Soil Salinity and Ambient Ozone: Lack of Stress Interaction for Field-Grown Alfalfa

DAVID M. OLSZYK,* EUGENE V. MAAS, GERRIT KATS, AND LELAND E. FRANCOIS

ABSTRACT

The interaction of ambient photochemical oxidants (primarily ozone, O₃) and salinity on vegetation was evaluated in the field for 'U.C. Salton' and 'Moapa' alfalfa (Medicago sativa L.). Salinity treatments were imposed by irrigating with waters having average electrical conductivities of 0.9, 3.4, and 6.3 dS m⁻¹, which resulted in mean saturated-soil extract conductivities in the root zone of approximately 1.5, 5.8, and 8.1 dS m⁻¹, respectively. Plants were exposed in open-top chambers to filtered or unfiltered air at ambient O₃ concentrations during three regrowth periods, and filtered or unfiltered air plus added O₃ during a fourth. No overall interaction between O₃ and salinity occurred for alfalfa growth or yield. The only general effect of O₃ itself was to increase the percent empty nodes at three of the four harvests. Percent empty nodes due to ozone tended to decrease with increasing salinity, but this interaction was statistically significant only for the second harvest. Salinity by itself was more detrimental to plants than O₃, causing occasional decreases in dry weight and height. Large differences in growth and yield occurred between the two cultivars, but they were not associated with O₃ or salinity sensitivity. At the levels tested, salinity would affect plants more than O₃ in areas where both stresses occur.

Additional Index Words: Air pollution, Crop loss, Medicago sativa L., Yield.

Vegetation growing under field conditions is rarely exposed to a single environmental stress; instead, different stresses occur simultaneously. For example, plant responses to air pollution are modified by soil and climatic factors (6, 17). Thus, the quantitative effects of air pollutants documented under closely controlled experimental conditions, e.g., photosynthetic changes, mineral content, or dry matter production, may not reflect effects occurring under field conditions.

Photochemical oxidants (primarily O₃) have been shown to affect the physiology, growth, and yield of many crops including alfalfa (Medicago sativa L.) (5, 12, 15, 17, 18). Alfalfa yields were reduced 30 to 40% with ambient O₃ concentrations in the South Coast Air Basin (12, 15, 18). Salinity is an existing or potential threat to crop production in most of the irrigated soils of California and other states (3, 4). It is estimated that crop yields are significantly reduced on at least 29% of the irrigated acreage of California with electrical conductivity of saturated-soil extracts ECₑ > 4 dS m⁻¹ (1). Parts of this acreage also are subject to detrimental effects of air pollution.

Salinity reduced O₃ effects on injury and yield for several crops, including alfalfa, pinto bean (Phaseolus vulgaris L.), and garden beet (Beta vulgaris L.) grown under laboratory conditions (7–10). Bytnerowicz and Taylor (2) found that salinity decreased O₃ injury in snap bean (P. vulgaris L.). High salinity, however, had no effect on O₃-induced reductions in snap bean dry weight. In these salinity-air pollutant studies, the beneficial effects of salinity in reducing air pollutant effects were attributed to salinity-pollutant interactions in causing stomatal closure and, therefore, less pollutant uptake (2). However, field studies of salinity-pollutant interactions have not been carried out. The results of Hoffman et al. (8) indicated that alfalfa would be subject to the interactive effects of O₃ and salinity under field conditions, and would be an ideal test crop to evaluate the interaction.

Thus, the primary objective of this study was to determine the effects of O₃ on alfalfa grown on nonsaline soil and at two levels of salinity stress in the field. A subordinate objective was to determine whether two alfalfa cultivars thought to differ in salt tolerance would also differ in resistance to O₃.

MATERIALS AND METHODS

Plant Culture

Two cultivars of alfalfa were used in this study: 'Moapa', a moderately O₃-sensitive cultivar that is also relatively sensitive to salinity, and 'U.C. Salton', a salt-tolerant line of unknown sensitivity to O₃. Seed was sown (broadcast) on 8 May 1985 in 18 plots, each 4.3 by 4.3 m. The seeding rate was adequate to produce approximately 400 plants m⁻². The plots were enclosed by concrete borders to a depth of 0.75 m and contained Pachappa fine sandy loam (mixed, thermic Haploxeralf). The seed bed was leveled before planting to facilitate flood irrigations.

Each cultivar was planted in separate halves of each plot. Initially, there were approximately 2900 plants per plot, 1450 of each cultivar. This large population allowed for adequate plant mass for the first harvest. As the growing season progressed, natural competition reduced the population in the plots. Yield was determined separately from all plants harvested from each of the two quarter circles (1.12 m² area of quadrant) for each cultivar in each plot. Plants located within 0.31 m of the chamber wall were not included in the yield because of wall effects on plant growth.

The plants received regular flood irrigations with either saline or nonsaline water approximately weekly to maintain the desired soil water and salinity levels. Tensiometers (Irrometers®) were installed at 0.3- and 0.6-m depths in the root zone to monitor soil water conditions. All plots were irrigated when the average soil matric potential reached approximately -50 kPa at a depth of 0.3 m. Plants were sprayed for aphids using Orthene® (o,s-dimethyl acetophosphoramo-dithioate) and Malathion (O,O-dimethyl phosphoro-dithioate ester of diethyl mercaptosuccinate).

the open plots because of carryover of salinity from previous
and 12.1 ± 1.4 dS m⁻¹ for the 0.9, 2.4, and 6.3 dS m⁻¹ irrigation
waters, respectively. However, ECe at 1.5 ± 0.2, 5.8 ± 0.5, and 8.4 ± 0.6 dS m⁻¹ for the 0.9, 3.4,
relatively uniform for filtered and ambient chamber treatments
water before planting to provide a nonsaline seedbed. After
CaCl₂ solution 15 d prior to planting to obtain a saline soil pro-
conductivity (EC) of 0.9 ± 0.1 dS m⁻¹. The medium and high
salinity levels were achieved by irrigating with tap water to which
equal weights of NaCl and CaCl₂ were added to obtain water
salinity treatments consisted of six open plots
ECe values were 4.4 ± 0.6, 6.3 ± 0.8, and 6.3
averaged 1.3 ± 0.2, 1.5 ± 0.2, and 1.7 ± 0.2 dS m⁻¹ at depths
Mean salinity increased with soil depth for both filtered and
ambient chamber plots as shown by data for the first three ex-
comparison purposes.
Plants were exposed to ambient O₃ within 3.0-m diam. prot-
there were four harvests during the growing season from 11
O₃-free air in chambers. Chamber treatments were blocked intotwo groups of six each. The chambers were on and exposures
occurred between 0700 and 2000 h (PST) daily for 7 d/week
ISAAC® interface and Apple® IIe computer system. There
ultraviolet O₃ analyzer. The data were collected with an
Target O₃ and salinity treatments consisted of six open plots
Ozone was added to the ambient chambers during the
fourth exposure period at a rate sufficient to add approximately
resulting in a total addition of 333 kg N ha⁻¹ and 452 kg K ha⁻¹.
These quadrants were the experimental units for the statistical
cultivar was then split into north and south quadrants to ac-
three salinity treatments was replicated twice. Soil
Table 1 includes the mean ECe values for the three salinity
Pollutant Exposures and Monitoring

Growth, Yield, and Injury

Leaf injury included the following sources of variation with degrees
of freedom in parentheses; block (1), salinity (2), air (1), oxidant
earlier, only the chamber data were included in the statistical
All parameters were tested statistically by an analysis of
variance (ANOVA) (16). Because soil salinity levels were higher
for the open plots than for the chamber plots, as described
over the entire rooting depth in each plot.

Ozone concentrations in filtered chambers averaged
less than normal during the third exposure period because
the summer (12). However, O₃ concentrations were much
Table 1

<table>
<thead>
<tr>
<th>Salinity Treatment</th>
<th>ECe Mean ± SD (dS m⁻¹)</th>
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<tbody>
<tr>
<td>Low</td>
<td>0.9 ± 0.1</td>
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<tr>
<td>Medium</td>
<td>3.4 ± 0.2</td>
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<tr>
<td>High</td>
<td>6.3 ± 0.3</td>
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Table 1. Growth and leaf loss of alfalfa harvested after four exposure periods.

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<tr>
<td></td>
<td></td>
<td>Total dry weight, kg m(^{-2})</td>
<td>Height, m</td>
<td>Soil salinity</td>
<td>Measured as EC (_e)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.5</td>
<td>0.37 ± 0.06</td>
<td>0.37 ± 0.05</td>
<td>0.59 ± 0.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.2</td>
<td>0.37 ± 0.04</td>
<td>0.33 ± 0.01</td>
<td>0.56 ± 0.11</td>
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<tr>
<td></td>
<td></td>
<td>9.0</td>
<td>0.34 ± 0.05</td>
<td>0.32 ± 0.01</td>
<td>0.49 ± 0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13.5</td>
<td>0.34 ± 0.05</td>
<td>0.32 ± 0.01</td>
<td>0.49 ± 0.05</td>
</tr>
</tbody>
</table>

Values ± SD are for four (dry wt.) or leaf loss observations; two or five from each of two blocked plots.

42 ± 16 40 ± 11 35 ± 9 40 ± 8 33 ± 15 39 ± 10 65 ± 17 74 \(-\) 15 49 ± 12 54 ± 9 50 ± 15 51 ± 18 57 ± 9 60 ± 12 43 ± 12 43 \(-\) ± 12 35 ± 13 43 \(-\) ± 14 72 ± 14 55 ± 12 37 ± 12 42 ± 10 31 ± 11 31 ± 13 19 ± 9 26 ± 7 51 ± 14 55 ± 17 33 ± 11 35 ± 12 28 ± 10 30 ± 9 63 ± 17 39 ± 12 53 ± 17 57 ± 19 42 ± 14 43 ± 13 44 ± 18 44 ± 15 59 ± 28 89 ± 9 46 ± 35 64 ± 34 74 ± 17 68 ± 17 52 ± 11 45 ± 15

The primary statistically significant O3 effect was enhanced leaf senescence (Table 3). Percent empty nodes, an indicator of premature leaf senescence, was significantly greater on plants grown in ambient than in filtered chambers at the 12 Aug., 5 Sept., and 18 Nov. 1985 harvests. There were few other significant differences between ambient and filtered chambers for any parameter or harvest. A slight trend toward lower dry weights for ambient vs. filtered chambers occurred at the 12 Aug. and 5 Sept. 1985 harvests (Table 1). However, variability among the small number of replicates made this difference difficult to detect except for dry weight of 5 Sept. 1985. The greater height for ambient vs. filtered chambers at the 9 October harvest can probably be attributed to the lodging of alfalfa stems in the filtered chambers (Table 1). This lodging decreased the overall plant height in ambient chambers more than any potential reduction in growth from O3.

The O3 concentration may have been too low in the ambient chamber during late September and early October (Table 2) to affect plant growth prior to the...

Physiological measurements, including stem water potential and leaf stomatal conductance and photosynthetic rate, indicated few changes in basic plant metabolism that could be attributed to any individual treatment or interaction between treatments. However, it should not be ruled out that this lack of effects may be primarily an artifact associated with inadequate frequency of measurement or replicate location also were found. These interactions tended to occur consistently over all parameters or dates. Instead, the interactions reflected particular differences in relative yield parameters for all harvests (Table 3). Total dry weight decreased with increasing salinity on 18 Nov. 1985.

Large differences in growth and yield were found between U.C. Salton and Moapa (Table 3). U.C. Salton had the lowest salinity level (2.5 dS m-') and Moapa, respectively, when grown in open air and the chamber itself. The increase in chamber effect as the environment became cooler in fall was documented previously for alfalfa exposed to air pollutants with different exposure systems (12).

The net effect of the chambers over the course of four exposure periods was an apparent decrease in stand count among the major treatment factors of salinity, air, and cultivar (11, Table 3). However, the interactions did not follow any particular pattern and are not discussed here. A number of significant interactions tended to occur at the other harvests, but the results were not statistically significant. The added O3 prior to the 18 Nov. 1985 harvest should have had an adverse effect on the alfalfa. However, the general slow growth due to cooler, overcast weather likely decreased the sensitivity of the plants to O3 during this period. A similar trend of defoliation was reduced at the high salinity level in the ambient chambers (Moapa) in ambient chambers. In contrast, stand count averaged 190 ± 25 and 204 ± 26 for U.C. Salton and Moapa, respectively, when grown in open air and the chamber on 5 Sept. 1985. A similar trend of defoliation was reduced at the high salinity level in the ambient chambers (Table 3). The O3enhanced chamber effect as the end of the study compared to open plots. The net effect of the chambers over the course of four exposure periods was an apparent decrease in stand count per plot at the end of the study compared to open plots.

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growth over four exposure periods, with a resulting greater stand count compared to open plots. However, this did not occur. The primary factor affecting stand count appeared to be the lodging of plants in both filtered and ambient chambers before the 9 Oct. and 18 Nov. 1985 harvests. Lodging shaded new sprouts in the chambers, reducing the viability of the plants.

DISCUSSION

Stress Interactions

These results indicate the complexity that can arise when studying the effects of interacting stresses on plants in the field. The small differences in the environment between chambers and open plots become much more significant with cooler temperatures or overcast weather as reported earlier for alfalfa, lettuce (Lactuca sativa L.), and wheat (Triticum aestivum L.) (12-14), and can be more important than other artificial environmental variables imposed in chambers.

An example of such a complex interaction was as follows. At higher salinity levels, alfalfa plants tended to be shorter and more rigid. This altered morphology reduced the tendency of plants to lodge in the chambers, resulting in potentially greater yields with higher salinity in chambers, but not outside. In addition, if filtered air results in healthier, more rapidly growing plants; then plants in the filtered air x low salinity treatment chamber may lodge the most and have the apparent lowest yield of any treatment. In contrast, plants in filtered air and low salinity treatments would likely have the highest yields when grown in the field without chambers.

Other recent studies of environmental stress X O₃ interactions also gave varied results, i.e., water stress from decreased irrigation affecting crop sensitivity to O₃ in the field. Heggestad et al. (6) found that a mild water stress acted synergistically to increase yield losses from ambient O₃ to soybean (Glycine max (L.) Merr.). Temple et al. (17) reported, conversely, that slight water stress decreased ambient O₃ injury to cotton (Gossypium hirsutum L.) at Shafter, CA, and that water stress itself significantly decreased yields. Both of these studies were conducted in open-top field chambers under ambient conditions with water stress treatments imposed by withholding irrigation water, and during the summer when confounding effects of chambers would be least important.

Modification of Estimated Ozone-Induced Crop Losses by Salinity

This study indicated that salinity decreases alfalfa productivity much more than ambient O₃. Since many California soils have high salinity problems, yields obtained at salinities >5 dS m⁻¹ in this study are representative of actual growing conditions for alfalfa in California. If the production of alfalfa is restricted by salinity, then the added yield loss caused by O₃ would be negligible. If geographical areas where salinity limits production could be identified for specific crops, these areas might be assigned an estimated yield loss of zero from O₃, regardless of the loss expected from the ambient O₃ data.

The study also indicated a lack of interaction between soil salinity and O₃ on crop productivity. If soil salinity was not great enough to have a significant effect on crop production in a specific area, then it is likely that salinity would not modify the sensitivity of the crop to O₃. Thus, in these areas the available O₃ dose-yield loss equations for that crop could be used, without any modification of the estimated loss caused by salinity.

Only limited levels of both factors were available in this study to evaluate statistically salinity X O₃ interactions. If additional studies were to indicate an interaction between salinity and O₃ on yield losses, then the available dose-yield loss equations would have to be modified to either increase or decrease the estimated yield loss with a specific O₃ dose depending on soil salinity.

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