Evaluation of Growth Stimulants on Short-day Onions

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SUMMARY. A 3-year study on the effects of growth stimulants on yield, bulb size, bulb quality, and storability of short-day onions (*Allium cepa* L.) was conducted at three locations. Treatments included 2-hydroxypropanoic acid, humic acids, humic acids in conjunction with micronutrients, and two formulations of cytokinin applied as a transplant dip and/or plant spray. There were no differences between 2-hydroxypropanoic acid and an untreated check at two different farm locations for onion yield, equatorial bulb diameter, or percent jumbos [≥ 3 inches (≥ 7.6 cm)] in 1997. Comparisons between untreated checks, 2-hydroxypropanoic acid, humic acids as a transplant dip or plant spray, and

humic acids with micronutrients, all applied as transplant dip or plant spray, indicated there were no differences among treatments for yield, pungency, soluble solids, equatorial bulb diameter, or percent marketable bulbs after 6 months in controlled atmosphere storage in 1997–98. In a final experiment, these treatments were evaluated in a factorial arrangement using the short-day onion cultivar Pegasus and a mixture of cultivars WI-609 and WI-3115, which are referred to as Wannamaker cultivar mix. ‘Pegasus’ displayed higher yield and lower soluble solids than the Wannamaker cultivar mix. Treatment with humic acids and micronutrients, or cytokinins resulted in greater percent marketable bulbs after 4.5 months of controlled atmosphere storage compared to the untreated check. No differences were observed among the treatments for pungency or bulb size. In addition, there was no treatment by cultivar interaction.

Short-day onions known as *Vidalia* onions are grown in southeastern Georgia. Historically, the best prices are received for jumbo onions [3 or more inches (7.6 cm) in diameter]; therefore, growers strive to increase percentage of jumbos to increase the profitability of their crop.

Several chemical products have been marketed to onion growers with claims of increasing bulb size and yield. These include 2-hydroxypropanoic acid (Propel, Entek Corp., Brea, Calif.), 0.012% cytokinin foliar formulation (Foliar Triggrr, Westbridge Inc., Vista, Calif.) or 0.004% cytokinin soil formulation (Soil Triggrr, Westbridge Inc.), and 10% humic acids solution (Super Shot-40, CropChem, Decatur, Ill.) in combination with 4% humic acids, seaweed extracts, and micronutrient solutions (Super PGA VII Plus, CropChem).

Growth regulators and growth stimulants have been used in a variety of ways on onions. Applications of ethephon reduced the incidence of flower stalk formation and improved the bulb diameter/stem diameter ratio in short-day onions (Cantliffe et al., 1978). Ethephon also reduced the oligosaccharide and total sugar content of onion cultivars Czerniakowska and Wolska (Ostrzycka and Gorecki, 1991). Boiadjev et al. (1987) recommended

the use of ethephon for onion seed production. Applications of ethephon when 70% of the onions were bolting and were not taller than 6 to 8 inches (15 to 20 cm) reduced seed stalk height and lodging. Similarly, Winkler et al. (1990) showed that applications of ethephon reduced flower stalk height by as much as 22%, while reducing the number of lodged stalks, increasing umbel diameter, and number of seed per umbel. Gibberellic acid (GA_3) has been shown to increase onion seed germination, root length, and shoot dry weight after seed treatment (Saxena et al., 1988). Holland (1996) reported that 2-hydroxypropanoic acid increased bulb diameter as well as yields and bulb weights in trials in Oregon and Washington.

One of the most widely used applications of growth regulators in onions is to retard shoot growth after harvest. Application of maleic hydrazide has been shown to inhibit onion shoot growth in storage (Abdel-Rahman and Isenberg, 1974). Their work also showed that applications of abscisic acid could induce early senescence and prolong storage life.

Humic acids and related products have been investigated with several crops for their ability to enhance growth. Humic acids are the high molecular weight (7,000 to 700,000 atomic weight) soluble portion of humus. It can be obtained from several sources, including the commercial source leonardite, a nonflammable byproduct of coal mining. It is not clear how the effects of these products work, whether it is due to increases in cation exchange capacity, which affect the retention and availability of nutrients or due to a hormonal effect, or a combination of both. Some studies suggest that these compounds can mimic plant hormones. O'Donnell (1973) found that humic acids at 0.05% to 0.10% concentration promoted root tip elongation in peas, which was similar to the effects of auxin compounds. Humic acids have also been shown to have bioassay effects similar to cytokinin and gibberellin (Hoang and Tichy, 1976).

Applications of humic acids from leonardite ore increased cabbage yield. The application rates were as high as 1.1 gal/acre (10 L·ha⁻¹) with 0.8 gal/acre (7.5 L·ha⁻¹) resulting in the best yields (Suwandi and Nurtika, 1987). Applications of humic acids to toma-

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toes (*Lycopersicon esculentum* Mill.) and olive trees (*Olea europaea* L.) also had a positive effect on growth and yield (Adani et al., 1998; Fernandez-Escobar et al., 1996).

The objective of this study was to evaluate the effects of several commercial growth stimulants on short-day onion yield, bulb size, and quality.

Materials and methods

In 1997, the same experiment with 'Sweet Vidalia' (Sunseeds, Morgan Hill, Calif.) short-day onions was conducted on grower farms, in Toombs and Tattnall Counties, Georgia. Onions were transplanted in Dec. 1996, on 4-ft-wide (1.2-m) beds with 6 ft (1.8 m) center to center between the

beds. Four rows were planted per bed with 18 inches (45.7 cm) between rows and a 4-inch (10.2-cm) in-row spacing. The experimental design was a randomized complete block design with two treatments and four replications. Each treatment plot consisted of a 10-ft (3-m) representative section of one bed.

The treatments consisted of an untreated check and 1.2 fl oz/gal (9.4 mL·L⁻¹) 2-hydroxypropanoic acid in a mixture of 0.6 fl oz/gal (4.7 mL·L⁻¹) nonionic surfactant (D-W Surfactant, Triangle Chemicals, Macon, Ga.), which reflects the manufacturer's recommended rate (Table 1, Expts. 1 and 2). The treatments were applied to runoff on 18 Mar. 1997 with a pump-

up hand sprayer. The rate was 20 gal/acre (187 L·ha⁻¹). Onions were grown following recommended practices for fertilization, irrigation, and pest management for short-day onions in Georgia.

Onions were harvested on 24 and 30 Apr. 1997 in Tattnall and Toombs Counties, respectively. The bulb roots were removed and the tops clipped approximately one inch above the bulb. Total marketable weights and equatorial bulb diameter were recorded immediately upon harvest.

During the 1998 growing season, an experiment was established at the Bamboo Farm and Coastal Gardens in Savannah, Ga. (Table 1, Expt. 3). This experiment consisted of seven

Table 1. Treatment list, formulations, trade names, rates, application methods and timing for each experiment.

Treatment	Formulation	Trade name	Rate ^z (fl oz/gal)	Application method	Application date
Experiment 1, Tattnall County, Ga., 1997					
1	2-hydroxypropanoic acid	Propel	1.2	Foliar spray	18 Mar. 1997
2	Water			Foliar spray	18 Mar. 1997
Experiment 2, Toombs County, Ga., 1997					
1	2-hydroxypropanoic acid	Propel	1.2	Foliar spray	18 Mar. 1997
2	Water			Foliar spray	18 Mar. 1997
Experiment 3, Bamboo Farm, Savannah, Ga., 1998					
1	Nothing				
2	Water and surfactant			Foliar spray	27 Feb. 1998
3	2-hydroxypropanoic acid	Propel	1.2	Transplant dip	27 Feb. 1998
4	2-hydroxypropanoic acid	Propel	1.2	Foliar dpray	27 Feb. 1998
5	10% humic acid + 5% adjuvants with 4% humic acid, unspecified seaweed extracts and micronutrients	Super Shot-40 and Super PGA VII Plus	1.6 0.4	Transplant dip and foliar spray	27 Feb. 1998 and as a spray every 10 d
6	10% humic acid + 5% adjuvants	Super Shot-40	1.6	Transplant dip and foliar spray	27 Feb. 1998 and as a spray every 10 d
7	4% humic acid, unspecified seaweed extracts and micronutrients	Super PGA VII Plus	0.4	Transplant dip and foliar spray	27 Feb. 1998 and as a spray every 10 d
Experiment 4, Bamboo Farm, Savannah, Ga., 1999					
Factorial design (5 × 2)					
1	Water + surfactant				
2	2-hydroxypropanoic acid	Propel	1.2	Foliar spray	21 Dec. 1998
3	10% humic acid and 5% adjuvants with 4% humic acid, unspecified seaweed extract and micronutrients	Super Shot-40 and Super PGA VII Plus	0.5 1.6	Transplant dip and foliar spray	Dip: 21 Dec. 1998 (0.6 fl oz/gal with Super PGA VII Plus only), Spray: 22 Mar. 1999, 1 Apr. 1999, 12 Apr. 1999
4	0.004% cytokinin	Soil Triggrr	0.16	Soil drench	21 Dec. 1998, 22 Mar. 1999
5	0.012% cytokinin	Foliar Triggrr	0.2	Foliar spray	21 Dec. 1998, 22 Mar. 1999
Cultivars					
1	Pegasus				
2	Wannamaker cultivar mix				

^z1.0 fl oz/gal = 7.8 mL·L⁻¹.

treatments arranged in a randomized complete block design with four replications. Plots were 5 × 5 ft (1.5 × 1.5 m) with two rows of onions spaced 1 ft (0.3 m) apart and 4 inches in-row. Ten-week-old 'Pegasus' (Asgrow Vegetable Seeds, Gonzales, Calif.) onion plants were transplanted on 6 Feb. 1998.

The fertilization program consisted of 600 lb/acre (673 kg·ha⁻¹) of 5N-4.4P-12.4K fertilizer and 190 lb/acre (213 kg·ha⁻¹) of 0N-8.7P-0K applied preplant. On 26 Feb. 1998, an additional 600 pounds/acre of 5N-4.4P-12.4K was broadcast. In addition, 200 lb/acre (224 kg·ha⁻¹) of CaNO₃ was broadcast on 23 Mar., 24 Apr., and 8 May 1998. Oxyfluorfen herbicide was applied on 26 Feb. 1998 at a rate (a.i.) of 0.06 lb/acre (0.07 kg·ha⁻¹). Plants were watered with an overhead impact sprinkler system to field capacity when soil conditions were at 50% or below field capacity.

Treatment 1 was the untreated check. Treatment 2 consisted of water and nonionic surfactant (D-W Surfactant) used at 0.6 fl oz/gal. Treatment 3 was 2-hydroxypropanoic acid with nonionic surfactant applied at 1.2 fl oz and 0.6 fl oz/gal, respectively. This treatment was applied as a dip where transplants were held in this solution for 2 min. Treatment 4 was the same as treatment 3, only it was applied to the plants as a spray to runoff (20 gal/acre) after transplanting. Treatment 5 consisted of 10% humic acids solution with 5% adjuvants (Super Shot-40) combined with a solution consisting of a 4% humic acids with unspecified seaweed extracts and boron (0.02%), cobalt (0.0005%), iron (0.10%), manganese (0.05%), molybdenum (0.0005%), and zinc (0.10%). This product is marketed as Super PGA VII Plus. These products were mixed at 1.6 fl oz/gal (12.5 mL·L⁻¹) for Super Shot-40 and 0.4 fl oz/gal (3.1 mL·L⁻¹) for Super PGA VII Plus. This treatment began as a transplant dip for 2 min, followed by spray to runoff applications of the solution approximately every 10 d, beginning on 27 Feb. 1998. Application dates were 27 Feb., 2, 13, 23 March, 2, 13, 24 Apr., and 8 and 18 May, 1998. Treatment 6 was mixed and applied as described for treatment 5, but consisted of Super Shot-40 alone. Treatment 7 was also mixed and applied the same as treat-

ment 5, but consisted of Super PGA VII Plus only.

Plants were harvested on 2 June 1998. Tops and roots were clipped from the bulbs, and yield and equatorial bulb diameter data were collected without curing. A five-bulb sample was evaluated for pungency by method A of Schwimmer and Weston (1961) and for percent soluble solids with a refractometer. The remaining bulbs from each plot were placed in controlled atmosphere storage with 3% oxygen and 5% carbon dioxide at 34 °F (1.1 °C) until 16 Dec. 1998, about 6.5 months. At this time the onions were removed from storage and evaluated for percent marketable bulbs.

In the 1998-99 growing season, further investigations continued with 2-hydroxypropanoic acid, humic acids, and a humic acids solution with seaweed extracts and micronutrients. In addition, two formulations of cytokinin were investigated (Table 1, Expt. 4).

A 2 × 5 factorial experiment was established at the Bamboo Farm and Coastal Garden in Savannah, Ga. The experiment was arranged in a randomized complete block design. The first factor was onion cultivar with two levels, either 'Pegasus', a late maturing cultivar or an equal mix of 'WI-3115' and 'WI-609' (Wannamaker International, St. Matthews, S.C.), which are early maturing cultivars. The second factor consisted of five treatments of various growth stimulants.

Onion transplants were established at their final spacing on 21 Dec. 1998 in 5 × 5 ft plots. The fertilizer program consisted of 1,000 lb/acre (1,121 kg·ha⁻¹) of 5N-4.4P-12.4K applied preplant. In addition, 200 lb/acre of CaNO₃ was applied on 27 Jan.,

8 and 26 Feb., and 2 and 22 Mar. 1999. Weed control consisted of a single application of oxyfluorfen herbicide at a rate (a.i.) of 0.12 lb/acre (0.13 kg·ha⁻¹).

Treatment 1 was water and non-ionic surfactant (D-W Surfactant) sprayed to runoff. Treatment 2 was 2-hydroxypropanoic acid with surfactant applied as a spray as described above in treatment 3 of Expt. 3. Treatment 3 was Super PGA VII Plus at a rate of 0.6 fl oz/gal used as a transplant dip. Transplants were soaked in this solution for 2 min before planting. In addition Super Shot-40 and Super PGA VII Plus were mixed at rates of 0.5 and 1.6 fl oz/gal (3.9 and 12.5 mL·L⁻¹), respectively. This mixture was sprayed on plants to runoff (20 gal/acre) on 22 March, 1 Apr., and 12 Apr. 1999.

Treatment 4 was a 0.004% cytokinin (Soil Triggrr) used at 0.16 fl oz/gal (1.2 mL·L⁻¹). This material was applied twice as a soil drench at 100 gal/acre (935 L·ha⁻¹), first before planting, and again on 22 Mar. 1999.

Treatment 5 consisted of 0.012% cytokinin (Foliar Triggrr) which was mixed at 0.2 fl oz/gal (1.6 mL·L⁻¹). This mixture was sprayed on the plants to runoff (20 gal/acre), immediately after transplanting and reapplied on 22 Mar. 1999.

The Wannamaker cultivar mix and 'Pegasus' were harvested on 26 Apr. 1999 and 17 May 1999, respectively. A 10-bulb sample from each plot was evaluated for pungency by method A of Schwimmer and Weston (1961).

Each bulb of a 10-bulb sample of the Wannamaker mix was measured for bulb equatorial diameter. 'Pegasus' bulbs were graded into size classes as small, <2.25 inches (5.7 cm); medium, <3 inches (7.6 cm); jumbo, >3 inches

Table 2. Effect of 2-hydroxypropanoic acid on yield and bulb size of short-day onions at two locations, 1997.

Location/ treatment	Bulb diam (inches) ^a	Percent jumbos (≥3 inches)	Yield (no. 50-lb bags/acre) ^a
Tattnall County			
2-hydroxypropanoic acid	2.6	18.9	698
Untreated	2.6	15.1	697
P > F	0.903	0.255	0.927
Toombs County			
2-hydroxypropanoic acid	2.6	16.1	784
Untreated	2.7	24.1	882
P > F	0.469	0.087	0.243

^a1.0 inch = 2.54 cm, 1 50-lb (22.7-kg) bag/acre = 56 kg·ha⁻¹.

Table 3. Effect of growth stimulant applications on short-day onions, 1998.

Treatment ^z	Yield (no. of 50-lb bags/acre) ^y	Bulb diam (inches) ^y	Pungency ($\mu\text{mol}\cdot\text{g}^{-1}$ fresh wt)	Soluble solids (% sugar)	Marketable onions after 6 months (%)
1	588	4.2	3.8	7.3	32
2	614	4.3	3.8	7.5	29
3	575	3.9	3.6	7.9	36
4	575	4.2	3.7	7.3	36
5	510	4.0	3.9	7.6	24
6	584	4.2	2.0	6.9	47
7	545	3.9	3.5	7.1	37
P > F	0.896	0.414	0.059	0.055	0.612

^zTreatments: 1) untreated check, 2) water and surfactant, 3) Propel as transplant dip, 4) Propel as plant spray, 5) Super Shot-40 and Super PGA VII Plus as transplant dip and plant spray, 6) Super Shot-40 as transplant dip and plant spray, 7) Super PGA VII Plus as transplant dip and plant spray.

^y1.0 inch = 2.54 cm, 1 50-lb (22.7-kg) bag/acre = 56 kg·ha⁻¹.

(7.6 cm) and <4 inches (10.2 cm); and colossal, >4 inches.

The onions from each plot of 'Pegasus', minus those used to evaluate for pungency and sugar content, were placed in controlled atmosphere storage of 3% oxygen and 5% carbon dioxide, at 34 °F. These onions were removed from storage on 4 Oct. 1999, after about 4.5 months in storage and evaluated for percent marketable onions.

Data were analyzed by ANOVA using Microsoft Excel 98 (Microsoft Corp., Seattle, Wash.) and Systat 5.2.1 (SPSS, Inc., Chicago, Ill.). All data involving percentages except sugar content were transformed before analysis with the arcsine transformation [$y = \arcsin(\text{square root}(x))$] to insure homogeneity of variance (Little and Hills, 1978).

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Results and discussion

There were no treatment effects in 1997 at the Tattnall County or the Toombs County locations for bulb diameter, percent jumbos, or yield (Table 2). In 1998, there were no differences among the treatments for effects on yield, bulb diameter, pungency, soluble solids, or percent marketable onions after 6 months of controlled atmosphere storage (Table 3).

The 1999 experiment showed no differences among growth stimulant

treatments for effects on yield, soluble solids, or pungency (Table 4). There was no interaction effect between cultivar and growth stimulant treatments for yield, soluble solids, or pungency. There were, however, differences for yield and soluble solids content due to cultivar, with 'Pegasus' having a higher yield and a lower soluble solid content compared to the Wannamaker mix. There was no difference between the cultivars for pungency.

There were no differences in 1999 for bulb diameter among the treatments for the Wannamaker cultivar mix, nor were there any differences among the treatments for effects on percent jumbo and colossal bulbs for 'Pegasus'. There were differences, however, among the growth stimulant treatments for percent marketable onions after 4.5 months in controlled atmosphere storage. Applications of Super Shot-40 in combination with Super PGA VII Plus, soil applied Triggrr, and foliar applied Triggrr resulted in a greater percentage of marketable onions compared to water and surfactant alone (Table 4). Applications of 2-hydroxypropanoic acid did not result in any improvement in marketable onions after storage compared to the nontreated control.

Manufacturer recommendations with the use of 2-hydroxypropanoic acid suggest applications when onion bulbs begin to expand. In the 1997

Table 4. Effect of growth stimulant applications on short-day onions, 1999.

Treatment	Yield (no. of 50-lb bags/acre) ^z	Soluble solids (% sugar)	Pungency (μmol·g ⁻¹ fresh wt)	Wannamaker	Pegasus				Marketable onions (% after 4.5 months)
				Mix bulb diam (inches) ^z	Percent in class				
					Small	Medium	Jumbo	Colassal	
Growth stimulants ^y									
1	335	6.9	4.5	2.8	3	13	55	29	68.7 b ^x
2	287	7.2	5.8	2.4	1	16	54	29	79.8 ab
3	353	7.1	5.0	2.7	2	11	85	3	86.5 a
4	321	6.9	5.0	2.6	3	9	75	13	91.3 a
5	344	7.2	4.5	2.6	2	7	61	31	83.8 a
Cultivar									
Pegasus	434	6.7	4.6						
Wannamaker Mix	222	7.5	5.3						
P > F					Percent jumbo and colossal				
Growth stimulant	0.517	0.444	0.194	0.258	0.550				0.025
Cultivar	0.000	0.000	0.081						
Growth stimulant × cultivar	0.288	0.551	0.325						

^z1.0 inch = 2.54 cm, 1 50-lb (22.7-kg) bag/acre = 56 kg·ha⁻¹.

^yGrowth stimulants: 1) water and surfactant, 2) Propel as spray, 3) Super Shot-40 & Super PGA VII Plus as transplant dip and sprayed three times beginning at bulbing, 4) Triggrr soil applied, 5) Triggrr foliar applied.

^xMeans followed by the same letter within the column are not significantly different by Fisher's protected LSD ($P \leq 0.05$).

experiment, the application was well after bulb expansion had begun. In the 1998 and the 1999 experiments, applications were moved back to coincide with transplanting. Short-day onions in Georgia will typically be showing some swelling of the bulb at time of transplanting therefore, we thought, this would be a good time for application. The transplant dip was used to increase the absorption of the material by the plant. Onions have a waxy leaf that is not conducive to absorption. The transplant dip exposed the roots as well as the tops to the treatment solution, which should enhance uptake. The transplant dip would also be convenient for growers, since they have to handle and transport the plants at this time anyway. The transplant dip did not result in any differences with 2-hydroxypropanoic acid applications. This contrasts to the findings of Holland (1996) where increases in size and yield were noted. This points out one of the weaknesses with using growth stimulants; if the results are not consistent over locations and years, their usefulness to growers is marginal at best.

Humus, as well as other organic materials, has been shown to have beneficial effects on many plants. These effects are partially due to the nutrient holding capacity, cation exchange capacity of organic matter, and partially due to hormonal effects. There may be other unknown mechanisms as well. The products tested here, Super Shot-40 and Super PGA VII Plus, are recommended by the manufacturer to be used in combination to enhance onion bulb size and yield. Studies have shown that applications of humic acids can have a positive effect on growth and yield for some vegetables. Although, there are many studies with positive effects on growth and yield with applications of humic acids, there are other studies where the results are inconclusive (Fortun et al., 1985; Nemec and Lee, 1992,). Our study showed no effect from humic acid products applied to onions with the exception of increasing percent marketable onions

after storage in one year. This kind of inconsistent success with these products appears to be the rule rather than the exception.

The literature is overwhelming in supporting cytokinin's effect and importance as a plant hormone. Exogenous applications to whole plants, however, have not been consistently shown to be effective. Our study supports the idea that exogenous applications of cytokinin to whole plants have been inconsistent.

Results of our studies do not support a benefit from the application of growth stimulants to short-day onions. Generally, growers expect to have 80% or more of their crop in the jumbo class so exogenous applications of growth stimulants, even if they worked, would be only marginally useful. Clearly, lack of positive results or variable results are of very little value to growers. Consistent results from year to year over a wide range of environments and conditions are necessary to justify the added costs to growers.

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