communications in soil science and plant analysis

COMMUN. IN SOIL SCI. PLANT ANAL., 14(8), 699-708 (1983)

INFLUENCE OF EXCESS SOIL-WATER AND N RATES ON LEAF DIFFUSIVE RESISTANCE AND STORAGE QUALITY OF TOMATO FRUIT

KEY WORDS: Aeration, stomata, flooding, soft-fruit syndrome, water logging

D. L. Karlen, R. E. Sojka,

Soil Scientist and Research Agronomist
USDA-ARS
Coastal Plains Soil & Water
Conservation Research Center
Florence, SC 29502

M. L. Robbins

Professor of Horticulture
Clemson University Coastal Experiment Station
Charleston, SC 29407
In cooperation with the
South Carolina Experiment Station, Clemson, SC 29631

ABSTRACT

Tomatoes (*Lycoperscion esculentum* Mill.) were grown in the greenhouse to determine if excess water and/or N rates are involved with a nonbacterial "soft-fruit" problem which has been encountered in the

Southeastern Coastal Plain. The treatments included flooding for 0, 5, or 8 days and three rates of N (245, 346, or 627 kg/ha). Flooding induced stomatal closure, hastened fruit maturation, and significantly reduced internal fruit firmness after 8 days of storage at 20°C, but N had no significant effect. Stomata closed approximately 3 days after plants were flooded and were permanently impaired in plants flooded for 8 days. These results suggest that for tomatoes grown on the Norfolk soil association (Typic Paleudults) irrigation applied during fruiting must be carefully managed to prevent excess soil-water in the root zone which can cause stomatal closure and subsequently influence the storage quality of the fruit.

INTRODUCTION

Packers of fresh market tomatoes (*Lycopersicon esculentum* Mill.) in the Southeastern Coastal Plain have frequently encountered a non-bacterial, "soft-fruit" problem which has caused severe economic losses. The tomatoes were produced by local growers who use intensive management practices which include mulching with plastic, staking the plants, irrigating, and often applying liberal applications of N fertilizers. The soils in these areas are somewhat poorly drained and frequently subjected to high water tables, but erratic rainfall patterns and a low water-holding capacity require growers to use both drainage and irrigation for successful crop production. Recently, to conserve energy and water, these growers have begun to use intensive trickle irrigation instead of sprinkler irrigation. This change in water management coincided with an increase in the "soft-fruit" problem causing many growers to speculate that trickle irrigation was causing this syndrome.

Water and N management practices have been shown to influence several physiological disorders in tomato including blossom-end rot and fruit cracking.[23,24,6] Bartz et al.[3] stated that excessive fruit softness and accelerated post-harvest decay were associated with high N fertility. They further concluded that high N can increase the innate susceptibility of tomato fruit to *Erwina carotovora var. carotovara*. Sims et al.[31] found that N had no definite effect upon the ripening rate of tomato fruit, but the fruit from plants which received high N fertilization had the shortest shelf life.

Bradford and Yang[5] reviewed the physiological response of plants to excess water and cited studies which show that water logging rapidl induces partial stomatal closure in a number of plant species. Sojka and Stolzy[32] suggested that the stomatal response to soil aeration was probably not a simple mechanical response, but one step in a chain of responses that involves secondary events in the soil environment and in the physiology of the plant. Hunt et al.[17] demonstrated that flooding a Typic Paleudult decreased relative leaf-water content and leaf-water potential of tobacco (Nicotiana tabacum L.) and noted that plant tissue soon became flacid, resulting in a loss of stem diameter increase. They speculated that these phenomena were related to a general loss of turgidity in the plant that would probably impact all morphological parts, including guard cells of stomata. In tomato, this same syndrome may impact ripening rate, fruit firmness, and storage quality. Therefore, a greenhouse experiment was conducted to determine if tomato response to excess water included stomatal closure and creation of the "soft-fruit" syndrome and whether N fertilization rate influenced the adverse effects of flooding.

MATERIALS AND METHODS

A Norfolk loamy sand (Typic Paleudult) which had high P, low K, and very low Ca and Mg concentrations was air dried, fumigated with methyl bromide, and limed with dolomite at a rate equivalent to 1400 kg/ha. Sixteen kilograms of soil were fertilized with N, P, K, S, Mg, Mn, and B at rates equivalent to 77, 70, 130, 120, 91, 5.6, and 0.7 kg/ha, respectively, and were placed in plastic pots at a bulk density of 1.6 g/cm^3 (which is the mean stable bulk density of Ap horizons for this soil). One hybrid tomato seedling (var. 'Tempo') was transplanted into each of 36 pots. Plastic sheets were placed over the soil surface to inhibit evaporation, insuring that water loss was primarily through transpiration. Average day and night temperatures were 27° and 21°C, respectively. The photoperiod was maintained at 12½ hours by supplementing daylight with incandescent and fluorescent lights.

By watering 1 or 2 times each day and periodically weighing the pots, the volumetric soil water content was maintained near 20% which for this soil, at a bulk density of 1.6 g/cm^3, corresponds to approximately 15 centibars (cb) of soil water tension. The N variable was initiated 4 weeks after transplanting by applying calcium nitrate every 1, 2, or 3 weeks. After 10 weeks of growth, the plants had been fertilized with N at rates equivalent to either 245, 346, or 627 kg/ha. Additional P, K, and S were applied to all plants at rates equivalent to 66, 250, and 67 kg/ha, respectively. Ten weeks after transplanting, when fruit in the first and second clusters were 7-10 cm in diameter, drainage holes were plugged with rubber stoppers, and the soil was flooded for 0, 5, or 8 days to create 3 flooding treatments labeled DD, F1, and F2, respectively. To terminate the flooding treatments, the stoppers were removed, and the pots were allowed to drain. The F1 and F2 treatments received post-treatment waterings after the pots drained, and weighing indicated the soil water content had returned to approximately 20% by volume.

Abaxial (R_{ab}) and adaxial (R_{ad}) leaf diffusive resistances were monitored with a Licor LI65[1/] meter and sensor at midday on the leaflet extending from the second uppermost node before, during, and after the water treatments were imposed. Parallel leaf diffusive resistance (R_s) was calculated from the abaxial and adaxial measurements according to equation 1.

$$1/\text{Parallel } R_s = (1/\text{Abaxial } R_s) + (1/\text{Adaxial } R_s) \qquad [1]$$

Mature green fruit from the first and second clusters were picked 11 and 8 days after the F1 and F2 flooding treatments had been terminated, respectively. Fruit were weighed and placed in storage at 20°C for 8 days. Internal fruit firmness was measured by slicing the fruit in one-half and measuring the resistance of the flesh to crushing on the blossom side with a penetrometer which had a rubber tip with a surface area of 1.4 cm^2. Petioles collected from the uppermost fully developed node prior to imposing the water treatments were dried at 70°C, ground, and digested with a mixture of sulfuric and selenous acids for total Kjeldahl N analysis. Data were analyzed using a randomized complete block design with three levels of N, three levels of flooding, and four replications.[33]

RESULTS AND DISCUSSION

The petiole N concentrations prior to initiating the flooding treatments were 2.81, 3.02, and 3.46% for the treatments fertilized with 245, 346, or 627 kg/ha of N, respectively. These N concentrations were within the lower part of the range reported by Geraldson et al.[14] The range of N concentrations showed no significant influence of N on fruit firmness (Table 1). Low petiole N concentration has been shown[26,27,28,29] to increase relative leaf water content, xylem pressure potential, and leaf diffisive resistance of plants. However, the effect of N level on R_s was not significant at P(.05) in our study.

Diffusive resistance in the nonflooded treatment (DD) remained relatively unchanged over time (Fig. 1). The short-term flooding (F1) and long-term flooding (F2) treatments which were initiated on Julian Day 28 showed a response lag of about 3 days which was followed by a rapid and dramatic rise in R_s, indicating stomatal closure. The F1 treatment showed signs of recovery after the pots were drained on Julian Day 33 as R_s was no longer significantly different from the nonflooded plots. The F2 treatment remained significantly more elevated throughout the observation period with only a slight drop in R_s, probably due to loss of tissue integrity or leaf necrosis, rather than due to a return of normal stomatal function. This response is similar to the way stomata reacted to long-term flooding in corn (Zea mays) reported by Wenkert et al.[34] In comparing adaxial and abaxial measure-

TABLE 1

Influence of Flooding and N Fertilization on Internal Firmness of Mature Green Tomato Fruit after 8 Days of Storage at 20°C

N Rate kg/ha	Water Treatment[a] DD	F1	F2	Avg.
	kg/cm^2			
245	3.92	1.87	2.15	2.64
346	3.20	2.72	1.28	2.40
627	2.36	2.87	1.84	2.36
Avg.[b]	3.16	2.49	1.75	

a Water treatment DD - nonflooded, F1 - flooded 5 days, F2 - flooded 8 days.
b LSD(.05) for N rate - N.S.
LSD(.05) for water treatment = 1.04
LSD(.05) for (N x water) interaction = N.S.

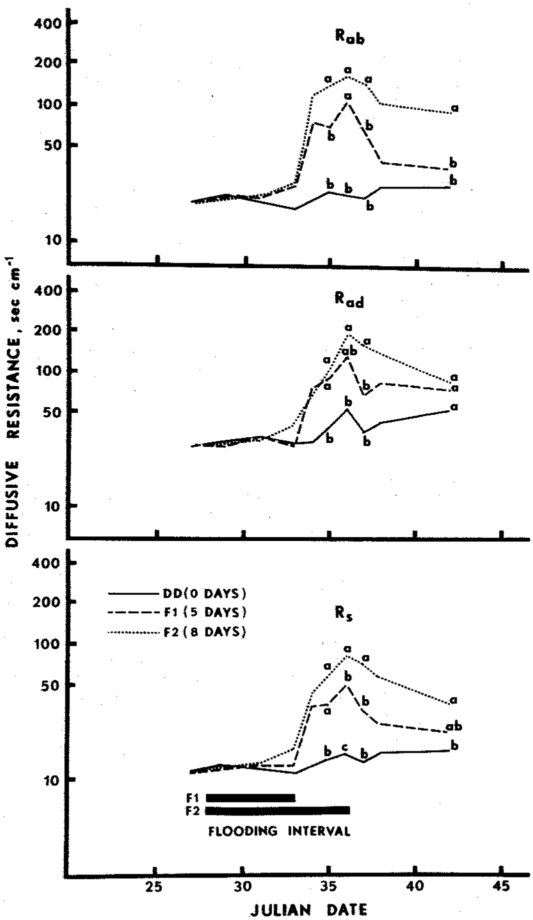

Fig. 1. Influence of flooding tomatoes for 0 (DD), 5 (F1), or 8 (F2) days on parallel (R_s), abaxial (R_{ab}), or adaxial (R_{ad}) diffusive resistance. Mean values for any single day identified by the same letter are not significantly different at P(.05).

ments, we found that R_{ad} was generally more elevated than R_{ab}, but R_{ab} was more sensitive to both onset of stress and recovery from stress. The stomatal responses to flooding in this experiment were similar to other reports of stomatal closure in leaves of flooded tomato plants[19] and to those reported as a result of low soil-O_2 availability for a range of species including tomato.[32] Sojka and Stolzy speculated that ethylene, whether produced in the plant or generated in the soil, was one factor influencing stomatal closure, although Bradford and Yang[5] and others have reported that ethylene caused no direct effect on stomatal behavior.

Campbell and Phene[7] found that when soil matric potential in a Plinthic Paleudult was wetter than -80 mb, the soil 0_2 concentration and yield of pearl millet (Panicum milliaceceum var. pearl) decreased. Hunt et al.[16,17,18] found that Norfolk and similar Coastal Plain soils, common in the tomato-producing area, produce significant amounts of ethylene when flooded and that ethylene accumulation was greatest in the Ap horizon. Therefore, because ethylene is known to be a mediator of flood-induced plant characteristics including leaf epinasty and senescence[5] and because improper water management can cause aeration problems in these soils, we hypothesized that these factors were also creating the "soft-fruit" problem.

In this experiment, the water variable subsequently produced a significant difference in the internal fruit firmness (Table 1). After 8 days in storage at 20°C, fruit from flooded plants were bright red and unmarketable because of their soft texture, but fruit from the nonflooded plants were firm and still "breaking" or pink in color.

Adding NO_3^- to poorly-aerated root systems has been shown to ameliorate plant response because of a variety of individual or combined mechanisms including substitution of NO_3^- for free 0_2 as an alternate electron acceptor[2,8,9,10,11,12,15,21,25,35] although Lee[20] questions this substitution. Reviews of NO_3^- and Eh interaction have also pointed out that an abundance of NO_3^- in the soil profile can poise Eh at a mildly-reduced state before a further drop and reduction of more stable compounds occurs.[30,22]

Bradford and Dilly[4] showed that $AgNO_3$ added to tomato plants grown under flooded conditions inhibited ethylene production and blocked the epinastic effect. They attributed this effect to the Ag ion rather than NO_3^-, but Gavinlertvatana et al.[13] reported promotion of ethylene in shoot cultures when $AgNO_3$ was added.

Hunt et al.[16] determined that >100 ppm NO_3^- lowered ethylene production in flooded Norfolk soils, but in our experiment the interaction between the N fertilization rate and the flooding treatments was statistically nonsignificant (Table 1). There were numerical differences, however, indicating that in the nonflooded (DD) treatment, firmness declined as N rate increased, while with short-term flooding (F1), firmness increased as N rate increased. These results suggest that in adequately-aerated soils, high N may induce softer fruit, but when soil O_2 is lowered for a brief time, high N may stabilize the tomato fruit. The severity of the stress induced in F2 apparently precluded amelioration by adding additional NO_3^-, because as shown by the R_s response, treatment F2 was much more severe than F1 and caused irreversible damage.

Fruit weight was not significantly influenced by preflooding N rate or by the flooding treatments. Fruit harvested from the second cluster were significantly smaller than fruit from the first cluster, but fruit size did not influence the firmness response. This indicated that flooding had caused a physiological response which resulted in a more rapid maturation of all fruit present when the treatments were imposed.

CONCLUSION

The results of this experiment show that excessive irrigation of a Norfolk loamy sand can induce stomatal closure and reduce the storage quality of tomato fruit. Although the N effects on fruit storage quality were not statistically significant, numerical trends indicated some amelioration of negative responses at higher N rates following short-term flooding, but the reverse was true in the absence of flooding. This suggests that high N may alleviate "soft-fruit" problems induced by short-term flooding, but in the absence of flooding, producers may risk greater damage by using high rates of N.

Finally, the "soft-fruit" symptoms observed in his experiment were similar to those described by the packers who encountered the problem commercially. However, since there were no problems when the water was well managed, this study emphasizes the importance of monitoring the soil water status with tensiometers or similar instrumentation and controlling the water supplied to the tomato crop so that aeration problems are prevented.

REFERENCES

1. Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U. S.

Department of Agriculture and does not imply its approval to the exclusion of other products or vendors that may also be suitable.
2. Arnon, D. I. 1937. Ammonium and nitrate nitrogen nutrition of barley and at different seasons in relation to hydrogen-ion concentrations, manganese, copper, and oxygen supply. Soil Sci. 44:91-113.
3. Bartz, J. A., C. M. Geraldson, and J. P. Crill. 1979. Nitrogen nutrition of tomato plants and susceptability of the fruit to bacterial soft rot. Phytophathology 69:163-166.
4. Bradford, K. J., and D. R. Dilley. 1978. Effects of root anaerobiosis on ethylene production, epinasty, and growth of tomato plants. Plant Physiol. 61:506-509.
5. Bradford, K. J., and S. F. Yang. 1981. Physiological responses of plants to waterlogging. HortSci. 16:25-30.
6. Burgess, D. H. 1979. Soil and plant water potentials in relation to tomato fruit cracking. M.S. Thesis. Michigan State Univ.
7. Campbell, R. B., and C. J. Phene. 1977. Tillage, matric potential, oxygen, and millet yield relations in a layered soil. Trans. ASAE. 20:271-275.
8. Drew, M. C., and E. J. Sisworo. 1977. Early effects of flooding on nitrogen deficiency and leaf chlorosis in barley. New Phytol. 79:567-571.
9. Drew, M. C., and E. J. Sisworo. 1979. The development of waterlogging damage in young barley plants in relation to plant nutrient status and changes in soil properties. New Phytol. 82:301-314.
10. Drew, M. C., E. J. Sisworo, and L. R. Saker. 1979. Alleviation of waterlogging damage to young barley plants by application of nitrate and a synthetic cytokinin, and comparision between the effects of waterlogging, nitrogen deficiency and root excision. New Phytol. 82:315-329.
11. Garcia-Novo, F., and R. M. M. Crawford. 1971. Soil aeration, nitrate reduction and flooding tolerance in higher plants. New Phytol. 72:1031-1039.
12. Garcia-Novo, F., and R. M. M. Crawford. 1973. Soil aeration, nitrate reduction and flooding tolerance in higher plants. New Phytol. 72:1031-1039.
13. Gavinlertvatana, P., P. E. Read, and H. F. Wilkins. 1980. Control of ethylene synthesis and action by silver nitrate and rhizobitoxive in petunia leaf sections cultured in vitro. J. Amer. Soc. Hort. Sci. 105:304-307.
14. Geraldson, C. M., G. R. Klacan, and O. A. Lorenz. 1973. Plant analysis as an aid in fertilizing vergetable crops. In L. M. Walsh and J. D. Beaton (eds.). Soil Testing and Plant Analysis. Soil Sci. Soc. of Amer., Madison, WI.
15. Gilbert, S. G., and J. W. Shine. 1942. The significance of oxygen in nutrient substrates for plants: the oxygen requirement. Soil Sci. 53:143-152.
16. Hunt, P. G., R. B. Campbell, and R. A. Moreau. 1980. Factors affecting ethylene accumulation in a Norfolk sandy loam soil. Soil Sci. 129:22-27.
17. Hunt, P. G., R. B. Campbell, R. E. Sojka, and J. E. Parsons. 1981. Flooding-induced soil and plant ethylene accumulation and water status response of field-grown tobacco. Plant and Soil 59:427-439.
18. Hunt, P. G., T. A. Matheny, R. B. Campbell, and J. E. Parsons. 1982. Ethylene accumulation in southeastern Coastal Plains

soils: Soil characteristics and oxidative-reductive involvement. Commun. in Soil Sci. and Plant Anal. 13:267-278.

19. Jackson, M. B., K. Gales, and D. J. Campbell. 1978. Effect of waterlogged soil conditions on the production of ethylene and on water relationships in tomato plants. J. Exp. Bot. 27:183-193.
20. Lee, R. B. 1978. Inorganic nitrogen metabolism in barley roots under poorly aerated conditions. J. Expt. Bot. 29:693-708.
21. Malovolta, E. 1954. Studies on the nitrogenous nutrition of rice. Plant Physiol. 29:98-99.
22. Patrick, W. H., and D. S. Mikkelsen. 1971. Plant nutrient behavior in flooded soil. In Fertilizer Technology and Use (R. A. Olson, T. J. Army, J. J. Hanway, and V. J. Kilmer (eds.) Soil Sci. Soc. Amer. Madison, Wis.
23. Pill, W. G., and V. N. Lambeth. 1980. Effects of soil water regime and nitrogen form on blossom-end rot, yield, water relations, and elemental composition of tomato. J. Amer. Soc. Hort. Sci. 105:730-734.
24. Pill, W. G., V. N. Lambeth, and T. M. Hinckley. 1978. Effects of nitrogen form and level on ion concentrations, water stress, and blossom-end rot incidence in tomato. J. Amer. Soc. Hort. Sci. 103:265-268.
25. Ponnamperuma, F. N. 1972. The chemistry of submerged soils. Advances in Agronomy. 24:29-96.
26. Radin, J. W. 1981. Water relations of cotton plants under nitrogen deficiency: IV. Leaf senescence during drought and its relation to stomatal closure. Physiol. Plant. 51:145-149.
27. Radin, J. W., and R. C. Ackerson. 1981. Water relations of cotton plants under nitrogen deficiency: III. Stomatal conductance, photosynthesis, and absisic acid accumulation during drought. Plant Physiol. 67:115-119.
28. Radin, J. W., and L. L. Parker. 1979a. Water relations of cotton plants under nitrogen deficiency: I. Dependence upon leaf structure. Plant Physiol. 64:495-498.
29. Radin, J. W., and L. L. Parker. 1979b. Water relations of cotton plants under nitrogen deficiency: II. Environmental interactions on stomata. Plant Physiol. 64:499-501.
30. Russel, E. W. 1976. The chemistry of waterlogged soils. In E. W. Russel (ed.) Soil Conditions and Plant Growth. Longmon Press. N.Y., N.Y. 849 p.
31. Sims, E. T., Jr., W. L. Ogle, D. O. Ezell, and K. B. Mack. 1963. The influence of nitrogen, potassium, and calcium on quality and post-harvest physiology of tomatoes. Assoc. Sou. Agr. Wkrs. Proc. 60:233-234.
32. Sojka, R. E., and L. H. Stolzy. 1980. Soil-oxygen effects on stomatal response. Soil Sci. 130:350-358.
33. Steel, R. G. D., and J. H. Torrie. 1960. Principles and procedures of statistics. McGray-Hill Book Co., Inc., NY.
34. Wenkert, W., N. R. Fausey, and H. D. Watters. 1981. Flooding responses in *Zea mays* L. Plant and Soil 62:351-366.
35. Willhite, F. M., A. R. Grable, and H. K. Rouse. 1965. Interaction of nitrogen and soil moisture on the production and persistence of Timothy in lysimeters. Agron. J. 57:479-481.

communications in
soil science
and
plant analysis