Ceres Trust Graduate Student Grant - Final Report

Project Title: Evaluation of carrot (*Daucus carota*, L.) for traits related to early seedling establishment and canopy growth in organic systems

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Abstract

Carrots are an important crop for many organic vegetable growers, but weed control remains a major challenge due to slow emergence and delayed canopy closure. The growth habit of carrots results in an extended critical weed free period, during which intensive and costly manual weeding is necessary for successful crop establishment. Varieties with rapid seedling growth and reduced time to canopy closure offer a potential solution to mitigate weed control in organic carrot production. However, little is known about shoot growth in carrots and additional research is needed to inform selection strategies and future breeding efforts. This project aimed to elucidate competitive responses in diverse carrot lines by observing emergence, canopy growth, and postharvest quality at different planting densities (50, 120, and 200 seeds/linear meter). Canopy height and width significantly increased with planting density, suggesting that higher planting densities may encourage competitive shoot growth in carrots and may be helpful for weed management. Although higher planting density significantly reduced emergence, the impact was negligible as the number of marketable roots at harvest was still higher than for low planting density. Results will be used to facilitate breeding efforts for improved growth habit in carrots.

Introduction

The characterization and selection of traits that can compete with weed growth is important for ensuring maximum productivity in many crops, especially in existing organic systems, where management of weeds with herbicide is not an option. This is particularly true in carrot (*Daucus carota,* L.), which is among the top ten vegetable crops worldwide and an important crop for many organic vegetable growers (Rubatzky & Yamaguchi, 1997; Singh & Lebeda, 2007; USDA-NASS, 2012). The proportion of carrot production on organic land in the US is higher than any other vegetable, with 14.3% of acreage grown on organic systems (USDA-NASS, 2012). In Wisconsin, carrot production contributes substantially to the organic market, primarily through CSAs and expanding markets through storage crops and winter shares, and farmers in Wisconsin have stated that carrots are key to bringing in customers.

Despite its popularity as an organic crop, carrot production is limited by erratic germination and slow seedling growth relative to other crops, requiring intensive weed management (Rubatzky et al., 1999). Within a given seed lot, carrot seedling emergence can spread over several weeks, with late-germinating seeds effectively become weed-like competitors to earlier emerged seedlings. Even after establishment, carrot canopy growth is slower than that of most weeds, making weed control often the most expensive cost of organic carrot production. Furthermore, a survey of carrot growers by the

Northern Organic Vegetable Improvement Cooperative (NOVIC, eorganic.info/group/5751) rated improved germination as a top breeding priority. However, the role of early seedling establishment and canopy growth in suppressing weeds has not been well characterized in carrot.

Based on field trials in CA, WA, and WI, it was noted that some genotypes grow more quickly and have larger canopies than typical carrots (**Figure 1**). These findings suggest genetic variability for top size and the potential to improve growth habit through selection. Carrot growers also recognize large differences among cultivars when comparing canopy size. Responses vary among cultivars, but the best performing cultivars in organic systems are not always commonly used cultivars in conventional systems (Bull et al., 2005; Murphy et al., 2007). William & Warren (1975) observed better carrot yield associated with canopy size, but there are no published reports providing insights into the genetics of this trait.

Figure 1. Carrot seeding size for lines with small (left) and large (right) canopy height at 30 DAP (days after planting).

Intraspecific competition is often stronger than interspecific competition, providing an opportunity to encourage more rapid canopy closure by increasing planting density (Li et al., 1996). This project aimed to improve the understanding of intraspecific competition in carrot by planting diverse breeding lines with small and large canopy size at different planting densities. The identification of carrot breeding stocks with improved competitive response will potentially reduce the need for timed weeding, cultivation, and other costs associated with weed control, in addition to informing breeding strategies. Information on these aspects of carrot will be of broad relevance to a better understanding of weed control in organic carrot production and crop performance both in the Midwest and the United States.

Materials and Methods

Plant Material

Lines with small (N = 4) and large (N = 4) canopy size were selected from the USDA carrot breeding program based on prior field evaluations. Industry standards included the varieties ‘Yellowstone’ and ‘Mokum’, which have large and small canopy size, respectively, and are grown by many organic producers. Breeding lines with small canopy size included 1111B, 3363B, and RedA x 6220B and lines with large canopy size included 2144A, P.D. x PI1326011, and 6307A x 6308B.

Experimental Design

Carrots were planted in 2015 on organic plots certified by the Midwest Organic Services Association (MOSA). Locations included the University of Wisconsin West Madison Agricultural Research Station (WMARS), Tipi Produce in Evansville, WI, and Crossroads Farm in Cross Plains, WI. Plots were laid out at each location in a RCBD with three blocks and each line was seeded at 50, 120, and 200 seeds/linear meter. Between row spacing was 60” at WMARS and 30” at Tipi Produce and Equinox Farms. Plots at WMARS were drip irrigated, while plots at Tipi Produce and Equinox Farms were primarily rainfed.

Measurements

Data was collected for percent emergence 30 days after planting. Height and width (cm) were measured at three random points in each plot and at three intervals of the growing season (30, 60, and 120 days after planting). Carrots were harvested 120 days after planting (DAP) and the number of marketable roots was counted (diameter > 1/2 inch, absence of defects including rot, growth crack, and forking). Fresh and dry shoot and root biomass (g) were recorded at harvest.

Statistics

Data was analyzed using R 3.2.3. Significance of location, planting density, and line on emergence, realized planting density, marketable roots, and biomass was determined using a Type III ANOVA and Tukey's HSD for pairwise comparisons.

The following fixed effects model was used to determine significance:

$$Y_{ijk} = \mu + C_i + D_j + L_k + (C \times D)_{ij} + (C \times L)_{ik} + (D \times L)_{jk} + (C \times D \times L)_{ijk} + r_{l(k)} + \varepsilon_{ijk}$$

Where:

Y_{ijk} is the dependent variable,

μ is the overall mean,

C_i is the main effect of carrot breeding line (i = 1, 2, 3, 4, 5, 6),

D_j is the main effect of planting density (j = 1, 2, 3),

L_k is the main effect of location (k = 1, 2, 3),

$(C \times D)_{ij}$ is the interaction of breeding line and planting density,

$(C \times L)_{ik}$ is the interaction of breeding line and location,

$(D \times L)_{jk}$ is the interaction of planting density and location,

$(C \times D \times L)_{ijk}$ is the interaction of breeding line, planting density, and location,

$r_{l(k)}$ is the effect of replication nested in location (k = 1, 2, 3, 4), and

ε_{ijkl} is the error ~iid $N(0, \sigma_{\varepsilon}^2)$

Results

Emergence

Percent emergence was used as a metric for seedling vigor, i.e. ability of a seedling to break through the soil crust. Planting density, line, and location all significantly affected percent emergence ($P < 0.001$) and no higher order interactions were significant, suggesting that planting density affected emergence similarly across lines and locations. Significant differences among lines indicate that genetic background may influence emergence. Pairwise comparisons using Tukey's HSD showed a significant decrease in emergence of 5.8% ($P < 0.05$) in carrots planted at high vs. low density (**Figure 2**).

Canopy Height and Width

Planting density significantly increased canopy height and width throughout the growing season ($P < 0.01$). For the first canopy width measurement (30 DAP), the interaction of planting density, location, and line was significant ($P < 0.001$). The interaction plot in **Figure 3** shows shifts in rank among genotypes at different planting densities and across locations, but in general canopy width increased with higher planting density. Width at 30 DAP was lowest at Tipi Produce and highest at WMARS, with a greater effect of planting density at WMARS relative to the other sites (**Figure 3**). One potential explanation for this observation is differences in inter-row spacing at WMARS and at the on-farm sites (Tipi Produce and Equinox Farms). There were shifts in rank among lines for canopy width at 30 DAP, but ranks of extremes were consistent across locations and planting densities, with P.D. x PI1326011 and 'Mokum' ranked the highest and 3363B, 1111B, and 2144A ranked the lowest (**Figure 3**).

At 30 DAP, high planting density significantly increased mean height by an average of 3.33 cm relative to low planting density. This effect perpetuated throughout the growing season, with a final mean difference of 2.62 cm between high and low planting density. Canopy width also increased with planting density, with the largest mean difference between high and low planting density (10.97 cm) occurring at 60 DAP.

The interaction of line and location significantly influenced canopy height (**Figure 4**) and canopy width ($P < 0.001$). Despite this interaction, there were still some observable patterns among lines. At the end of the season, 'Yellowstone' had the highest canopy height across all three sites, while 1111B, 3363B, and 'Mokum' were consistently among the shortest lines throughout the growing season (**Figure 4**). Both P.D. x PI1326011 and 6307A x 6308B were among the tallest lines at the middle of the season and declined in height at the end of the season. This reduction in height may have resulted from susceptibility to *Alternaria* leaf blight (ALB), a fungal pathogen that attacks the leaf tissue of carrot plants.

Marketable Roots

The percentage of marketable roots was affected by the interactions of planting density x line ($P < 0.001$) and of location x line ($P < 0.001$). As planting density increased, the percentage of marketable roots tended to increase, but the amount of increase varied by line (**Figure 5**). Mean increases in the percentage of marketable roots at higher planting density were modest for 'Yellowstone' (5.64%) and 6307A x 6308B (6.11%) and more dramatic for lines 2144A (20.23%) and 1111B (17.28%).

Shoot and Root Biomass

Planting density significantly impacted both shoot and root biomass ($P < 0.001$). On average, shoot and root biomass was 2.25 g and 6.00 g lower at high vs. low planting density, respectively. Effects of line and location were also significant for shoot biomass ($P < 0.001$) and no significant interactions were observed. The interaction of line and location was significant for root biomass ($P < 0.05$) and, in general, root biomass was lowest at Tipi Produce and highest at WMARS (**Figure 6**). Although shifts in rank are evident among lines, 'Yellowstone' had consistently higher root biomass while 1111B and 3363B were consistently low (**Figure 6**).

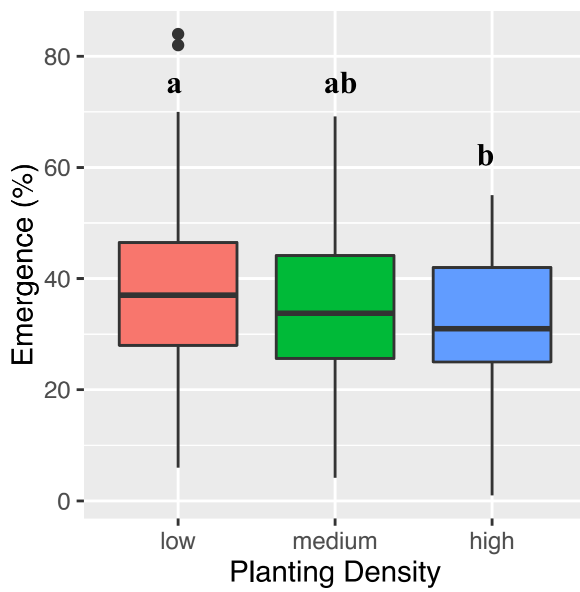

Figure 2. Boxplots of percent emergence by planting density. Different letters indicate a significant difference based on Tukey's HSD ($P < 0.05$).

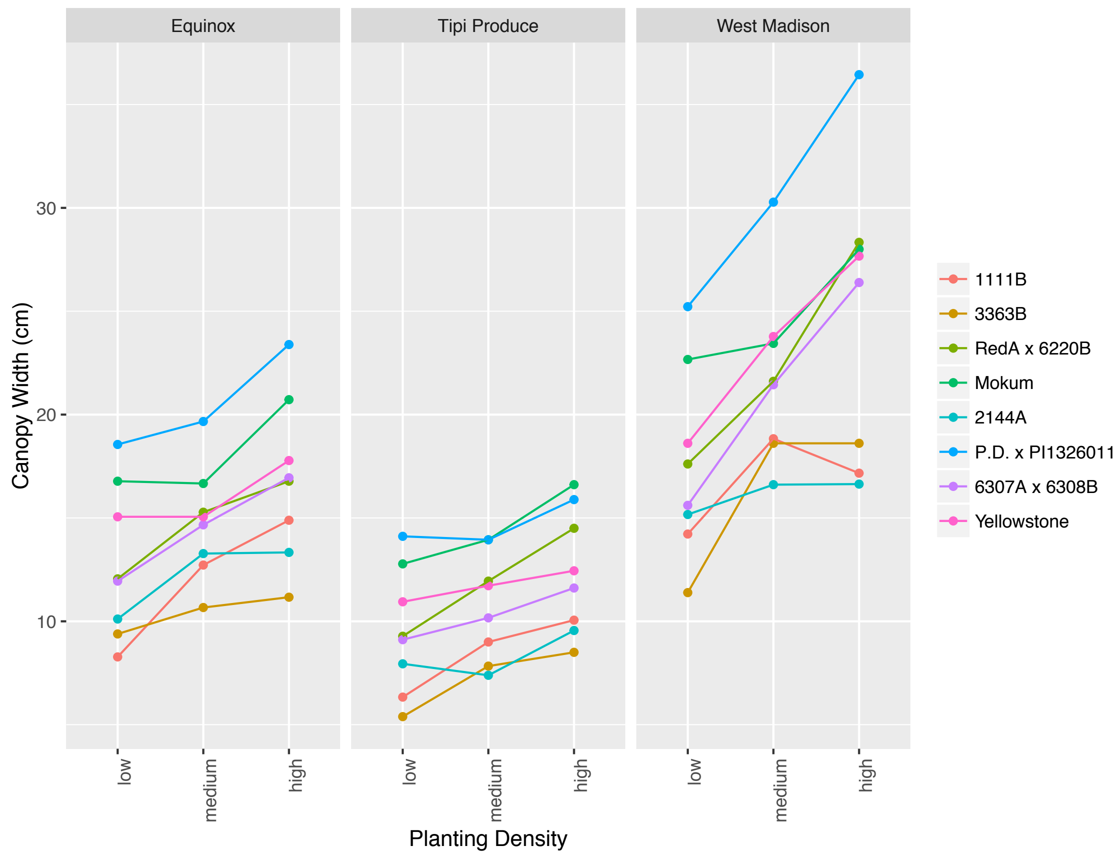

Figure 3. Three-way interaction plots of planting density x line x location for canopy width at 30 days after planting.

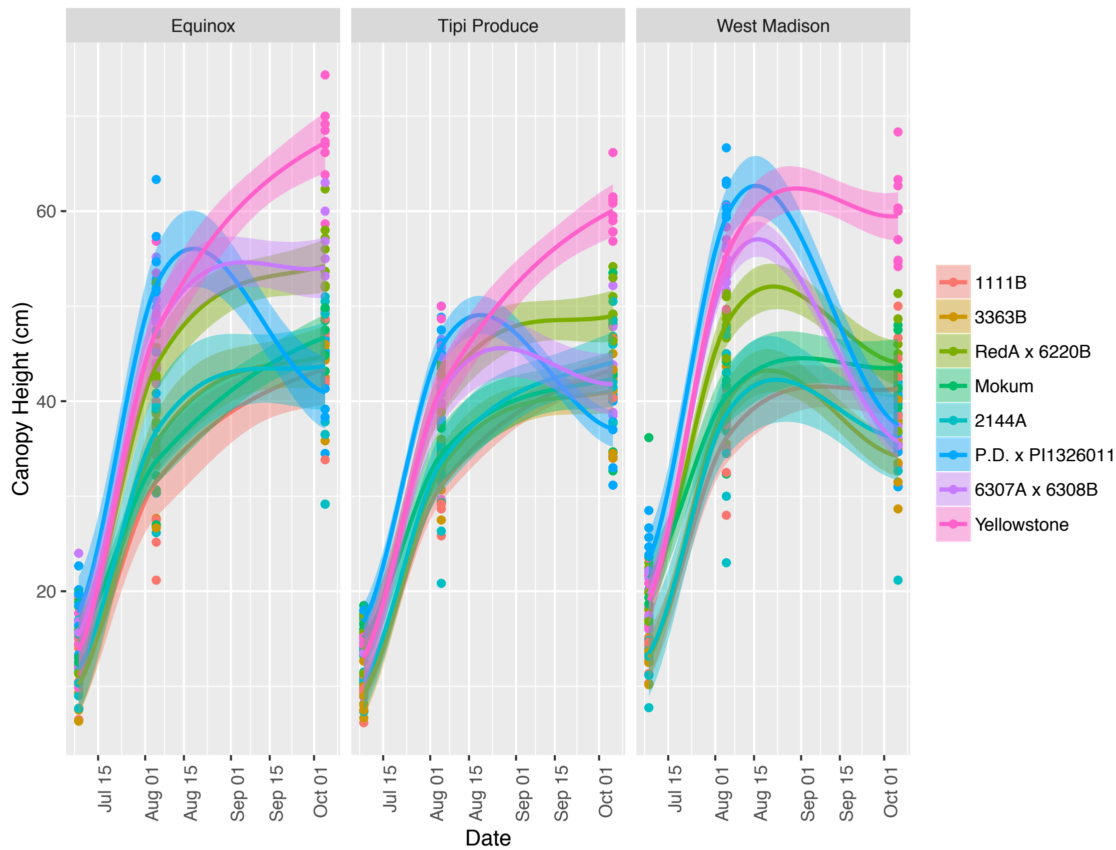

Figure 4. Canopy height (cm) for each line at three locations (Equinox Farms, Tipi Produce, and West Madison Agricultural Research Station). Regression lines were fitted using LOESS (locally weighted smoothing) and shading indicates standard error bounds.

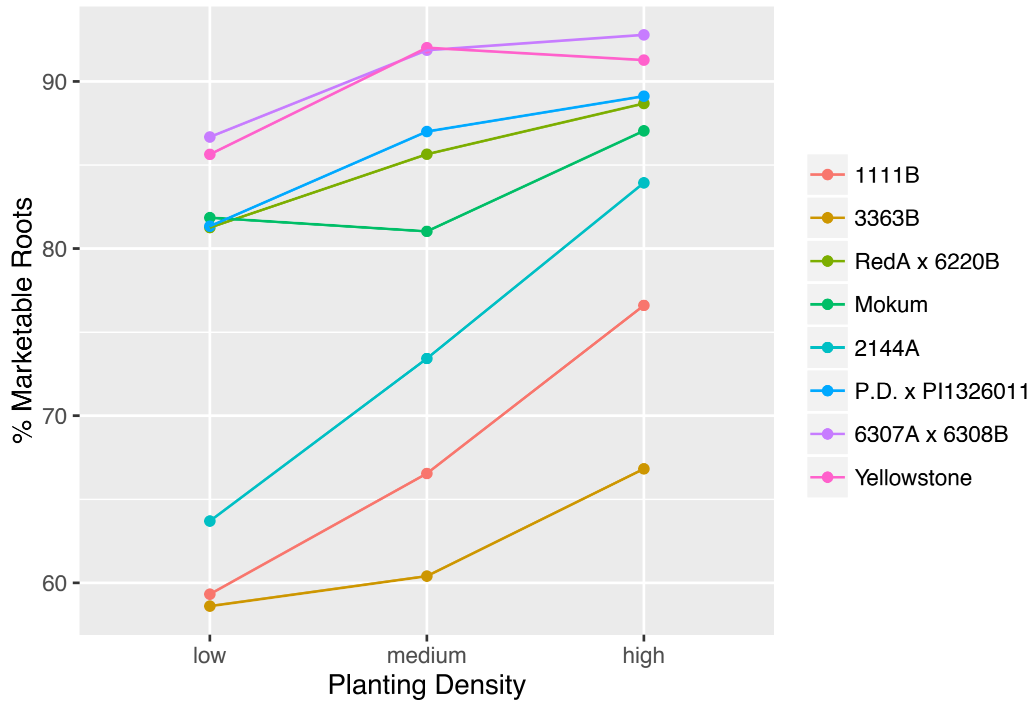

Figure 5. Two-way interaction plot of planting density x line for percentage of marketable roots.

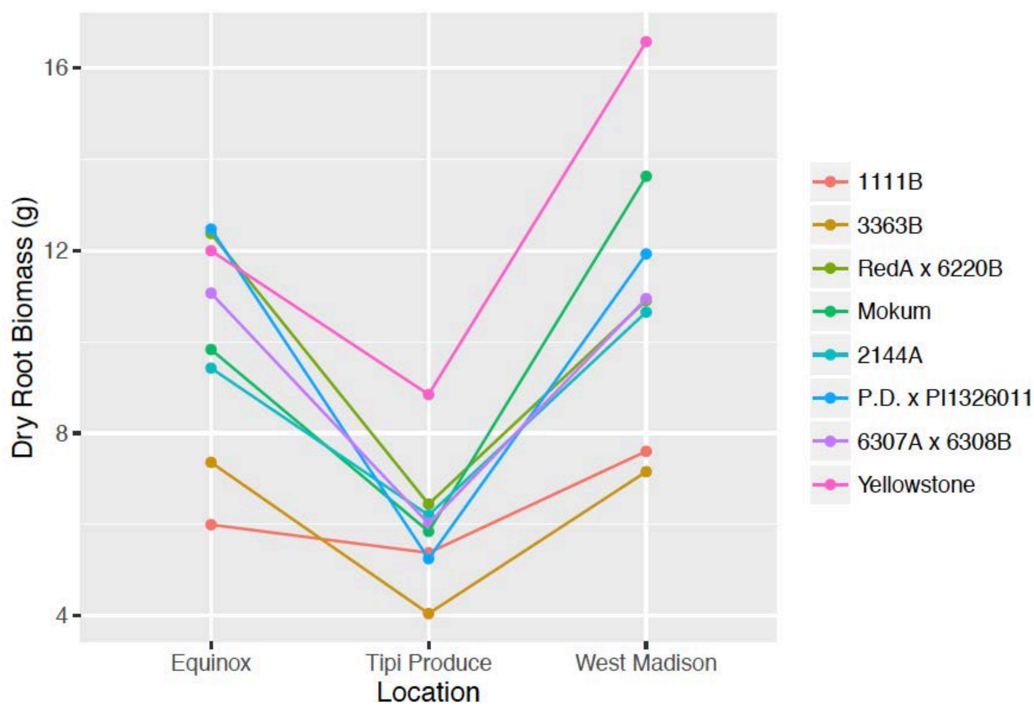

Figure 6. Two-way interaction plot of line x location for dry root biomass (g).

Conclusions

Carrot varieties with rapid initial growth and canopy establishment are a desirable option for weed control in organic systems. In this study, we observed increases in canopy height and width at higher planting density, which could potentially help suppress weed growth and improve crop performance. Significant line by location interaction was observed for most traits, which may be due to variable seedling emergence across locations. Future studies may be able to account for these differences by thinning to uniform densities.

In addition to increasing canopy height and width, higher planting density significantly raised the percentage of marketable roots for select lines (e.g. 2144A and 1111B), suggesting that increased planting density may help reduce defects. While higher planting density did increase canopy height and width, there was a corresponding decrease in shoot and root biomass per plant. Observations by Steve Pincus, who is well known for the quality of his carrot production at Tipi Produce, support these conclusions. While producing carrots, Steve has observed increased uniformity and reduced sprangle/forking at higher planting densities, with the caveat that the growing season must be extended to achieve marketable roots.

This experiment is currently being repeated in the summer 2016 field season at WMARS to confirm preliminary results and determine the stability of effects across years. Other items of interest for this data and future studies include further exploration of interaction effects, comparisons of relative growth rate, and effects of planting density on source-sink relationships between the shoot and the root. The results of this experiment confirm the presence of genetic variation for canopy size in carrots, which is promising for future breeding efforts. Line by location interactions were significant, but may not heavily influence breeding efforts as the highest and lowest ranking lines were consistent across locations for all traits. Future studies on weed competitiveness and the genetic basis of canopy size in carrots will also help determine the efficacy of planting density and genetic background on weed suppression.

Outreach

Methods and results of this project were shared as a poster presentation at the 2014 American Society of Horticultural Science (ASHS) meeting and at the 2015 Midwest Organic and Sustainable Education Service (MOSES) meeting. An oral presentation was also given at the 2015 Organic Agriculture Research Symposium (OARS). The objectives and progress of the experiment were shared during field tours during the West Madison Organic Agriculture Field Day and the 2015 Student Organic Seed Symposium (SOSS).

Acknowledgements

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References

Bull, C.T., J. Muramoto, S.T. Koike, J. Leap, C. Shennan and P. Goldman. 2005. Strawberry cultivars and mycorrhizal inoculants evaluated in California organic production fields. Crop Management Online: http://www.plantmanagementnetwork.org/pub/cm/research/2005/strawberry/.

Li, B., Watkinson, A.R., and Hara, T. 1996. Dynamics of competition in populations of carrot (*Daucus carota)*. Ann. Bot. 78: 203-214.

Murphy, K.M., K.G. Cambell, S.R. Lyon and S.S. Jones. 2007. Evidence of varietal adaption to organic farming systems. Field Crops Research.102:172-177.

Rubatzky, V.E., and M. Yamaguchi. 1997. World Vegetables (2nd ed.) Chapman and Hall, N.Y. 843 pp.

Rubatzky, V.E., C.F. Quiros, and P.W. Simon. 1999. Carrots and related vegetable Umbelliferae. CABI Publishing. New York, N.Y. 294 pp.

Singh, R. J. and A. Lebeda. 2007. Landmark Research in Vegetable Crops. In: Genetic Resources, Chromosome Engineering, and Crop Improvement Series, Volume 3, Chapter 1. Edited by R. J. Singh. CRC Press, Boca Raton, FL. pp. 1-16.

U.S. Department of Agriculture-National Agricultural Statistics Service. 2008.2007 Census of Agriculture. USDA, Washington, DC. Online: http://www.agcensus.usda.gov/Publications/2007/Full_Report/index.asp

U.S. Department of Agriculture-National Agricultural Statistics Service. 2012. Agricultural Statistics. USDA, Washington, DC.

William, R. D. G. F. Warren. 1975. Competition between purple nutsedge and vegetables. Weed Sci. 23:317-323.