ONION RESPONSE TO PHOSPHORUS APPLICATION STRATEGIES AND IN-SEASON NUTRIENT SUPPLEMENTATION, 2014

Clinton C. Shock, Jose M. Pinto, Erik B. G. Feibert, and Lamont D. Saunders, Malheur Experiment Station, Oregon State University, Ontario, OR

Introduction

In the field, germinating onion seed and new onion seedlings can have difficulty obtaining adequate phosphorus for ideal early growth. Low soil temperatures in the spring in Oregon and Idaho reduce soil phosphorus availability. In addition, soil fumigation to improve onion health can have negative effects, reducing mycorrhizal fungi that enhance nutrient absorption by onion roots. Treasure Valley soils are generally alkaline. Phosphorus solubility in alkaline soils can be low due to reactions with calcium and magnesium forming low solubility compounds. High soil lime content can exacerbate the low solubility of phosphorus in alkaline soils. Phosphorus fertilization at planting could enhance early season onion growth. Phosphate supplementation through a drip irrigation system during the season could also result in yield enhancements. Two methods that can be used to determine the need for in-season nutrient supplementation are root tissue analysis and soil solution analysis. This trial tested phosphorus application at planting and nutrient supplementation during the season based on tissue and soil solution tests using two onion varieties at two plant populations. Onion plant populations were representative of those used in the Treasure Valley of Oregon and Idaho (120,000 plants/acre) and plant populations used in many other parts of the world (450,000 plants/acre).

Materials and Methods

Onions were grown in 2014 on an Owyhee silt loam. The field had been planted to wheat in 2013. In the fall of 2013, the wheat stubble was shredded and the field was irrigated. The field was then disked, moldboard plowed, and groundhogged. A soil analysis taken in the fall of 2013 showed a pH of 7.9, 1.27% organic matter, 181% base saturation, 21 ppm of phosphorus (P), 418 ppm of potassium (K), and less than 1.5% lime. Based on the soil analysis, 500 lb of sulfur (S)/acre, 3 lb of manganese (Mn)/acre, and 1 lb of boron (B)/acre were broadcast before plowing. Phosphorus was intentionally not added in the fall. After plowing, the field was fumigated with Vapam® at 15 gal/acre and bedded at 22 inches.

Seed was planted on March 18 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 with customized John Deere Flexi Planter units equipped with disc openers. Immediately after planting, the onions received a narrow band of Lorsban 15G® at 3.7 oz/1,000 ft of row (0.82 lb

ai/acre) over the planted rows, and the soil surface was rolled. Onion emergence started on April 7.

The field had drip tape laid at 4-inch depth between 2 onion beds during planting. The drip tape had emitters spaced 12 inches apart and 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 experimental design was a split-split plot randomized complete block with six replicates. There were six main treatments with variable fertilization, timing, and methods of application:

1. Check, no P sidedress at planting, nutrients added by fall soil analysis only plus 100 lb nitrogen (N)/acre.
2. No P sidedress at planting, nutrients added by fall soil analysis, then nutrients added through the season based on root tissue analysis.
3. No P sidedress at planting, nutrients added by fall soil analysis, then nutrients added through the season based on root tissue and soil solution analysis.
4. No P sidedress at planting, nutrients added by fall soil analysis, then nutrients added through the season based on root tissue and soil solution analysis, except P that was only added if the soil solution tests indicated the need for it.
5. No P sidedress at planting, nutrients added by fall soil analysis, then nutrients added through the season based on root tissue and soil solution analysis, except K that was only added if the soil solution tests indicated the need for it.
6. Phosphorus, Avail, and humic acid sidedress at planting, nutrients added by fall soil analysis, then nutrients added through the season based on root tissue analysis.

Two onion varieties (‘Vaquero’, Nunhems, Parma, ID and ‘Avalon’, Crookham, Caldwell, ID) were planted as split plots within each main plot. Each variety split plot was divided into two plant population split-split plots (120,000 plants/acre and 450,000 plants/acre). Main plots were 4 double rows wide by 54 ft long. Variety split plots were 27 ft long and plant population split-split plots were 13.5 ft long.

On March 20, treatment 6 was sidedressed between the seed row and the drip tape at 3-inch depth. For treatment 6, P was applied as phosphoric acid (NUE 0-30-0, Bio-Gro, Mabton, WA) at 26 lb P/acre. For treatment 6, 6 gal/acre of humic acid (CHB Premium 6, Bio-Gro, 5% humic acid) and Avail (Simplot, Caldwell, ID) at 0.5% of the final volume, were added to the phosphoric acid.

On May 14, split-split plots were thinned by hand to 120,000 plants/acre (4.75 inches between plants in each single row) and 450,000 plants/acre plots (1.4 inches between plants in each single row).

Starting on June 4 and every week thereafter, four plants along with their bulbs with roots were sampled from the nonharvest rows of each plot of each treatment and the bulbs and roots washed in deionized water. One composite sample from each treatment consisting of the roots from all plots in each treatment was sent to Western Laboratories, Inc. (Parma, ID) for nutrient analysis. Starting in July only 3 plants were sampled per plot for the composite treatment sample.

Every week starting on June 4, soil samples from treatments 3, 4, and 5 were sent to Western Laboratories, Inc. for soil solution analysis. Each sample consisted of a composite of 7 soil cores to 9-inch depth from the center of nonharvested onion double rows in each plot. Soil solution analysis is a proprietary analysis developed by Western Laboratories, Inc. that uses a weak acid extraction of the soil nutrients to simulate the extraction capacity of plant roots. Soil solution analysis estimated the amount of each nutrient that the soil can supply to the crop per day.

For treatments 2 to 6, nutrients were applied weekly based on root tissue and/or soil solution analysis (Table 11). Each treatment had a separate mainline that supplied water to the drip tape in all plots within that treatment. Nutrients were injected independently into the drip irrigation system of each treatment using an Ozawa Precision Metering Pump (Ozawa R and D, Ontario, OR).

Onions were irrigated automatically to maintain the soil water tension (SWT) in the onion root zone below 20 cb. Soil water tension was measured in each 450,000-plant/acre split-split plot in the Vaquero split plot in each main plot of replicate 3. Soil water tension in each split-split plot of replicate 3 was measured 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. 1998). The GMS were connected to the datalogger via multiplexers (AM 410 multiplexer, Campbell Scientific, Logan, UT). The datalogger read the sensors and recorded the SWT every hour. The datalogger automatically made irrigation decisions every 12 hours as previously described (Shock et al. 2002). The irrigation decisions were based on the average SWT of all plots.

The irrigation durations were 7 hours, 10 min to supply 0.48 inches of water per irrigation as had been previously shown to optimize onion performance at Ontario in silt loam (Shock et al. 2005). The irrigations were controlled by the datalogger using a controller (SDM CD16AC controller, Campbell Scientific, Logan, UT) connected to a solenoid valve. 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 automated irrigation system was started on June 9. Irrigations were terminated on September 2.

The onions were managed to minimize yield reductions from weeds, pests, diseases, water stress, and nutrient deficiencies. For weed control, the following herbicides were applied. On April 21, Prowl® H_2O at 0.83 lb ai/acre (2 pt/acre) was broadcast. On May 8, Goal Tender® at 0.09 lb ai/acre (4 oz/acre), Buctril® at 0.25 lb ai/acre (16 oz/acre), and Poast® at 0.38 lb ai/acre (24 oz/acre) were broadcast. On June 5, Poast at 0.38 lb ai/acre (24 oz/acre) was broadcast.

For thrips control, the following insecticides were applied: Movento® at 5 oz/acre on May 27 and June 5 (ground applications), Radiant® at 10 oz/acre on June 12 (ground application), Agri-Mek® at 16 oz/acre on June 19 (ground application), and 30 (aerial application), Lannate® at 0.9 lb ai/acre on July 6 and 13 (aerial applications), and Radiant at 10 oz/acre on July 22 and 27 (aerial applications).

For disease control, Quadris Opti® was broadcast aerially on August 18.

All split-split plots were evaluated for maturity and for severity of symptoms of iris yellow spot virus (IYSV) on August 20. Onions were evaluated subjectively for maturity by visually rating the percentage of onions with the tops down and the percent dryness of the foliage. The number

of bolted onion plants was counted in each plot. Each plot was 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 onions were lifted on September 10 to field cure. Onions from the 9 ft of the middle 2 rows in each split-split plot were topped by hand and bagged on September 17. The bags were put in storage on September 23. 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 11.

During grading, all bulbs from each split-split plot were counted. Bulbs were then separated according to quality: bulbs without blemishes (No. 1s), split bulbs (No. 2s), and bulbs infected with neck rot (*Botrytis allii*) in the neck or side, plate rot (*Fusarium oxysporum*), or black mold (*Aspergillus niger*). 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). For the purposes of this report, all No. 1 bulbs were considered marketable. In markets where colossal and supercolossal bulbs are desired and plant populations are low, very few of the bulbs are small. In markets where medium and small bulbs are desired and plant populations are high, there are very few colossal and supercolossal bulbs. 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 were compared using analysis of variance, ANOVA. Means separation was determined using a protected Fisher's least significant difference test at the 5% probability level, LSD (0.05).

Results and Discussion

Soil water tension remained close to the target of 20 cb during the season (Fig. 1).

Root tissue concentrations of N, P, K, S, calcium (Ca), zinc (Zn), magnesium (Mg), Mn, copper (Cu), and B went below their critical levels at different times during the season for all treatments (Tables 1-10). These nutrients were supplemented to all treatments, except treatment 1, which received only 100 lb N/acre and treatments 4 and 5 where the P and K, respectively, were based exclusively on the soil solution results (Table 11). Treatment 4, which received P based on soil solution analysis only, did not require any P. Treatment 5, which received K based on soil solution analysis only, did not require any K.

Based on the root tissue analysis, root nitrate concentrations were below the critical level for all treatments until July 1. After July 1, root tissue nitrate concentrations of some of the treatments went above the critical level on some of the sampling dates. Root tissue nitrate concentrations of the check treatment, which received 100 lb N/acre, only went above the critical level on the last sampling on August 15. Based on the root tissue analysis, the onions became K deficient by July 1 and never recovered in spite of the repeated application of K through the drip system. Phosphorus root tissue content went below the critical level in the middle of July and only recovered at the last sampling on August 15 in spite of the application of P through the drip system.

Soil solution analysis for treatments 3, 4, and 5 showed that levels of all nutrients, except Mn, remained above critical levels all season (Table 12). Levels of Mn were below the critical level until July 22. Based on the soil solution analyses, Mn was applied to treatments 3, 4, and 5. Analysis of total available N in the soil samples taken for the soil solution tests showed that there were substantial amounts of available N in the top foot of soil all season, except for treatment 4 on the July 8 sampling (Table 13).

Effects of the fertilization treatments

There was no significant difference in any onion yield category between fertigation treatments for either variety or plant population (Table 14). Averaged over the two varieties and the two plant populations, the check treatment had a lower percentage of leaf dryness on August 20 than the other treatments and lower IYSV severity than treatments 3, 4, and 6 (Table 15).

Effects of the plant populations

Averaged over varieties and treatments, supercolossal, colossal, and jumbo yields were higher with the 120,000-plants/acre population than with the 450,000-plants/acre population (Table 14). Averaged over varieties and treatments, total yield, medium yield, small yield, and storage rot were higher with the 450,000 plants/acre. These differences in the proportion of yield by bulb size were expected based on previous studies on onion grade response to plant population (Shock et al. 2004, 2013).

Economic benefits of the fertilization treatments

Based on the fall soil analysis, yield responses to P and K application would not be expected. For fumigated soils with low lime content in the Treasure Valley, when soil P concentration is 20 ppm or higher, no added P is required (Sullivan et al. 2001). In the Treasure Valley, when soil K concentration is 100 ppm or higher, no added K is required (Sullivan et al. 2001). Our fall soil analysis showed 21 ppm P, 418 ppm K, and less than 1.5% free lime. Research at the Parma Research and Extension Center showed that even on a soil with low P concentration (6.8-8.2 ppm P) and high lime content (11-12% lime), onion yield responded to added P in only 1 out of the 3 years of research (Brown 2001).

The lack of yield response to nutrient supplementation based on tissue tests in this trial was consistent with the soil solution analyses, that showed levels of all nutrients, except Mn, remained above critical levels all season, despite treatment 4 receiving no P and treatment 5 receiving no K.

The 2013 fertigation trial was conducted on a silt loam with pH of 7.3, and 22 ppm P, 355 ppm K, and less than 1.5% free lime (Shock et al. 2013). The 2013 results showed that there was no difference in yield between the check treatment and the treatments supplemented with nutrients based on root tissue testing. There was also no benefit from P supplementation at planting in 2013. According to the soil solution analyses in 2013, only Cu went below the critical level at some samplings.

Conclusions

The 2013 and 2014 trials were conducted on fumigated Owyhee silt loam soils with adequate levels of P and K, and low free lime. P supplementation at planting did not increase onion yield or grade either year. Nutrient supplementation during the season based on root tissue analyses did not increase onion yield or grade either year. Nutrient supplementation during the season based on soil solution analyses was only indicated for Cu in 2013 and Mn in 2014, which did not increase onion yield or grade. These results suggest that onion growers may be able to reduce nutrient applications through the use of soil solution testing.

Acknowledgements

This project was funded by the Idaho-Eastern Oregon Onion Committee, cooperating onion seed companies, Oregon State University, the Malheur County Education Service District and supported by Formula Grant no. 2014-31100-06041 and Formula Grant no. 2014-31200-06041 from the USDA National Institute of Food and Agriculture.

References

Brown, B.D. 2001. Onion response to fumigation and P placement. In: Proc. Western Nutrient Management Conf., Vol. 4. March 8-9, 2001. Salt Lake City, UT.

Shock, C.C., J. Barnum, and M. Seddigh. 1998. Calibration of Watermark soil moisture sensors for irrigation management. Irrigation Association. Proceedings of the International Irrigation Show. Pages 139-146. San Diego, CA.

Shock, C.C., E.B.G. Feibert, L.D. Saunders, and E.P. Eldredge. 2002. Automation of subsurface drip irrigation for crop research. American Society of Agricultural Engineers. World Congress on Computers in Agriculture and Natural Resources. Iguazu Falls, Brazil. Pages 809-816.

Shock, C.C., E.B.G. Feibert, and L.D. Saunders. 2004. Plant population and nitrogen fertilization for subsurface drip-irrigated onion. HortScience 39:1722-1727.

Shock, C.C., E.B.G. Feibert, and L.D. Saunders. 2005. Onion response to drip irrigation intensity and emitter flow rate. HortTechnology 15:652-659.

Shock, C.C., E.B.G. Feibert, and L.D. Saunders. 2013. Onion variety response to plant population and irrigation system. Oregon State University Agricultural Experiment Station Ext/CrS 144:35-62.

Shock, C.C., E.B.G. Feibert, and L.D. Saunders. 2013. Onion response to phosphorus application strategies and in-season nutrient strategies. Oregon State University Agricultural Experiment Station Ext/CrS 149:47-56.

Sullivan, D.M., B.D. Brown, C.C. Shock, D.A. Horneck, R.G. Stevens, G.Q. Pelter, and E.B.G. Feibert. 2001. Nutrient management for onions in the Pacific Northwest. Pacific Northwest Ext. Publ. 546.

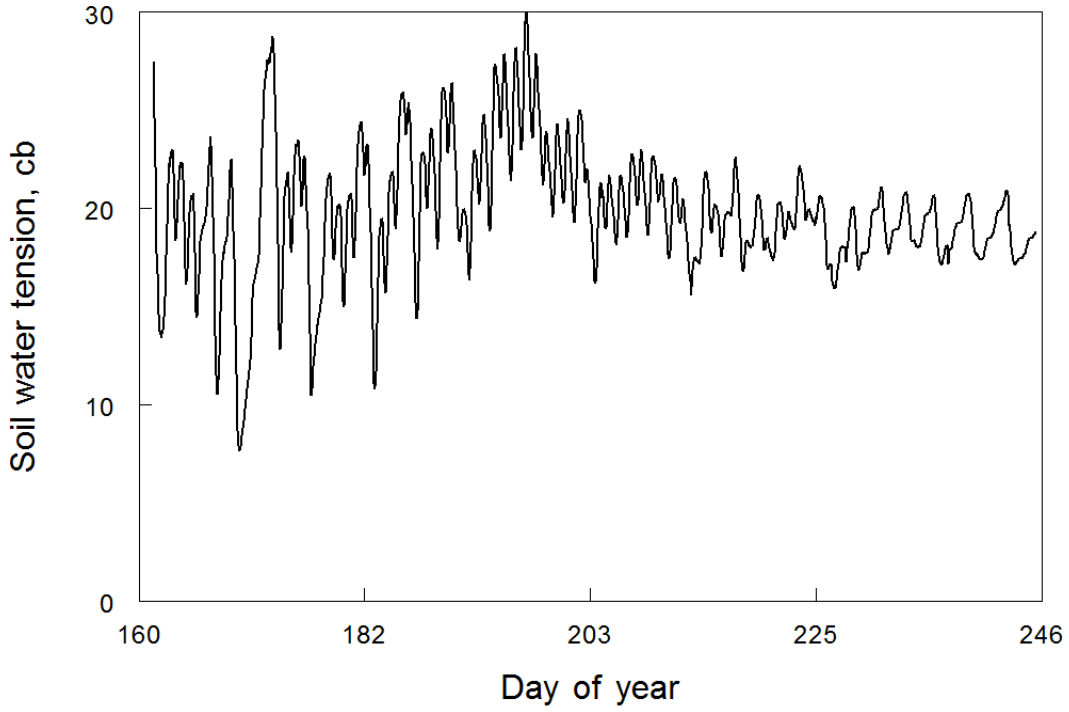

Figure 1. Soil water tension at 8-inch depth for onions irrigated at a soil water tension of 20 cb. Malheur Experiment Station, Oregon State University, Ontario, OR, 2014.

Table 1. Nitrate-N concentration (ppm) in onion root tissue for six fertigation treatments. Malheur Experiment Station, Oregon State University, Ontario, OR, 2014.

		Treatment					
Date	Sufficiency range	1	2	3	4	5	6
4-Jun	8239	1612	121	575	419	357	369
17-Jun	7108	1605	1862	2265	2446	2383	974
24-Jun	5020	3297	2639	3422	4491	2238	3593
1-Jul	4411	1837	1617	3806	4998	4716	1677
8-Jul	3802	1605	1735	2172	1416	1731	1789
15-Jul	3193	1650	2361	4404	4288	3444	3078
22-Jul	2584	2260	2937	4606	2793	2014	3425
29-Jul	1975	1015	755	2005	1933	1593	
5-Aug	1366	721	868	1947	2168	1790	1355
14-Aug	583	1876	2610	1804	2737	1700	2118

Table 2. Phosphorus concentration (%) in onion root tissue for six fertigation treatments. Malheur Experiment Station, Oregon State University, Ontario, OR, 2014.

		Treatment					
Date	Sufficiency range	1	2	3	4	5	6
4-Jun	0.32 - 0.7	0.31	0.31	0.29	0.27	0.28	0.30
17-Jun	0.32 - 0.7	0.38	0.43	0.32	0.39	0.39	0.45
24-Jun	0.32 - 0.7	0.31	0.43	0.70	0.36	0.50	0.44
1-Jul	0.32 - 0.7	0.88	0.92	0.48	0.38	0.49	0.78
8-Jul	0.32 - 0.7	0.55		0.26	0.48	0.55	0.42
15-Jul	0.32 - 0.7	0.29	0.29	0.28	0.29	0.27	0.48
22-Jul	0.32 - 0.7	0.32	0.30	0.31	0.30	0.29	0.31
29-Jul	0.32 - 0.7	0.15	0.17	0.28	0.26	0.29	0.13
5-Aug	0.32 - 0.7		0.19	0.30	0.27	0.20	0.19
14-Aug	0.32 - 0.7	0.91	0.82	0.70	0.50	0.70	0.88

Table 3. Potassium concentration (%) in onion root tissue for six fertigation treatments. Malheur Experiment Station, Oregon State University, Ontario, OR, 2014.

		Treatment					
Date	Sufficiency range	1	2	3	4	5	6
4-Jun	2.7 - 6	4.14	4.17	3.82	3.56	3.52	3.68
17-Jun	2.7 - 6	3.14	3.48	3.33	3.40	3.52	3.59
24-Jun	2.7 - 6	2.53	3.12	3.34	2.78	2.99	3.50
1-Jul	2.7 - 6	1.96	2.49	2.34	1.86	2.10	2.52
8-Jul	2.7 - 6	1.57		3.21	2.11	2.13	0.82
15-Jul	2.7 - 6	1.94	1.84	1.91	1.62	1.61	2.11
22-Jul	2.7 - 6	2.83	2.08	1.99	1.64	1.37	2.55
29-Jul	2.7 - 6	5.57	5.02	1.25	1.04	0.81	5.20
5-Aug	2.7 - 6		2.93	1.31	1.10	0.72	3.00
14-Aug	2.7 - 6	1.38	0.85	0.98	1.09	0.77	0.87

Table 4. Sulfur concentration (%) in onion root tissue for six fertigation treatments. Malheur Experiment Station, Oregon State University, Ontario, OR, 2014.

		Treatment					
Date	Sufficiency range	1	2	3	4	5	6
4-Jun	0.24 - 0.85	0.85	0.94	0.86	0.81	0.84	0.92
17-Jun	0.24 - 0.85	0.99	1.26	0.91	1.02	1.04	1.34
24-Jun	0.24 - 0.85	1.11	1.15	1.18	1.02	1.03	1.29
1-Jul	0.24 - 0.85	0.84	0.96	1.05	1.03	1.21	1.16
8-Jul	0.24 - 0.85	0.96		0.20	0.23	0.23	0.56
15-Jul	0.24 - 0.85	1.06	1.14	1.08	1.21	1.09	1.37
22-Jul	0.24 - 0.85	1.00	1.08	0.98	1.18	1.04	1.00
29-Jul	0.24 - 0.85	0.12	0.11	1.25	1.20	0.96	0.11
5-Aug	0.24 - 0.85		0.31	0.93	1.07	1.01	0.24
14-Aug	0.24 - 0.85	1.31	1.20	0.74	1.31	1.48	1.35

Table 5. Calcium concentration (%) in onion root tissue for six fertigation treatments. Malheur Experiment Station, Oregon State University, Ontario, OR, 2014.

		Treatment					
Date	Sufficiency range	1	2	3	4	5	6
4-Jun	0.4 - 1.2	0.75	0.76	0.60	0.62	0.66	0.69
17-Jun	0.4 - 1.2	0.90	0.65	0.77	0.52	0.66	0.68
24-Jun	0.4 - 1.2	1.03	0.85	0.81	1.07	0.93	0.89
1-Jul	0.4 - 1.2	0.89	0.87	0.73	0.87	0.93	0.90
8-Jul	0.4 - 1.2	0.96		2.10	1.88	1.42	0.59
15-Jul	0.4 - 1.2	0.89	1.03	0.97	1.13	1.28	0.90
22-Jul	0.4 - 1.2	1.09	1.10	1.98	1.04	1.02	1.16
29-Jul	0.4 - 1.2	2.62	2.67	1.23	1.25	1.34	2.50
5-Aug	0.4 - 1.2		0.51	1.24	1.37	2.15	0.49
14-Aug	0.4 - 1.2	0.88	1.20	1.82	1.02	1.40	1.20

Table 6. Magnesium concentration (%) in onion root tissue for six fertigation treatments. Malheur Experiment Station, Oregon State University, Ontario, OR, 2014.

		Treatment					
Date	Sufficiency range	1	2	3	4	5	6
4-Jun	0.3 - 0.6	0.51	0.52	0.46	0.45	0.46	0.51
17-Jun	0.3 - 0.6	0.52	0.51	0.49	0.46	0.49	0.46
24-Jun	0.3 - 0.6	0.54	0.51	0.48	0.50	0.45	0.55
1-Jul	0.3 - 0.6	0.44	0.42	0.41	0.40	0.41	0.45
8-Jul	0.3 - 0.6	0.37		0.53	0.41	0.42	0.18
15-Jul	0.3 - 0.6	0.34	0.36	0.34	0.36	0.35	0.37
22-Jul	0.3 - 0.6	0.39	0.39	0.55	0.34	0.36	0.38
29-Jul	0.3 - 0.6	1.31	1.19	0.39	0.41	0.36	1.40
5-Aug	0.3 - 0.6		0.11	0.36	0.35	0.41	0.11
14-Aug	0.3 - 0.6	0.29	0.35	0.32	0.32	0.34	0.34

Table 7. Zinc concentration (%) in onion root tissue for six fertigation treatments. Malheur Experiment Station, Oregon State University, Ontario, OR, 2014.

		Treatment					
Date	Sufficiency range	1	2	3	4	5	6
4-Jun	25 - 50	41	36	35	34	35	33
17-Jun	25 - 50	44	22	31	34	40	36
24-Jun	25 - 50	46	42	41	34	52	33
1-Jul	25 - 50	19	18	22	17	22	18
8-Jul	25 - 50	22		25	31	58	23
15-Jul	25 - 50	16	15	25	24	19	21
22-Jul	25 - 50	12	11	15	16	11	10
29-Jul	25 - 50	3	4	16	19	16	4
5-Aug	25 - 50		21	24	23	21	35
14-Aug	25 - 50	10	20	12	13	18	11

Table 8. Manganese concentration (%) in onion root tissue for six fertigation treatments. Malheur Experiment Station, Oregon State University, Ontario, OR, 2014.

		Treatment					
Date	Sufficiency range	1	2	3	4	5	6
4-Jun	35 - 100	171	156	165	155	156	160
17-Jun	35 - 100	179	104	152	113	150	144
24-Jun	35 - 100	112	128	135	113	131	112
1-Jul	35 - 100	92	100	101	93	87	95
8-Jul	35 - 100	79		111	137	204	93
15-Jul	35 - 100	50	54	72	60	70	102
22-Jul	35 - 100	49	42	78	50	41	40
29-Jul	35 - 100	23	24	55	62	53	51
5-Aug	35 - 100		125	67	65	84	135
14-Aug	35 - 100	23	50	46	25	28	22

Table 9. Copper concentration (%) in onion root tissue for six fertigation treatments. Malheur Experiment Station, Oregon State University, Ontario, OR, 2014.

		Treatment					
Date	Sufficiency range	1	2	3	4	5	6
4-Jun	6 - 20	17	15	14	17	19	16
17-Jun	6 - 20	26	16	8	12	13	20
24-Jun	6 - 20	9	8	12	12	9	8
1-Jul	6 - 20	15	13	15	14	13	10
8-Jul	6 - 20	9		7	6	9	4
15-Jul	6 - 20	8	9	5	5	9	6
22-Jul	6 - 20	10	7	15	14	4	7
29-Jul	6 - 20	6	9	9	7	8	2
5-Aug	6 - 20		11	7	6	5	12
14-Aug	6 - 20	8	9	8	9	5	10

Table 10. Boron concentration (%) in onion root tissue for six fertigation treatments. Malheur Experiment Station, Oregon State University, Ontario, OR, 2014.

		Treatment					
Date	Sufficiency range	1	2	3	4	5	6
4-Jun	19 - 60	20	21	17	17	18	18
17-Jun	19 - 60	13	15	18	16	19	14
24-Jun	19 - 60	16	14	28	16	31	15
1-Jul	19 - 60	17	15	15	16	17	17
8-Jul	19 - 60	21		18	27	19	13
15-Jul	19 - 60	9	12	22	20	21	15
22-Jul	19 - 60	14	18	38	12	17	18
29-Jul	19 - 60	24	21	16	13	21	24
5-Aug	19 - 60		44	21	19	29	51
14-Aug	19 - 60	14	16	11	12	11	15

Table 11. Nutrients[a] applied to onions (lb/acre) through drip tape during the season for six fertigation treatments. Malheur Experiment Station, Oregon State University, Ontario, OR.

	Treatment																													
	1	2										3										4								
Date	N	N	P	K	S	Ca	Zn	Mg	Mn	Cu	B	N	P	K	S	Ca	Zn	Mg	Mn	Cu	B	N	P	K	S	Ca	Zn	Mg	Mn	Cu	B
5-Jun	40	40	10									40	10								0.2	40									0.2
12-Jun	40											40										40									
19-Jun	20											20	10								0.2	20				1.0			0.3		0.2
25-Jun		20									0.2	20									0.2	20									0.2
2-Jul		20		20			0.3				0.2			10			0.3		0.3		0.2			10			0.3		0.3		0.2
10-Jul		20		20			0.3	5.0		0.2	0.2	20	10		10				0.3		0.2	23		10	10				0.3	0.3	
17-Jul		20	10	20			0.3				0.2		10	10			0.3		0.3	0.3				10			0.3		0.3	0.3	
24-Jul			10	20			0.3				0.2		10	10			0.3							10			0.3				0.2
31-Jul		20	10		10		0.3		0.3				10	10			0.3				0.2			10			0.3				0.2
7-Aug		20	10				0.3	5.0					10	10			0.3							10			0.3			0.3	0.2
Total	100	160	50	80	10		1.8	10.0	0.3	0.2	1.0	140	70	50	10		1.5		0.9	0.3	1.2	143		60	10	1.0	1.5		1.2	0.9	1.4

	Treatment																				
	5										6									
Date	N	P	K	S	Ca	Zn	Mg	Mn	Cu	B	N	P	K	S	Ca	Zn	Mg	Mn	Cu	B
5-Jun	40	10								0.2	40	10								0.2
12-Jun	40										40									
19-Jun	20	10								0.2	20	10								0.2
25-Jun	20									0.2	20									0.2
2-Jul						0.3		0.3		0.2	20		20			0.3				0.2
10-Jul				10				0.3		0.2	20		20			0.3	5.0		0.2	0.2
17-Jul		10				0.3		0.3			20		20			0.3				0.2
24-Jul		10				0.3			0.3	0.2		10	20			0.3				0.2
31-Jul		10				0.3						10		10		0.3			0.2	
7-Aug		10				0.3			0.3			10					5.0			
Total	120	60		10		1.5		0.9	0.6	1.2	180	50	80	10		1.5	10.0		0.4	1.4

[a]N: Urea ammonium nitrate solution 32-0-0
P: NUE 0-30-0 (Bio-Gro, Mabton, WA)
K: NUE Special K24 0-0-24 (Bio-Gro, Mabton, WA)
Mg: Magnesium Dextro-Lac, Agro K Corp., Minneapolis, MN
Mn: Che-Man 5%, PHT, J.R. Simplot Co., Boise, ID
Zn: System-Zn, Agro K Corp., Minneapolis, MN
Cu: Copper Dextro-Lac, Agro K Corp., Minneapolis, MN
B: Concept Boron 10%, Ag Concept Corp., Bliss, ID

Table 12. Weekly soil solution analyses for fertigation treatments 3, 4 and 5. Data represent the amount of each plant nutrient per day that the soil can potentially supply to the crop. Numbers following each nutrient are the critical levels. Malheur Experiment Station, Oregon State University, Ontario, OR.

	N, 2			P, 0.7			K, 10			S, 4.5			Ca, 2			Mg, 1		
Date	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5
	lb/day																	
17-Jun	14.1	16.7	23.1	2.5	2.7	2.6	71.4	67.7	71.1	50.0	52.6	53.0	56.6	57.8	57.4	18.4	18.3	18.2
24-Jun	15.4	20.1	21.0	1.6	1.5	1.5	56.0	54.9	57.4	18.6	19.6	20.8	34.1	34.6	34.4	15.1	15.4	15.2
1-Jul	16.3	22.7	16.3	1.6	1.5	1.4	59.4	56.0	56.0	20.2	21.6	17.0	34.6	34.7	33.9	16.0	15.8	15.3
8-Jul	38.1	2.6	12.9	1.0	1.4	1.5	53.1	55.4	75.1	16.0	9.4	14.0	37.0	39.3	41.1	18.4	15.4	17.6
15-Jul	25.3	24.4	20.1	2.0	1.9	2.2	57.4	55.7	57.4	21.6	17.8	19.6	33.7	32.8	33.2	14.2	14.4	14.6
22-Jul	26.6	20.1	11.6	3.2	3.2	3.3	68.3	58.9	62.6	17.0	15.4	14.2	32.0	31.5	31.0	14.1	13.2	13.0
29-Jul	27.0	24.0	14.6	3.9	3.7	3.9	58.9	57.7	58.6	27.2	29.4	24.4	46.9	47.5	46.3	15.8	15.8	15.5
5-Aug	22.7	23.1	17.1	2.8	2.3	3.0	58.3	60.9	56.0	22.4	22.2	21.8	38.5	39.5	38.2	15.1	15.6	14.9
14-Aug	34.7	43.7	32.1	2.9	2.8	2.8	64.0	63.4	62.6	26.6	27.6	23.8	55.5	36.4	35.6	29.4	29.9	29.3
Avg.	24.5	21.9	18.8	2.4	2.3	2.5	60.8	59.0	61.9	24.4	24.0	23.2	41.0	39.3	39.0	17.4	17.1	17.1

	Zn, 2			Cu, 1			Mn, 2		
Date	3	4	5	3	4	5	3	4	5
	oz/day								
17-Jun	4.0	4.0	4.0	5.0	6.0	5.0	1.3	1.3	1.4
24-Jun	3.0	3.0	3.0	3.0	2.0	4.0	1.1	1.0	1.1
1-Jul	3.0	3.0	3.0	3.0	4.0	6.0	1.3	1.3	1.3
8-Jul	2.0	2.0	2.0	4.0	6.0	2.0	1.5	1.3	1.7
15-Jul	3.0	3.0	3.0	6.0	7.0	5.0	1.6	1.5	1.6
22-Jul	3.0	3.0	3.0	3.0	3.0	4.0	2.4	2.4	2.5
29-Jul	3.0	3.0	3.0	2.0	2.0	2.0	4.2	3.7	3.6
5-Aug	3.0	3.0	3.0	2.0	2.0	2.0	2.7	2.0	2.7
14-Aug	3.0	3.0	3.0	9.0	6.0	9.0	3.8	3.8	3.7
Avg.	3.0	3.0	3.0	4.1	4.2	4.3	2.2	2.0	2.2

Table 13. Soil available N (lb/acre) in top foot of soil during the season measured from weekly soil samples. Malheur Experiment Station, Oregon State University, Ontario, OR.

	Treatment		
Date	3	4	5
17-Jun	99	117	162
24-Jun	108	141	147
1-Jul	114	159	114
8-Jul	267	18	90
15-Jul	177	171	141
22-Jul	186	141	81
29-Jul	189	168	102
5-Aug	159	162	120
14-Aug	243	306	225
Average	171	154	131

Table 14. Onion yield response to at-planting phosphorus applications and in-season fertigation for two varieties and two plant populations. Malheur Experiment Station, Oregon State University, Ontario, OR. Continued on next page.

		Plant population			Marketable yield by grade										
Variety	Treatment	Target	Actual	Total yield	Total	>4¼ in	4-4¼ in	3-4 in	2¼-3 in	Small	No. 2s	Total rot	Neck rot	Plate rot	Bulb counts >4¼ in
		-------- plants/acre --------			---------- cwt/acre ----------							--- % of total yield ---			#/50 lb
Vaquero	1	120,000	119,448	835.5	806.4	0.0	73.9	676.1	51.8	4.7	0.0	3.5	3.4	0.0	
	2	120,000	127,763	860.5	834.8	0.0	57.0	717.1	51.7	9.0	0.0	2.9	2.9	0.0	
	3	120,000	131,722	829.6	814.2	3.7	57.2	683.5	60.8	9.0	2.5	1.6	1.6	0.0	35.7
	4	120,000	120,107	798.1	748.1	3.5	53.1	618.8	63.4	9.3	2.8	6.0	6.0	0.0	31.3
	5	120,000	125,387	852.1	833.0	3.9	82.5	667.1	66.2	13.4	1.3	2.1	2.1	0.0	34.2
	6	120,000	115,928	807.1	794.6	0.0	64.5	670.8	52.9	6.4	0.0	1.5	1.5	0.0	
		average	123,392	830.5	805.2	1.8	64.7	672.2	57.8	8.7	1.1	2.9	2.9	0.0	33.7
	1	450,000	327,766	1022.1	926.2	0.0	4.8	311.1	449.7	160.6	0.0	9.5	9.5	0.0	
	2	450,000	330,186	980.3	836.3	0.0	0.0	251.5	390.7	194.2	0.0	14.4	14.4	0.0	
	3	450,000	311,752	925.1	676.5	0.0	0.0	191.9	335.3	149.4	0.0	28.3	28.3	0.0	
	4	450,000	346,024	975.5	849.4	0.0	0.0	237.8	405.9	205.7	0.0	12.9	12.8	0.1	
	5	450,000	352,183	1066.5	995.5	0.0	4.3	329.0	454.4	207.7	0.0	6.7	6.7	0.0	
	6	450,000	291,250	972.5	867.0	0.0	2.5	319.1	370.4	175.0	0.0	10.7	10.6	0.1	
		average	326,527	990.3	858.5	0.0	1.9	273.4	401.1	182.1	0.0	13.7	13.7	0.0	
Avalon	1	120,000	131,766	1026.7	957.3	0.0	228.1	680.6	38.2	10.4	2.1	6.6	6.6	0.0	
	2	120,000	132,250	1027.6	956.6	23.7	197.8	677.6	44.8	12.7	0.0	7.0	7.0	0.0	33.2
	3	120,000	127,147	959.4	800.9	13.6	161.3	547.1	66.1	12.7	0.0	16.2	16.2	0.0	32.5
	4	120,000	125,167	967.9	873.6	6.2	195.0	618.0	41.0	13.4	0.0	9.8	9.8	0.0	35.5
	5	120,000	126,487	950.8	852.3	11.3	188.7	577.8	57.1	17.4	0.0	9.9	9.9	0.0	28.9
	6	120,000	128,027	993.0	883.0	17.7	233.6	580.8	41.1	9.8	1.4	10.6	10.5	0.1	32.1
		average	128,474	987.6	887.3	12.1	200.7	613.7	48.0	12.8	0.6	10.0	10.0	0.0	32.4
	1	450,000	327,766	1147.3	852.1	0.0	8.4	379.0	328.7	136.1	0.0	25.9	25.8	0.1	
	2	450,000	323,586	1070.9	635.3	0.0	9.9	275.1	229.0	121.3	0.0	41.1	41.1	0.0	
	3	450,000	344,704	1119.2	733.7	0.0	2.2	291.5	287.1	152.9	0.0	34.5	34.5	0.0	
	4	450,000	334,805	1179.7	884.5	0.0	4.9	426.9	335.2	117.5	0.0	25.2	25.2	0.0	
	5	450,000	319,407	1113.4	714.0	0.0	3.3	342.9	249.0	118.7	0.0	35.8	35.8	0.0	
	6	450,000	330,846	1082.0	715.4	0.0	6.6	312.7	258.6	137.6	0.0	34.2	34.2	0.0	
		average	330,186	1118.8	755.8	0.0	5.9	338.0	281.3	130.7	0.0	32.8	32.8	0.0	

Table 14. Continued. Onion yield response to at-planting phosphorus applications and in-season fertigation for two varieties and two plant populations. Malheur Experiment Station, Oregon State University, Ontario, OR.

		Plant population			Marketable yield by grade										
Variety	Treatment	Target	Actual	Total yield	Total	>4¼ in	4-4¼ in	3-4 in	2¼-3 in	Small	No. 2s	Total rot	Neck rot	Plate rot	Bulb counts >4¼ in
		-------- plants/acre --------		---------- cwt/acre ----------								--- % of total yield ---			#/50 lb
Average	1	120,000	125,607	931.1	881.9	0.0	151.0	678.3	45.0	7.6	1.0	5.0	5.0	0.0	
	2	120,000	130,006	936.5	890.2	10.8	121.0	699.1	48.6	10.7	0.0	4.8	4.8	0.0	33.2
	3	120,000	129,227	900.4	807.0	9.1	114.0	609.1	63.7	11.1	1.2	9.5	9.5	0.0	33.6
	4	120,000	122,637	883.0	810.9	4.9	124.0	618.4	52.2	11.4	1.4	7.9	7.9	0.0	33.4
	5	120,000	125,987	905.9	843.5	7.9	140.4	618.4	61.2	15.6	0.6	6.4	6.4	0.0	30.7
	6	120,000	121,977	900.0	838.8	8.8	149.0	625.8	47.0	8.1	0.7	6.0	6.0	0.0	32.1
		average	125,907	909.5	845.4	6.9	133.2	641.5	52.9	10.7	0.8	6.6	6.6	0.0	32.6
	1	450,000	327,766	1084.7	889.1	0.0	6.6	345.0	389.2	148.4	0.0	17.7	17.6	0.0	
	2	450,000	326,886	1025.6	735.8	0.0	5.0	263.3	309.9	157.7	0.0	27.7	27.7	0.0	
	3	450,000	329,726	1031.0	707.7	0.0	1.2	246.2	309.0	151.3	0.0	31.7	31.7	0.0	
	4	450,000	340,415	1077.6	866.9	0.0	2.4	332.4	370.6	161.6	0.0	19.1	19.0	0.0	
	5	450,000	335,795	1090.0	854.7	0.0	3.8	336.0	351.7	163.2	0.0	21.3	21.3	0.0	
	6	450,000	311,048	1027.2	791.2	0.0	4.5	315.9	314.5	156.3	0.0	22.5	22.4	0.0	
		average	328,606	1,056.0	807.6	0.0	3.9	306.4	340.8	156.4	0.0	23.3	23.3	0.0	
		Average													
	1		226,686	1007.9	885.5	0.0	78.8	511.7	217.1	78.0	0.5	11.3	11.3	0.0	
	2		237,395	983.0	809.7	5.2	60.5	471.7	184.9	87.4	0.0	16.7	16.7	0.0	33.2
	3		229,476	965.7	757.3	4.5	57.6	427.7	186.4	81.2	0.6	20.6	20.6	0.0	33.6
	4		231,526	980.3	838.9	2.4	63.2	475.4	211.4	86.5	0.7	13.5	13.5	0.0	33.4
	5		235,452	1001.9	849.4	3.8	69.1	471.0	212.8	92.6	0.3	14.1	14.1	0.0	30.7
	6		216,512	963.6	815.0	4.4	76.8	470.8	180.7	82.2	0.4	14.3	14.2	0.0	32.1
LSD (0.05)															
Treatment			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Variety			NS	NS	NS	NS	NS	NS	NS	NS	NS	3.9	NS	NS	NS
Population			12,422	27.4	NS	2.9	14.9	30.3	19.3	11.1	NS	3.3	5.6	NS	NS
Variety X Population			NS	NS	66.2	NS	21.1	42.8	27.3	15.7	NS	4.6	NS	NS	NS
Treatment X Population			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Treatment X Variety X Population			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 15. Onion maturity, bolting, and iris yellow spot virus (IYSV) severity response to at-planting phosphorus applications and in-season fertigation for two varieties and two plant populations. Malheur Experiment Station, Oregon State University, Ontario, OR. Continued on next page.

			Maturity Aug 20			
			Tops down	Leaf dryness		
Variety	Treatment	Plant population			Bolting	IYSV
		plants/acre	---------- % ----------			0-5
Vaquero	1	120,000	25.0	25.0	4.6	1.8
	2	120,000	30.0	28.3	5.9	1.8
	3	120,000	26.7	26.7	2.8	2.0
	4	120,000	25.0	28.3	2.7	1.8
	5	120,000	28.3	26.7	3.2	1.8
	6	120,000	26.7	28.3	2.6	2.2
		average	26.9	27.2	3.6	1.9
	1	450,000	53.3	23.3	18.6	1.2
	2	450,000	63.3	28.3	12.2	1.3
	3	450,000	60.0	30.0	12.8	1.5
	4	450,000	66.7	31.7	11.1	1.7
	5	450,000	65.0	26.7	11.2	1.7
	6	450,000	66.7	28.3	14.3	1.7
		average	62.5	28.1	13.4	1.5
Average			44.7	27.6	8.5	1.7
Avalon	1	120,000	36.7	28.3	10.5	1.7
	2	120,000	41.7	30.0	7.8	2.0
	3	120,000	35.0	30.0	8.2	2.0
	4	120,000	35.0	30.0	9.2	2.0
	5	120,000	38.3	30.0	7.7	1.7
	6	120,000	36.7	28.3	6.8	2.2
		average	37.2	29.4	8.4	1.9
	1	450,000	68.3	26.7	19.1	1.2
	2	450,000	75.0	28.3	18.5	1.5
	3	450,000	76.7	30.0	16.8	1.7
	4	450,000	73.3	30.0	16.2	1.5
	5	450,000	75.0	30.0	15.6	1.7
	6	450,000	83.3	30.0	16.9	1.5
		average	75.3	29.2	17.2	1.5
Average			56.3	29.3	12.8	1.7

Table 15. Continued. Onion maturity, bolting, and iris yellow spot virus (IYSV) severity response to at-planting phosphorus applications and in-season fertigation for two varieties and two plant populations. Malheur Experiment Station, Oregon State University, Ontario, OR.

			Maturity Aug 20			
Variety	Treatment	Plant population	Tops down	Leaf dryness	Bolting	IYSV
		plants/acre	---------- % ----------			0-5
Average	1	120,000	30.8	26.7	7.5	1.8
	2	120,000	35.8	29.2	6.8	1.9
	3	120,000	30.8	28.3	5.8	2.0
	4	120,000	30.0	29.2	5.9	1.9
	5	120,000	33.3	28.3	5.6	1.8
	6	120,000	31.7	28.3	4.7	2.2
		average	32.1	28.3	6.1	1.9
	1	450,000	60.8	25.0	18.9	1.2
	2	450,000	69.2	28.3	15.3	1.4
	3	450,000	68.3	30.0	15.0	1.6
	4	450,000	70.0	30.8	13.7	1.6
	5	450,000	70.0	28.3	13.4	1.7
	6	450,000	75.0	29.2	15.6	1.6
		average	68.9	28.6	15.3	1.5
		Average				
	1	285,000	45.8	25.8	13.2	1.5
	2	285,000	52.5	28.8	11.2	1.7
	3	285,000	49.6	29.2	10.4	1.8
	4	285,000	50.0	30.0	9.8	1.8
	5	285,000	51.7	28.3	9.7	1.7
	6	285,000	53.3	28.8	10.2	1.9
LSD (0.05)						
Treatment			NS	2.4	NS	0.3
Variety			2.8	NS	NS	NS
Population			2.8	NS	1.6	0.1
Variety X Population			NS	NS	NS	NS
Treatment X Population			NS	NS	NS	NS
Treatment X Variety X Population			NS	NS	NS	NS