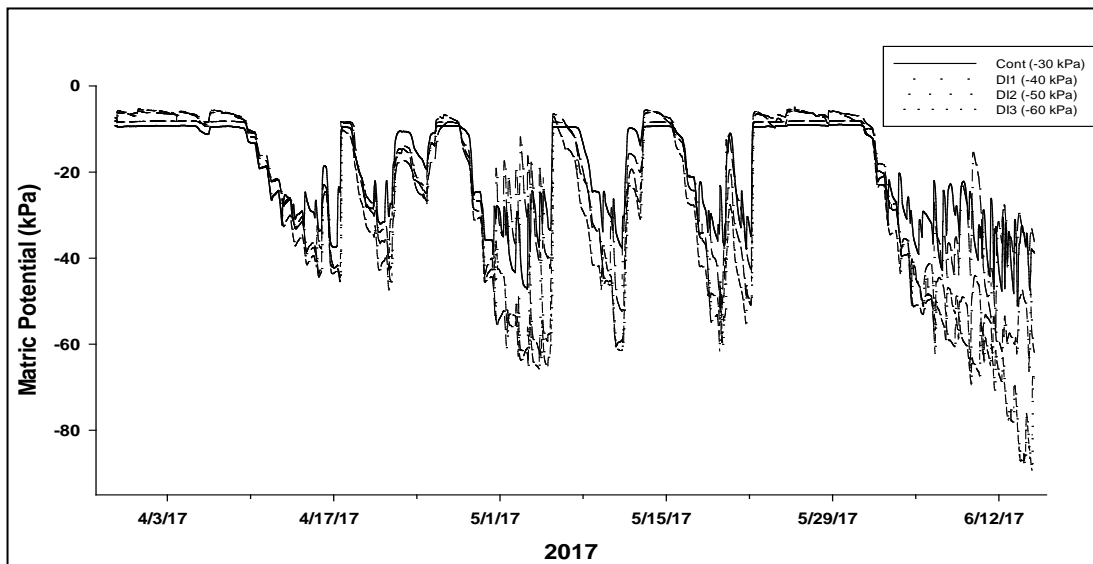


Figure 3. Soil matric potential dynamics during treatment period (average of four MPS-6 sensors per treatment)

Yield

In all three seasons, ripe fruits were harvested every 3 to 5 days from six plants in each plot. Fruits were categorized into 3 groups based on their mass and weighed separately. The number of fruits in each category was recorded. Irrigation WUE for the control and deficit irrigation treatments was calculated as the ratio of total yield to irrigation water applied from transplanting to harvest.

2014/15 Growing Season: Significant differences were observed for yield, number of fruits per plant and amount of irrigation water applied between the control and the deficit irrigation treatments, whereas average fruit weight and irrigation WUE were not significantly different (Table 1). The control treatment produced significantly higher yield than DI2 and DI3. DI1 had significantly higher yield than DI3 whereas the difference between DI2 and DI3 was not significant. The number of fruits per plant was significantly higher for the control and DI1 treatment compared to DI3. The amount of irrigation water applied for the control treatment was significantly higher than all deficit irrigation treatments, and that of DI1 and DI2 than DI3. There was no significant difference in irrigation WUE, however, as the reduced water applications resulted in proportional yield losses.

Table 1. Fruit yield (g/plant), number of fruits per plant, average fruit weight (g), irrigation application per plant (L) and irrigation water use efficiency (WUE) (g/L) during 2014/15. All values indicated are mean \pm SEM. Significant differences ($P < 0.05$) are separated by Tukey's test.

Treatment	Fruit Yield (g/plant)	Number of Fruits per Plant	Average Fruit Weight (g)	Irrigation Application (L/Plant)	Irrigation WUE (g/L)
Cont.	600.5 \pm 13.9 ^a	56.2 \pm 1.5 ^a	10.7 \pm 0.2	19.4 \pm 0.4 ^a	31.2 \pm 1.1
DI1	537.3 \pm 16.6 ^{ab}	49.2 \pm 1.5 ^a	11.0 \pm 0.2	16.9 \pm 0.2 ^b	31.8 \pm 0.9
DI2	463.8 \pm 15.8 ^{bc}	45.0 \pm 1.6 ^{ab}	10.9 \pm 0.4	16.1 \pm 0.3 ^b	28.9 \pm 0.8
DI3	410.4 \pm 17.7 ^c	34.8 \pm 1.1 ^b	11.2 \pm 0.2	14.0 \pm 0.1 ^c	29.3 \pm 1.4

2016/17 Growing Season: The control treatment resulted in the highest yield (6.9%, 7.9%, and 11.3% than DI1, DI2 and DI3, respectively) and number of fruits per plant. However, these differences were not significant. Individual fruit weights were similar for the control and deficit irrigation treatments. There were significant differences in irrigation application and irrigation water use efficiency. Irrigation application was significantly higher and irrigation water use efficiency significantly lower for the control treatment compared to the three deficit irrigation treatments; whereas differences between the three deficit irrigation treatments were not significant for both parameters (Table 2).

Table 2. Fruit yield (g/plant), number of fruits per plant, average fruit weight (g), irrigation application per plant (L) and irrigation water use efficiency (WUE) (g/L) during 2016/17. All values indicated are mean \pm SEM. Significant differences ($P < 0.05$) are separated by Tukey's test.

Treatment	Fruit Yield (g/plant)	Number of Fruits per Plant	Average Fruit Weight (g)	Irrigation Application (L/Plant)	Irrigation WUE (g/L)*
Cont.	644.5 \pm 3.6	52 \pm 1.4	12.5 \pm 0.3	18.4 \pm 1.4 ^a	37.3 \pm 2.8 ^b
DI1	600.1 \pm 12.5	48 \pm 0.7	12.6 \pm 0.1	9.9 \pm 0.8 ^b	63.3 \pm 3.2 ^a
DI2	593.7 \pm 15.7	48 \pm 1.0	12.4 \pm 0.1	8.7 \pm 0.2 ^b	69.9 \pm 2.7 ^a
DI3	571.9 \pm 15.5	46 \pm 0.8	12.4 \pm 0.3	9.3 \pm 0.1 ^b	61.7 \pm 2.0 ^a

* Irrigation application and WUE are based on measurements over the treatment application period only.

Fruit Size Distribution

The fruit size distribution for the harvests made during the study period indicated that a high percentage (91.3% in 2015 and 87.4% in 2017) of the fruits harvested weighed less than 20 g (Figure 4). Fruits weighing between 10 and 20 g made up 41.0% (2015) and 47.7% (2017) of the total fruits on average, whereas fruits weighing between 0 and 10 g constituted 50.3% (2015) and 39.7% (2017).

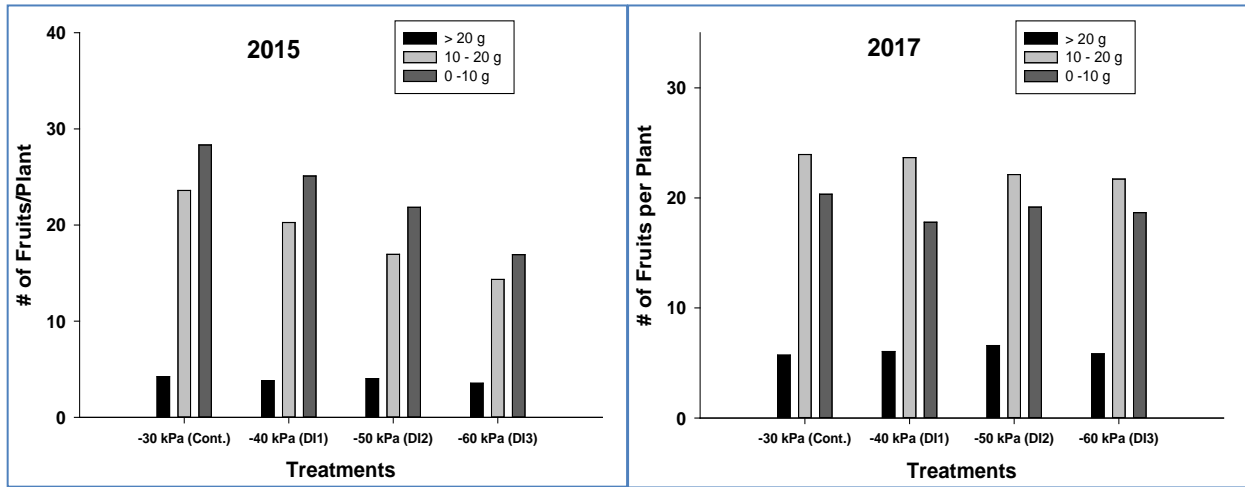


Figure 4. Fruit size distribution for the 2015 and 2017 harvests

Plant Growth

At the end of the 2015/16 and 2016/17 growing seasons, sampled plants were uprooted with their root balls and destructively harvested to measure plant growth parameters. The number of branch crowns per plant was counted. Leaves were separated from stems and the leaf area was measured using Li-3000C leaf area meter (LI-COR, Lincoln, NE). Fresh mass for leaves and stems was recorded to the nearest 0.1 g. Roots were carefully separated from the soil in the root ball by washing and the fresh root mass was recorded to the nearest 0.1g. All biomass was dried to a constant weight at 70°C and the dry masses were recorded.

During the 2015/16 season, significant differences were observed only for root dry mass, with the control treatment resulting in a significantly higher root dry mass as compared to the DI3 treatment. Difference in the number of branch crowns, leaf area, shoot dry mass, total dry mass and root to shoot ratio were not significant (Table 3).

Table 3. Plant growth parameters - # of branch crowns, leaf area, root and shoot dry mass and root to shoot ratio - as affected by soil moisture regimes. Irrigation treatments were controlled at the following matric potential levels: -30 kPa (Cont.), -40 kPa (DI1), -50 kPa (DI2) and -60 kPa (DI3). All values indicated are mean \pm SEM. Significant differences ($P < 0.05$) are separated by Tukey's test.

Treatment	# Branch Crowns	Leaf Area (m ²)	Root Dry Mass (g/plant)	Shoot Dry Mass (g/plant)	Root to Shoot Ratio
Cont.	6.8 \pm 0.4	0.22 \pm 0.01	8.8 \pm 0.4 ^a	40.9 \pm 1.5	0.21 \pm 0.01
DI1	5.7 \pm 0.3	0.20 \pm 0.01	6.7 \pm 0.2 ^{ab}	36.9 \pm 2.6	0.19 \pm 0.01
DI2	5.8 \pm 0.1	0.19 \pm 0.00	6.6 \pm 0.6 ^{ab}	36.3 \pm 0.5	0.18 \pm 0.01
DI3	5.2 \pm 0.1	0.19 \pm 0.01	5.3 \pm 0.4 ^b	36.9 \pm 1.3	0.15 \pm 0.01

During the 2016/17 season, differences in all measured growth parameters between the control and three deficit irrigation treatments were not statistically significant (Table 4).

Table 4. Plant growth parameters - # of branch crowns, leaf area, root and shoot dry mass and root to shoot ratio - as affected by soil moisture regimes. Irrigation treatments were controlled at the following matric potential levels: -30 kPa (Cont.), -40 kPa (DI1), -50 kPa (DI2) and -60 kPa (DI3). All values indicated are mean \pm SEM. Significant differences ($P < 0.05$) are separated by Tukey's test.

Treatment	# Branch Crowns	Leaf Area (m ²)	Root Dry Mass (g/plant)	Shoot Dry Mass (g/plant)	Root to Shoot Ratio
Cont.	8.0 \pm 0.2	0.66 \pm 0.02	7.9 \pm 0.1	95.5 \pm 4.1	0.08 \pm 0.0
DI1	8.0 \pm 0.1	0.62 \pm 0.0	7.5 \pm 0.5	91.9 \pm 1.1	0.08 \pm 0.0
DI2	7.7 \pm 0.2	0.60 \pm 0.01	7.9 \pm 0.3	94.6 \pm 2.7	0.08 \pm 0.0
DI3	7.9 \pm 0.1	0.57 \pm 0.02	8.6 \pm 0.3	92.8 \pm 1.1	0.09 \pm 0.0

Fruit Quality Parameters

Fruit quality parameters - pH, titrable acidity, total soluble solids (degree Brix) - were analyzed for fruits from all growing season. First, refrigerated fruit samples (~500 g) were allowed to thaw and reach room temperature (20°C). Then, juice was extracted by pressing fruits and filtering through a coffee filter. pH was measured using a hand held pH meter (Hanna Instruments). Total soluble solids/degree Brix was measured using a digital benchtop refractometer. For titrable acidity determination, 10 g juice was transferred to a 250 ml beaker. 50 ml deionized water was added to the juice and the resulting solution was titrated using 0.1 N NaOH solution to an end point pH of 8.2. Titrable acidity results are expressed as % of citric acid. The results obtained (Table 5) showed that there were no significant difference for all fruit quality parameters measured for all seasons.

Table 5. Strawberry fruit quality parameters: titrable acidity (TA), total soluble solids content/degree Brix (TSS) and sugar to acid ratio during 2014/15 and 2015/16. All values indicated are mean \pm SEM. Significant differences ($P < 0.05$) are separated by Tukey's test.

Treatment	2015				2017			
	pH	TA (%)	TSS (%)	Sugar to Acid ratio	pH	TA (%)	TSS (%)	Sugar to Acid ratio
Cont.	3.4 \pm 0.01	0.9 \pm 0.01	7.4 \pm 0.09	8.0 \pm 0.03	3.5 \pm 0.01	1.1 \pm 0.01	7.5 \pm 0.12	6.9 \pm 0.14
DI1	3.3 \pm 0.01	0.9 \pm 0.01	7.5 \pm 0.12	7.8 \pm 0.12	3.5 \pm 0.01	1.1 \pm 0.01	7.8 \pm 0.06	6.9 \pm 0.09
DI2	3.4 \pm 0.01	1.0 \pm 0.01	7.8 \pm 0.04	8.3 \pm 0.05	3.5 \pm 0.01	1.1 \pm 0.01	7.6 \pm 0.09	6.8 \pm 0.08
DI3	3.3 \pm 0.01	0.9 \pm 0.01	7.7 \pm 0.05	8.2 \pm 0.09	3.5 \pm 0.01	1.1 \pm 0.01	7.7 \pm 0.18	6.9 \pm 0.14

Acknowledgements

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