Conf. on Transportation of Perishables, Asilomar, Calif. p. 124–127.
10. Radspinner, W. A. 1954. Commercial aspects of ripening mature-green tomatoes with ethylene gas. Pre-Pack-Age 8(4):17–18, 20–21.
11. Showalter, R. K. 1960. Watermelon color as affected by maturity and storage. Proc. Fla. State Hort. Soc. 73:289–293.
12. Showalter, R. K. 1975. Sampling watermelons for soluble solids. Proc. Fla. State Hort. Soc. 88:272–276.

HortScience 17(6):948–949. 1982.

The Effect of Density and Postplanting Fertilization on Response of Lettuce to CO_2 Enrichment[1]

M. M. Peet[2] and D. H. Willits[3]
North Carolina State University, Raleigh, NC 27650

Additional index words. *Lactuca sativa*, vegetable production, plant spacing, greenhouse

Abstract. **Plants of lettuce (*Lactuca sativa* L. cvs. Parris Island Cos and Great Lakes 659) were grown in greenhouses at 2 spacings and with 2 levels of postplanting fertilization with and without CO_2 enrichment. CO_2 enriched plants averaged 29% higher head fresh weights and 40% higher leaf areas. In terms of fresh weight increases, enrichment response was greater in 'Great Lakes 659' than 'Parris Island Cos' and in high rather than low fertility treatments. In terms of leaf area increases, low-density treatments responded more than high-density treatments to enrichment. Increases in leaf area with enrichment were similar in the 2 cultivars and the 2 fertilization treatments.**

Lettuce is highly responsive to CO_2 enrichment, exhibiting an increase in both yield and earliness (1, 3, 8). Thus, CO_2 addition to the greenhouse atmosphere is recommended for lettuce production in Ontario, Michigan, and England (1, 2, 8). Information is not available on how planting density changes affect response to CO_2. High-density-grown plants may be light- rather than CO_2-limited and so might be expected to have less of a response to enrichment. Enrichment, on the other hand, may allow plants to compensate for crowding.

To test these alternatives, we grew plants at 2 spacings in CO_2-enriched and nonenriched greenhouses. We also used 2 types which differed in growth habit: 'Parris Island Cos', which has an upright growth form, and 'Great Lakes 659', a crisphead type with sprawling growth habit.

Seeds of both lettuce cultivars were sown in 3.2-cm 'Speedling' trays on Nov. 25, 1981, and transplanted on Dec. 17 into raised soil beds in each of 2 houses, a CO_2-enriched house and a nonenriched control house. Each cultivar was grown at 2 spacings: 12 × 12 cm (144 cm^2) and 24 × 24 cm (576 cm^2). All beds were given preplanting fertilization of 44.8 kg/ha N, 16.5 kg/ha P, and 23 kg/ha K. Half the treatments were given 10.6 kg/ha N, 4.6 kg/ha P, and 8.8 kg/ha K 3 weeks after planting, with the remaining treatments receiving no postplanting fertilization. Each treatment was replicated 4 times. Six interior plants were sampled in each treatment.

Temperature set points in the 2 houses were identical with minimums of 17.2/11.6°C and with cooling set at 23.8°, 25.5°, or 26.7°. The control house was heated and cooled by conventional means with heat being provided by a natural gas unit heater and the first 2 levels of cooling by a 2-speed fan. The third level, if needed, was provided by pad cooling at the high ventilation rate. The heating and cooling equipment in the enriched house was supplemented with a rock bed into which heat was vented in a closed-loop fashion during the day and from which heat was reclaimed at night. Both houses were controlled by a computer which gave priority to the rock bed for both heating and cooling. When the rock bed became fully charged or could no longer supply adequate cooling, outside ventilation was used. In this way, substantial cooling was provided for the house without the need for venting, making CO_2 enrichment possible for the entire day for large portions of the year. Details of the system and its operating characteristics are reported elsewhere (7).

Enrichment in the CO_2 house was maintained at about 1000 ppm from 0800 to 1600 HR. CO_2 levels were monitored in the enriched house with a conductimetric meter based on the design of Kimball and Mitchell (4). The CO_2 was supplied in tanks as a liquid. Provisions were made to discontinue enrichment in the event that outside ventilation was required to maintain temperature. Meter calibration was checked every other day using test gases of 1068 and 0 ppm CO_2. Calibration shifts in excess of 10% were corrected by adjusting the offset potentiometer. CO_2 concentrations varied between about 950 and 1100 ppm depending upon factors such as uptake rate and infiltration. CO_2 concentrations were not monitored in the control house.

All plants were harvested Feb. 16, 1982. Fresh weights were obtained on a sample of 6 plants in each replicate. Leaf areas were measured on a sample of 1 plant per replicate. Only leaves with at least the greater part of 1 surface exposed to light were included to indicate the leaf area available for transpiration and photosynthesis. Thus, leaf areas of inner head leaves were not measured.

Weather was unusually cloudy during the period of lettuce growth. Solar radiation measurements made via an Eppley pyranometer mounted outside the greenhouses indicated an average daily insolation rate of 8.1 mJ/m^2 on a horizontal plane during the 62 days of the test. Data compiled by Liu and Jordan (5) show an average rate of 9.1 mJ/m^2 per day can be expected for Greensboro, N.C., the closest location for which long term historical data are available. This represents a reduction of 11% in total solar energy received compared to an average year. Total solar radiation for Raleigh, N.C., is not available from the National Oceanic and Atmospheric Administration (NOAA), but percent possible sunshine is reported. For the 62 days of the test the percent possible sunshine reported was 42% whereas the 26-yr average for the months of December, January, and February through 1980 is 56%. Once again, this indicates the degree of cloudiness experienced.

High-CO_2-grown plants averaged 29% greater fresh weight of heads (Table 1). This compares to the increases of 21 and 26% reported in England at a similar spacing (20 × 20 cm) with enrichment to 800 and 1200 ppm CO_2, respectively (3). Plants in the 2 density treatments responded similarly to CO_2 enrichment. Thus, our data suggest that densities should not be altered with CO_2 enrichment.

Low-density-grown plants were larger than high-density plants, with 61% greater fresh weight. Even though individual plant weights were lower, more than twice as much weight per unit area was produced in the high-density treatments (8.8 kg/m^2) than in the low-density treatments (3.5 kg/m^2). The high-density spacing was, however, considerably

[1]Received for publication June 11, 1982. Paper No. 8513 of the Journal Series of the North Carolina Agricultural Research Service, Raleigh, NC 27650.
The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.
[2]Department of Horticultural Science.
[3]Department of Biological and Agricultural Engineering.

Table 1. Effect of CO_2 enrichment, planting density, and postplanting fertilization on per-plant fresh weights of 'Parris Island Cos' and 'Great Lakes 659' lettuce.

CO_2 level	Fresh wt (g) ± SE							
	Parris Island Cos				Great Lakes 659			
	Low density		High density		Low density		High density	
	High fert.	Low fert.	High fert.	Low fert.	High fert.	Low fert.	High fert.	Low fert.
1000 ppm	202±11	195±27	122±30	99±19	298±25	279±9	212±21	177±25
Ambient	160±8	157±4	94±4	93±10	209±21	186±10	118±15	133±4

Table 2. Effect of CO_2 enrichment and planting density on leaf area in lettuce cultivars.

CO_2 level	Leaf area (cm^2) ± SE			
	Low density		High density	
	Great Lakes	Parris Island Cos	Great Lakes	Parris Island Cos
1000 ppm	6010±1097	3863±205	1229±177	1496±255
Ambient	3636±335	2567±156	1472±250	1331±189

closer together than the recommended spacing for those cultivars, and head shape would have been unacceptable in many of the high-density plants. This is similar to the finding of Chrimes (2) in spacing trials with lettuce in England.

The 2 cultivars were strikingly different in their response to CO_2 enrichment: 'Great Lakes 659' increased 50% with enrichment and 'Parris Island Cos' increased only 23%. This may reflect a higher growth potential in 'Great Lakes 659', as head weights were higher overall than in 'Parris Island'. This is in contrast to the results of Hand (3) with butterhead lettuce cultivars which did not differ greatly in response to CO_2 enrichment. Butterhead cultivars did, however, show a greater response to CO_2 during rapid postrosette growth periods. This supports the conclusion that CO_2 response is greatest under rapid growth conditions in lettuce.

The response to CO_2 was greater in the treatments given postplanting fertilization (44%) than in the treatments given only preplant fertilization (32%). This was seen even though fertilized treatments overall yielded only slightly (7%) heavier heads than nonfertilized treatments. This suggests that where CO_2 enrichment is used postplanting fertilization can be justified (11% increase in head weights), although it would not be necessary otherwise to add fertilizer after planting. In Michigan, higher nutrient levels are recommended for CO_2-enriched lettuce (8).

Although the leaf areas of enriched plants were 39% higher overall than nonenriched (Table 2), planting density greatly affected the response to CO_2 enrichment. Leaf areas did not differ significantly between enriched and nonenriched plants in the high-density treatments, but in the low planting density, leaf areas of enriched plants were 50% higher for 'Parris Island' and 65% higher for 'Great Lakes 659'. This differs from the results of Hand (3), who found no effect of CO_2 enrichment on leaf area of greenhouse lettuce in England. In his study, head weight increase with enrichment was solely a result of increase in weight per unit leaf area. Sionit et al. found that leaf areas increased with enrichment in wheat, however (6).

Fertilization treatments did not affect leaf areas. 'Great Lakes 659' had a greater leaf area than 'Parris Island' at low but not high densities.

Thus, in using CO_2 enrichment to increase head weights of winter-grown lettuce, densities and fertilization practices need not be altered, but greater response can be expected from some cultivars than others. Our data suggest rapidly growing cultivars are more responsive. CO_2 enrichment also can be used to increase leaf areas but here the effect was much greater at low density. Because of unusually cloudy conditions, high-density plants were probably light-, rather than CO_2-limited.

Literature Cited

1. Fisher, J. C. and J. K. Muehmer. 1978. Greenhouse lettuce production. Ontario Ministry of Agr. & Food, Pub. 78-001.
2. Chrimes, J. 1980. Space for profit. Grower 94(Nov.):25–27.
3. Hand, D. 1980.Winter CO_2 enrichment. Grower 94(Dec.):17–20.
4. Kimball, B. A. and S. T. Mitchell. 1979. Low-cost carbon dioxide analyzer for greenhouses. HortScience 14:180–182.
5. Liu, B. Y. H. and R. C. Jordan. 1967. Availability of solar energy for flat-plate solar heat collectors. p. 1–18 In: R. C. Jordan (ed.). Low temperature applications of solar energy. Amer. Soc. Heat. Refrig. Air-Cond. Eng., New York.
6. Sionit, N., D. Mortensen, B. R. Strain, and H. Hellmers. 1981. Growth response of wheat to CO_2 enrichment and different levels of mineral nutrition. Agron. J. 73:1023–1027.
7. Willits, D. H. and M. M. Peet. 1981. CO_2 enrichment in a solar energy collection/storage greenhouse. Amer. Soc. Agr. Eng. Paper 81-4525, presented to the 1981 winter meeting, Chicago, Ill.
8. Wittwer, S. H. and S. Honma. 1979. Greenhouse tomatoes, lettuce and cucumbers. Michigan State Univ. Press., East Lansing.

HortScience 17(6):949–950. 1982.

Response of 'McFarlin' Cranberry to Nitrogen Sprays[1]

A. Y. Shawa[2]

Washington State University, Coastal Washington Research and Extension Unit, Long Beach, WA 98631

Additional index words. *Vaccinium macrocarpon*, yield components, pollen germination

Abstract. **Two nitrogen formulations, urea and ammonium sulfate, were applied as aqueous sprays to 'McFarlin' cranberry (*Vaccinium macrocarpon*, Ait.) vines at the rate of 0, 1.12, 2.24, 3.36, 4.48, and 5.60 kg N/ha at 5, 50, and 80% bloom. Urea applied 3 times during bloom at 4.48 kg N/ha increased yield. The nitrogen treatments had no significant effect on soluble solids, pH, or fruit breakdown.**

Yield in cranberries is the product of 5 morphological components that occur sequentially: 1) number of uprights per unit area; 2) proportion of fruiting uprights; 3) number of flowers per fruiting upright; 4) berries set per number of flowers; and 5) berry weight (5, 6, 7, 9). Nitrogen may be a limiting factor in cranberry growth and fruit development. The demand for this element is high especially during berry set and enlargement. To satisfy demand, frequent leaf feeding may be used. Foliar feeding is not a substitute for soil fertilizer treatment, but can provide an alternative method for getting nutrients into vines when demand exceeds absorption rates. Washington research has shown that nutritional foliar sprays containing 10% N, 5.3% P, and 2% Zn (10–12–0 + Zn 2%) can significantly increase size and weight of berries

[1]Received for publication Nov. 14, 1981. Scientific Paper No. 6067. College of Agriculture Research Center, Washington State University, Pullman, Project 1889.

The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

[2]Horticulturist and County Extension Agent, Rt. 1, Box 570. The author appreciates the technical assistance of John Wang.