An Assessment of Potato Losses Caused by Oxidant Air Pollution in New Jersey

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ABSTRACT

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During 1978 and 1980, three potato cultivars were grown in the field and harvested according to standard commercial practices. A drench of EDU, (*N*-[2-(2-oxo-1-imidazolidinyl)ethyl]*N'*-phenylurea), an antioxidant, was applied to one-half the plants to protect against oxidant injury. The order of foliar sensitivity of these cultivars to oxidant was Norland>Norchip>Green Mountain. Generally, foliar injury was a function of the cumulative oxidant dose, and the time of maximum plant susceptibility was cultivar-dependent. When over 60% of the foliage was injured, tuber yield was reduced 25 and 31% in plants of cultivars Norland and Norchip, respectively. Yield reduction was traced to smaller sized potatoes in the Norland cultivar and to fewer tubers in the Norchip cultivar. The specific gravity of Norland tubers was significantly reduced in both years. When the two cultivars showed equally severe foliar injury, tuber yield of Norchip showed a greater reduction than Norland.

Additional key words: ozone, tuber quality.

Although ozone (O_3) has been recognized to be a plant pathogen for over two decades, the effect of the gas on the productivity of agricultural crops has not been suitably quantified. In the past, two approaches were taken to estimate yield losses: a predictive model basically using air pollution emission data and crop sensitivity (1), and on-site surveys in which foliar injury was arbitrarily related to yield loss (7). The methodology for deriving both estimates has been subject to great uncertainty. A more recent approach is that taken by the National Crop Loss Assessment Network (NCLAN) in which selected crops are grown in open-top chambers and exposed to known doses of O_3 added to charcoal-filtered ambient air (18). Two disadvantages associated with this approach are the creation of an artificial environment (chamber effect) and failure to imitate the random nature of ambient air pollutant doses. Therefore, we thought it necessary to conduct actual field tests in which the yield of a crop exposed to ambient air pollution during an entire growing season was compared to the yield obtained when a crop was protected with an antioxidant. This method has been successfully used for measuring reductions in bean yields in O_3 polluted areas (9,13).

For over 20 years, O_3 lesions have been observed on field plantings of potato throughout New Jersey (5). It was recognized very early that cultivars of potato were differentially susceptible to O_3 (2). Following a field test in 1977, we reported that air pollution had no effect on tuber yield or quality of cultivar Norchip potato tubers despite injury to 15% of the foliage. Because this was a statistically significant amount of foliar injury, we speculated that its relatively late occurrence (5 August) may have minimized its influence on tuber bulking (4).

This paper reports the results of further experiments with potato conducted in 1978 and 1980. By clarifying the relationship between antioxidant dosage in ambient air, foliar symptoms, and tuber production, we hope not only to quantify current crop loss, but also to provide a basis for predicting it in the future.

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MATERIALS AND METHODS

Three potato cultivars were chosen for the experiment: Norland and Norchip, which are grown commercially in the northeastern United States and are considered O_3-sensitive, and Green Mountain, which is an old cultivar that we suspected might be O_3-resistant. The three cultivars were tested in 1980, and two, Norland and Norchip, in 1978. Seed pieces were planted at the Rutgers University Vegetable Research Farm, New Brunswick, NJ, on 25 April 1980 and 6 April 1978. A randomized complete block design was used containing six replications of single-row plots, 81 × 732 cm, with plants spaced 30.5 cm apart. In order to be able to compare "polluted" plants with controls, an antioxidant was applied to one-half the plots. EDU (*N*-[2-(2-oxo-1-imidazolidinyl) ethyl]*N'*-phenylurea) was applied as a drench to the base of plants at a rate of 6.7 kg a.i./ha every 3 wk from June to September and an equal volume of water was applied to the base of control plants (4 L per plot).

Fertilizer (5-10-5, N-P-K) was applied at 1,569 kg/ha on 10 April 1980 and 2,242 kg/ha of pulverized dolomitic limestone was broadcast and disked into the soil. Similarly on 6 April 1978, 1,345 kg of 16-8-8 fertilizer per hectare was incorporated into the field. Additional fertilizer (ammonium nitrate) was banded into the soil at 202 kg/ha on 16 June 1980. Preemergence herbicides alachlor (Lasso), metribuzin (Sensor), linuron (Lorax), and simazine (Princep) at 1.68 kg a.i./ha, 1.40 kg a.i./ha, 0.56 kg a.i./ha, and 2.24 kg a.i./ha, respectively, were used for weed control in 1978. Weeds were eliminated through manual cultivation in 1980. Because this air pollution experiment was part of a more extensive investigation on potato productivity in 1978, various insecticide and fungicide treatments were applied uniformly to all plots. Aldicarb, at 3.36 kg a.i./ha, was applied to the soil during planting, and after emergence insects were controlled with foliar applications of the following insecticides: permethrin (Ambush) at 0.22 kg a.i./ha on 27 July 1978; methyl parathion (Penncap) at 1.12 kg a.i./ha on 20 July 1978; methamidophos (Monitor) at 0.28 kg a.i./ha on 20 July 1978; parathion (Parathion) at 2.24 kg a.i./ha on 6 July 1978; endosulfan (Thiodan) at 5.25 kg a.i./ha on 6 July 1978; oxamyl (Vydate) at 0.56 kg a.i./ha on 6 July 1978; carbofuran (Furadan) at 1.12 kg a.i./ha on 23 June 1978; and phosalone (Zolone) at 0.84 kg a.i./ha on 15 June 1978. In 1980, the only insecticide used was fenvalerate

(Pydrin) at 0.13 kg a.i./ha on 13 and 17 July. Fungicides applied as foliar sprays included: maneb (Manzate) at a rate of 2.24 kg a.i./ha on 23 June and 6 July 1978 and captafol (Difolitan) at 1.68 kg a.i./ha on 20 and 27 July 1978 and 5, 8, and 15 August 1978. Irrigation was used to supplement natural rainfall.

During the growing season the condition of potato foliage was inspected weekly, and at least four times per year a leaf injury rating was assigned to each plant in a plot. Ratings were made on the basis of the percentage of leaves exhibiting toxicity symptoms and the severity of injury, and a mean value (0–100%) calculated for each plot. The oxidant concentration of ambient air was measured continuously with a Mast Meter (Mast Development Company, Inc., Davenport, IA 52803) calibrated by the buffered neutral KI method (12), and accumulated dosage for each observation period calculated. The instrument responds to oxidizing substances other than O_3, but with much lower efficiency.

Potato tubers were harvested when fully mature on 29 August 1980 and 23 August 1978. They were graded and weighed, and the total yield was calculated in terms of cwt/A (metric conversions are given in table footnotes). The percent of the yield attributed to tubers in marketable size classes (size 1 = greater than 4.86 cm in diameter, and size 2 = greater than 6.35 cm) was recorded. In 1980, the percent yield attributable to four sizes was also calculated: $<$4.76 cm, 4.76–6.35, 6.35–8.26, and 8.26–10.16 cm and the total number of tubers in each class was recorded. To obtain specific gravity measurements, tubers were washed, dried, and weighed in air and in water. Data were subjected to ANOVA and Duncan's multiple range test (17).

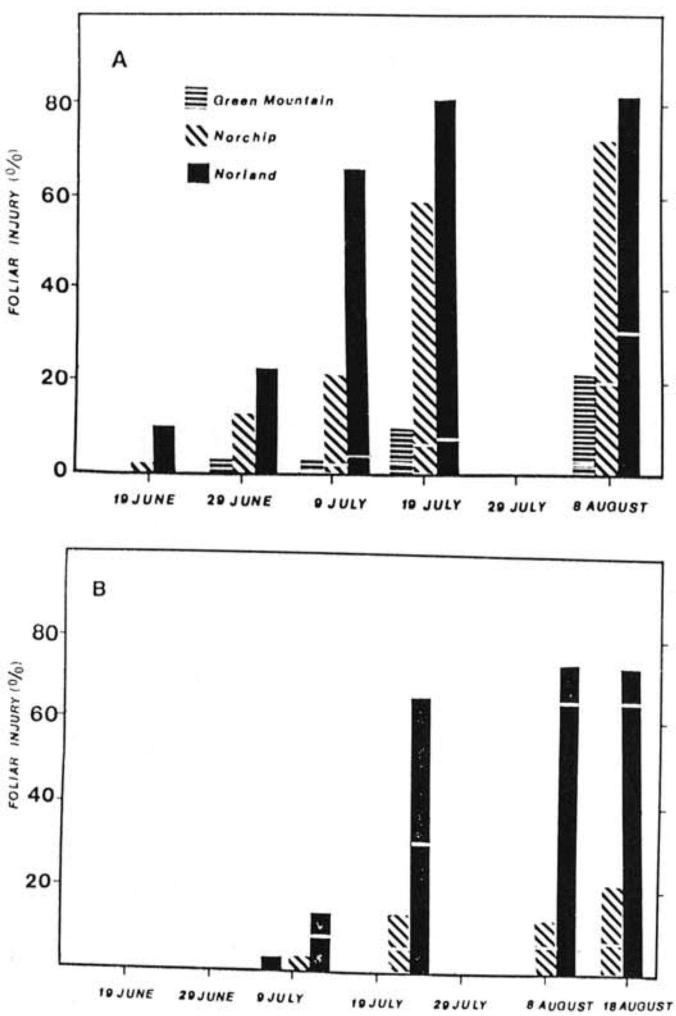

Fig. 1. Percent foliar injury on potato cultivars during the growing seasons of **(A)** 1980 and **(B)** 1978. White bar indicates amount of injury on EDU-treated plants.

RESULTS

The most common symptom on potato foliage was purple-to-black stippling on the adaxial surface of the older leaves. Bronzing of the adaxial and abaxial surfaces was less frequent, as was upward rolling of the leaf margins. The order of foliar injury was Norland>Norchip>Green Mountain. As the season progressed, the percent injury on each plant increased. In 1980, foliar injury occurred much earlier and was more severe (Fig. 1A and B) than in 1978. EDU-treated plants had significantly less injury than nontreated plants, but toward the end of the season even treated plants exhibited foliar injury.

When the cumulative oxidant dose (ppm·hours) was calculated for each growing season (Fig. 2), it was apparent that ambient air pollution was significantly greater in 1980 than in the three previous years. Moreover, at the onset of the 1980 growing season the oxidant dosage was greater than later in the season. Maximum foliar injury increased with dose in Norchip, but not in Norland.

When percent leaf injury was plotted against cumulative oxidant dose in 1980, it was apparent that the cultivars differed in the timing of maximum symptom development (Fig. 3). Norland showed the greatest increase in injury between 27 June and 29 July, Norchip between 17 July to 29 July, and Green Mountain between 29 July and 11 August.

In 1980, Norland tuber yield was reduced 24% and Norchip 31%

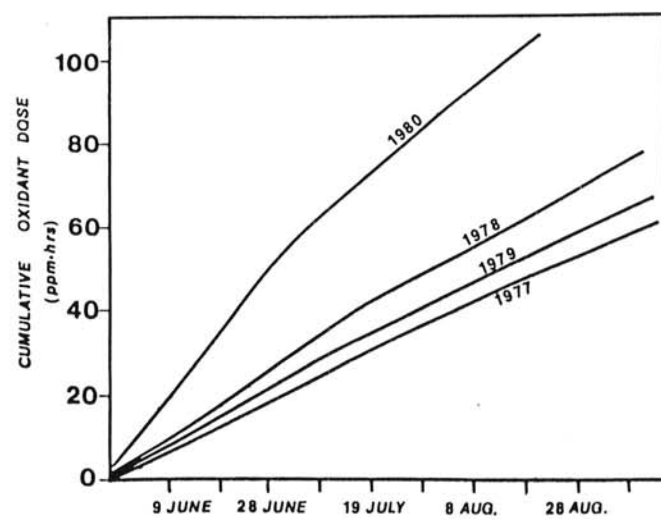

Fig. 2. Comparison of ambient oxidant dosage in New Brunswick, NJ, during the growing seasons of 1977–1980.

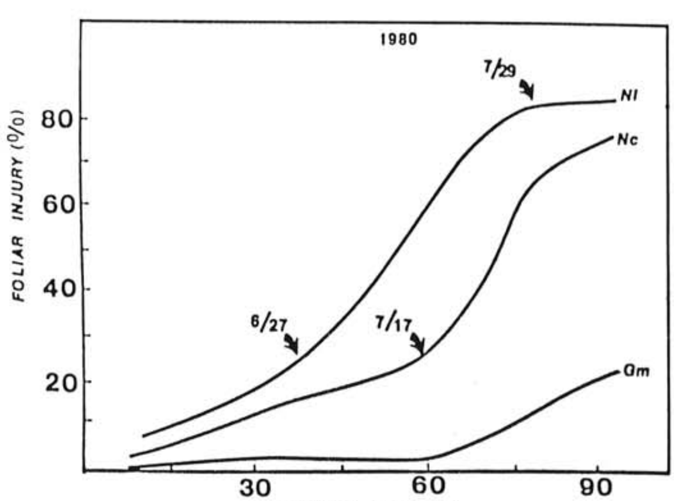

Fig. 3. Comparison of foliar sensitivity of the Norland (Nl), Norchip (Nc), and Green Mountain (Gm) potato cultivars as a function of dose and time.

in the absence of EDU, and in 1978 Norland yield was also reduced 25% (Table 1). Air pollution did not generally affect the percent yield of marketable size 1 and size 2 tubers. Only in 1980 was there a significant difference between the nontreated and EDU-treated Norland tubers (Table 1). When the yield was distributed according to four size categories and the total number of tubers compared in nontreated and EDU-treated tubers (Table 2), it was evident that the reduced yield in Norland was due to the presence of more small tubers. However, in Norchip the reduced yield was due to a lower total number of tubers and, hence, a lower yield in each size category.

In 1980, the specific gravity of Norland tubers was significantly reduced and the specific gravity of Norchip and Green Mountains was unaltered (Table 1).

DISCUSSION

The predominant symptoms on potato foliage in field experiments in New Jersey were attributed to O_3. Stipple was generally most pronounced on the upper surface of the mature leaves. Little or no undersurface leaf speckling was observed in 1978 and 1980. Hooker (10) has reported that such undersurface leaf spotting is not due to O_3 inasmuch as it appears on leaves of plants in charcoal-filtered air. On the basis of foliar injury, plants of cultivar Norland were more sensitive than Norchip, and both were significantly more sensitive than Green Mountain. Mosley et al (14) gave similar relative ratings to Norland and Norchip grown in northcentral Ohio. Hooker (10) listed Norchip among the more sensitive cultivars in southeastern Michigan, and Heggestad (8) found Norland to be the cultivar most sensitive to naturally polluted air near Washington, DC. Apparently no one has recorded observations on Green Mountain in the field, although Brennan et al (2) reported that in greenhouse tests plants of cultivars Green Mountain and Kennebec were more tolerant than those of cultivars Chippewa, Cobbler, Plymouth, Pungo, and Katahdin.

The degree of foliar injury observed during a season correlated with the cumulative dose of oxidant in ambient air. As the dose increased, foliar injury increased. In 1980, the cumulative dose increased more rapidly at the onset of the growing season than in previous years and, correspondingly, plant injury was observed earlier than in previous years. In 1980, the total cumulative dose was almost twice as high as in 1978, and although Norland had little additional injury, foliar injury on Norchip increased by a factor of 3. Apparently the Norland cultivar was so sensitive that even the lower dose in 1978 evoked a severe response. Exposure to lower doses will be required to establish a lower limit for foliar injury to Norland.

The curves depicting percent leaf injury as a function of cumulative dose are cultivar dependent (Fig. 3). Whether the time at which plants are most sensitive (greatest increase in injury/unit dose) relates to a given oxidant dose or susceptible age is not clear. Following an accumulative oxidant dose of 37 ppm·hours Norland foliar injury accelerated, whereas a dose of 60 ppm·hours was required to obtain the same effect with Norchip. In New Jersey, Norland plants mature about 3 wk before Norchip, and Norchip precedes Green Mountain by 2 wk; therefore, optimal foliar sensitivity is attained first in Norland, then Norchip, and finally Green Mountain. If ambient oxidant levels are more or less uniformly distributed from June to September, an early or late-maturing cultivar could eventually develop an equal amount of foliar injury. However, if high O_3 concentrations are more frequent in June and July, then early maturing cultivars might develop more leaf injury than late-maturing ones.

TABLE 1. Tuber yield, percentage of yield in marketable grade Size 1 (>4.76 cm) and Size 2 (>6.35 cm) and specific gravity of nontreated and EDU[x]-treated Irish potato cultivars grown in New Jersey[y]

Year and cultivar	Market yield (MT/ha)		Percentage of tubers				Specific gravity	
			Size 1		Size 2			
	−	+[z]	−	+	−	+	−	+
1980								
Norland	19.82 bA	26.10 aA	90 a	94 a	36 aB	53 aB	1.052 bC	1.056 bC
Norchip	14.78 cD	21.39 aD	87 a	87 b	32 a	34 b	1.071 a	1.071 a
Green Mountain	27.78 a	24.42 a	89 a	85 b	22 b	24 b	1.068 a	1.067 a
Mean	19.38 E	23.86 E	88	89	32 F	40 F	1.063	1.064
1978								
Norland	40.77 bG	54.66 aG	97 a	98 a	79 a	77 a	1.048 b	1.053 b
Norchip	50.40 a	56.11 a	94 a	94 a	60 b	59 b	1.068 a	1.071 a
Mean	45.58 H	55.89 H	95	96	69	68	1.056	1.062

[x]EDU is *N*-[2-(2-oxo-1-imidazolidinyl)ethyl]*N'*-phenylurea, an antioxidant.
[y]Means within a vertical column sharing the same lower case letter are not significantly different according to Duncan's multiple range test, $P=0.05$. Pairs of means in the same horizontal row sharing the same capital letters are significantly different, $P=0.05$. Values are means of six replicates for the Norland and Norchip cultivars and three replicates for the Green Mountain cultivar. To convert market yield from MT/ha to cwt/A, multiply values by 8.929.
[z]Represents EDU (+) and non-EDU (−) treatments.

TABLE 2. Yield and number of tubers in four size classes of nontreated and EDU[x]-treated Irish potato cultivars grown in New Jersey in 1980[y]

Tuber diameter range (cm)	Norland				Norchip				Green Mountain			
	Tubers (100s/ha)		Mkt. yield (MT/ha)		Tubers (100s/ha)		Mkt. yield (MT/ha)		Tubers (100s/ha)		Mkt. yield (MT/ha)	
	−	+[z]	−	+	−	+	−	+	−	+	−	+
<4.76	553 A	407 A	2.02 B	1.46 B	615	869	2.35	3.25	1,378	1,086	3.25	4.37
4.76–6.35	901	921	11.42	11.09	941	1,202	9.18 C	12.99 C	1,509	1,230	20.50	16.80
6.35–8.26	432	560	7.95 D	13.89 D	281 E	410 E	5.04 F	7.73 F	437	284	7.28	7.62
8.26–10.16	12	37	0.45	1.01	20	25	0.56	0.67	0	0	0	0
Total	1,899	1,926	19.82 G	26.10 G	1,857 H	2,504 H	14.78 I	21.39 I	3,326	2,600	27.78	24.42

[x]EDU is *N*-(2-[2-oxo-1-imidazolidinyl]ethyl)*N'*-phenylurea, an antioxidant.
[y]Pairs of means in the same horizontal row followed by the same capital letters are significantly different, $P=0.05$, according to Duncan's multiple range test. Values are means of six replicates for the Norland and Norchip cultivars and three replicates for the Green Mountain cultivar. To convert market yield from MT/ha to cwt/A, multiply values by 8.929.
[z]Represents EDU (+) and non-EDU (−) treatments.

TABLE 3. Impact of accumulated oxidant dose on foliar injury and tuber yield for three field-grown potato cultivars in New Brunswick, NJ[a]

Year	Oxidant dose (ppm hours)	Norland Foliar injury[b] (%)	Norland Yield[c] (%)	Norchip Foliar injury (%)	Norchip Yield (%)	Green Mountain Foliar injury (%)	Green Mountain Yield (%)
1977	50	...	...	15	98	...	...
1979	60	...	...	...	...	12	100
1978	65	75	75*[d]	21	90	...	...
1980	110	84	76*	75	69*	22	100

[a] Values are means of six replicates during 1977, 1979, and 1980, except for the Green Mountain cultivar which had three replicates in 1980. All cultivars in 1978 were means of four replicates.
[b] Maximum percent foliar injury on non-EDU treated plants recorded during the growing season.
[c] Tuber yield as a percent of EDU treated plots.
[d] Asterisk (*) indicates that tuber yield for nontreated plots was significantly reduced, $P = 0.05$, according to Duncan's multiple range test compared to EDU-treated plots.

It is interesting that EDU failed to prevent symptoms of O_3 injury on plants late in the growing season. Among several explanations that might be given are the lowered metabolic state of the mature plant reduced the absorption and physiological activity of EDU or that the cumulative O_3 dose exceeded that which could be alleviated by EDU (3). Actually the failure of EDU to protect leaves of fully matured plants may not have practical significance in respect to productivity. After foliage has accomplished the function of exporting photosynthate to the tubers, it has no particular use.

In the discussion that follows, the difference in yield between nontreated and EDU-treated Norland and Norchip plants is attributed to the protection that the antioxidant provided against ozone phytotoxicity. Inasmuch as Norchip produced the same yields in nontreated and EDU-treated plots in 1977 when the oxidant dose was low, it seemed reasonable to assume that EDU per se did not have the capacity to stimulate yield under field conditions. Also, EDU had no significant effect on the yield of plants of cultivar Green Mountain in 1980, nor in 1979 when plots were replicated six times (*unpublished*).

In interpreting the relationship between foliar injury and tuber yield, one must take into account the tuber development period for each cultivar. Although tuber yield curves were not available for Norland or Norchip, data for the cultivar Superior showed that tuber production increased from 19 June to 29 July in 1980 and then leveled off. Realizing that maximum tuber yield for Norland precedes that of Superior by 1 wk, we assume that Norland showed peak tuber yield around 21 July, and Norchip, about 15 August. Foliar injury appearing later than those dates would have little impact on tuber yield. On that basis, we equate 66% foliar injury with tuber yield reduction in Norland and 75% with yield reduction in Norchip. It is interesting that when the cultivars sustained equally severe foliar injury, Norchip suffered a greater reduction in yield than Norchip, reversing the sensitivity rating based on foliar injury. We recognize that foliar injury is the most visible aspect of O_3 toxicity, but we do not underestimate the possible importance of increased respiratory and decreased photosynthetic rates in O_3-exposed plants on final tuber yields (6).

The only published data with which to compare foliar injury and tuber yields in the field are those of Mosley et al (14). They presented a graph relating foliar injury (on a scale of 1 to 6) to average yield for 59 potato cultivars and selections. When they observed 1–40% leaf injury, tuber yield was reduced 18% and when the foliage injury exceeded 40%, tuber yield was reduced 37%.

Obviously a reduction in tuber yield could occur through a reduction in size or in total number of tubers. In cultivar Norland the adverse effect on yield could be traced to a decrease in the number of larger-size potatoes (>5.72 cm). On the other hand, the reduction of tuber yield in the cultivar Norchip could be traced to a decrease in total number and not to a disproportionate change in a particular size class. Cultivar plants of Green Mountain, which exhibited no decrease in yield, had both a comparable size distribution and total number for untreated and EDU-treated plants.

Specific gravity is an indirect measurement of dry matter content of potato tubers (11). High-specific-gravity potatoes not only yield a higher percentage of processed product, but also a higher quality product. Although the trait is genetically controlled, it is also influenced by environmental conditions such as temperature and irrigation (14). In 1980, the Norland tubers showed a statistically significant decrease in specific gravity. Although the reduction appears small (0.004), potato breeders attach commercial significance to such changes (16). Because the specific gravity of Norland is normally less than that of Norchip and other desirable cultivars, this additional decrease could be commercially as well as statistically significant. This quality parameter has not been investigated in any other air pollution field test. However, Pell et al (15), in a greenhouse experiment, reported a significant decrease in total solids in Kennebec and Norland potatoes. Because specific gravity was only affected in one cultivar (Norland, 1980), we suggest that quality changes in the field may be cultivar-dependent.

In conclusion, our data can be summarized (Table 3) as follows: Norland was indeed sensitive to oxidant, with significant foliar injury and yield reduction occurring at a 65 ppm·hour dose. Norchip foliage was not as sensitive to oxidant as Norland, and as a result could sustain 21% injury without altering the tuber yield. However, when foliar injury increased to 75%, the yield loss exceeded that of Norland even though leaf injury was comparable. Green Mountain foliage was relatively insensitive to oxidant, and its yield was unaffected by oxidant levels throughout the study.

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