MANAGEMENT OF ONION CULTURAL PRACTICES TO CONTROL THE EXPRESSION OF IRIS YELLOW SPOT VIRUS, 2009

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Introduction

Onion plants infected with iris yellow spot virus (IYSV) can progressively lose leaf area, resulting in reduced yield and bulb size. The virus is transmitted by onion thrips (*Thrips tabaci*), so 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, 2008). However, management factors that could be used to reduce plant stress, such as irrigation and fertilization, 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 four 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 2008 prior to planting, the wheat stubble was shredded and the field was irrigated and disked. Soil analysis indicated the need for 100 lb phosphate (P_2O_5)/acre, 20 lb potassium (K_2O)/acre, 100 lb sulfur (S)/acre, 7 lb maganese (Mn)/acre, and 5 lb zinc (Zn)/acre, which were broadcast in the fall of 2008 after disking. The field was then moldboard-plowed, groundhogged, roller-harrowed, fumigated with Telone® C-17 at 20 gal/acre, and bedded at 22 inches.

Onion seed of four varieties (‘Evolution’, D. Palmer Seed Co., Yuma AZ; ‘Vaquero’ and ‘Joaquin’, Nunhems, Parma ID; ‘Charismatic’, Seminis Seed Co., Saint Louis, MO) was planted on March 19 in double rows spaced 3 inches apart at 9 seeds/ft of single row. Each double row was planted on a 22-inch bed 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 double row was 11 inches.

On April 9, the onion beds received a narrow band of Lorsban® 15G at 3.7 oz per 1,000 ft of bed (0.82 lb ai/acre) and the soil surface was rolled. Onion emergence started on April 13. On May 20, alleys 7 ft wide were cut between plots, leaving plots 23 ft long. On May 21 and May 22, 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 again by dividing into the four 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, 2009.

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.
[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 four sprinklers at the top and another four sprinklers at the bottom of each plot. The risers were 3 ft tall and spaced 14.7 ft apart. The first riser was located at the plot corner. Each riser had a guard that prevented 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 upper 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 September 2.

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 29 and ending on August 21.

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 June 4 and ended on September 5.

The amount of water applied to 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 13 until the onions were lifted.

Starting on June 6, 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 2. 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-foot depths was taken from each replicate on June 2. 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 the first two replicates. 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 7 prior to onion emergence. On April 27, Prowl H_2O ® at 0.95 lb ai/acre and Select® at 0.125 lb ai/acre were applied for weed control. On May 11, 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. Starting on June 1 and ending August 7, the onions were treated every 10 days 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-split plot starting June 9 and ending July 20. 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 3, August 17, and September 3. 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-split plot on August 19. 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 18 and September 1. The number of bolted onion plants in each plot was counted.

Bulbs in each plot were rated for single centers on September 15, 16, and 17. In each split-split-split plot, 25 onions ranging in diameter from 3.5 to 4.25 inches 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 14 to cure in the field. Onions from the middle two rows in each plot were topped by hand and bagged on September 21. The bags were put in storage on September 24. The storage shed was ventilated to maintain air temperature as close to 34°F as possible. Onions were graded out of storage on December 14, 15, and 16, 2009.

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), regressions were run between the average season SWT, IYSV severity on August 18, and marketable yield.

Results and Discussion

The sprinkler- and furrow-irrigated treatments were among those with the highest average maximum daily soil temperature, and the drip-irrigated treatments were among the treatments with the lowest average maximum daily soil temperature (Table 2).

The average season SWT increased with the increasing irrigation criteria for the drip-irrigated treatments (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 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-irrigated treatment at 30 cb and the sprinkler-irrigated treatment had the lowest total water applied. The total ET_c for the season was 34.0 inches. The two furrow-irrigated treatments, drip irrigation at 10, 15, and 20 cb, and drip irrigation at 20 cb with occasional sprinkler irrigation all applied more water than ET_c. Drip irrigation at 30 cb and sprinkler irrigation were among the treatments with the highest water-use efficiency. 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. 2). The thrips population was low for all plots in early June, but by late June exceeded the recommended threshold for effective control measures, based on 15 thrips/plant (Jensen 2005). There were no significant differences in thrips counts between treatments (Table 4).

There were no significant differences in IYSV severity between treatments (Table 4). Iris yellow spot virus symptom severity was low in 2009, averaging 1 (scale of 1-5) over all onions on September 3.

Powdery mildew (PM) symptoms were very few, and were observed only in late August. There were no significant differences between treatments in PM severity. The variety Evolution had the highest powdery mildew severity rating, followed by Joaquin. Charismatic and Vaquero had no powdery mildew (Table 4).

Averaged over varieties and N rates, drip irrigation at 15 and 20 cb, and furrow irrigation were among the treatments with the highest marketable onion yield (Table 5). Averaged over varieties and N rates, sprinkler irrigation resulted in lower marketable and supercolossal yield than drip irrigation at 10 and 15 cb. Drip irrigation at 10 cb resulted in significantly lower marketable yield than drip irrigation at 15 cb. 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 resulted in lower marketable yield than drip irrigation at 15 cb.

Averaged over irrigation systems and N rates, Charismatic had the highest and Joaquin had the lowest marketable yield, and Joaquin had the highest and Vaquero had the lowest supercolossal yield.

There was no significant interaction of N rate with irrigation and 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 June 2 showed that in the top 2 ft of soil there was 125 lb of available N. The N mineralization test showed that in the top 2 ft of soil, there was 239 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 a large part of the N requirements of the crop.

Averaged over varieties and N rates, drip irrigation at 10 cb was 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. Drip irrigation at 15 and 20 cb had significantly higher percentage of single-centered bulbs than furrow irrigation. Averaged over irrigation systems and N rates, the varieties differed significantly in percentages of single-centered bulbs; from highest to lowest were Joaquin, Evolution, Vaquero, and Charismatic.

Conclusions

The results of this trial show that the higher soil moisture achieved with drip irrigation at 15 and 20 cb and with furrow irrigation at 25 cb resulted in higher onion yield and grade. Soil water tensions of 15 to 20 cb for drip irrigation and of 25 cb for furrow irrigation are recommended for onion 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 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). In this trial, drip irrigation at 10 cb resulted in lower marketable yield than drip irrigation at 15 cb, which might have been related to the higher than normal precipitation in June (2.3 inches).

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 when considering the irrigation management. The datalogger checked the SWT and irrigated the plots if necessary every 6 hours. This resulted in the SWT of the drip treatments not exceeding the criterion (Figs. 1a and 1b). In commercial production the irrigation frequency could be less, resulting in the SWT often exceeding 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, that onion yields often show little response to N fertilizer (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). 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 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 from July 1 to September 5 at 2-inch depth for onions submitted to 9 irrigation treatments, Malheur Experiment Station, Oregon State University, Ontario, OR, 2009.

Irrigation system	Irrigation criterion	Soil temperature
	cb	°F
Drip	10	66.9
Drip	15	67.9
Drip	20	67.5
Drip	30	70.9
Drip	15/25	70.9
Sprinkler	20	84.6
Drip/spr.	20	68.8
Furrow	20-25	81.0
Furrow/spr.	20-25	74.1
LSD (0.05)		10.6

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, 2009.

Irrigation system	Irrigation criterion	Average hourly soil water tension	Standard deviation	Total water applied[a]	Marketable yield	Water use efficiency
	cb	cb		inches	cwt/acre	cwt/inch
Drip	10	9.6	2.7	37.5	959.1	25.8
Drip	15	13.1	3.7	34.8	1017.9	29.2
Drip	20	15.7	5.4	36.5	1003.1	27.6
Drip	30	21.0	6.7	30.8	954.7	31.3
Drip	15/25	15.5	5.3	33.1	950.1	28.8
Sprinkler	20	14.5	4.4	27.9	912.1	32.9
Drip/spr.	20	15.0	4.8	37.2	975.7	26.3
Furrow	25	16.3	6.8	58.3	1008.5	17.3
Furrow/spr.	25	14.3	6.5	71.0	1023.7	14.4
LSD (0.05)		1.1	0.9	3.7	56.7	3.3

[a]Total water applied from emergence to the last irrigation: includes precipitation (5.3 inches) and 6 inches of drip irrigation applied to all plots from emergence to the start of the irrigation treatments on June 4. 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 about 12.4 inches for the furrow-irrigated treatment and 25.2 inches for the furrow-irrigated plus optional sprinkler-irrigation treatment.

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

Irrigation	Irrigation criterion	Thrips count average	IYSV[a] Aug. 3	IYSV[a] Aug. 18	IYSV[a] Sept. 1	PM Sept. 1	Maturity Sept. 1 tops down	Maturity Sept. 1 dryness
	cb	No./plant	0-5				%	
Evolution								
Drip	10	41.0	0.3	0.9	0.8	0.6	25.0	20.0
Drip	15	33.3	0.3	0.8	0.8	1.3	38.3	15.0
Drip	20	34.7	0.3	0.8	1.1	2.3	22.5	17.5
Drip	30	34.9	0.3	0.8	0.9	0.4	26.3	18.8
Drip	15/25	35.0	0.3	0.8	1.1	0.2	23.3	16.7
Sprinkler	20	34.4	0.3	0.9	0.9	0.0	22.9	17.1
Drip/spr.	20	35.3	0.3	0.9	0.9	0.0	34.4	20.0
Furrow	25	31.9	0.3	0.8	1.1	0.7	41.3	21.3
Furrow/spr.	25	34.4	0.2	1.0	1.1	0.0	37.5	20.0
	average	35.0	0.3	0.8	1.0	0.6	30.2	18.5
Vaquero								
Drip	10	38.2	0.3	1.0	1.1	0.0	26.7	22.2
Drip	15	32.3	0.3	0.9	1.2	0.0	45.0	18.8
Drip	20	37.6	0.3	0.9	1.0	0.0	31.3	17.5
Drip	30	34.6	0.3	1.0	0.9	0.0	36.3	20.0
Drip	15/25	33.5	0.3	1.0	1.2	0.0	40.0	18.6
Sprinkler	20	32.7	0.3	0.9	0.9	0.0	37.8	17.8
Drip/spr.	20	36.5	0.3	1.1	1.0	0.0	52.5	21.3
Furrow	25	35.3	0.2	0.9	0.9	0.0	48.6	20.0
Furrow/spr.	25	34.6	0.3	1.0	0.9	0.0	42.5	21.3
	average	35.0	0.3	1.0	1.0	0.0	40.1	19.7
Joaquin								
Drip	10	34.5	0.3	0.9	0.9	0.2	25.7	20.0
Drip	15	34.8	0.3	0.9	1.1	0.0	32.5	21.3
Drip	20	33.4	0.3	0.8	1.1	1.3	31.1	17.8
Drip	30	35.5	0.3	0.8	1.2	0.0	31.3	18.8
Drip	15/25	33.3	0.2	0.8	1.1	0.0	23.3	16.7
Sprinkler	20	36.3	0.3	0.9	1.1	0.0	35.6	20.0
Drip/spr.	20	34.6	0.3	0.9	1.0	0.0	25.0	21.7
Furrow	25	33.0	0.3	0.8	0.9	0.0	31.3	18.8
Furrow/spr	25	33.0	0.2	0.8	0.9	0.0	36.7	20.0

Irrigation	Irrigation criterion	Thrips count average	IYSV[a] Aug. 3	IYSV[a] Aug. 18	IYSV[a] Sept. 1	PM Sept. 1	Maturity Sept. 1 tops down	Maturity Sept. 1 drynes s
	cb	No./plant	------------------- 0-5 -------------------				-------- % --------	
.								
	average	34.3	0.3	0.8	1.0	0.2	30.3	19.4
			Charismatic					
Drip	10	31.7	0.2	0.8	1.1	0.1	52.5	21.3
Drip	15	36.4	0.3	0.8	1.0	0.0	39.0	16.0
Drip	20	33.8	0.3	0.7	0.9	0.0	32.9	20.0
Drip	30	31.5	0.3	0.7	0.9	0.0	35.0	20.0
Drip	15/25	35.2	0.2	0.8	1.1	0.0	37.1	20.0
Sprinkler	20	35.1	0.3	0.8	0.9	0.0	45.7	18.6
Drip/spr.	20	34.8	0.3	0.9	0.9	0.0	46.7	21.1
Furrow	25	38.8	0.3	0.8	0.7	0.0	41.1	16.7
Furrow/spr.	25	33.0	0.2	0.8	1.0	0.0	40.0	21.4
	average	34.5	0.3	0.8	1.0	0.0	41.1	19.4
			Average					
Drip	10	36.4	0.3	0.9	1.0	0.2	32.5	20.9
Drip	15	34.4	0.3	0.8	1.0	0.3	38.8	17.8
Drip	20	34.9	0.3	0.8	1.0	0.9	29.4	18.1
Drip	30	34.1	0.3	0.8	1.0	0.1	32.2	19.4
Drip	15/25	34.3	0.3	0.8	1.1	0.1	30.0	17.8
Sprinkler	20	34.6	0.3	0.9	1.0	0.0	35.6	18.4
Drip/spr.	20	35.3	0.3	0.9	1.0	0.0	40.6	20.9
Furrow	25	34.9	0.3	0.8	0.9	0.2	40.3	19.1
Furrow/spr.	25	33.7	0.2	0.9	1.0	0.0	39.1	20.6
	average	34.7	0.3	0.9	1.0	0.2	35.4	19.2
LSD (0.05)								
Irrigation		NS	NS	NS	NS	0.3	NS	NS
N rate		NS	NS	NS	NS	NS	NS	NS
Variety		NS	NS	0.04	NS	0.2	8.2	NS
Irrig. X N rate		NS	NS	NS	NS	NS	NS	NS
Irrig. X Var.		NS	NS	NS	NS	0.6	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, 2009 (continued on next page).

Irrigation system	Irrigation criterion	Total	Marketable yield by grade						No. 2	Small	Rot	Bulb counts
			Total	>4 in	>4¼ in	4-4¼ in	3-4 in	2¼-3 in				>4¼ in
		---------- cwt/acre ----------									%	#/50 lb
		Evolution										
Drip	10	1017.5	987.6	739.5	216.3	523.2	238.9	9.2	9.7	2.3	1.8	14.0
Drip	15	1116.7	1095.6	774.2	273.7	546.9	263.0	12.0	3.9	5.9	1.0	14.2
Drip	20	1048.2	1018.4	735.3	267.3	468.0	270.9	12.2	12.0	4.0	1.3	14.2
Drip	30	968.7	942.7	647.5	187.8	459.7	283.7	11.6	9.9	5.4	1.1	13.9
Drip	15/25	1000.4	970.3	702.8	233.7	469.1	250.2	17.2	7.1	5.9	1.8	14.2
Sprinkler	20	896.3	868.6	592.4	167.7	391.5	295.8	13.6	9.4	2.7	1.8	15.1
Drip/spr.	20	989.5	961.3	719.8	242.9	476.9	233.0	8.5	9.5	2.8	1.6	14.3
Furrow	20-25	990.6	963.6	731.8	286.6	445.2	223.1	8.7	4.1	2.0	2.0	13.7
Furrow/spr.	20-25	1084.2	1060.7	827.9	279.5	548.4	224.3	8.5	3.1	4.8	1.4	13.6
	average	1012.4	985.4	719.0	239.5	481.0	253.7	11.3	7.6	4.0	1.6	14.1
		Vaquero										
Drip	10	1009.2	972.8	681.4	221.1	460.3	281.6	9.8	5.1	2.9	2.8	14.0
Drip	15	1042.4	1022.6	737.1	201.1	536.0	273.7	11.9	3.9	3.6	1.2	12.0
Drip	20	992.5	969.1	646.5	191.0	455.4	311.6	11.1	4.2	2.1	1.8	13.7
Drip	30	989.3	972.5	674.9	196.2	478.7	286.8	10.8	0.6	2.8	1.4	13.7
Drip	15/25	994.8	968.2	667.6	157.8	509.9	290.2	10.4	6.4	4.8	1.6	13.7
Sprinkler	20	967.7	945.4	671.7	150.7	477.5	305.1	12.1	2.6	2.9	1.7	13.8
Drip/spr.	20	1032.4	1011.7	767.6	203.3	537.2	257.2	13.9	5.6	4.8	1.0	13.9
Furrow	20-25	1088.3	1063.2	808.3	338.9	469.5	248.3	6.5	3.4	2.7	1.8	13.1
Furrow/spr.	20-25	1099.9	1077.3	803.2	250.7	552.5	267.7	6.4	4.3	1.8	1.5	13.5
	average	1024.1	1000.3	717.6	212.3	497.4	280.2	10.3	4.0	3.1	1.6	13.5
		Joaquin										
Drip	10	880.7	850.0	663.7	272.9	390.8	178.2	8.1	6.8	2.7	2.4	13.3
Drip	15	904.8	877.6	700.4	339.1	361.3	167.8	9.4	2.2	4.0	2.3	13.4
Drip	20	974.6	952.8	736.6	323.5	413.1	205.7	10.5	10.5	1.6	1.0	13.7
Drip	30	874.7	855.6	710.5	343.6	366.9	137.0	8.1	4.5	2.5	1.4	12.9
Drip	15/25	880.4	860.3	681.4	332.4	349.0	171.7	7.2	1.1	2.9	1.9	13.7
Sprinkler	20	878.0	856.6	602.9	234.2	390.4	221.6	10.5	3.5	3.8	1.5	14.0
Drip/spr.	20	853.6	822.8	681.6	329.6	352.0	133.8	7.4	6.5	1.6	2.7	13.4
Furrow	20-25	913.1	891.4	759.8	403.0	356.8	121.5	10.0	4.3	4.5	1.4	12.6
Furrow/spr.	20-25	922.1	891.8	727.4	364.7	369.0	148.9	9.3	9.1	2.1	2.1	12.9
	average	898.0	873.2	696.0	327.0	372.1	165.1	8.9	5.4	2.9	1.9	13.3

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
		cwt/acre									%	#/50 lb
		Charismatic										
Drip	10	1036.0	1010.6	741.9	277.3	464.6	252.6	16.1	5.7	4.3	1.5	13.8
Drip	15	1107.9	1079.7	797.6	295.2	502.5	267.2	14.9	7.6	5.0	1.5	14.1
Drip	20	1105.9	1089.3	816.9	307.0	509.9	259.7	12.7	6.0	5.4	0.5	13.5
Drip	30	1067.8	1047.9	774.6	241.2	529.0	263.9	13.8	4.5	5.3	0.9	12.4
Drip	15/25	1041.2	1021.2	785.1	291.1	494.0	223.8	12.3	2.4	5.1	1.2	14.3
Sprinkler	20	1008.4	984.2	708.7	212.0	496.7	260.6	14.9	6.2	5.4	1.3	14.4
Drip/spr.	20	1074.8	1060.2	784.9	295.5	486.3	264.2	14.1	4.5	3.2	0.7	13.7
Furrow	20-25	1129.1	1109.9	861.7	317.6	544.1	234.7	13.4	4.0	5.5	0.9	13.4
Furrow/spr.	20-25	1122.7	1089.6	856.8	413.5	466.7	197.9	11.5	10.1	4.7	1.5	14.3
	average	1077.1	1054.7	792.0	294.5	499.3	247.2	13.8	5.7	4.9	1.1	14.3
		Average										
Drip	10	989.9	959.1	707.2	245.3	461.9	241.1	10.9	6.8	3.1	2.1	13.8
Drip	15	1042.4	1017.9	753.1	278.6	483.9	243.2	12.2	4.6	4.6	1.5	13.5
Drip	20	1026.2	1003.1	731.3	272.7	458.6	260.3	11.5	8.3	3.2	1.2	13.8
Drip	30	975.1	954.7	699.5	242.2	458.6	242.8	11.1	4.9	4.0	1.2	13.2
Drip	15/25	974.4	950.1	707.1	257.4	449.7	231.1	11.8	4.2	4.6	1.7	14.0
Sprinkler	20	935.8	912.1	644.3	191.3	438.4	269.8	12.6	5.1	3.6	1.6	14.3
Drip/spr.	20	998.7	975.7	740.6	264.1	471.2	229.2	11.2	6.5	3.2	1.4	13.9
Furrow	20-25	1031.5	1008.5	792.1	335.9	456.2	206.5	9.9	4.0	3.7	1.5	13.2
Furrow/spr.	20-25	1050.9	1023.7	798.3	325.6	481.1	208.2	8.9	6.6	3.3	1.7	13.5
	average	1002.8	978.3	730.4	268.1	462.2	236.9	11.1	5.7	3.7	1.5	13.7
N rate												
lb N/acre												
100		1010.9	985.3	736.1	274.5	463.6	236.5	10.7	6.2	3.8	1.6	13.7
200		994.7	971.3	725.8	261.7	460.8	237.3	11.5	5.1	3.6	1.5	13.7
LSD (0.05)												
Irrigation		52.7	52.9	73.1	78.8	NS	NS	NS	NS	NS	NS	NS
N rate		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Variety		20.6	20.3	25.3	18.4	22.7	15.2	3.3	NS	1.3	NS	0.4
Irrig. X N rate		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Irrig. X Var.		NS	NS	NS	NS	68	NS	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 single centers for four onion varieties submitted to nine irrigation treatments, Malheur Experiment Station, Oregon State University, Ontario, OR, 2009 (continued on next page).

Irrigation	Irrigation criterion	Multiple center			Single center	
		large	medium	small	Functional[a]	single
	cb	%				
		Evolution				
Drip	10	5.0	9.5	6.5	85.5	79.0
Drip	15	10.0	10.7	3.3	79.3	76.0
Drip	20	5.5	11.0	6.5	83.5	77.0
Drip	30	11.4	12.4	7.4	76.2	68.8
Drip	15/25	6.7	10.7	5.3	82.7	77.3
Sprinkler	20	6.9	8.6	2.9	84.6	81.7
Drip/spr.	20	10.6	13.7	5.7	75.7	69.9
Furrow	25	14.5	14.0	7.0	71.5	64.5
Furrow/spr.	25	14.0	16.5	7.0	69.5	62.5
	average	9.4	11.9	5.7	78.7	73.0
		Vaquero				
Drip	10	8.0	13.3	11.1	78.7	67.6
Drip	15	12.5	18.5	12.5	69.0	56.5
Drip	20	17.0	19.0	10.0	64.0	54.0
Drip	30	15.8	14.0	12.5	70.3	57.8
Drip	15/25	7.4	14.3	9.1	78.3	69.1
Sprinkler	20	12.4	14.2	8.0	73.3	65.3
Drip/spr.	20	13.0	19.0	15.0	68.0	53.0
Furrow	25	19.4	22.9	9.7	57.7	48.0
Furrow/spr.	25	15.0	21.5	11.0	63.5	52.5
	average	13.4	17.4	11.0	69.2	58.2
		Joaquin				
Drip	10	3.4	4.0	2.3	92.6	90.3
Drip	15	6.0	6.0	2.0	88.0	86.0
Drip	20	6.2	9.4	5.9	84.4	78.5
Drip	30	10.5	10.0	4.0	79.5	75.5
Drip	15/25	4.9	9.3	1.3	85.8	84.4
Sprinkler	20	4.4	7.6	4.4	88.0	83.6
Drip/spr.	20	7.3	6.7	4.0	86.0	82.0

Irrigation	Irrigation criterion	Multiple center			Single center	
		large	medium	small	Functional[a]	single
	cb	--------------------------------- %			----------------------------------	
Furrow	25	8.2	9.2	4.9	82.6	77.6
Furrow/spr.	25	12.4	7.6	4.9	80.0	75.1
	average	7.1	7.7	3.8	85.2	81.4
			Charismatic			
Drip	10	24.5	21.0	9.5	54.5	45.0
Drip	15	32.8	25.2	5.2	42.0	36.8
Drip	20	36.0	25.1	6.9	38.9	32.0
Drip	30	35.0	30.5	12.0	34.5	22.5
Drip	15/25	25.0	33.0	11.3	42.0	30.7
Sprinkler	20	29.7	27.4	12.6	42.9	30.3
Drip/spr.	20	36.0	30.2	4.4	33.8	29.3
Furrow	25	53.9	21.0	6.7	25.1	18.4
Furrow/spr.	25	52.6	24.6	5.7	22.9	17.1
	average	36.2	26.5	8.3	37.4	29.1
			Average			
Drip	10	10.4	12.3	7.6	77.4	69.8
Drip	15	16.8	16.0	5.9	67.3	61.4
Drip	20	15.3	15.6	7.3	69.1	61.8
Drip	30	18.2	16.7	9.0	65.1	56.1
Drip	15/25	10.3	16.0	6.3	73.7	67.3
Sprinkler	20	12.8	14.0	6.9	73.3	66.4
Drip/spr.	20	17.7	18.4	7.4	63.9	56.5
Furrow	25	25.1	16.7	7.0	58.2	51.2
Furrow/spr.	25	22.3	17.0	7.1	60.8	53.6
	average	16.5	15.8	7.2	67.6	60.5
LSD (0.05)						
Irrigation		5.1	NS	NS	18.5	7.7
N rate		NS	NS	NS	NS	NS
Variety		3.6	3.5	3.1	3.1	3.6
Irrig. X N rate		NS	NS	NS	NS	NS
Irrig. X Var.		NS	NS	NS	NS	NS

[a]single center + small multiple center.

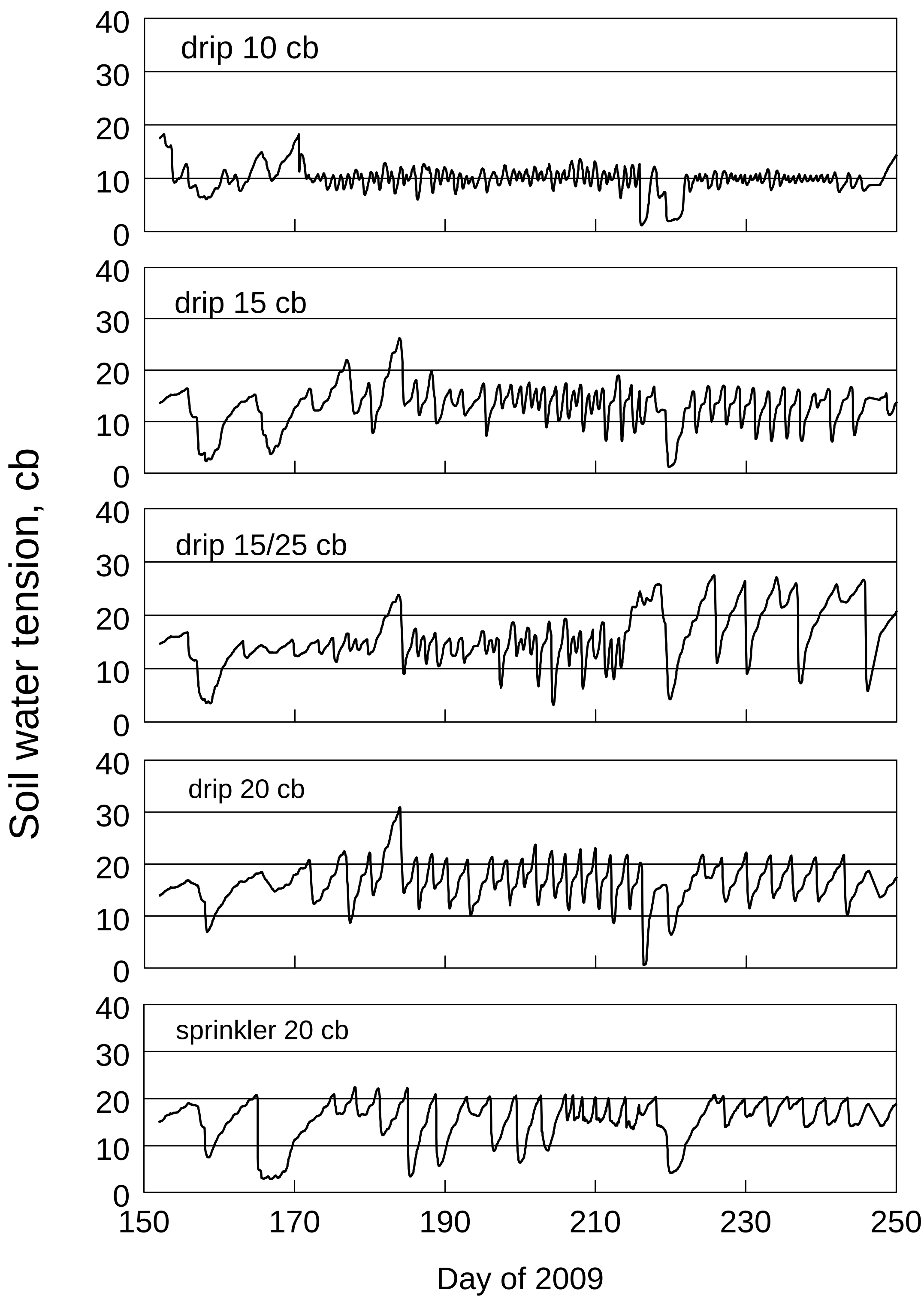

Figure 1a. Soil water tension at 8-inch depth over time for onions submitted to nine irrigation treatments, Malheur Experiment Station, Oregon State University, Ontario, OR, 2009.

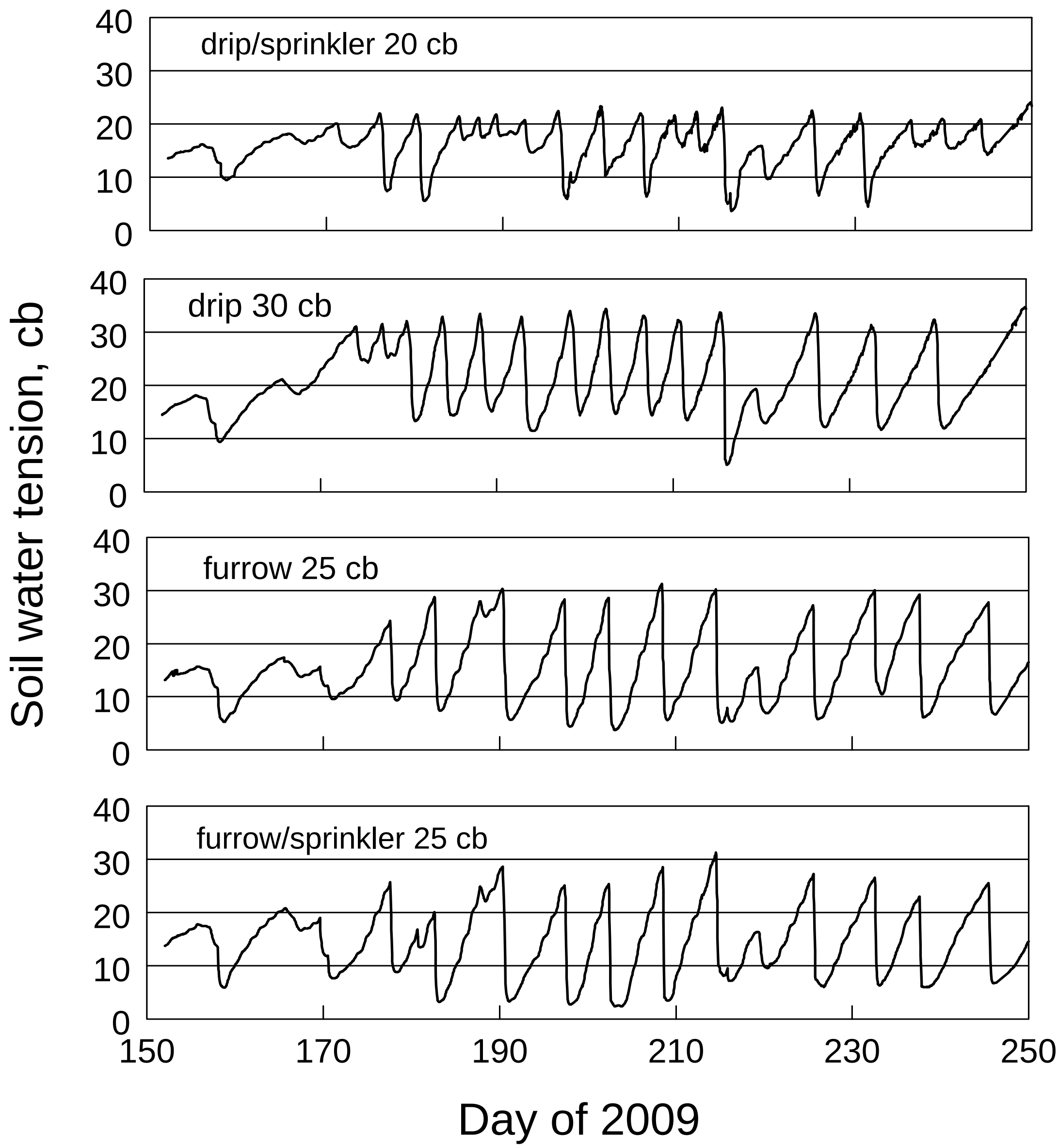

Figure 1b. Soil water tension at 8-inch depth over time for onions submitted to nine irrigation treatments, Malheur Experiment Station, Oregon State University, Ontario, OR, 2009.

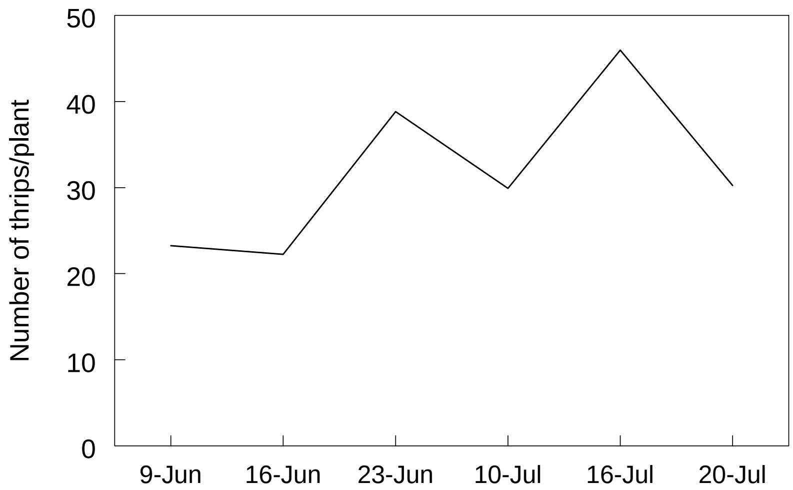

Figure 2. Thrips population counts per onion plant over time. Counts presented here were the average over irrigation treatments, N rates, and varieties (288 plots). On each date thrips on 10 onion plants/plot were counted. Malheur Experiment Station, Oregon State University, Ontario, OR, 2009.