ONION INTERNAL QUALITY IN RESPONSE TO ARTIFICIAL HEAT AND HEAT MITIGATION DURING BULB DEVELOPMENT

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Introduction

In 2014 and 2015 there was an increase in internal onion bulb decomposition of one or more scales in onion bulbs grown in the Treasure Valley. Unlike neck rot or plate rot, this internal decomposition is difficult to detect externally, and can result in quality issues in marketing. We have thought that the internal decomposition is associated with one or more scales that do not finish forming completely into the neck, resulting in small gaps close to the neck. The 2014 and 2015 growing seasons were unusually warm, suggesting that excessive heat could be associated with the problems of internal decomposition. This trial sought to determine whether heat is a factor in bulb decomposition and whether or not treatments that increase or reduce the heat load in the soil and onion bulbs would affect the expression of internal bulb decomposition.

Materials and Methods

Onions were grown in 2017 on an Owyhee silt loam previously planted to wheat. A soil analysis taken in the fall of 2016 showed that the top foot of soil had a pH of 8.1, 3.0% organic matter, 9 ppm nitrate, 3 ppm ammonium, 50 ppm phosphorus (P), 341 ppm potassium (K), 16 ppm sulfur (S), 2927 ppm calcium (Ca), 502 ppm magnesium (Mg), 269 ppm sodium, 2.2 ppm zinc (Zn), 5 ppm manganese (Mn), 0.6 ppm copper (Cu), 4 ppm iron, and 0.5 ppm boron (B). In the fall of 2016, the wheat stubble was shredded and the field was irrigated. The field was then disked, moldboard plowed, and groundhogged. Based on a soil analysis, 22 lb P/acre, 42 lb K/acre, 200 lb S/acre, 2 lb Zn/acre, 2 lb Mn/acre, and 1 lb B/acre were broadcast before plowing. After plowing, the field was fumigated with K-Pam® at 15 gal/acre and bedded at 22 inches.

Onion seed was planted on April 5 in double rows spaced 3 inches apart at 9 seeds/ft of single row. Each double row was planted on beds spaced 22 inches apart. Planting was done in rows running east to west with customized John Deere Flexi Planter units equipped with disc openers. Immediately after planting, the field received a narrow band of Lorsban 15G® at 3.7 oz/1000 ft of row (0.82 lb ai/acre) over the seed rows and the soil surface was rolled. Onion emergence started on April 20. On May 9, alleys 4 ft wide were cut between split plots, leaving split plots 23 ft long. On May 25, the seedlings were hand thinned to a spacing of 4.75 inches between individual onion plants in each single row, or 120,000 plants/acre.

The experimental design was a split-plot randomized complete block with six replicates. There were four treatments to affect temperature as the main plots and two varieties as split plots within each main plot. Each split plot was planted with 4 double rows wide and 27 ft long. The two varieties were 'Joaquin' and 'Granero' (Nunhems, Parma, ID). The four treatments were: 1) untreated check, 2) artificial heat, 3) kaolinite, and 4) straw mulch. Kaolinite and straw mulch were treatments intended to reduce the heat load on the onions. The artificial heat was applied using one heat cable (self-regulating heat cable, maximum temperature 185°F, Chromalox, Pittsburgh, PA) laid next to each of the middle 2 double rows in the center of each heated plot. The heat cables were turned on and run continuously starting on June 26 and ending September 5. Kaolinite clay (Surround WP, Novasource, Phoenix, AZ) was applied at 45 lb/acre in a solution of 0.45 lb kaolinite/gal of water. The kaolinite was applied with a backpack sprayer by aiming the nozzle at the base of the onion plants on the south side of each double row. The kaolinite was applied on June 26 and July 18. The straw was applied between the onion double rows at 243 ft^3/acre (32 7.5-ft^3 bales/acre) on May 30.

The field had drip tape laid at 4-inch depth between pairs of beds during planting. The drip tape had emitters spaced 12 inches apart and an emitter flow rate of 0.22 gal/min/100 ft (Toro Aqua-Traxx, Toro Co., El Cajon, CA). The distance between the tape and the center of each double row of onions was 11 inches.

The onions were managed to minimize yield reductions from weeds, pests, diseases, water stress, and nutrient deficiencies. For weed control, the following herbicides were broadcast: Prowl® H_2O at 0.83 lb ai/acre (2 pt/acre) and Poast® at 0.25 lb ai/acre (16 oz/acre) on May 4; GoalTender® at 0.09 lb ai/acre (4 oz/acre) and Buctril® at 16 oz/acre on May 15; and Prowl H_2O at 0.31 lb ai/acre (0.75 pt/acre) and Poast at 0.5 lb ai/acre (32 oz/acre) on June 4.

For thrips control, the following insecticides were applied by ground: Movento® at 5 oz/acre on May 26; Movento at 5 oz/acre and Aza-Direct® at 12 oz/acre on June 2; Agri-Mek® SC at 3.5 oz/acre on June 15 and 23. The following insecticides were applied by air: Radiant® at 10 oz/acre on July 1, 8, and 30; Lannate® at 3 pt/acre on July 17 and 23.

Urea ammonium nitrate solution (URAN) was applied through the drip tape five times from May 26 to June 28, supplying a total of 105 lb N/acre. Starting on June 19, root tissue and soil solution samples were taken every week from borders of check treatment plots and analyzed for nutrients by Western Laboratories, Inc., Parma Idaho (Tables 1 and 2). Nutrients were applied through the drip tape only if both the root tissue and soil solution analyses concurrently indicated a deficiency (Table 3). Nitrogen was applied only at the fixed amount previously mentioned, because the soil solution tests indicated the soil was supplying ample amounts of N (Table 4). Potassium was deficient in both the soil and the roots on several sampling dates. A total of 197 lb K/acre was applied in 26- to 31-lb increments during the growing season based on the soil and tissue analyses.

Table 1. Onion root tissue sufficiency levels and nutrient content, Malheur Experiment Station, Oregon State University, Ontario, OR, 2017.

Nutrient		19-Jun	4-Jul	11-Jul	17-Jul	24-Jul	31-Jul	7-Aug
NO_3-N (ppm)	Sufficiency range	7667	7200	6833	5000	3500	1834	1000
NO_3-N (ppm)		7325	6868	5773	4847	4903	6090	5218
P (%)	0.32 - 0.7	0.45	0.52	0.44	0.52	0.34	0.27	0.33
K (%)	2.7 - 6.0	2.20	2.58	2.40	1.97	1.48	1.88	0.96
S (%)	0.24 - 0.85	0.84	0.96	1.09	0.98	0.76	0.90	0.99
Ca (%)	0.4 - 1.2	0.61	0.67	0.74	0.85	1.10	0.94	1.18
Mg (%)	0.3 - 0.6	0.39	0.38	0.37	0.36	0.41	0.40	0.41
Zn (ppm)	25 - 50	55	52	48	39	32	32	31
Mn (ppm)	35 - 100	193	183	160	144	139	118	83
Cu (ppm)	6 - 20	24	18	14	12	10	10	12
B (ppm)	19 - 60	30	29	33	41	32	23	25

Table 2. Weekly soil solution analyses. Data represent the amount of each plant nutrient per day that the soil can potentially supply to the crop. Malheur Experiment Station, Oregon State University, Ontario, OR, 2017.

Nutrient	Critical level, lb/ac or g/ac	19-Jun	4-Jul	11-Jul	17-Jul	24-Jul	31-Jul	7-Aug
N	Critical levels	7.8	5.5	4.6	4	3	2	1.5
N		7.7	10.9	14.3	17.1	16.6	18.6	23.7
P	0.7 lb/acre	0.3	0.5	0.6	0.7	1.0	1.4	0.9
K	5 lb/acre	1.5	1.8	2.1	2.6	3.0	3.7	4.5
S	1 lb/acre	1.6	2.1	2.6	3.2	3.8	3.9	2.5
Ca	3 lb/acre	10.0	8.8	8.6	6.9	5.6	5.8	4.7
Mg	2 lb/acre	6.4	7.3	6.6	7.7	8.3	9.2	7.2
Zn	28 g/acre	6	15	18	24	30	39	39
Mn	28 g/acre	9	27	21	27	30	36	42
Cu	12 g/acre	3	9	15	18	21	24	24

Table 3. Nutrients applied through the drip irrigation system, Malheur Experiment Station, Oregon State University, Ontario, OR, 2017.

Date	N	K
	------ lb/acre -------	
26-May	30	
5-Jun	15	
15-Jun	15	
20-Jun	30	31
28-Jun	15	
6-Jul		31
11-Jul		26
18-Jul		31
26-Jul		26
1-Aug		26
9-Aug		26
total	105	197

Table 4. Soil available N (NO_3 + NH_4) in the top foot of soil, Malheur Experiment Station, Oregon State University, Ontario, OR, 2017.

Date	Available soil N, lb/acre
19-Jun	54
4-Jul	76
11-Jul	100
17-Jul	120
24-Jul	116
31-Jul	130
7-Aug	166

Onions were irrigated automatically to maintain the soil water tension (SWT) in the onion root zone below 20 cb (Shock et al. 2000). Soil water tension in each treatment plot was measured with two granular matrix sensors (GMS, Watermark Soil Moisture Sensors Model 200SS, Irrometer Co., Inc., Riverside, CA) installed at 8-inch depth in the center of the double row. Sensors had been calibrated to SWT (Shock et al. 1998). The GMS were connected to the datalogger via multiplexers (AM 16/32, Campbell Scientific, Logan, UT). The datalogger (CR10X, Campbell Scientific) read the sensors and recorded the SWT every hour. The datalogger automatically made irrigation decisions every 12 hours. The field was irrigated if the average of the 24 sensors in the check and kaolinite treatments was a SWT of 20 cb or higher. The irrigations were controlled by the datalogger using a controller (SDM CD16AC, Campbell Scientific) connected to a solenoid valve. Irrigation durations were 8 hours, 19 min to apply 0.48 inch of water. The water was supplied from a well and pump that maintained a continuous and constant water pressure of 35 psi. The pressure in the drip lines was maintained at 10 psi by a pressure regulating valve. The automated irrigation system was started on June 5 and irrigations ended September 5.

Onion bulb temperatures and soil surface temperatures were measured weekly in the mid-afternoon using an infrared thermometer (Close Focus IR, ThermoWorks, Salt Lake City, UT) starting on June 26 and ending August 18. After August 18 the leaves shaded the soil and bulbs and walking among the onions to obtain temperature data would have substantially injured the plants. Bulb and soil temperature measurements were made as close as practical to 2 p.m. (12:30 p.m. to 3:30 p.m.) on clear days. The bulb temperatures were measured on the south side of the bulbs furthest from the drip tape and approximately 0.5 inches above the soil surface. The soil surface temperature was measured approximately 0.5 inches to the south from the same bulbs. Four temperature measurements for the bulbs and the soil were taken weekly in each plot. Soil temperature at 4-inch depth was measured in each plot using digital thermometers (Hanna Instruments, Limena, Italy) read twice weekly at 4 p.m. from July through August.

Onions were evaluated for maturity, severity of symptoms of iris yellow spot virus (IYSV), and bolting on August 8. Onions in each plot were evaluated subjectively for maturity by visually rating the percentage of onions with the tops down and the percent dry leaves. For IYSV, onions in each plot were given a subjective rating on a scale of 0 to 5 of increasing severity of IYSV symptoms. The rating was 0 if there were no symptoms, 1 if 1-25% of foliage was diseased, 2 if 26-50% of foliage was diseased, 3 if 51-75% of foliage was diseased, 4 if 76-99% of foliage was diseased, and 5 if 100% of foliage was diseased. The number of bolted onion plants was counted in each plot.

The onions were lifted on September 25 to cure in the field. Onions from the middle two double rows in each split plot were topped by hand and bagged on October 2. The bags were put into storage on October 11. 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 November 1.

During grading, bulbs were separated according to quality: bulbs without blemishes (No. 1s), split bulbs (No. 2s), bulbs infected with the fungus *Botrytis allii* in the neck or side, bulbs infected with the fungus *Fusarium oxysporum* (plate rot), bulbs infected with the fungus *Aspergillus niger* (black mold), and bulbs infected with unidentified bacteria in the external scales. The No. 1 bulbs were graded according to diameter: small (<2¼ inches), medium (2¼-3 inches), jumbo (3-4 inches), colossal (4-4¼ inches), and supercolossal (>4¼ inches). Bulb counts per 50 lb of supercolossal onions were determined for each split plot by weighing and counting all supercolossal bulbs during grading. Marketable yield consisted of No.1 bulbs larger than 2¼ inches.

During grading, two bags of No. 1 bulbs (with no observable external decomposition) from each plot were saved for evaluations of internal bulb quality. On November 15, 2017 and January 29, 2018, 25 bulbs from each plot were cut longitudinally and evaluated for the presence of incomplete scales, dry scales, internal bacterial rot, and internal rot caused by *Fusarium proliferatum* or other fungi. Incomplete scales were defined as scales that had either more than 0.25 inch from the center of the neck missing or any part missing lower down in the bulb. Dry scales were defined as scales that had dry parts at the top of the bulb or any place lower down on one or more scale.

Treatment differences were determined using analysis of variance. Means separation was determined using a protected Fisher's least significant difference test at the 5% probability level, LSD (0.05). The least significant difference LSD (0.05) values in each table should be considered when comparisons are made between treatments. A statistically significant difference in a characteristic between two treatments exists if the difference between the two treatments for that characteristic is equal to or greater than the LSD value for that characteristic. The effects of mid-day bulb temperature or soil temperature on bulb yield, yield components, or internal decomposition were determined by regression.

Results and Discussion

The rate of accumulation and total number of growing degree-days (50-86°F) in 2017 were close to the 24-year average, until July (Fig. 1). July had higher than average growing degree-days (Fig. 2).

Surface soil and bulb temperatures for the check treatment onions were on average 35°F and 13°F higher, respectively, than ambient air temperature for the corresponding measurements (Table 5). On average, the artificial heat treatment resulted in the highest and straw mulch resulted in the lowest surface soil temperatures. On average, the artificial heat treatment resulted in the highest 4-inch depth soil temperature and the highest bulb temperatures, with the other treatments having relatively similar 4-inch soil and bulb temperatures as the check.

There was a statistically significant interaction between treatment and variety only for colossal bulb yield. For Joaquin, straw mulch and kaolinite treatments resulted in the highest colossal bulb yield and artificial heat resulted in the lowest colossal bulb yield. The differences in colossal yield among treatments for Granero were not statistically significant. Averaged over heat treatments, Joaquin had higher yields than Granero. Averaged over the two varieties, artificial heat resulted in the lowest total, marketable, and colossal bulb yield. Total and marketable bulb yields for the other treatments were not statistically different. Averaged over the two varieties, straw mulch and kaolinite treatments resulted in the highest colossal bulb yield, and artificial heat resulted in the lowest colossal bulb yield.

For Joaquin, marketable and colossal bulb yields decreased with increasing bulb and soil temperature (Fig. 4 and 6). For Granero, marketable yield decreased with increasing bulb and soil temperature (Fig. 5 and 7).

Straw mulch and kaolinite resulted in among the lowest percentage of tops down on August 16 (Table 6). Artificial heat resulted in the highest percentage of leaf dryness and straw mulch resulted in the lowest percentage of leaf dryness on August 16.

Improved yields with the use of straw mulch with drip irrigation can be a result of more optimum temperatures and also of modification of the soil moisture by a reduction of evaporation from the soil surface. The average SWT in June and July in the check and kaolinite treatments were similar (16.6 cb and 16.4 cb, respectively) since they were irrigated based on the average of all their sensors (Fig. 3). The average SWT in June and July in the heat treatment (17.8 cb) was slightly higher than the check and kaolinite treatments. The average SWT in June and July in the straw mulch treatment (15.5 cb) was slightly lower than the check and kaolinite treatments. These small differences in SWT were unlikely to have a significant effect on onion yield based on previously published work (Shock et al. 2000).

Most of the internal decomposition was found in bulbs having incomplete scales, regardless of the presence or absence of dry scales (Table 7). The total amount of internal decomposition in this trial in November ranged from 0% for Granero with straw mulch to 10% for Granero submitted to artificial heat (Table 7). In January, the total amount of internal decomposition ranged from 0.8% for Granero with straw mulch to 13.9% for Joaquin submitted to artificial heat. Averaged over treatments and varieties, the total amount of internal decomposition in January (5.1%) was higher than in November (3.3%). In November, most of the internal decomposition was due to neck rot and black mold, averaging 1.4 and 1.5%, respectively (Table 8). In January most of the internal decomposition was due to neck rot, which increased to 3.9% while black mold decreased slightly to 1.3%. There was very little internal decomposition caused by bacterial rot and *Fusarium proliferatum* in this trial.

Averaged over varieties and dates, bulbs submitted to artificial heat had the highest percentage of bulbs with internal rot. The kaolinite and straw mulch treatments were among the treatments with the lowest percentage of bulbs with internal rot. Averaged over varieties and dates, bulbs submitted to artificial heat had the highest percentage of bulbs with black mold. The kaolinite and straw mulch treatments were among the treatments with the lowest percentage of bulbs with black mold. There was no statistically significant difference in percentage of bulbs with neck rot between treatments, but there was a trend for the heat treatment to result in higher neck rot and for the straw mulch and kaolinite treatments to result in lower neck rot. Averaged over the two varieties, bulb internal decomposition increased with increasing bulb and soil temperature (Figs. 8 and 9).

The results of this trial in 2017 are similar to the results of the 2016 trial (Shock et al. 2017), when straw mulch resulted in the highest supercolossal and colossal bulb yields. In 2016, artificial heat was among the treatments with the lowest colossal bulb yield. In contrast to 2017, bulb yield and size for the kaolinite treatment were not different from the check treatment in 2016. In 2016, internal decomposition was lower, averaging 1.4% over all treatments compared to 3.3% in 2017. In 2016, there were no statistically significant differences in internal decomposition between treatments, but the heat treatments had a later start and a much shorter duration in 2016.

Acknowledgements

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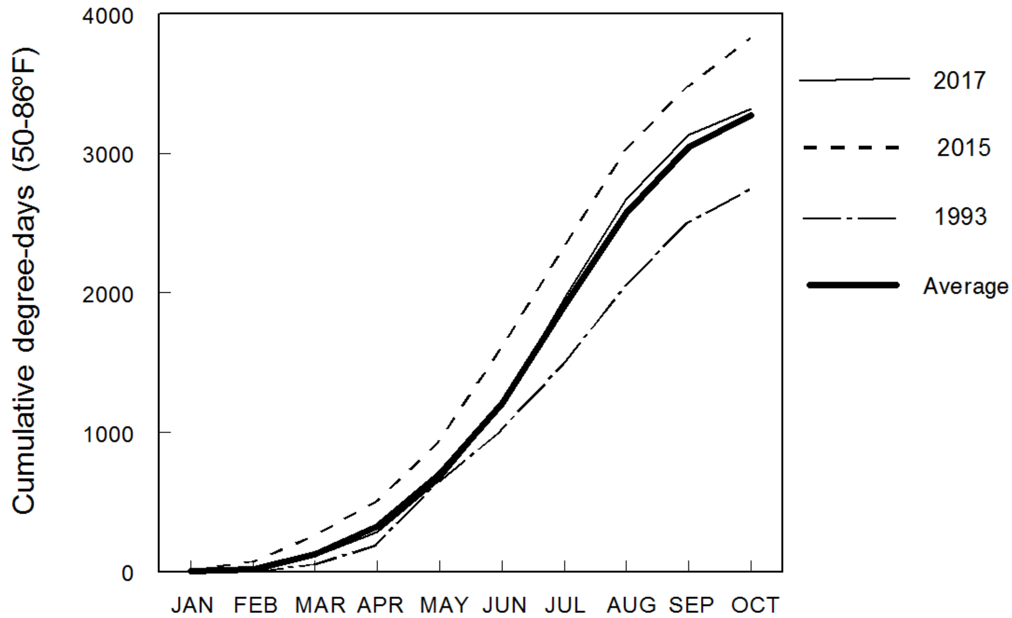

Figure 1. Cumulative growing degree-days (50-86°F) for 2015-2017 and 24-year average, Malheur Experiment Station, Oregon State University, Ontario, OR, 2017.

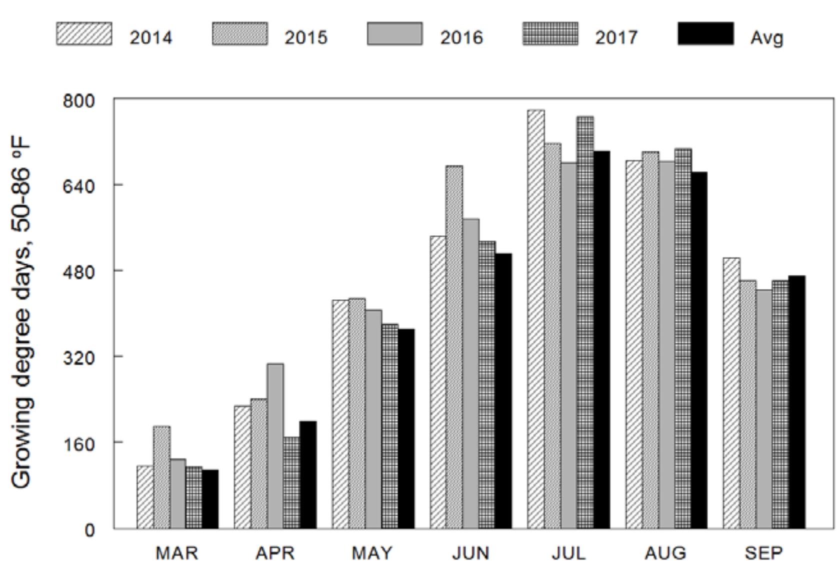

Figure 2. Monthly growing degree-days (50-86°F) for 2014-2017 and 24-year average, Malheur Experiment Station, Oregon State University, Ontario, OR, 2017.

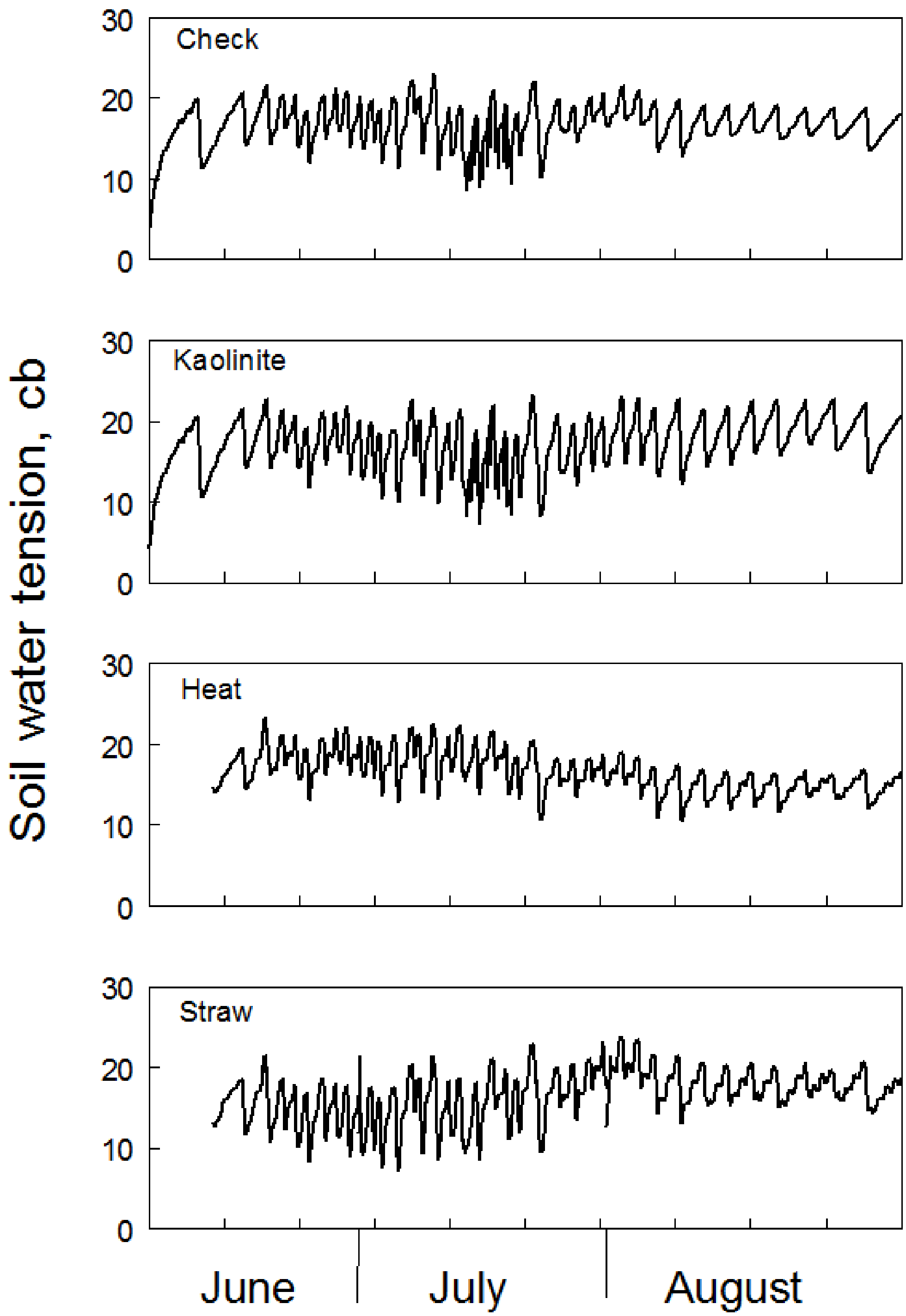

Figure 3. Soil water tension over time for four treatments. Average soil water tension in June and July was 16.6 cb, 16.4 cb, 17.8 cb, and 15.5 cb for the check, kaolinite, artificial heat, and straw mulch treatments, respectively. Malheur Experiment Station, Oregon State University, Ontario, OR, 2017.

Table 5. Soil and onion bulb temperature (°F) measurements for four management treatments to affect bulb and soil surface temperatures. Measurements were made between 12:30 and 3:30 p.m. on the south side of the onion bulbs one half inch above the soil surface and one half inch south of the same onion bulbs. Ambient air temperature was recorded at 2 p.m. Solar noon was close to 2 p.m. Malheur Experiment Station, Oregon State University, Ontario, OR, 2017.

	Ambient air									
	26-Jun	6-Jul	14-Jul	20-Jul	28-Jul	4-Aug	11-Aug	18-Aug	Average	
	89	93	92	89	89	91	89	86	91	
	Soil surface									Soil 4-inch depth
	26-Jun	6-Jul	14-Jul	20-Jul	28-Jul	4-Aug	11-Aug	18-Aug	Average	Average
Check	101.0	128.6	132.3	134.7	125.4	129.6	124.1	135.3	126.4	76.6
Heat	103.4	149.0	142.5	136.0	135.6	142.7	138.7	143.7	136.5	82.5
Kaolinite	103.2	128.3	127.6	125.9	124.4	123.2	118.5	130.9	122.7	76.6
Straw	100.6	118.8	119.7	125.7	117.5	125.8	115.4	117.7	117.6	74.9
LSD (0.05)	NS	14.0	6.9	7.0	7.4	7.7	8.9	7.0	4.0	2.2
	Bulb									
	26-Jun	6-Jul	14-Jul	20-Jul	28-Jul	4-Aug	11-Aug	18-Aug	Average	
Check	91.2	105.1	108.6	103.7	104.2	105.2	105.0	109.2	104.0	
Heat	95.0	111.4	116.3	109.4	112.9	112.7	115.4	117.2	111.3	
Kaolinite	91.9	104.6	103.4	101.1	102.3	101.7	102.8	109.1	102.1	
Straw	92.6	101.7	99.8	100.8	101.9	105.9	105.9	111.4	102.5	
LSD (0.05)	NS[a]	3.2	8.6	4.1	4.4	3.7	2.7	4.3	2.5	

[a]Not significant.

Table 6. Yield and grade of two varieties of onions submitted to four temperature treatments, Malheur Experiment Station, Oregon State University, Ontario, OR, 2017.

			Marketable yield by grade													
Variety	Treatment	Total yield	Total	>4¼ in	4-4¼ in	3-4 in	2¼-3 in	Small	No. 2s	Bulb counts >4¼ in	Total rot	Neck rot	Plate rot	Split root	Tops down	Leaf dryness
		cwt/acre								#/50 lb	%					
Joaquin	Check	1065.2	1056.6	38.5	217.0	768.5	32.5	7.0	0.0	30.6	0.0	0.0	0.0	0.0	46.0	9.0
	Heat	862.3	841.1	32.5	140.1	612.1	56.3	9.2	0.7	27.9	0.9	0.0	0.9	0.1	60.0	12.0
	Kaolinite	1088.2	1074.2	35.3	290.8	727.1	21.0	7.1	0.0	31.4	0.4	0.0	0.4	0.0	26.0	8.0
	Straw	1110.3	1103.5	44.8	297.3	738.8	22.6	4.0	0.0	32.2	0.1	0.0	0.1	0.0	28.0	6.0
	average	1031.5	1018.8	37.8	236.3	711.6	33.1	6.8	0.2	30.5	0.4	0.0	0.4	0.0	40.0	8.8
Granero	Check	988.8	974.7	17.5	168.5	755.1	33.5	7.7	0.0	31.1	0.3	0.0	0.3	0.1	82.0	12.0
	Heat	871.8	852.9	12.7	169.2	645.6	25.4	4.9	0.0	31.1	1.1	0.0	1.1	0.1	78.0	16.0
	Kaolinite	1034.8	1021.6	14.8	162.7	811.7	32.3	7.4	0.0	29.2	0.1	0.0	0.1	0.1	70.0	12.0
	Straw	1053.4	1041.6	16.4	185.5	809.7	30.1	7.0	0.0	32.9	0.3	0.0	0.3	0.0	72.0	9.0
	average	987.2	972.7	15.4	171.5	755.5	30.3	6.7	0.0	31.1	0.4	0.0	0.4	0.1	75.5	12.3
Average	Check	1027.0	1015.6	28.0	192.8	761.8	33.0	7.3	0.0	30.8	0.2	0.0	0.2	0.0	64.0	10.5
	Heat	866.1	845.8	24.6	151.7	625.5	44.0	7.5	0.4	29.2	1.0	0.0	1.0	0.1	69.0	14.0
	Kaolinite	1059.1	1045.5	24.1	220.9	773.3	27.2	7.3	0.0	30.3	0.2	0.0	0.2	0.1	48.0	10.0
	Straw	1081.9	1072.6	30.6	241.4	774.2	26.3	5.5	0.0	32.5	0.2	0.0	0.2	0.0	50.0	7.5
	average	1008.5	994.9	26.8	201.7	733.7	32.6	6.9	0.1	30.7	0.4	0.0	0.4	0.1	57.8	10.5
LSD (0.05)																
Treatment		81.0	81.0	NS	27.0	78.7	NS	NS	NS	NS	0.4	NS	0.4	0.1	18.0	2.9
Variety		27.6	29.0	10.6	28.6	34.1	NS	NS	NS	NS	NS	NS	NS	NS	8.6	1.5
Treatment X variety		NS[a]	NS	NS	57.2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a]Not significant.

Table 7. Internal defects on November 15, 2017 and January 29, 2018 for two varieties of onions submitted to four treatments, Malheur Experiment Station, Oregon State University, Ontario, OR, 2017. Continued on next page.

November

		All bulbs							Diseased bulbs						
		Complete scales			Incomplete scales			Total	Complete scales			Incomplete scales			Total
Variety	Treatment	no dry scale	dry scale	total	no dry scale	dry scale	total		no dry scale	dry scale	total	no dry scale	dry scale	total	
		%													
Joaquin	Check	63.3	0.0	63.3	28.7	8.0	36.7	100	0.0	0.0	0.0	2.0	0.7	2.7	2.7
	Heat	59.3	0.0	59.3	21.3	19.3	40.7	100	0.7	0.0	0.7	4.7	3.3	8.0	8.7
	Kaolinite	66.0	1.3	67.3	30.0	2.7	32.7	100	0.0	0.0	0.0	0.7	0.0	0.7	0.7
	Straw	60.7	0.7	61.3	29.2	9.9	39.1	100	0.0	0.0	0.0	0.0	1.3	1.3	1.3
	average	62.3	0.5	62.8	27.3	10.0	37.3	100	0.2	0.0	0.2	1.8	1.3	3.2	3.3
Granero	Check	31.3	0.0	31.3	53.9	16.3	70.1	100	0.0	0.0	0.0	0.0	1.9	1.9	1.9
	Heat	38.0	0.0	38.0	43.9	18.0	61.9	100	0.0	0.0	0.0	5.5	4.7	10.1	10.1
	Kaolinite	35.3	0.0	35.3	56.2	8.6	64.9	100	0.0	0.0	0.0	0.7	0.0	0.7	0.7
	Straw	39.3	0.7	40.0	54.0	6.0	60.0	100	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	average	36.0	0.2	36.2	52.0	12.2	64.2	100	0.0	0.0	0.0	1.5	1.7	3.2	3.2
Average	Check	47.3	0.0	47.3	41.3	12.1	53.4	100	0.0	0.0	0.0	1.0	1.3	2.3	2.3
	Heat	48.7	0.0	48.7	32.6	18.7	51.3	100	0.3	0.0	0.3	5.1	4.0	9.1	9.4
	Kaolinite	50.7	0.7	51.3	43.1	5.7	48.8	100	0.0	0.0	0.0	0.7	0.0	0.7	0.7
	Straw	50.0	0.7	50.7	41.6	7.9	49.6	100	0.0	0.0	0.0	0.0	0.7	0.7	0.7
	average	49.2	0.3	49.5	39.7	11.1	50.8	100	0.1	0.0	0.1	1.7	1.5	3.2	3.3

January

		All bulbs							Diseased bulbs						
		Complete scales			Incomplete scales			Total	Complete scales			Incomplete scales			Total
Variety	Treatment	no dry scale	dry scale	total	no dry scale	dry scale	total		no dry scale	dry scale	total	no dry scale	dry scale	total	
		%													
Joaquin	Check	36.0	0.0	36.0	32.8	31.2	64.0	100.0	0.0	0.0	0.0	2.4	2.4	4.8	4.8
	Heat	24.8	0.8	25.6	40.7	33.7	74.4	100.0	0.0	0.0	0.0	12.3	1.6	13.9	13.9
	Kaolinite	36.0	0.8	36.8	34.4	28.8	63.2	100.0	0.0	0.0	0.0	2.4	0.0	2.4	2.4
	Straw	41.6	1.6	43.2	27.2	29.6	56.8	100.0	0.0	0.0	0.0	0.8	0.8	1.6	1.6
	average	34.6	0.8	35.4	33.8	30.8	64.6	100.0	0.0	0.0	0.0	4.5	1.2	5.7	5.7
Granero	Check	6.4	0.0	6.4	32.0	61.6	93.6	100.0	0.0	0.0	0.0	3.2	2.4	5.6	5.6
	Heat	8.0	0.0	8.0	24.0	68.0	92.0	100.0	0.0	0.0	0.0	7.2	2.4	9.6	9.6
	Kaolinite	8.0	0.0	8.0	17.0	74.9	91.9	100.0	0.0	0.0	0.0	0.8	1.7	2.5	2.5
	Straw	4.8	0.0	4.8	36.3	58.7	95.0	100.0	0.0	0.0	0.0	0.8	0.0	0.8	0.8
	average	6.8	0.0	6.8	27.3	65.8	93.1	100.0	0.0	0.0	0.0	3.0	1.6	4.6	4.6
Average	Check	21.2	0.0	21.2	32.4	46.4	78.8	100.0	0.0	0.0	0.0	2.8	2.4	5.2	5.2
	Heat	16.4	0.4	16.8	32.3	50.9	83.2	100.0	0.0	0.0	0.0	9.8	2.0	11.8	11.8
	Kaolinite	22.0	0.4	22.4	25.7	51.8	77.5	100.0	0.0	0.0	0.0	1.6	0.8	2.4	2.4
	Straw	23.2	0.8	24.0	31.8	44.2	75.9	100.0	0.0	0.0	0.0	0.8	0.4	1.2	1.2
	average	20.7	0.4	21.1	30.5	48.3	78.9	100.0	0.0	0.0	0.0	3.7	1.4	5.1	5.1

Table 7. (Continued) Internal defects averaged over two dates for two varieties of onions submitted to four treatments, Malheur Experiment Station, Oregon State University, Ontario, OR, 2017.

Average		All bulbs							Diseased bulbs						
		Complete scales			Incomplete scales			Total	Complete scales			Incomplete scales			Total
Variety	Treatment	no dry scale	dry scale	total	no dry scale	dry scale	total		no dry scale	dry scale	total	no dry scale	dry scale	total	
		%													
Joaquin	Check	49.6	0.0	49.6	30.4	20.0	50.4	100.0	0.0	0.0	0.0	1.2	1.6	2.8	2.8
	Heat	42.0	0.4	42.4	29.5	28.1	57.6	100.0	0.4	0.0	0.4	9.0	2.4	11.4	11.8
	Kaolinite	50.8	1.2	52.0	32.0	16.0	48.0	100.0	0.0	0.0	0.0	1.6	0.0	1.6	1.6
	Straw	51.6	0.8	52.4	27.9	19.9	47.9	100.0	0.0	0.0	0.0	0.4	0.8	1.2	1.2
	average	48.5	0.6	49.1	30.0	21.0	51.0	100.0	0.1	0.0	0.1	3.0	1.2	4.2	4.3
Granero	Check	21.2	0.0	21.2	41.9	37.8	79.7	100.0	0.0	0.0	0.0	1.6	2.4	4.0	4.0
	Heat	23.6	0.0	23.6	33.2	43.2	76.4	100.0	0.0	0.0	0.0	6.9	4.0	10.9	10.9
	Kaolinite	20.4	0.0	20.4	38.6	41.0	79.7	100.0	0.0	0.0	0.0	0.8	0.8	1.6	1.6
	Straw	22.8	0.4	23.2	43.8	33.0	76.7	100.0	0.0	0.0	0.0	0.4	0.0	0.4	0.4
	average	22.0	0.1	22.1	39.4	38.7	78.1	100.0	0.0	0.0	0.0	2.4	1.8	4.2	4.2
Average	Check	35.4	0.0	35.4	36.2	28.9	65.0	100.0	0.0	0.0	0.0	1.4	2.0	3.4	3.4
	Heat	32.8	0.2	33.0	31.3	35.6	67.0	100.0	0.2	0.0	0.2	7.9	3.2	11.1	11.3
	Kaolinite	35.6	0.6	36.2	35.3	28.5	63.8	100.0	0.0	0.0	0.0	1.2	0.4	1.6	1.6
	Straw	37.2	0.6	37.8	35.8	26.5	62.3	100.0	0.0	0.0	0.0	0.4	0.4	0.8	0.8
LSD(0.05)															
Treatment		NS[a]	NS	NS	NS	NS	NS		NS	NS	NS	NS	1.8	6.5	6.8
Variety		9.9	NS	9.9	8.4	7.8	6.4		NS	NS	NS	NS	NS	NS	NS
Date		8.0	NS	7.1	NS	5.6	6.4		NS	NS	NS	1.2	NS	1.2	1.2
Treatment X variety		NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS
Treatment X date		NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	1.7	NS	NS
Trt. X var. X date		NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS
Variety X date		NS	NS	NS	14.3	8.0	NS		NS	NS	NS	NS	NS	NS	NS

[a]Not significant.

Table 8. Internal decomposition by disease type on November 15, 2017 and January 29, 2018 for two varieties of onions submitted to four treatments, Malheur Experiment Station, Oregon State University, Ontario, OR, 2017. Continued on next page.

Variety	Treatment	Bacterial rot	*Fusarium proliferatum*	Neck rot	Black mold
November					
		--------------- % ---------------			
Joaquin	Check	0.0	0.0	0.0	0.7
	Heat	0.0	0.0	6.4	2.7
	Kaolinite	0.0	0.0	0.8	0.0
	Straw	0.0	0.0	0.0	0.6
	average	0.0	0.0	1.8	1.0
Granero	Check	0.0	0.0	0.0	1.9
	Heat	1.6	0.0	4.2	5.3
	Kaolinite	0.0	0.0	0.0	0.7
	Straw	0.0	0.0	0.0	0.0
	average	0.4	0.0	1.0	2.0
Average	Check	0.0	0.0	0.0	1.3
	Heat	0.8	0.0	5.3	4.0
	Kaolinite	0.0	0.0	0.4	0.3
	Straw	0.0	0.0	0.0	0.3
	average	0.2	0.0	1.4	1.5

Variety	Treatment	Bacterial rot	*Fusarium proliferatum*	Neck rot	Black mold
January					
		--------------- % ---------------			
Joaquin	Check	0.0	0.0	2.4	2.0
	Heat	0.0	0.0	12.3	2.9
	Kaolinite	0.0	0.0	2.4	0.0
	Straw	0.0	0.0	0.8	0.7
	average	0.0	0.0	4.5	1.4
Granero	Check	0.0	0.8	4.8	0.0
	Heat	0.0	0.0	7.2	3.3
	Kaolinite	0.0	0.0	0.8	1.4
	Straw	0.0	0.0	0.8	0.0
	average	0.0	0.2	3.4	1.2
Average	Check	0.0	0.4	3.6	1.0
	Heat	0.0	0.0	9.8	3.1
	Kaolinite	0.0	0.0	1.6	0.7
	Straw	0.0	0.0	0.8	0.3
	average	0.0	0.1	3.9	1.3

Table 8. (Continued) Internal decomposition by disease type averaged over two dates for two varieties of onions submitted to four treatments, Malheur Experiment Station, Oregon State University, Ontario, OR, 2017.

Average Variety	Treatment	Bacterial rot	*Fusarium proliferatum*	Neck rot	Black mold
			--------------- % ---------------		
Joaquin	Check	0.0	0.0	1.2	1.3
	Heat	0.0	0.0	9.4	2.8
	Kaolinite	0.0	0.0	1.6	0.0
	Straw	0.0	0.0	0.4	0.7
	average	0.0	0.0	3.1	1.2
Granero	Check	0.0	0.4	2.4	1.0
	Heat	0.8	0.0	5.7	4.3
	Kaolinite	0.0	0.0	0.4	1.0
	Straw	0.0	0.0	0.4	0.0
	average	0.2	0.1	2.2	1.6
Average	Check	0.0	0.2	1.8	1.2
	Heat	0.4	0.0	7.5	3.6
	Kaolinite	0.0	0.0	1.0	0.5
	Straw	0.0	0.0	0.4	0.3
LSD(0.05)					
Treatment		NS	NS	NS	1.9
Variety		NS	NS	NS	NS
Date		NS	NS	1.3	NS
Treatment X variety		NS	NS	NS	NS
Treatment X date		NS	NS	NS	NS
Trt. X var. X date		NS	NS	NS	NS
Variety X date		NS	NS	NS	NS

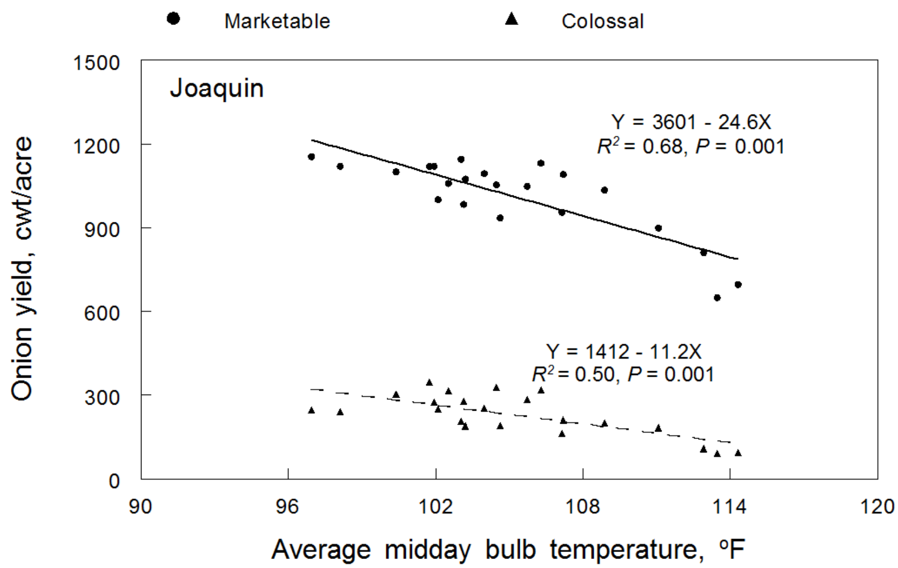

Figure 4. Onion yield response to average midday bulb temperature for Joaquin. Malheur Experiment Station, Oregon State University, Ontario, OR, 2017.

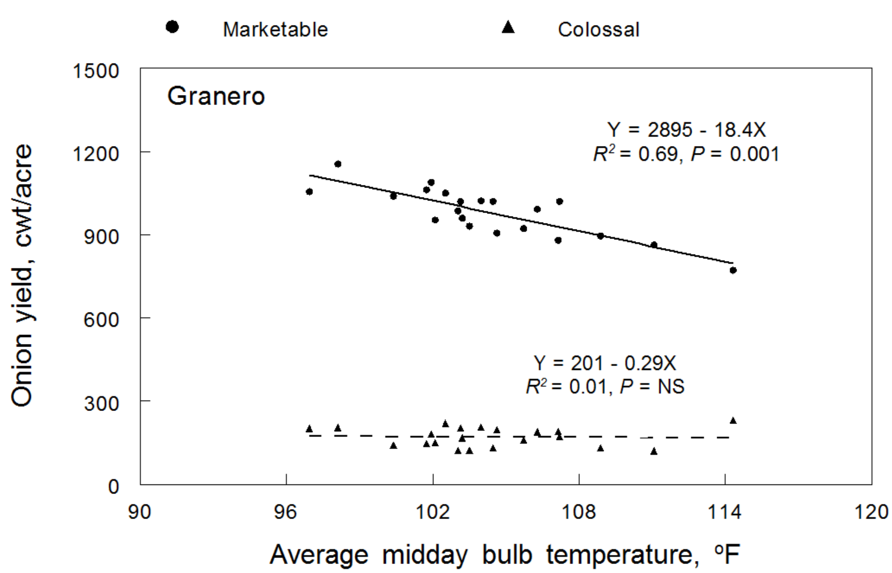

Figure 5. Onion yield response to average midday bulb temperature for Granero. Malheur Experiment Station, Oregon State University, Ontario, OR, 2017.

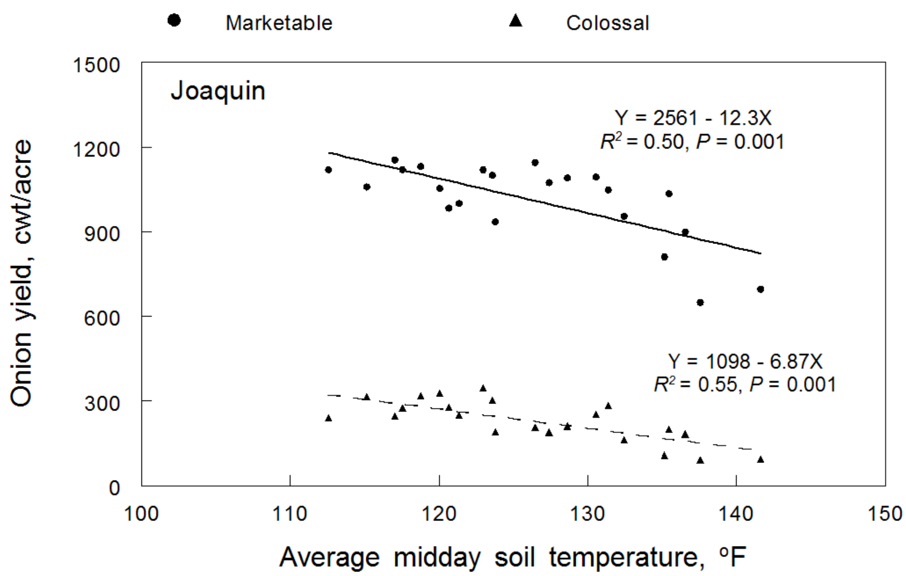

Figure 6. Onion yield response to average midday soil temperature for Joaquin. Malheur Experiment Station, Oregon State University, Ontario, OR, 2017.

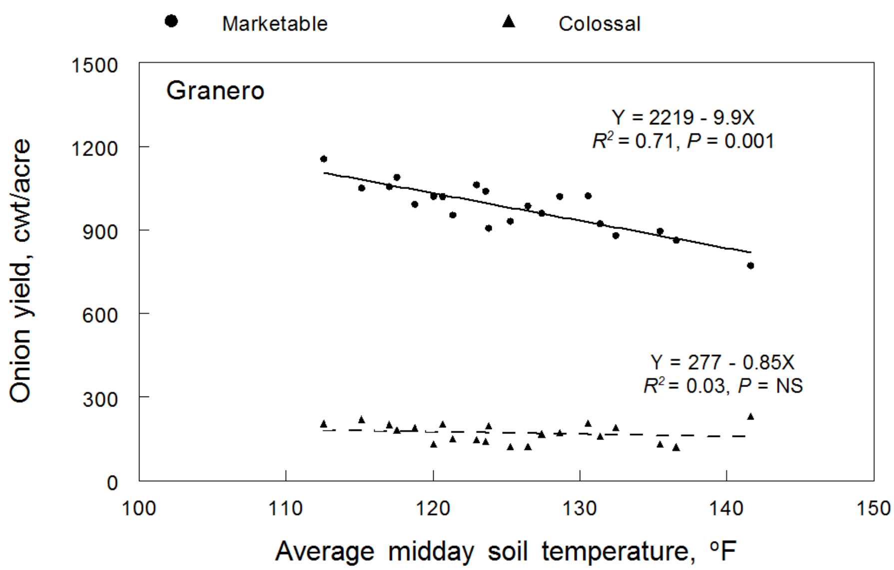

Figure 7. Onion yield response to average midday soil temperature for Granero. Malheur Experiment Station, Oregon State University, Ontario, OR, 2017.

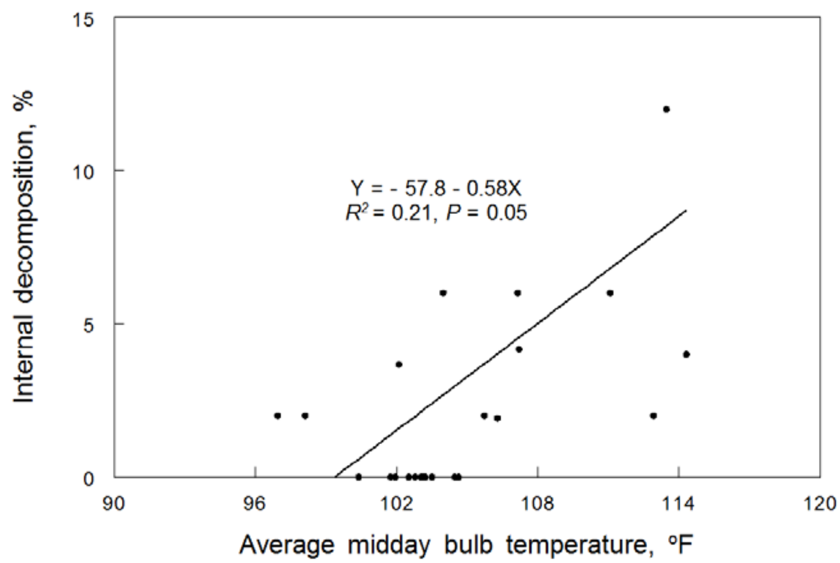

Figure 8. Onion internal decomposition out of storage on November 15 in response to average midday bulb temperature averaged over two varieties. Malheur Experiment Station, Oregon State University, Ontario, OR, 2017.

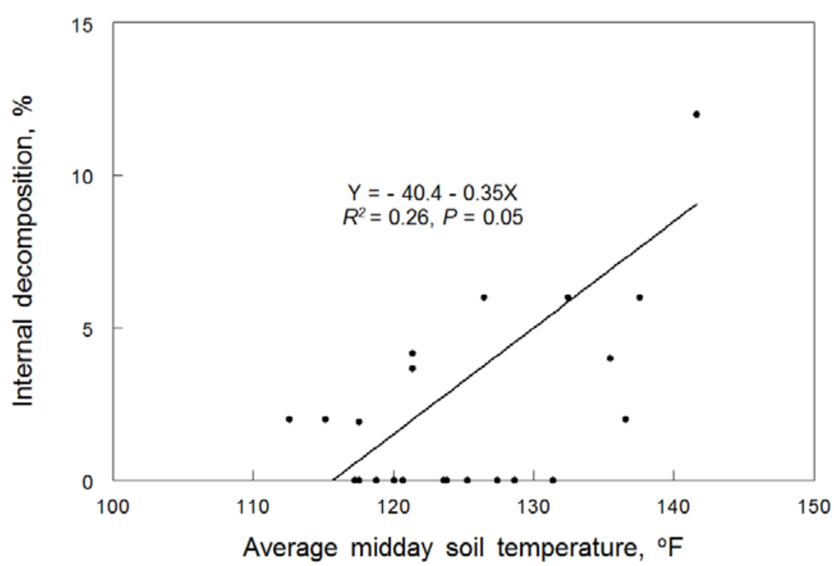

Figure 9. Onion internal decomposition out of storage on November 15 in response to average midday soil temperature averaged over two varieties. Malheur Experiment Station, Oregon State University, Ontario, OR, 2017.