MANAGEMENT OF ONION CULTURAL PRACTICES TO CONTROL THE EXPRESSION OF IRIS YELLOW SPOT VIRUS

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Introduction

Onion plants infected with iris yellow spot virus (IYSV) can progressively lose leaf area, resulting in reduced yield and reduced bulb size. The virus is transmitted by onion thrips (*Thrips tabaci*). The incidence of IYSV can be increased by inadequate control of onion thrips. Thrips control has become more difficult through increased thrips resistance to insecticides. A certain degree of varietal tolerance to thrips and IYSV has been determined (Shock et al. 2007, 2008a and b).

Management factors such as irrigation and fertilization that reduce plant stress might reduce the intensity of thrips and IYSV infestations. Onion stress that results in greater expression of negative IYSV effects could be caused by high temperature or by excessively dry soil. This trial tested the response of three onion varieties to water stress level, irrigation system, and nitrogen fertilizer rate.

Materials and Methods

The onions were grown on a Greenleaf silt loam previously planted to wheat. In the fall of 2009 prior to planting, the wheat stubble was shredded and the field was irrigated and disked. A soil sample taken in the fall of 2009 showed: pH 7.8, organic matter 1.6 percent, 29 ppm phosphorus (P), 379 ppm potassium (K), 19 ppm sulfate (SO_4), 2,442 ppm calcium (Ca), 556 ppm magnesium (Mg), 60 ppm sodium (Na), 2.6 ppm zinc (Zn), 1.4 ppm copper (Cu), 6 ppm manganese (Mn), 10 ppm iron (Fe), and 0.9 ppm boron (B). Based on sufficiency ranges for plant nutrients, soil analysis indicated the need for 100 lb phosphate (P_2O_5)/acre, 24 lb sulfur (S)/acre, 2 lb Mn/acre, 4 lb Zn/acre, and 1 lb B/acre. These nutrients were broadcast in the fall of 2009 after disking. The field was then moldboard-plowed, groundhogged, roller-harrowed, and bedded at 22 inches. The field was not fumigated due to a shortage of product.

Onion seed of three varieties (‘Vaquero’ and ‘Joaquin’, Nunhems, Parma ID; ‘Charismatic’, Seminis Seed Co., Saint Louis, MO) was planted on March 17, 2010 at 9 seeds/ft of row. Two rows spaced 3 inches apart were planted on each 22-inch bed. The seed was planted with a customized planter using John Deere Flexi Planter units equipped with disc openers. Drip tape with emitters spaced 12 inches apart and emitter flow rate of 0.22 gal/min/100 ft (T-tape, T-systems International, San Diego, CA) was laid at 4-inch depth between 2 onion beds at the same time as planting. The distance between the tape and the center of each bed was 11 inches. The water application rate was 0.06 inch per hour.

The onion beds received a narrow band of Lorsban 15G® at 3.7 oz/1,000 ft of bed (0.82 lb ai/acre, preventive control of onion maggot) and the soil surface was rolled immediately after planting. After planting the field was drip-irrigated long enough to have the wetting front reach just beyond the onion row farthest from the drip tape. Onion emergence started on April 15. On May 19, alleys 7 ft wide were cut between plots, leaving plots 23 ft long. On May 20 and May 21, the seedlings were hand thinned to a plant population of 2 plants/ft of single row. The 6-inch spacing between individual onion plants in each single row was equivalent to 95,000 plants/acre.

The experimental design was a randomized complete block design with split-split plots and four replicates. The main plots were the irrigation treatments (Table 1). Each irrigation plot was split into two nitrogen (N) rates (100 or 200 lb N/acre). Each N-rate split plot was split into the three varieties. Each variety in each split-split plot consisted of 4 double onion rows (88 inches wide) and 23 ft long.

Table 1. Irrigation main plot treatment specifications, Malheur Experiment Station, Oregon State University, Ontario, OR, 2010.

Treatment	Irrigation system	Irrigation criterion[a]	Irrigation intensity
		cb	inches per irrigation
1	Drip	10	0.12
2	Drip	15	0.24
3	Drip	20	0.48
4	Drip	30	0.48
5	Drip	15/25[b]	0.24/0.48[c]
6	Sprinkler	20	0.48
7	Drip/optional sprinkler	20	0.48
8	Furrow	25	3.9[d]
9	Furrow/optional sprinkler	25	3.9

[a]soil water tension at 8-inch depth measured in centibars (cb). 0 cb corresponds to saturated soil.
[b]15 cb until July 31, then 25 cb thereafter.
[c]0.24 inch/irrigation until July 31, then 0.48 inch/irrigation thereafter.
[d]total water applied based on limited furrow inflow measurements.

The sprinkler- and furrow-irrigated plots (treatments 6, 8, and 9) had the unneeded drip tape removed in early May. The sprinkler-irrigated onions (treatments 6,7, and 9) had three sprinklers at the top and another three sprinklers at the bottom of each plot. The risers were 3 ft tall and spaced 22 ft apart. The first riser was located at the plot corner. Each riser had a guard preventing the nozzle from applying water to the adjacent plots. The sprinklers were R10 turbos (Nelson Irrigation, Walla Walla, WA) with 0.75-gal/min flow-control nozzles. The sprinkler water application rate was designed to apply 0.16 inch/hour at a pressure of 35 psi.

Each furrow-irrigated plot (treatments 8 and 9) had a gated pipe at the upperend and a tail ditch at the lower end. At each irrigation, the onions were irrigated for 6 to 12 hours. The last furrow irrigation occurred on August 26.

Onions in each drip- and sprinkler-irrigated plot (treatments 1-7) were irrigated automatically and independently according to the irrigation criterion and intensity predetermined for each treatment (Table 1). The irrigation duration for each treatment was adjusted so that when irrigated the maximum number of times, all irrigation systems had the capacity to deliver up to a maximum of 0.48 inch of water per day. The furrow-irrigated onions were irrigated manually when the soil water tension (SWT) at 8-inch depth reached 25 cb. The drip- and furrow-irrigated onions with optional sprinkler irrigation (treatments 7 and 9) received sprinkler irrigation of 0.48 inch of water once a week during the hottest part of the growing season starting on June 26 and ending on August 26.

Soil water tension was measured in each main plot with four granular matrix sensors (GMS, Watermark Soil Moisture Sensors Model 200SS, Irrometer Co., Riverside, CA) installed at 8-inch depth in the center of the double row. Sensors had been calibrated to SWT (Shock et al. 1998a). The GMS were connected to the datalogger via four multiplexers (AM 410 multiplexer, Campbell Scientific, Logan, UT). The datalogger read the sensors and recorded the SWT every hour.

The datalogger made irrigation decisions for each drip- and sprinkler-irrigated main plot every 6 hours. The individual irrigation decisions for each plot were based on the average SWT. The irrigations were controlled by the datalogger using a controller (SDM CD16AC controller, Campbell Scientific, Logan, UT) connected to solenoid valves in each plot. The water for the drip and sprinkler plots was supplied by a well that maintained a continuous and constant water pressure of 35 psi. The pressure in the drip lines was maintained at 10 psi by pressure regulators in each plot. The amount of water applied to each plot was recorded daily at 8:00 a.m. from a water meter installed between the solenoid valve and the drip tape. The automated irrigation system was started on May 20 and ended on September 7.

The amount of water applied and the amount of water infiltrated in the furrow-irrigated plots was estimated from measurements of furrow inflow and outflow. The difference between inflow and outflow is the amount of water infiltrated. The inflow and outflow measurements were taken every 2 hours on 4 furrows in each of 2 plots during 3 irrigations. Inflow was determined by measuring the volume of water coming out of the gate in 10 seconds. To measure outflow, trapezoidal flumes were installed at the furrow ends. Outflow was determined by measuring the level of the water in the flume. Flume water level measurements were converted to flow rate using an equation developed by measurements of flume water height and outflow.

Onion evapotranspiration (ET_c) was calculated with a modified Penman equation (Wright 1982) using data collected 300 yards away by an AgriMet weather station. Onion ET_c was estimated and recorded from crop emergence on April 15 until the onions were lifted on September 13.

Starting on June 3, the high-N split plots in each irrigation main plot received 40 lb N/acre and the low-N split plots received 20 lb N/acre weekly until the last application on July 1. The N fertilizer for the drip plots was injected through the drip tape as uran. The N fertilizer for the sprinkler plots was applied as urea broadcast on the surface of the onion beds. The N fertilizer for the furrow plots was applied as urea to the top half of each furrow. The total amount of N applied during the growing season was 200 lb N/acre for the high-N treatment and 100 lb N/acre for the low-N treatment. A composite sample of the soil from the first- and second-ft depths was taken from each replicate on April 27. The soil was analyzed for nitrate and ammonium and for potentially mineralizable N.

Soil temperature was measured with four temperature probes installed at 2-inch depth in the bed center in each irrigation plot in replicates one and two. Soil temperature was recorded hourly using a datalogger (CR10, Campbell Scientific).

The onions were managed to minimize yield reductions from weeds, pests, diseases, and other nutrient deficiencies. Weeds were controlled with an application of Roundup® at 1 lb ai/acre on April 8 prior to onion emergence. On April 19, Prowl H_2O® at 0.95 lb ai/acre was applied for weed control. On May 14, Goal® at 0.16 lb ai/acre, Buctril® at 0.19 lb ai/acre, and Volunteer® at 0.25 lb ai/acre were applied for weed control. On June 25, July 8, and July 16, the field was sprayed with Aza-Direct® at 0.0062 lb ai/acre and Success® at 0.25 lb ai/acre at 30 psi and 20 gal/acre with a backpack sprayer for thrips control.

Thrips populations were measured every 10 days in each split-split plot starting in early June and ending in early August. Thrips populations were measured by counting the total number of thrips on each of 10 plants per split-split plot.

Onions in each plot were evaluated subjectively for severity of symptoms of IYSV on August 9 and August 24. Twenty consecutive plants in one of the two middle rows in each plot were rated. Each plant was given a rating on a scale of 0 to 5 of increasing severity of symptoms, where the rating was 0 if there were no symptoms, 1 if 1 to 25 percent of foliage was diseased, 2 if 26 to 50 percent of foliage was diseased, 3 if 51 to 75 percent of foliage was diseased, 4 if 76 to 99 percent of foliage was diseased, and 5 if 100 percent of foliage was diseased. Onions in each plot were evaluated subjectively for severity of symptoms of powdery mildew (*Leveillula taurica*) on September 2 using the same rating scale as for IYSV.

Presence of IYSV in leaf tissue was determined by the double antibody sandwich-enzyme-linked immunosorbent assay (DAS-ELISA, Agdia, Inc., Elkhart, IN). Three leaf tissue samples for ELISA were collected from each split-split plot on August 25. Each sample consisted of two fully developed leaves from one plant.

Onion plant maturity was evaluated subjectively in each plot by visually rating the percentage of onions with the tops down and the percent dryness of the foliage. The percent maturity was calculated as the average percentage of onions with tops down and the percent dryness. All plots were evaluated for maturity on August 27. The number of bolted onion plants in each plot was counted.

Bulbs were rated for single centers on September 6, 7, and 8. In each split-split plot, 25 onions ranging in diameter from 3.5 to 4.25 inches from a border row were rated. The onions were cut equatorially through the bulb middle and, if multiple centered, the long axis of the inside diameter of the first single ring was measured. These multiple-centered onions were ranked according to the inner diameter of the first single ring: "small" had diameters less than 1.5 inches, "medium" had diameters of 1.5-2.25 inches, and "large" had diameters greater than 2.25 inches. Onions were considered "functionally single centered" for processing if they were single centered or had a small multiple center.

The onions were lifted on September 13 to cure in the field. Onions from the middle two rows in each plot were topped by hand and bagged on September 17. The bags were put in storage on September 24. The storage shed was ventilated and the temperature was slowly decreased to maintain air temperature as close to 34°F as possible. Onions were graded out of storage on December 15 and 16, 2010.

During grading, bulbs were separated according to quality: bulbs without blemishes (No. 1s), split bulbs (No. 2s), neck rot (bulbs infected with the fungus *Botrytis allii* in the neck or side), plate rot (bulbs infected with the fungus *Fusarium oxysporum*), and black mold (bulbs infected with the fungus *Aspergillus niger*). The No. 1 bulbs were graded according to diameter: small (<2.25 inches), medium (2.25-3 inches), jumbo (3-4 inches), colossal (4-4.25 inches), and supercolossal (>4.25 inches). Bulb counts per 50 lb of supercolossal onions were determined for each plot of every variety by weighing and counting all supercolossal bulbs during grading.

Treatment differences in yield, grade, maturity, single centeredness, thrips counts, and disease severity ratings were compared using three-way analysis of variance (ANOVA) where factor A was irrigation treatment, factor B was replicate, factor C was N rate, and factor D was variety. Treatment differences in water applied and water use efficiency were compared using one-way ANOVA, where factor A was irrigation treatment and factor B was replicate. Means separation was determined with Fisher's least significant difference test at the 5 percent probability level (LSD, 0.05). Within the group of drip-irrigated treatments (averaged over N rate and variety), regression analyses were run between the average season SWT, IYSV severity on August 24, and marketable yield.

Results and Discussion

There were no significant differences in average maximum daily soil temperature between irrigation treatments (Table 2).

The average season SWT increased with the increasing irrigation SWT criteria for the drip-irrigated treatments as planned (Table 3). The average SWT for the furrow-irrigated treatment was similar to that of the drip-irrigated treatment at 20 cb. As expected, the furrow-irrigated treatments had a greater oscillation in soil water than the wetter drip-irrigated treatments, getting wetter during irrigations and drier between irrigations (Figs. 1a and 1b).

The furrow-irrigated treatment with optional sprinkler irrigation had the highest total applied water, followed by the furrow-irrigated treatment (Table 3). The drip treatment irrigated at 30 cb and the sprinkler-irrigated treatment had the lowest total water applied. The total ET_c for the season was 29.1 inches. All treatments, except drip irrigation at 30 cb, applied more water than ET_c. Drip irrigation at 30 cb and drip irrigation at 15 cb early/25 cb late were among the treatments with the highest water-use efficiency (cwt marketable yield per inch of water applied). The furrow-irrigated treatment and furrow + sprinkler-irrigated treatment had the lowest water-use efficiency.

The thrips population reached a maximum in mid-July and then decreased (Fig. 4). The thrips population exceeded the recommended threshold for effective control measures, based on 15 thrips/plant (Jensen 2005) from late June to the mid-July. There were no significant differences in thrips counts between treatments (Table 4).

Iris yellow spot virus symptom severity was low in 2010, averaging 1.1 (scale of 1-5) over all plots on August 24 (Table 4). Although there were significant differences in virus severity between irrigation treatments on August 9, the differences were too small for meaningful conclusions to be made. There were no significant differences in IYSV severity between treatments on August 24 (Table 4). No powdery mildew symptoms were observed in 2010. Vaquero had the highest IYSV severity. Averaged over varieties and irrigation treatments, fertilization at 200 lb N/acre resulted in higher IYSV severity than at 100 lb N/acre.

Averaged over varieties and N rates, drip irrigation at 10, 15, 15/25, and 20 cb, and drip at 20 cb with optional sprinkler irrigation were among the treatments with the highest marketable onion yield (Table 5). For the drip-irrigated treatments, average SWT was negatively related to marketable yield and yield of bulbs larger than 4 inches (Figs. 2-3). Drip irrigation at 10 and 15 cb were among the treatments with the highest colossal and supercolossal bulb yields. Drip irrigation at 30 cb, sprinkler irrigation, and furrow irrigation were among the treatments with the lowest marketable yield and lowest yield of supercolossal bulbs. Drip or furrow irrigation with optional sprinkler irrigation did not significantly increase onion yield. Increasing the SWT irrigation criterion from 15 to 25 cb after August 1 did not result in lower marketable yield than drip irrigation at 15 cb, but resulted in lower supercolossal bulb yield. Responses of the varieties to irrigation treatment were similar, with Charismatic having the highest and Vaquero the lowest total and colossal yield.

There were no significant interactions of N rate with irrigation or variety. Averaged over irrigation treatments and varieties, there was no significant difference in yield or grade between N rates. The analysis of the soil sample taken on April 27 showed that in the top 2 ft of soil there was 149 lb of available N. The N mineralization test showed that in the top 2 ft of soil, there was 163 lb of mineralizable N that could be available to the crop during the season. The N requirements for a 900-cwt/acre onion crop are estimated to be 342 lb N/acre (Sullivan et al. 2001). Nonfertilizer sources of N in this trial could have fulfilled most of the N requirements of the crop.

Averaged over varieties and N rates, drip irrigation at 10 cb and sprinkler irrigation were among the treatments with the highest percentage of single-centered bulbs (Table 6). Drip irrigation at 30 cb and furrow irrigation were among the treatments with the lowest percentage of single-centered bulbs. Averaged over irrigation treatments and varieties, fertilization at 200 lb N/acre resulted in a higher percentage of large multiple-centered bulbs than 100 lb N/acre. Averaged over irrigation systems and N rates, the varieties differed significantly in percentages of single-centered bulbs. Joaquin had 80.7 percent single-centered bulbs, Vaquero had 62 percent single-centered bulbs, and Charismatic had 40.9 percent single-centered bulbs.

Conclusions

Over the 4 years of this trial (2007-2010), there were either no differences in thrips counts and IYSV severity between irrigation treatments or the differences were too small and not consistent for meaningful conclusions to be made.

The results of this trial show that the higher soil moisture achieved with drip irrigation at 10, 15 and 20 cb resulted in higher onion yield and grade. Soil water tensions of 15 to 20 cb for drip irrigation and 25 cb for furrow irrigation are recommended for onions on silt loam soil in the Treasure Valley (Shock et al. 1998b, 2000). Previous research at the Malheur Experiment Station has also shown that drip irrigations at a SWT wetter than 20 cb or furrow irrigations at a SWT wetter than 25 cb can result in high yield and grade, but in years with rainfall, very wet conditions also result in higher losses to storage decomposition (Shock et al. 1998b, 2000).

For the drip-irrigated treatments, as the soil was maintained slightly drier, the marketable yield decreased. Drip irrigation at 30 cb resulted in lower marketable yield than drip irrigation at 15 cb. These results are important considering the intensive irrigation management used in this trial. The datalogger checked the SWT and irrigated the plots if necessary every 6 hours for all treatments. This resulted in the SWT of the drip treatments not getting much higher than the criterion between irrigations (Figs. 1a and 1b). In commercial production the irrigation frequency could be less, resulting in the SWT often getting much higher than the criterion. These results reinforce the importance of careful irrigation management to avoid yield and grade losses.

The lack of difference in onion yield and grade between N rates in this trial is in agreement with previous results of onion yields often showing little response to N fertilizer in furrow or drip irrigations (Miller et al. 1993; Shock et al. 2001, 2004). As shown in this trial and in previous research, high amounts of N can be provided to an onion crop by natural sources, e.g., residual available N, N mineralization, and N in irrigation water (Shock et al. 2001, 2004, 2007, 2008a and b, 2009). The only reason that the 200 lb N/acre was used in this trial was the possibility that higher N might help IYSV-infected plants to sustain growth, leaf area, and productivity, an advantage that did not occur.

The furrow-irrigation management in this trial might not be realistic on a commercial scale. The plots in this trial were only 23 ft long, allowing extremely uniform furrow irrigation that is difficult to achieve on a commercial scale without risk of over-irrigation, N leaching, and bulb decomposition in a considerable part of the field. In commercial fields, well-managed drip irrigation will probably result in smaller losses of N from the onion root zone than furrow irrigation.

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Table 2. Average daily maximum soil temperature at 2-inch depth from July 11 to September 5 for onions submitted to nine irrigation treatments, Malheur Experiment Station, Oregon State University, Ontario, OR, 2010.

Irrigation system	Irrigation criterion	Soil temperature
	cb	°F
Drip	10	66.7
Drip	15	65.7
Drip	20	67.8
Drip	30	68.2
Drip	15/25	67.0
Sprinkler	20	68.0
Drip/spr.	20	68.1
Furrow	20-25	65.1
Furrow/spr.	20-25	67.3
LSD (0.05)		NS

Table 3. Average hourly soil water tension, total water applied, marketable yield, and water use efficiency (cwt marketable yield per inch of water applied) for onions submitted to nine irrigation treatments, Malheur Experiment Station, Oregon State University, Ontario, OR, 2010.

Irrigation system	Irrigatio n criterion	Average hourly soil water tension	Standar d deviation	Total water applied[a]	Marketabl e yield	Water use efficiency
	cb	cb		inches	cwt/acre	cwt/inch

Drip	10	10.5	3.2	43.5	793.8	18.3
Drip	15	13.3	3.6	37.6	770.5	20.6
Drip	20	15.7	4.8	38.3	750.0	19.9
Drip	30	21.6	7.6	28.1	689.0	24.9
Drip	15/25	15.4	5.2	33.4	758.2	22.7
Sprinkler	20	15.3	4.8	31.3	688.6	22.0
Drip/spr.	20	15.8	5.0	43.4	780.5	18.0
Furrow	25	14.4	8.2	71.1	701.2	9.9
Furrow/spr.	25	11.5	7.2	80.9	746.8	9.2
LSD (0.05)		1.9	1.0	4.5	68.1	2.5

[a]Total water applied from emergence to the last irrigation includes precipitation (4.5 inches) and 3.2 inches of drip irrigation applied to all plots from emergence to the start of the irrigation treatments on May 21. For the furrow-irrigated plots, the total water applied was estimated from limited furrow inflow measurements. Based on inflow and outflow measurements, the total amount of water infiltrated was estimated to be 23.5 inches for the furrow-irrigated treatment and 33.3 inches for the furrow-irrigated with optional sprinkler-irrigation treatment.

Table 4. Iris yellow spot virus (IYSV) leaf damage severity ratings, and onion maturity in response to irrigation system and variety, Malheur Experiment Station, Oregon State University, Ontario, OR, 2010 (continued on next page).

Irrigation	Irrigation criterion	Thrips count Average	IYSV[a] Aug. 9	IYSV[a] Aug. 24	Maturity Aug. 27 Tops down	Maturity Aug. 27 Dryness	Bolting
	cb	No./plant	------ 0-5 ------		---------------- %	----------------	
Vaquero							
Drip	10	17.4	1.006	1.056	40.0	28.8	0.00
Drip	15	17.4	1.038	1.125	43.8	37.5	0.00
Drip	20	19.2	1.013	1.063	47.5	40.0	0.00
Drip	30	18.0	0.994	1.025	70.0	41.3	0.00
Drip	15/25	18.8	1.019	1.106	53.8	37.5	0.13
Sprinkler	20	16.7	1.025	1.044	31.3	42.5	0.75
Drip/spr.	20	18.6	1.019	1.075	42.5	36.3	0.00
Furrow	20-25	17.9	0.988	1.063	38.8	32.5	0.00
Furrow/spr.	20-25	15.9	0.994	1.113	30.0	28.8	0.38
	average	17.8	1.011	1.074	44.2	36.1	0.14
Joaquin							
Drip	10	18.2	1.006	1.063	17.5	17.5	0.00
Drip	15	16.1	0.994	1.050	18.8	18.8	0.25
Drip	20	17.9	0.975	1.131	23.8	23.8	0.00
Drip	30	17.3	0.994	1.013	31.3	30.0	0.25
Drip	15/25	16.4	1.006	1.069	23.8	22.5	0.63
Sprinkler	20	17.6	1.006	1.081	15.0	23.8	0.63
Drip/spr.	20	15.6	1.006	1.056	22.5	23.8	0.13
Furrow	20-25	18.1	0.963	1.088	16.3	16.3	0.13
Furrow/spr.	20-25	18.3	0.988	1.106	15.0	15.0	1.38
	average	17.3	0.993	1.073	20.4	21.3	0.38
Charismatic							
Drip	10	18.5	1.000	1.125	31.3	16.3	0.00
Drip	15	17.1	0.994	1.063	35.0	21.3	0.00
Drip	20	16.9	1.000	1.075	42.5	25.0	0.13
Drip	30	19.4	1.006	1.088	53.8	32.5	0.00
Drip	15/25	17.0	0.988	1.075	41.3	23.8	0.00
Sprinkler	20	17.1	1.006	1.075	27.5	21.3	0.63
Drip/spr.	20	17.6	1.019	1.075	28.8	23.8	0.00
Furrow	20-25	17.5	0.969	1.088	26.3	16.3	0.13
Furrow/spr.	20-25	18.9	0.981	1.088	21.3	15.0	0.25
	average	17.8	0.996	1.084	34.2	21.7	0.13

[a] Disease severity rating: 0 = no symptoms, 1 = 1-25% of foliage diseased, 2 = 26-50% of foliage diseased, 3 = 51-75% of foliage diseased, 4 = 76-99% of foliage diseased, and 5 = 100% of foliage diseased.

Table 4. Continued

Irrigation	Irrigation criterion	Thrips count Average	IYSV[a] Aug. 9	IYSV[a] Aug. 24	Maturity Aug. 27 Tops down	Maturity Aug. 27 Dryness	Bolting
	cb	No./plant	------- 0-5 -------		------------------ % -----------------		
Average							
Drip	10	18.0	1.004	1.081	29.6	20.8	0.00
Drip	15	16.9	1.008	1.079	32.5	25.8	0.08
Drip	20	18.0	0.996	1.090	37.9	29.6	0.04
Drip	30	18.3	0.998	1.042	51.7	34.6	0.08
Drip	15/25	17.4	1.004	1.083	39.6	27.9	0.25
Sprinkler	20	17.1	1.013	1.067	24.6	29.2	0.67
Drip/spr.	20	17.3	1.015	1.069	31.3	27.9	0.04
Furrow	20-25	17.8	0.973	1.079	27.1	21.7	0.08
Furrow/spr.	20-25	17.7	0.988	1.102	22.1	19.6	0.67
	average	17.6	1.000	1.077	32.9	26.3	0.21
N rate							
lb N/acre							
100		17.6	0.995	1.072	30.7	24.6	0.21
200		17.6	1.005	1.081	35.1	28.1	0.21
LSD (0.05)							
Irrigation		NS	0.002	NS	6.3	5.9	0.04
N rate		NS	0.010	NS	NS	NS	NS
Variety		NS	0.009	NS	2.2	1.7	NS
Irrig. X N rate		NS	NS	NS	NS	NS	NS
Irrig. X Var.		NS	NS	NS	6.4	NS	NS
N rate X Var.		NS	NS	NS	NS	NS	NS
Irrig. X N rate X Var.		NS	NS	NS	NS	NS	NS

[a] Disease severity rating: 0 = no symptoms, 1 = 1-25% of foliage diseased, 2 = 26-50% of foliage diseased, 3 = 51-75% of foliage diseased, 4 = 76-99% of foliage diseased, and 5 = 100% of foliage diseased.

Table 5. Onion yield and grade in response to irrigation system, N rate, and variety, Malheur Experiment Station, Oregon State University, Ontario, OR, 2010 (continued on next page).

Irrigation system	Irrigation criterion	Total	Marketable yield by grade Total	>4 in	>4¼ in	4-4¼ in	3-4 in	2¼-3 in	No. 2	Small	Rot	Bulb counts >4¼ in
	cb	cwt/acre									%	#/50 lb
Vaquero												
Drip	10	847.3	754.5	237.1	19.2	217.9	505.3	12.1	0.0	6.2	9.9	15.0
Drip	15	813.3	750.4	188.6	13.8	174.7	547.1	14.8	0.9	3.5	7.3	14.5
Drip	20	812.5	743.2	191.7	9.6	182.1	530.4	21.1	0.6	4.2	7.7	15.7
Drip	30	699.4	671.7	83.5	2.3	81.2	556.3	31.9	0.0	6.4	3.0	14.4
Drip	15/25	811.1	754.3	193.9	7.3	186.5	540.1	20.4	0.8	6.0	6.1	14.0
Sprinkler	20	730.9	663.4	96.1	1.0	95.1	545.0	22.3	0.0	4.2	8.8	16.2
Drip/spr.	20	818.3	776.3	194.8	11.5	183.3	565.4	16.1	0.0	5.4	4.4	14.3
Furrow	20-25	752.5	709.5	121.5	3.2	118.3	564.6	23.4	0.0	4.2	5.0	16.4
Furrow/spr.	20-25	789.0	733.1	168.1	10.9	157.2	504.1	60.9	0.0	5.7	6.5	17.7
	average	786.0	728.5	163.9	8.8	155.2	539.8	24.8	0.3	5.1	6.5	15.4
Joaquin												
Drip	10	868.2	827.9	316.6	35.9	280.7	498.7	12.6	0.0	4.1	4.2	17.1
Drip	15	858.8	784.4	251.3	22.3	229.0	521.0	12.1	0.0	5.0	8.1	15.7
Drip	20	806.4	754.1	214.7	19.7	195.0	519.8	19.6	0.0	6.4	5.8	16.9
Drip	30	722.3	698.2	130.1	11.6	118.5	538.3	29.8	0.0	7.7	2.3	19.0
Drip	15/25	804.2	739.7	209.4	11.2	198.2	512.1	18.2	0.5	3.1	7.5	14.6
Sprinkler	20	718.7	663.3	93.5	1.7	91.7	542.5	27.3	0.0	3.4	7.2	20.3
Drip/spr.	20	804.5	749.9	224.5	22.9	201.5	513.9	11.5	1.5	4.7	6.0	16.9
Furrow	20-25	755.9	707.7	131.8	16.5	115.3	558.1	17.8	0.0	5.5	5.6	18.7
Furrow/spr.	20-25	789.9	734.0	170.6	9.6	161.0	548.7	14.7	0.0	4.3	6.3	19.8
	average	792.1	739.9	193.6	16.8	176.8	528.1	18.2	0.2	4.9	5.9	17.7

Table 5. Continued.

Irrigation system	Irrigation criterion	Total	Marketable yield by grade Total	>4 in	>4¼ in	4-4¼ in	3-4 in	2¼-3 in	No. 2	Small	Rot	>4¼ in
	cb	----------	----------	----------	----------	cwt/acre	----------	----------	----------	----------	%	#/50 lb
Charismatic												
Drip	10	905.9	799.1	340.2	36.8	303.4	450.1	8.9	0.0	4.5	11.3	16.0
Drip	15	856.9	776.6	311.0	32.9	278.1	440.6	25.0	0.0	4.4	8.8	15.9
Drip	20	829.8	752.6	218.5	8.5	210.0	518.0	16.1	0.8	7.4	8.5	15.1
Drip	30	746.9	697.1	153.6	7.0	146.6	521.1	22.5	0.0	6.2	5.3	14.4
Drip	15/25	846.2	780.7	235.8	13.0	222.7	531.9	13.0	0.0	5.0	7.0	14.5
Sprinkler	20	816.4	739.1	218.2	9.0	209.2	503.0	17.9	0.9	2.6	9.0	18.9
Drip/spr.	20	870.9	815.4	348.0	20.2	327.7	451.3	16.1	0.0	4.4	5.9	15.3
Furrow	20-25	788.7	686.3	187.7	6.2	181.5	486.4	12.2	0.0	5.2	12.3	16.5
Furrow/spr.	20-25	828.2	773.4	235.1	13.9	221.1	523.5	14.8	0.0	3.3	6.3	15.2
	average	832.2	757.8	249.8	16.4	233.4	491.8	16.3	0.2	4.8	8.3	15.7
Average												
Drip	10	873.8	793.8	298.0	30.6	267.3	484.7	11.2	0.0	4.9	8.5	16.2
Drip	15	843.0	770.5	250.3	23.0	227.3	502.9	17.3	0.3	4.3	8.1	15.4
Drip	20	816.3	750.0	208.3	12.6	195.7	522.7	18.9	0.5	6.0	7.3	16.1
Drip	30	722.8	689.0	122.4	7.0	115.4	538.6	28.1	0.0	6.8	3.5	17.0
Drip	15/25	820.5	758.2	213.0	10.5	202.5	528.0	17.2	0.4	4.7	6.9	14.4
Sprinkler	20	755.3	688.6	135.9	3.9	132.0	530.2	22.5	0.3	3.4	8.3	18.9
Drip/spr.	20	831.3	780.5	255.8	18.2	237.5	510.2	14.6	0.5	4.8	5.4	15.6
Furrow	20-25	765.7	701.2	147.0	8.6	138.3	536.4	17.8	0.0	5.0	7.6	17.7
Furrow/spr.	20-25	802.4	746.8	191.3	11.5	179.8	525.4	30.1	0.0	4.5	6.4	17.7
	average	803.5	742.1	202.4	14.0	188.4	519.9	19.7	0.2	4.9	6.9	16.5
N rate												
lb N/acre												
100		803.5	743.0	202.1	13.5	188.6	523.7	17.1	0.2	4.6	6.8	15.9
200		803.4	741.2	202.7	14.5	188.3	516.1	22.4	0.3	5.3	7.0	16.7
LSD (0.05)												
Irrigation		64.8	68.1	77.2	9.0	70.8	27.6	NS	NS	NS	NS	NS
N rate		NS	NS	NS	NS	NS	NS	NS	NS	1.6	NS	NS
Variety		15.1	NS	18.9	NS	17.1	15.7	NS	NS	NS	NS	NS
Irrig. X N rate		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Irrig. X Var.		NS	NS	56.6	NS	51.3	47.1	NS	NS	NS	NS	NS
N rate X Var.		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Irrig. X N rate X Var.		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 6. Onion center classification for three onion varieties submitted to nine irrigation treatments and two N rates, Malheur Experiment Station, Oregon State University, Ontario, OR, 2010.

Irrigation system	Irrigation criterion	N rate	Multiple center large	Multiple center medium	Multiple center small	Single center functional[a]	Single center single
	cb	lb/acre	--------------------	%		--------------------	
			Average over varieties				
Drip	10	100	10.3	16.9	2.7	72.8	70.1
		200	10.3	12.0	6.0	77.7	71.7
Drip	15	100	14.3	22.3	4.7	63.3	58.7
		200	18.7	16.3	7.0	65.0	58.0
Drip	20	100	15.3	18.7	6.0	66.0	60.0
		200	15.7	23.0	3.3	61.3	58.0
Drip	30	100	14.7	24.7	6.0	60.7	54.7
		200	26.3	18.0	6.0	55.7	49.7
Drip	15/25	100	13.0	18.3	3.3	68.7	65.3
		200	19.9	20.9	3.3	59.2	55.8
Sprinkler	20	100	7.0	15.7	6.3	77.3	71.0
		200	12.0	12.0	7.0	76.0	69.0
Drip/spr.	20	100	16.0	20.3	4.0	63.7	59.7
		200	16.0	22.3	2.3	61.7	59.3
Furrow	25	100	18.7	17.7	9.0	63.7	54.7
		200	13.8	21.7	7.1	64.5	57.4
Furrow/spr.	25	100	14.7	21.7	4.3	63.7	59.3
		200	9.0	18.7	3.0	72.2	69.2
	Average	100	13.8	19.6	5.1	66.6	61.5
		200	15.8	18.3	5.0	65.9	60.9
			Average over N rates and varieties				
Drip	10		10.3	14.5	4.3	75.2	70.9
Drip	15		16.5	19.3	5.8	64.2	58.3
Drip	20		15.5	20.8	4.7	63.7	59.0
Drip	30		20.5	21.3	6.0	58.2	52.2
Drip	15/25		16.5	19.6	3.3	63.9	60.6
Sprinkler	20		9.5	13.8	6.7	76.7	70.0
Drip/spr.	20		16.0	21.3	3.2	62.7	59.5
Furrow	25		16.3	19.7	8.0	64.1	56.0
Furrow/spr.	25		11.9	20.2	3.7	68.0	64.3
			Average over irrigation and N rates				
	Vaquero		12.2	20.2	5.7	67.7	62.0
	Joaquin		4.7	10.7	3.8	84.6	80.7
	Charismatic		27.4	26.0	5.7	46.6	40.9
LSD (0.05)							
Irrigation			6.2	NS	NS	NS	8.2
N rate			2.0	NS	NS	NS	NS
Variety			3.0	3.5	NS	NS	5.4
Irrig. X N rate			6.2	NS	NS	NS	NS
Irrig. X Var.			9.1	NS	NS	NS	NS

[a]single center + small multiple center.

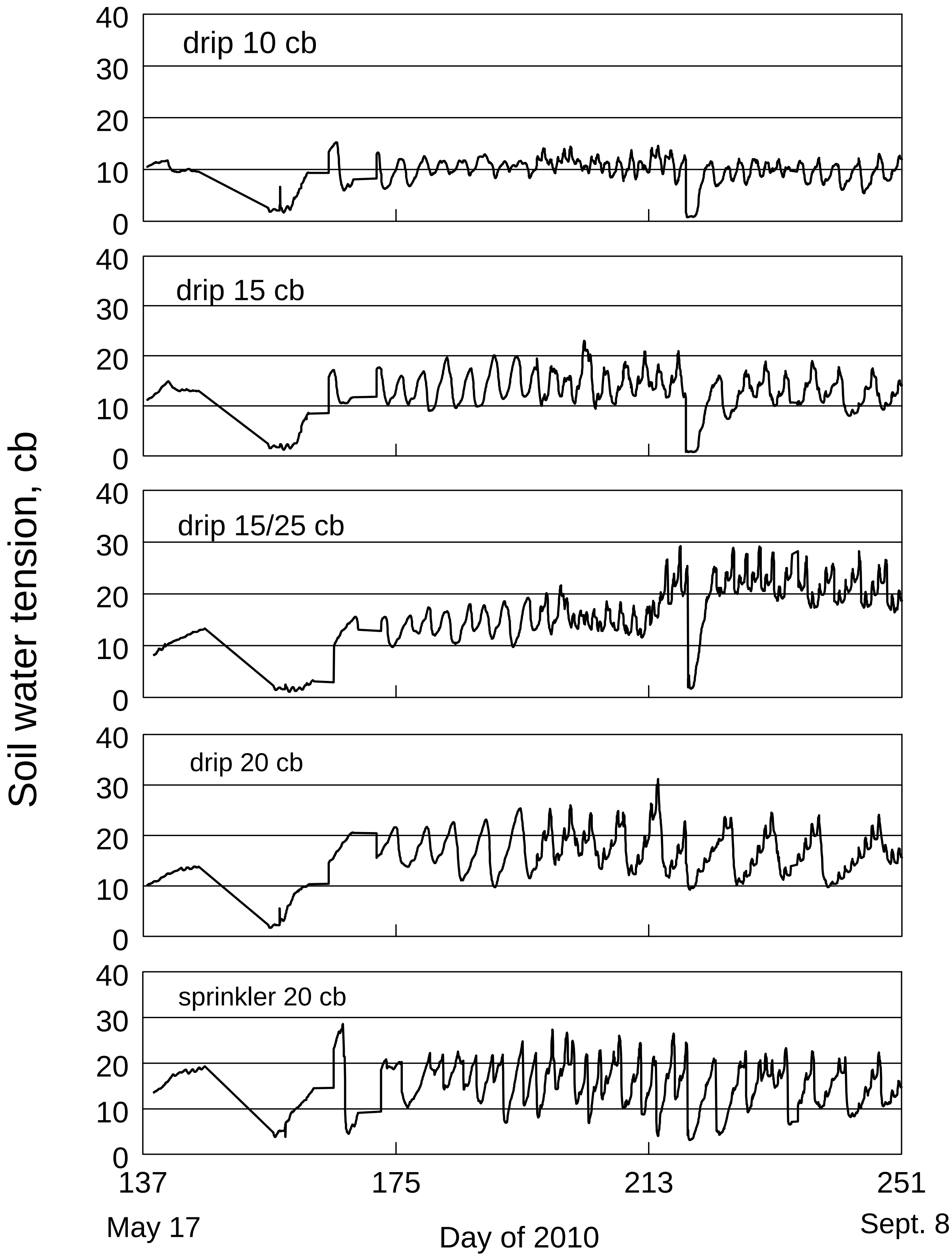

Figure 1a. Soil water tension at 8-inch depth over time for onions submitted to nine irrigation treatments, Malheur Experiment Station, Oregon State University, Ontario, OR, 2010.

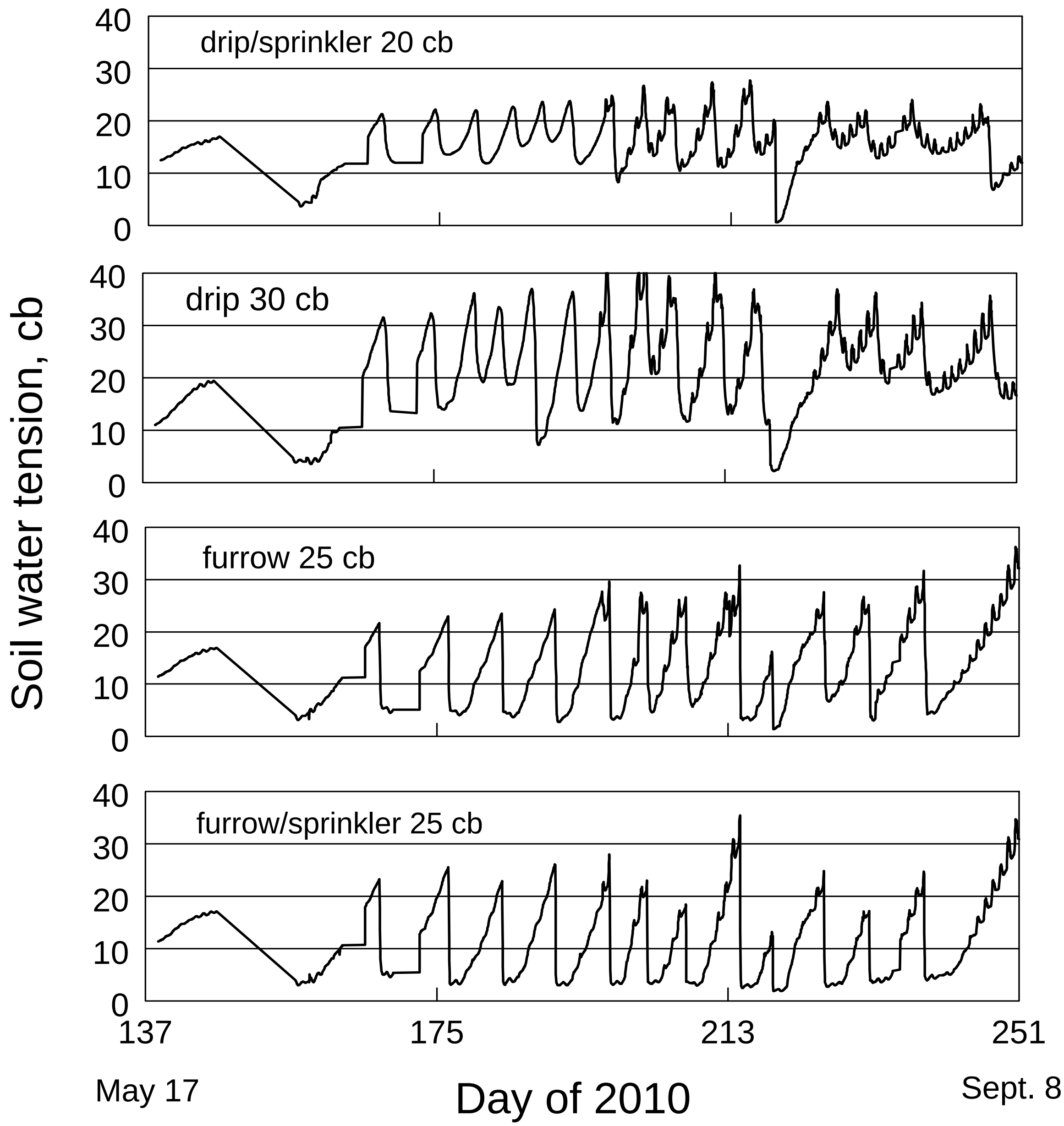

Figure 1b. Soil water tension at 8-inch depth over time for onions submitted to nine irrigation treatments, Malheur Experiment Station, Oregon State University, Ontario, OR, 2010.

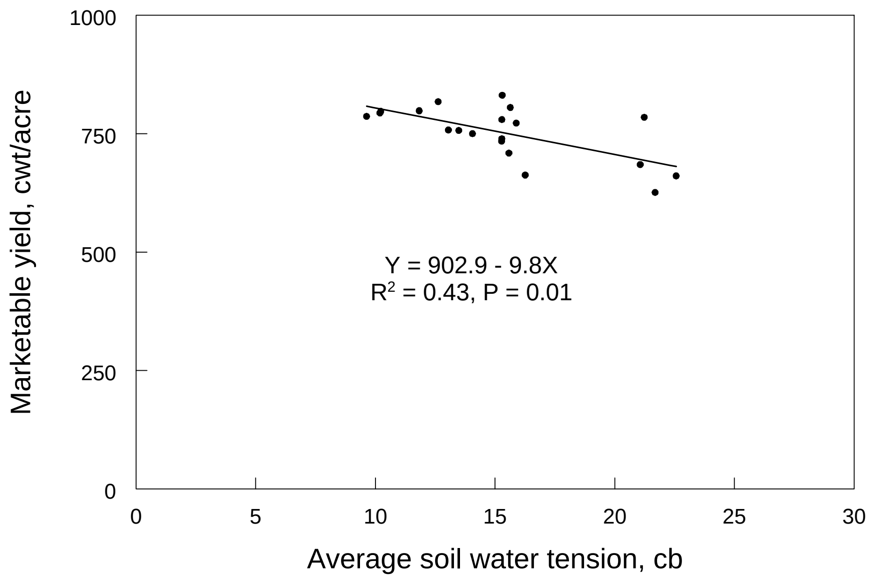

Figure 2. For drip-irrigated onion treatments (averaged over N rate and variety) the average soil water tension was negatively related to marketable yield. Malheur Experiment Station, Oregon State University, Ontario, OR, 2010.

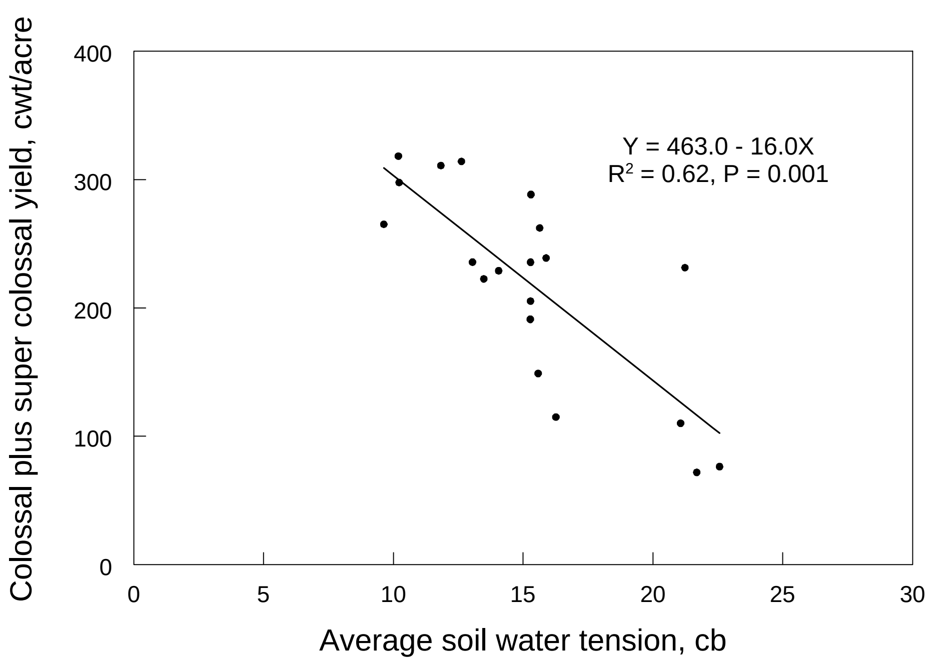

Figure 3. For drip-irrigated onion treatments (averaged over N rate and variety) the average soil water tension was negatively related to yield of bulbs larger than 4 inches (colossal plus supercolossal yield). Malheur Experiment Station, Oregon State University, Ontario, OR, 2010.

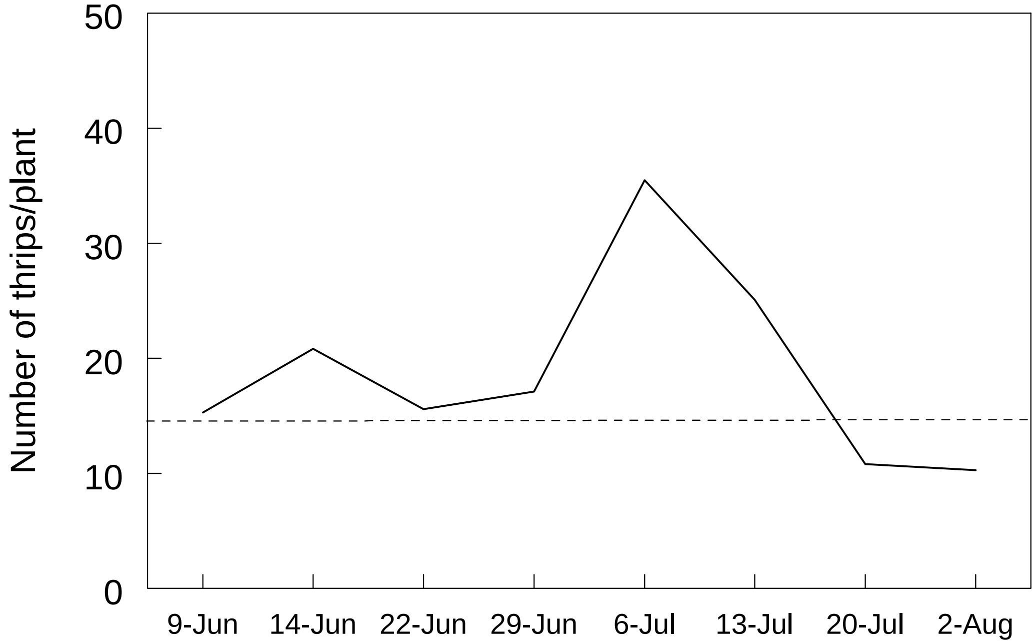

Figure 4. Thrips population counts per onion plant over time. Counts presented here were the average over irrigation treatments, N rates, and varieties (216 plots). On each date thrips on 10 onion plants/plot were counted. The recommended threshold for control is 15 thrips per plant. Malheur Experiment Station, Oregon State University, Ontario, OR, 2010.