Harvest Date Effect on Yield and Controlled-atmosphere Storability of Short-day Onions

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Abstract. This study was undertaken to evaluate the effect of harvest date on yield and storage of short-day onions in controlled-atmosphere (CA) storage conditions. In general, harvest yields increased with later harvest dates. Yields of jumbo (>7.6 cm) onions primarily showed a quadratic or cubic response to harvest date, first increasing and then showing diminished or reduced marginal yields. Medium (>5.1 to ≤7.6 cm) onions generally showed diminished yield with later harvests as jumbos increased. Neither days from transplanting to harvest nor calculated degree days were reliable at predicting harvest date for a particular cultivar. Cultivars (early, midseason, and late maturing) performed consistently within their harvest class compared to other cultivars for a specific year, but could not be used to accurately predict a specific number of days to harvest over all years. Only three of the eight statistical assessments of percent marketable onions after CA storage were significant with two showing a linear increase with later harvest date and one showing a cubic trend, first increasing, then decreasing, and finally increasing again based on harvest date.

Determining an optimum time to harvest onions is important both to maximize yield and quality. For short-day onions this has traditionally been for fresh market consumption. With the recent adoption of CA storage, optimum harvest date for storage has also become a concern.

Onion maturity often refers to percent tops down, which is the percent of onions with necks weak enough for the tops to breakover and lay on the ground. Onions adapted to northern climates will reach maximum yield when 100% mature but may actually continue to grow after the tops are down (Suojala, 2001). By contrast (Bottcher, 1999) reported that optimum harvest resulting in least losses for long-term outdoor storage occurred when 90% of the tops are down and 40% to 50% of the leaves are dry. In another study of long-

day onions, it was concluded that the optimum time to harvest was when 50% of the tops were down (Sypien-Perlowska et al., 1984).

Harvest date of long-day onions can also affect onion quality. For optimum skin quality mid-August was the best time for undercutting onions, however, higher yields resulted with mid-September undercutting with only a slight reduction in skin quality (Rickard and Wickens, 1977). In a similar study of onions harvested at different intervals from early August to late September it was found that onions harvested in middle to late August had the best quality with high dry matter content and sugars, which remained relatively high through storage to the following May (Elkner et al., 1984).

The effect of harvest date on quality can also extend to disease incidence. The incidence of *Pseudomonas alliicola* infection in the cultivar Lyaskovski 58 was minimized if onions were harvested when tops had just begun to break over and were allowed to dry in the field for 15 d (Vitanov, 1976).

Optimum harvest date for short-day onions will differ from onions adapted to northern climates (intermediate and long-day onions).

'Texas Grano 438' grown in Quibor, Lara State, Venezuela did not show any differences in yield or bulb size based on harvest dates of 80, 94, or 101 d after transplanting (Rodriguez et al., 1998). Other quality parameters, such as percent dry matter and soluble solids, did show significant differences with optimum harvest occurring 80 d after transplanting.

The Vidalia onion industry is located in southeast Georgia where conditions are ideal for producing short-day, low-pungency onions. This region has mild winter temperatures, abundant irrigation water, and low sulfur soils, which all contribute to onion quality (Boyhan and Torrance, 2002).

Low O₂ (3%), high CO₂ (5%), refrigerated (1 °C) storage was adopted by the Vidalia onion industry about 14 years ago as a means to expand marketing beyond the then traditional 4 to 6 weeks after harvest (Boyhan and Torrance, 2002). There is now CA storage capacity for about half of the crop (≈56,750 t). The industry has expanded rapidly primarily due to CA storage with a 3.5 times increase in production area to about 5,700 ha in 2002.

Although CA storage has been beneficial in extending marketability of Vidalia onions, problems with quality, post-storage shelf life, and diseases have led to inconsistent results. In some cases over half of the stored onions have been discarded due to disease problems. Onion maturity at time of storage can also influence onion regrowth after their removal from storage.

Onion storage has been investigated in several studies. Factors that have been evaluated include irrigation, harvest date, environmental conditions, cultivar, use of growth regulators, and fertilization.

Studies in Egypt on irrigation and harvest dates indicate that onions have higher disease incidence with increased number of irrigations and with the earliest harvests (25% of tops down) (Ali and Yamani, 1977). Balogh (1975) found that respiration rates in onions could be used to determine optimum harvest date. Reducing soil water potential late in the season to control storage diseases had no effect compared to maintaining soil water potential at -20 kPa throughout the season with the long-day cultivar Vision in Oregon (Shock et al., 2000).

Yield of both 'Texas Grano 1015Y' and 'Granex 33' was greatest at the fourth harvest of five total harvests with 144 and 124 d from transplanting, respectively in Bradenton, Fla. (Sargent et al., 2001). During 2 weeks postharvest at 20 °C decay increased among the later harvested onions with 'Granex 33' having less decay compared to 'Texas Grano 1015Y'.

In another study Wall and Corgan (1994) found with onion cultivars NuMex BR1, NuMex Sunlite, NuMex Starlite and Buffalo that onion bulb weight increased with delayed harvest up to 15 d after 80% mature necks. They also found differences in disease incidence with 'Buffalo' and 'NuMex Sunlite' having the lowest incidence. Bulb disease incidence differed based on year of harvest and the best overall performance occurred when onions were harvested with 80% mature necks.

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Preharvest environmental conditions affect onion storage. In Skeerniewice, Poland it was found that if temperatures were high during July and August resulting in rapid maturation, the storability of the onions was poor compared to years with lower temperatures and a slower rate of maturation (Grzegorzewska, 1999).

Cultivar can also play a role in postharvest storability of onions. In Buenos Aires province, Argentina the cultivar Valcatorce INTA stored best compared to six other cultivars (Saluzzo et al., 1998). Other cultivars in this trial were earlier maturing and more suitable for fresh consumption. Onion quality, based on measurements of pungency (pyruvate test) and soluble solids, can change during refrigerated storage. These changes appear to be cultivar specific. For example, pungency increased in 'Granex 33' after 3 months of storage, but decreased in 'Dehydrator #3' and 'Rio Unico' (Kopsell and Randle, 1997).

There have been attempts to improve the storability of onions with preharvest treatments. Several desiccants have been tested to dry onions prior to storage. In one such study, ethephon, white spirit, endothal, and paraquat increased disease and sprouting (Bubl et al., 1979). Maleic hydrazide and ethephon were effective in reducing sprouting of cultivar Local Red in storage in 1 of 2 years (Goburdhun, 1995). Treatments with 4000 to 5000 ppm of maleic hydrazide applied 2 weeks before harvest were effective at inhibiting sprouting of the cultivar Faisalabad for 6 months under ambient conditions (Shafi, 1980).

Fertilizer source whether organic or inorganic has not been a factor in onion storage based on a 3-year study in Slovenia. Comparisons of two rates of mineral fertilizer along with compost, farmyard manure, and poultry litter had no effects on the storability of onions (Jakse and Mihelic, 2001).

Although all Vidalia onions are short-day onions, the cultivars grown can be placed into one of three broad maturity classes as early, midseason, and late based on when the tops breakover (Boyhan et al., 2001). The earliest group are referred to as Japanese overwintering onions and are relatively new to the Vidalia onion growing region having been in the region for <10 years. There is not as clear a distinction for mid- and late-season onions with considerable overlap between cultivar harvest dates.

The objectives of the first experiment was to evaluate harvest date and a broad range of cultivars for yield and storability under CA conditions. The objectives of the second and third experiments were to evaluate cultivars in specific harvest classes for yield and storability as well as the effect of harvest date on these parameters.

Materials and Methods

Experiment 1. Plants of 15 cultivars (Table 1) were transplanted on 12 Nov. 1998 to their final spacing at an on-farm location in Toombs County, Georgia in a split-plot design with cultivar as the main plot effect and harvest date as a sub-plot effect with 3 replications. Beds were formed with a 1.8-m center-to-center spacing

Table 1. Harvest date and cultivar evaluation for harvest, postcured, and post-CA yield in the 1998–99 growing season.

Variety	Harvest yield (kg·ha ⁻¹)	Post cure yield (kg·ha ⁻¹)	After 5 months storage (kg·ha ⁻¹)
Nirvana (RCS 1027)	47,619 a	42,593 a	14277 ab
King Midas (RCS 1919)	45,702 a	42,135 a	17866 a
Georgia Boy (DPS 1032)	44,572 ab	39,828 ab	11385 ab
Sweet Advantage (1058)	43,767 ab	38,156 ab	12183 ab
RCS 1063	42,890 ab	38,933 ab	15114 ab
Sweet Success (1514)	42,437 abc	38,674 ab	11984 ab
Sweet Vidalia	42,085 abc	36,605 ab	11227 ab
Sweet Melody	38,504 bcd	33,939 bc	9811 ab
2012	36,126 cd	32,308 bcd	11146 ab
Mr. Max	32,717 de	27,672 cde	9671 ab
Sunseed F ₁	32,174 de	27,832 cde	11485 ab
Centaur (Asgrow 6712)	29,027 e	24,868 e	8255 b
Pegasus	28,819 e	24,828 e	7237 b
Granex 33	28,656 e	24,868 de	8294 b
Evita	26,622 e	23,057 e	7916 b
Harvest (days after transplanting)			
159	29,964 c	24,935 b	12273 a
166	38,958 b	34,055 ab	11994 a
174	43,421 a	40,269 a	9298 b
Probabilities			
Variety	0.000	0.000	0.000
Harvest	0.000	0.000	0.019
Variety × harvest	0.253	0.895	0.546

*Values followed by the same letter within a column for either variety or harvest are not different by Duncan's multiple range test ($p \leq 0.05$).

and four rows were set on each bed. Rows were set 30.5 cm between rows and 12.7 cm in-row. The experimental unit was 3.05 m of bed. Fertility, and weed, disease, and insect control followed the Univ. of Georgia Cooperative Extension Service recommendations for short-day onions (Boyhan et al., 2001). Onions were overhead irrigated with about 2.5 cm of water each week unless a rain event occurred which supplied sufficient moisture to preclude the need for irrigation that week. At the end of February when onion bulbs begin rapid expansion, this was increased to about 3.8 cm per week.

All cultivars were harvested on 20 Apr., 27 Apr., and 5 May 1999; 159, 166, and 174 d after transplanting, respectively. They were weighed immediately after harvest and then transported to the Vidalia Onion Res. Lab. in Tifton, Ga., where they were cured in an unvented greenhouse for 48 h, weighed again and sorted into size classes, which were also weighed. Size classes included small (<6.4 cm), medium (≥6.4 to <7.6 cm), large (≥7.6 to ≤8.9 cm), and jumbo (>8.9 cm). Only medium, large, and jumbo onions were considered marketable. Onions from early harvests were temporarily held in refrigerated storage (1.1 °C, 70% relative humidity) until all the harvests were completed.

Upon completion of all harvests, graded marketable onions were then placed in CA storage (3% O₂, 5% CO₂, 70% RH, and 1.1 °C). Onions were removed from CA storage on 11 Oct. 1999 and were separated into marketable and nonmarketable onions and both groups were weighed with percent marketable weights reported.

Experiment 2. 'Sweet Vidalia' and 'Centaur' were transplanted on 30 Nov. 1999 at the Vidalia Onion and Vegetable Research Center in Lyons, Ga., to the same spacing and following the same production recommendations as indicated above. Each variety was arranged in a randomized complete block design of four

replications with days after transplanting as the treatments. The experimental unit was 6.1 m of bed. Onions were harvested on 6 Apr., 13 Apr., 20 Apr., 25 Apr., 10 May, and 17 May 2000, which were 128, 135, 142, 147, 162, and 169 d after transplanting, respectively. After drying in the field for 2 d the tops and roots were removed and the bulbs were weighed. The bulbs were then heat cured (35 °C) for a minimum of 3 d and graded into size classes: medium (>5.1 to ≤7.6 cm) and jumbo (>7.6 cm). Medium and jumbo sizes were then placed in CA storage, as described above, until 11 Oct. 2000, at which time they were sorted into marketable and unmarketable onions and weighed. Percent marketable onions are reported.

Experiment 3. 'PS 7292', 'WI-609', and 'Pegasus', were transplanted on 27 Nov. 2000 to a spacing as noted above using an experimental design as noted in expt. 2. 'PS 7292' was harvested on 13 Apr., 19 Apr., 26 Apr., 2 May, 15 May, and 17 May 2001, which were 137, 143, 150, 156, 169, and 171 d after transplanting. 'WI-609' was harvested on 27 Mar., 4 Apr., 13 Apr., 19 Apr., 26 Apr., and 2 May 2001, which were 120, 128, 137, 143, 150, and 156 d after transplanting. 'Pegasus' was harvested on 26 Apr., 2 May, 15 May, 17, and 22 May 2001, which were 150, 156, 169, 171, and 176 d after transplanting, respectively. Harvested onions were field weighed, heat cured, graded, and weighed again as described above. They were then placed in CA storage, as described above, until 2 Oct. 2001 when they were sorted into marketable and unmarketable onions and weighed with percent marketable onions reported.

Results

In the 1998–99 growing season there were significant differences among varieties as to yield, and more interestingly, there were

Probabilities				
Year	Harvest wt	Jumbo	Medium	% Marketable after CA storage
1999	0.100	0.089	0.004	0.646
2000	0.000	0.000	0.000	0.207
Polynomial contrasts and Fisher's protected LSD ($p \leq 0.05$)				
1999				
Linear	---	---	0.002	---
Quadratic	---	---	0.068	---
LSD	---	---	1.2	---
2000				
Linear	0.000	0.903	0.000	---
Quadratic	0.001	0.028	0.000	---
Cubic	0.908	0.192	0.001	---
LSD	4.0	2.5	1.5	---

Fig. 1 Harvest and graded (jumbos and mediums) yields for days after transplanting with percent marketable yield after about 4.5 months of CA storage with top chart indicating 1999 and bottom chart indicating 2000 for 'Centaur'.

differences based on harvest dates (Table 1). Harvest yield increased the later the harvest as did cured yield, but post-CA storage yield was greater among the earlier harvested onions. This observation led to subsequent experiments evaluating specific cultivars with a greater number of days to harvest.

Examination of 'Centaur' for the 1998–1999 season showed no significant increase in harvest weights based on days to harvest (Fig. 1). In addition, there were no differences in yield of jumbos based on days to harvest,

but there was a significant linear decrease in yield of mediums with later harvest dates. Finally there was no difference among days to harvest for percent marketable onions after CA storage.

In the 1999–2000 season, 'Centaur' harvest yields and graded jumbos and mediums differed significantly based on days to harvest (Fig. 1). Both the harvest weight and jumbos showed a significant quadratic trend with days to harvest while there was a significant cubic trend with mediums. With an LSD of 4 kg/plot 'Centaur'

field yield was significantly higher 169 d after transplanting than 147 d after transplanting or any earlier field yield. The harvest yield 162 d after transplanting was not significantly greater than 147 d or 169 d after transplanting.

Yield of jumbo 'Centaur' 142 d and 147 d after transplanting was significantly greater than 135 d after transplanting. There were few jumbos and mediums 162 d after transplanting and they were not measured 169 d after transplanting because of late season bacterial (*Burkholderia* spp.) infections.

Finally, 'Centaur' showed no difference in percent marketable onions after CA storage based on number of days to harvest. Overall, storage of 'Centaur' in 2000 was very poor with percent marketable onions below 18% for all harvest dates.

Evaluation of 'Pegasus' during the 1998–99 season showed a significant linear increase in field yield with increase in number of days to harvest (Fig. 2). Field weights increased from 159 d after transplanting to 166 d after transplanting, but field weights 166 d after transplanting did not differ from field weights 174 d from transplanting. There was no difference in jumbo class onions based on days to harvest for 'Pegasus', but there was a significant downward linear trend for mediums from 159 d from transplanting to 174 d from transplanting. There was no difference in percent marketable onions after CA storage for days to harvest.

During the 2000–01 season, 'Pegasus' field yield increased significantly from 150 d to harvest to 156 d to harvest as well as from 156 d to harvest to 169 d to harvest. There were no differences between field yields from 169 d to harvest to 171 d to harvest, but they did differ from 176 d to harvest. Overall there was a significant linear increase in field or harvest yields of 'Pegasus' with days to harvest. Yields of jumbo and medium 'Pegasus' showed significant cubic and linear trends, respectively (Fig. 2). Yields of jumbo were greater 169 and 171 d after transplanting then 150 or 156 d after transplanting. Yields of medium 'Pegasus' decreased from harvest 150 d after transplanting to 156 d after transplanting. In addition, there was a significant decrease in yield from 156 d after transplanting to 171 d after transplanting. Onions harvested 176 d after transplanting were not graded because of total loss due to bacterial diseases during heat curing.

The percent marketable onions of 'Pegasus' after CA storage showed a significant cubic trend with a decrease in marketable onions from 150 d after transplanting to 156 d after transplanting and an increase from 156 d after transplanting to 169 d after transplanting. This was followed by a significant decrease in marketable onions from 169 d after transplanting to 171 d after transplanting.

There were significant differences among days to harvest for 'Sweet Vidalia' during the 1998–99 season for harvest yield, and yield of jumbo and medium onions (Fig. 3). Both the harvest yield and jumbo yield showed a significant quadratic trend for days to harvest. Yield of jumbos increased sharply from 159 to

Probabilities				
Year	Harvest wt	Jumbo	Medium	% Marketable after CA storage
1999	0.003	0.078	0.029	0.355
2001	0.000	0.000	0.000	0.008
Polynomial contrasts and Fisher's protected LSD ($p \leq 0.05$)				
1999				
Linear	0.001	---	0.017	---
Quadratic	0.105	---	0.108	---
LSD	2.9	---	2.2	---
2001				
Linear	0.000	0.142	0.000	0.385
Quadratic	0.962	0.000	0.078	0.138
Cubic	0.582	0.000	0.368	0.002
LSD	10.2	8.3	1.4	17%

Fig. 2. Harvest and graded (jumbos and mediums) yields for days after transplanting with percent marketable yield after about 4.5 months of CA storage with top chart indicating 1999 and bottom chart indicating 2001 for 'Pegasus'.

166 d after transplanting and then decreased when harvested 174 d after transplanting while the field harvest did not show such a pronounced quadratic effect. Yield of medium onions showed a decreasing linear trend with increased days to harvest.

With an LSD of 2.1 kg/plot, 'Sweet Vidalia' field yield increased significantly with harvests 166 d from transplanting compared to 159 d

from transplanting, but field yield 174 d from transplanting was not different from yields 166 d from transplanting (Fig. 3). Jumbo and medium yields differed significantly based on number of days to harvest. There was no difference in the percent marketable onions after CA storage in 1999.

'Sweet Vidalia' harvest yield increased with a quadratic trend in the 1999-2000 growing

season. Harvest yield was significantly greater 135 d after transplanting than 128 d after transplanting, but did not differ from yields 142 d after transplanting. Harvest yields 162 and 169 d from transplanting were significantly greater than harvest yields 142 d from transplanting, but did not differ from harvests 147 d after transplanting in 2000.

'Sweet Vidalia' jumbo yields increased quadratically, while mediums decreased linearly for days to harvest in 2000. Jumbo yields were higher 135 d from transplanting than 128 d from transplanting, but did not differ from 147 d from transplanting. Finally, jumbo yields 147 d from transplanting were higher than jumbo yields 135 d from transplanting. Medium yields 135 d from transplanting differed significantly from mediums harvested 128 and 142 d from transplanting. Medium yields 142 and 147 d from transplanting were not different. There was no difference in percent marketable yield post-CA storage for 'Sweet Vidalia'.

A single year of data from the 2000-01 growing season was collected for both cultivars WI-609 and PS 7292 (Fig. 4 and 5). 'WI-609' showed a significant quadratic effect for both harvest yield and jumbos, while mediums had a significant cubic trend (Fig. 4). There was also a significant cubic trend in percent marketable onions after CA storage.

There was a significant increase in 'WI-609' harvest yields from 128 d after transplanting compared to yields 120 d from transplanting. Yields were also greater from harvests 137 d from transplanting compared to 128 d from transplanting. In addition, yields were greater from harvests 143 d after transplanting compared to harvests 137 d after transplanting and harvests 150 d from transplanting were greater than from 143 d after transplanting. There was no difference in field yield from harvests 150 d after transplanting compared to field yields 156 d after transplanting for 'WI-609'.

There were more 'WI-609' jumbos harvested 128 d after transplanting than 120 d after transplanting and more jumbos 137 d from transplanting compared to 128 d from transplanting. Jumbo yield 143 d from transplanting was not significantly greater than 137 d from transplanting. In addition, jumbo yield 143 d from transplanting did not differ from jumbo yields 150 d from transplanting or 156 d from transplanting.

'WI-609' medium yields were significantly greater 128 d from transplanting than 120 or 137 d from transplanting. Medium yields 137 d after transplanting did not differ from mediums yields 143 d after transplanting, but were >150 or 156 d after transplanting.

The percent marketable yield after CA storage increased for 'WI-609' from 120 to 137 d from transplanting where it peaked at 55% before declining significantly to 22% for harvests 143 d after transplanting. CA stored onions then increased significantly to 70% marketable onions for those harvested 156 d after transplanting.

'PS 7292' had an increasing linear effect for harvest yield in the 2000-01 season (Fig. 5). Onions harvested 150 d after transplanting were significantly greater than onions harvested 137

Probabilities				
Year	Harvest wt	Jumbo	Medium	% Marketable after CA storage
1999	0.001	0.002	0.004	0.128
2000	0.000	0.000	0.000	0.170
Polynomial contrasts and Fisher's protected LSD ($p \leq 0.05$)				
1999				
Linear	0.000	0.068	0.002	---
Quadratic	0.009	0.001	0.225	---
LSD	2.1	2.4	1.9	---
2000				
Linear	0.000	0.000	0.000	---
Quadratic	0.006	0.000	0.339	---
Cubic	0.608	0.397	0.884	---
LSD	5.9	4.8	1.8	---

Fig. 3. Harvest and graded (jumbos and mediums) yields for days after transplanting with percent marketable yield after about 4.5 months of CA storage with top chart indicating 1999 and bottom chart indicating 2000 for 'Sweet Vidalia'.

or 143 d after transplanting. Harvest yield 169 d after transplanting was significantly greater than harvests 150 or 156 d after transplanting, but did not differ from harvests 171 d after transplanting.

'PS 7292' graded jumbos had a significant cubic trend for harvest date. Jumbo yield 150 d after transplanting was greater than 137 or 143 d after transplanting, but was less than jumbo

yields 156 d after transplanting. Jumbo yield 169 d after transplanting was greater than jumbo yield 156 d after transplanting, but did not differ from harvests 171 d after transplanting.

Graded mediums of 'PS 7292' had a cubic trend for harvest date. Medium yields were greater 143 d after transplanting than 137 or 150 d after transplanting. 'PS 7192' medium yields were less 156 d after transplanting than

150 d after transplanting and greater than on 169 or 171 d after transplanting.

The percent marketable yield of 'PS 7292' had an increasing linear trend (Fig 5.). In total, 150 d after transplanting, 54% of 'PS 7292' onions were marketable after CA storage, which was significantly greater than onions harvested 143 d after transplanting, but not greater than percent marketable onions 137 d after transplanting. The percent marketable onions 169 d after transplanting was 63%, which was significantly greater than the percent marketable onions for onions harvested 156 d after transplanting, but did not differ from percent marketable onions harvested 171 d after transplanting.

Discussion

During the 1998-99 season harvest dates represented middle to late harvest dates for the onions in the study. During the 1999-2000 and 2000-01 seasons, harvest dates were chosen to represent a maturity range that was well before mature (no weakness in the neck and tops green) to past harvest maturity (tops down with many dried leaves) for the specific cultivar. These ranges, it was reasoned, represented a wide enough harvest window to give an assessment of the effect of days to harvest for the parameters tested (field yield, graded yield, and CA storability).

Harvest yield in almost all cases continued to increase the later the onions were harvested. This agrees with several other studies as reported by Brewster (1990). Short-day onions are harvested while tops are still somewhat green usually when 20% to 50% of the tops are down (broken over at the neck) in southeast Georgia. Presumably any increase in size after the tops are down is due to water uptake since it is unlikely that photosynthates are being translocated to the bulb. Sargent et al. (2001) indicated that field yields began to decline during later harvests at the Bradenton, Fla. location, but had a linear increase over the harvest dates at the Ft. Pierce, Fla. location with days to harvest of 94 to 132 from transplanting for 'Granex 33'. By contrast, during the 3 years of our study days to harvest from transplanting date ranged from 120 d for 'WI-609' to 176 d for 'Pegasus'. Rickard and Wickens (1977) found that a specific date was the best criteria for determining optimum harvest, which contrasts with our finding where an assessment of tops down was a better indicator of optimum maturity because of the variation in number of days to harvest from year to year. This difference may be due to environmental differences between summer production of long-day onions and winter production of short-day onions.

Yield of jumbos, by contrast, generally showed diminishing marginal or reduced yields with later harvests. Jumbo onions are the primary grade growers are interested in producing in southeast Georgia as they usually command the highest prices. Typically, growers expect that 80% of their graded onions will be in this size class. Yields of medium sized onions tend to decrease with later harvests, because the onions continue to increase in size.

Growers have several criteria they wish to

Probabilities				
Year	Harvest wt	Jumbo	Medium	% Marketable after CA storage
WI-609	0.000	0.000	0.000	0.000
Polynomial contrasts and Fisher's protected LSD ($p \leq 0.05$)				
WI-609				
Linear	0.000	0.000	0.003	0.000
Quadratic	0.022	0.007	0.001	0.770
Cubic	0.823	0.938	0.000	0.002
LSD	3.7	7.1	2.0	14%

Fig. 4. Harvest and graded (jumbos and mediums) yields for days after transplanting with percent marketable yield after about 4.5 months of CA storage for 'WI-609' in 2001.

meet as it pertains to harvesting onions. First is maximizing jumbo yield. Second, for early varieties, harvesting as early as possible while maintaining onion quality, which would include a preponderance of jumbos, curability, and resistance to regrowth. Finally, late maturing onions should meet the above criteria and must be harvested before warm season bacterial diseases cause significant losses. Having a reliable method to predict the optimum harvest date would be helpful to growers, but we have been unable to devise a reliable method other than through visually examining bulbs for adequate size and assessing the percent tops down or weakness in the neck.

Maynard and Hochmuth (1997) indicated that onion growth outside the range of 2 to 29 °C is negligible. Calculating degree days with a minimum of 2 or 4 °C and a maximum of 29 °C resulted in no more information for maximizing jumbo yields than actual days to harvest for a particular cultivar.

The number of days to harvest can vary from about 135 to 155 d for the earliest cultivars to 165 to 175 d for the latest cultivars based on our study. Because onions are daylength sensitive, predicting optimum harvest date by counting days to harvest from planting date can be problematic because earlier planted onions usually take longer to mature. In addition, the number of days to harvest for a particular cultivar can change dramatically from year to year because of environmental factors such as temperature, rainfall, and to a lesser extent disease and/or insect pressure. Although these factors all make it difficult to predict a specific optimum harvest date, cultivars that are classed

as early, midseason or late remain remarkably consistent within their maturity class relative to other cultivars within a particular year.

Finally, growers have been encouraged to put their most mature onions into CA storage. The initial analysis of the cultivar evaluation in 1999 was intriguing because it suggested that earlier harvested onions may do better in CA storage than later harvested onions (Table 1). A complete analysis of the harvest date information from the 1999 cultivar evaluation for individual cultivars based on harvest date, however, reflects a much less important contribution of harvest date to CA storability. Data for individual cultivars was analyzed both for percent marketable onions after CA storage as well as for post-CA yield based on harvest date (data not shown). With percent marketable yield only three cultivars had significantly higher percent marketable yields with earlier harvests; 'Nirvana', 'Mr. Max', and 'Yellow Granex Improved', while all other cultivars were not significant for post-CA percent marketable yields. An analysis of the actual yields where you might expect to see greater differences due to differences of sample size placed in CA, the only cultivar with a significantly greater post-CA yield for earlier harvest was 'Sweet Vidalia'. There were no other significant yield differences among the varieties for harvest date. In the original factorial analysis of cultivar and harvest date the F-test critical value is 3.10 (degrees of freedom: 2-numerator, 88-denominator) for harvest date, whereas an analysis of individual cultivars for harvest date has a critical F test value of 6.94 (degrees of freedom: 2-numerator, 4-denominator). This higher F value required

for individual analyses dramatically reduces finding significant differences. This is important because growers are more likely to grow only a few cultivars usually based on cultivar harvest date (e.g., early, midseason, and late).

We also plotted percent culls at harvest against percent marketable after CA storage (data not shown) because a higher incidence of culls might have an inverse predictive value for percent marketable onions from CA storage. This also did not shed any light on the problem.

There does not appear to be any predictive value in harvest date and its affect on CA storability as the initial study suggested. Growers will continue to have to rely on assessing optimum maturity for size and carefully examining onions before CA storage to maximize onion quality and minimize losses to diseases.

In addition, of the eight statistical assessments of percent marketable yield after CA storage for harvest date, only three had a statistical significance with two of these linear increases in percent marketable onions with later harvests and one a cubic effect. Overall, these results are unreliable at predicting onion performance after CA storage and certainly differ from the initial 1999 assessment. Brewster (1990) reported on several studies where storability was optimum at some point before maximum yield when tops were completely down. These were indicated from various studies from 50% to 70% tops down, but were for long-day onions put in ambient storage. Our study had more uneven results and may reflect specific problems with CA storage of short-day onions.

The very earliest maturing varieties such as 'WI-609' will reach maximum maturity with all tops down early in the season usually well before warm season bacterial diseases become problematic. This means growers can harvest these onions later, increasing their overall size and presumably the percent of graded jumbos. Growers, however, are more likely to harvest these onions as early as possible since onions harvested during the first 1 to 2 weeks of the season command high prices.

Late maturing onions such as 'Pegasus' are particularly susceptible to late season bacterial diseases (*Burkholderia* spp.). This was particularly evident with 'Centaur' in 2000 and 'Pegasus' in 2001 as well as 'Sweet Vidalia' in 2000 when harvest yields from later harvests were greater, but after heat curing none of the onions were marketable. Heat curing accelerates the growth of bacterial diseases rendering the onions unmarketable. This problem may be partially ameliorated with shortened curing times or relying strictly on field curing.

In some regions of the world, long curing times (1 to 2 weeks) at temperatures from 25 to 30 °C or above are preferred because it helps control Botrytis neck rot (*Botrytis allii* Munn), while imparting a dark brown color to onions (Brewster, 1990; Tucker and Drew, 1982). In Georgia, darkening of the onion is considered unappealing, since the market is based on mild onions with a yellow or tan appearance. Heat curing is used, but is usually restricted to 24 to 48 h to dry down necks and control Botrytis neck rot, which is the main disease of CA stored

Probabilities				
Year	Harvest wt	Jumbo	Medium	% Marketable after CA storage
PS 7292	0.000	0.000	0.000	0.024
Polynomial contrasts and Fisher's protected LSD ($p \leq 0.05$)				
Linear	0.000	0.000	0.000	0.012
Quadratic	0.214	0.001	0.306	0.603
Cubic	0.596	0.011	0.000	0.246
LSD	7.7	7.1	1.5	24%

Fig. 5. Harvest and graded (jumbos and mediums) yields for days after transplanting with percent marketable yield after about 4.5 months of CA storage for 'PS 7292' in 2001.

onions in Georgia. In the first year of the study, >50% of the culls after CA storage were due to *Botrytis* neck rot with about 12% due to bacterial diseases and in the second year over 99% of the culls were due to *Botrytis* neck rot. No data on disease was collected in the third year. Heat curing has been recommended by several state extension services including Texas, Oregon, and Georgia (Boyhan et al., 2001; Hall et al., 2000; Hemphill, 2002). Recommendations for heat curing have ranged from 27 to 38 °C and from 3 to 14 d (Gunkel et al., 1971). This is problematic for onions in Georgia because of their high susceptibility to bacterial diseases. Any increase in the drying time could be devastating if bacterial diseases are present.

Attempts to control *Botrytis* neck rot through field applications of fungicides have not been very successful either (Maude, 1990). This disease can enter the onion bulb below the soil line where fungicides can't reach; along with entry through the neck when tops are removed at harvest. Once the pathogen is inside the onion, it is difficult or impossible to detect in the grading and culling process. Further, research has shown that *Botrytis* neck rot, although incapable of sporulating in CA storage, continues to grow under these conditions rendering the infected bulb unsalable when removed from storage (Purvis and Brock, 2003).

Shrinkage or weight loss in CA storage was about 8% to 9% for all cultivars in the study and remained remarkably consistent regardless of cultivar, harvest date, or year of the study. There was no problem noted with sprouted onions removed from CA storage, but presumably this could become a problem with some of these onions as they moved through the marketing stream to the consumer.

In conclusion, growers will still have to rely on their experience with the crop to determine optimum harvest date. Clearly, specific days to harvest or degree day calculations will not work with short-day onions because they are day-length sensitive and different climatic conditions each year will influence harvest date. Growers will have to assess bulb size, disease pressure, and maturity indices such as tops down or weakened necks to determine optimum harvest date. Finally, harvest date does not appear to affect CA storability of short-day onions.

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