# ETHYLENE IN A COMPACTED FIELD SOIL AND ITS EFFECT ON GROWTH, TUBER QUALITY, AND YIELD OF POTATOES[1]

R.B. Campbell and R.A. Moreau[2]

## Abstract

Ethylene ($C_2H_4$) produced by soil microorganisms at concentrations sufficient to affect root development has previously been identified in the gas phase of anaerobic or partially anaerobic soils. This research was initiated to establish the existence of and to determine concentrations of $C_2H_4$ in soil in relation to matric potential, oxygen ($O_2$) and compaction, and effects on growth and tuber yield of potatoes (*Solanum tuberosum* L.). Ethylene initially appeared at the 10-cm depth after 2.5-cm/day increments of water were applied by furrow irrigation for 3 days. Levels of $C_2H_4$ increased to 18.4 ppm and $O_2$ decreased to 8% after 12.5 cm of water had been applied in 2.5-cm increments for 5 days. Ethylene was found in two partially compacted plots. High $C_2H_4$ concentrations and low $O_2$ levels in the soil atmosphere were associated with reduced top growth, leaf injury, lower tuber quality, and a 20% decrease in potato yields. Since $C_2H_4$ and low $O_2$ levels occur simultaneously in soil, further research is needed to identify their individual effects on root and tuber development.

## Resumen

El Etileno ($C_2H_4$) producido por los microorganismos del suelo a concentraciones suficientes para afectar el desarrollo radicular, ha sido previamente identificado en la fase gaseosa de suelos anaeróbicos o parcialmente anaeróbicos. Esta investigación fue iniciada para establecer la existencia y determinar concentraciones de $C_2H_4$ en suelos en relación al potencial mátrico, oxígeno ($O_2$) y compactación y su efecto en crecimiento y rendimiento de tubérculos en papa (*Solanum tuberosum* L.). El etileno inicialmente apareció a los 10 cms de profundidad después de que 2.5 cms/día de agua fueron aplicados en riego por surco durante 3 días. Los niveles de $C_2H_4$ aumentaron a 18.4 ppm y el $O_2$ decreció a 8% después de que 12.5 cm de agua fueron aplicados a razón de 2.5 cm/día durante 5 días. El etileno fue encontrado en dos parcelas parcialmente compactas. Altas concentraciones de $C_2H_4$ y niveles bajos de $O_2$ en la atmósfera del suelo,

[1] Contribution from the Coastal Plains Soil and Water Conservation Research Center, SEA-AR, USDA, Florence, S.C. 29502, in cooperation with the South Carolina Agricultural Experiment Station.
[2] Soil Scientist and Agricultural Science Assistant, respectively.
Received for publication July 14, 1978
KEY WORDS: Compaction, aeration, soil $C_2H_4$, matric potential, potato yield, and potato quality.

estuvieron asociados a crecimiento apical reducido, daño en hojas, baja calidad del tubérculo y una merma de 20% del rendimiento en papa. Ya que el $C_2H_4$ y bajas concentraciones de $O_2$ ocurren simultáneamente en el suelo, mayor investigación es necesaria a fin de identificar sus efectos individuales en desarrollo radicular y del tubérculo.

## Introduction

Ethylene ($C_2H_4$) at concentrations inhibitory to plant root growth was identified in anaerobic or partially anaerobic soil in England by Smith and Russell (11). Smith and Dowdell (9) showed that high soil water content was associated with a decrease in oxygen ($O_2$) and the occurrence of $C_2H_4$ in sandy loam soil. They observed considerable variability in $C_2H_4$ concentration between sampling points in the field at low $O_2$ levels. Other field factors that influenced the amount of $C_2H_4$ in soil were temperature and energy-rich substrates. They noted deleterious $C_2H_4$ concentrations affecting root growth in clay and sandy loams in the spring and early summer when soils are wet after rainfall.

Physiological effects of $C_2H_4$ levels on plants have been extensively reviewed by Pratt and Goeschl (7), Abeles (1), and Burg et al. (2). Of the cereal crops, barley was most susceptible to $C_2H_4$ injury (10). At 1/ and 20/ppm $C_2H_4$, seminal root extension rate was reduced 55 and 80% for barley and 25 and 40% for rye, respectively. Reductions in wheat and oats were intermediate between barley and rye. Tobacco and tomato were more sensitive than cereals, and rice was the least sensitive of all crops tested (10). The order of tolerance of various crops to waterlogging apparently follows the order of their tolerance to $C_2H_4$ levels.

Ethylene has been shown to suppress tuber-initiation of potatoes (4). The respiration rate of potato tubers was 5 to 10 times the normal rate after they were exposed to 10-ppm $C_2H_4$ (8). Mingo-Castal et al. (5) reported that $C_2H_4$ affected root growth and prevented accumulation of starch and red anthocyanin in tubers with etiolated potato sprout sections cultured in vitro. The effect of $C_2H_4$ levels on root and tuber growth in the field has not been extensively studied.

The role of in-soil $C_2H_4$ levels in crop production is particularly important in areas where high soil temperatures promote high rates of microbial activity, and in compact sandy soils when rainfall substantially exceeds potential evapotranspiration for intervals during the growing season.

A study was initiated at Florence, S.C. to identify the actual existence of $C_2H_4$ and to determine the $C_2H_4$ concentrations in the gaseous phase of soil pores in relation to soil compaction and excessive water in the soil profile. Potatoes were planted in the test site to help identify apparent effects of $O_2$ and $C_2H_4$ levels on plant tissues and tubers.

*Procedure*

The experimental site was a Norfolk sandy loam (Typic Paleudult) of the southeastern Coastal Plains. This soil profile had an $A_2$ horizon with a bulk density of 1.65 g/cm$^3$ and a sandy clay B horizon (3).

Eight plots (2.7×6 m) consisting of five rows each were disk-plowed, fertilized (112, 149, 23 kg/ha of N, P, K, respectively), and planted to potatoes, "Irish Cobbler" (*Solanum tuberosum* L.) in late February, 1975. A second application of N, consisting of $NH_4NO_3-N$ at 74 kg/ha, was distributed along the potato rows on May 5. All potato plots were hand-weeded and were harvested and graded on 25 June, 1975.

When the plants were about 8 cm high (21 April, 1975) four soil compaction treatments were imposed using traffic from pneumatic tires of a medium-sized, 4-wheel tractor, as follows: 1) no wheel compaction, 2) wheel compaction to the left of the planted row, 3) wheel compaction to the right side of the planted row, and 4) compaction on both sides of the planted row.

One-half of the experimental plots were irrigated from 3 to 9 June. The quantity of water applied, time of application, and the amounts of rainfall are shown graphically in Fig. 1A.

Gas tight syringes were used to extract gas samples from stainless steel gas exchange chambers which had a total exchange volume of 55 cm$^3$ (4-m radius by 1-cm depth). The chambers were buried 10-cm deep between and within potato rows. The porous cup of each tensiometer was buried at the same depth as the gas exchange chambers to measure soil matric potential, ($\psi$). Soil-air samples were collected and analyzed for $C_2H_4$ and $O_2$ contents daily each morning between 3 and 17 June, except for 8 June when no samples were taken. Soil and matric potential was determined at the same time that gas samples were obtained in the field. Evaporation from a USWB 1.22 meter diameter pan was measured daily.

Ethylene was separated from other soil gases with a 1.8-m×55-mm activated alumina column connected to a flame ionization detector of a Hewlett Packard Model 5752 gas chromatograph. The gas chromatograph was operated isothermally at 100° C, using $N_2$ as the carrier gas. The peak area from the recorded output of the chromatograph for each gas sample was compared with a curve derived from standard mixtures of $C_2H_4$ in air. Ethylene concentrations were determined by cutting and weighing the chart paper to determine peak area. The minimum detectable $C_2H_4$ concentration, using 1-ml gas samples was about 0.02 ppm. Oxygen concentrations were determined with a Chematronics Model LP-10P $O_2$ sensor mounted in an LP-10 small volume cuvette.[1]

[1] Mention of company or trademark is for the reader's benefit and does not constitute endorsement of a particular product by the U.S. Department of Agriculture over others that may be commercially available.

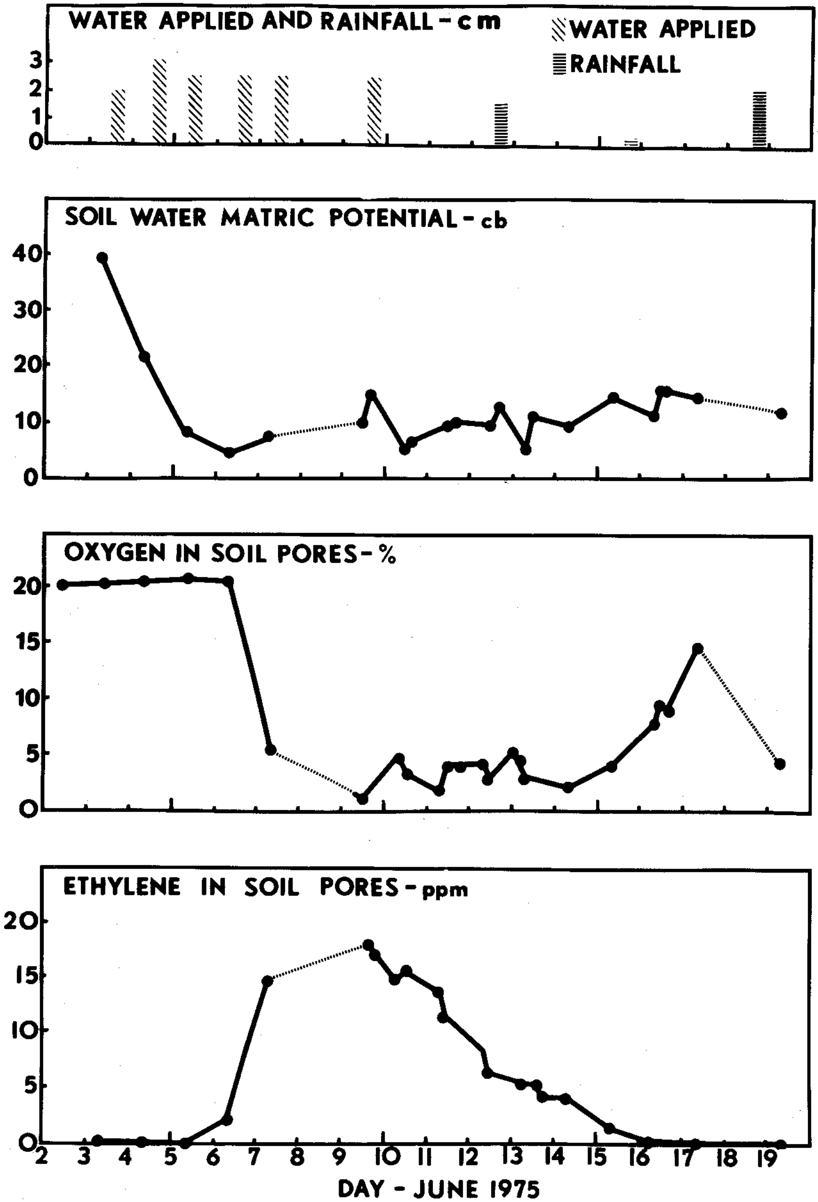


FIG. 1. Water applied, rainfall, soil water matric potential, oxygen and ethylene in a partially compacted-irrigated sandy loam soil.

Physical effects on plant growth were photographed and tuber yield and quality factors such as size, shape and skin blemishes were assessed at harvest (6 June, 1975).

## Results and Discussion

### *Appearance and Concentration of $C_2H_4$ in Soil*

The first trace of $C_2H_4$ (0.1 ppm) was detected in the soil in one of the partially compacted plots on 5 June after 2.5 cm of water had been applied for 2 consecutive days. A day later, 2.4 ppm $C_2H_4$ was detected in the second partially compacted plot after a total of 7.5 cm of water had been applied. The plot on which we first identified $C_2H_4$ produced a maximum of 7.4 ppm $C_2H_4$ as compared with 18.4 ppm in the second plot. Concentrations of $C_2H_4$, obtained in the second plot and plotted in relation to time in Fig. 1D, showed $C_2H_4$ increased to 12.5 ppm on 7 June. By 9 June, the $C_2H_4$ concentration increased to 18.4 ppm and then decreased at a constant rate to undetectable concentration ($<0.02$) by 16 June within 9 days after we observed the maximum concentration. The maximum concentration may have actually exceeded 18.4 ppm on 8 June because the $C_2H_4$ concentration was increasing on 6 and 7 June and then decreasing on 9 and 10 June.

Drought conditions prevailed during the 2-week period before water application. Total rainfall for the period was 3 cm as compared with the potential evapotranspiration (estimated from U.S.W.B. pan evaporation) of 10.6 cm. At the time of the initial water application (3 June), the matric potential at the 10-cm depth was $-42$ cb. After an initial water application of 2 cm, an additional 13.2 cm was applied in 5 approximately equal increments (Fig. 1A). Two applications increased $\psi$ to $-6$ cb in 2 days. For the remainder of the test, $\psi$ averaged $-7.2$ cb with a standard deviation of $\pm 3.2$, while soil $O_2$ levels averaged about 5% (Fig. 1B, 1C).

Soil $O_2$ remained at saturation levels (20.8%) for 1 day after the initial 2.4 ppm of $C_2H_4$ was detected and then it decreased to 8% in the gas phase of the soil atmosphere within 1 day. From 9 to 15 June, the average $O_2$ level was 3.5% with a standard deviation of $\pm 1.04$.

Changes in soil $O_2$ concentrations lagged 1 or 2 days behind tensiometric responses. Although $O_2$ values remained at relatively constant low levels, $C_2H_4$ concentrations continued to decrease, resulting in an inverse relationship between $O_2$ and $C_2H_4$ concentrations between 7 and 15 June. Possibly microbes were using $C_2H_4$ or they were using a precursor, thus blocking further $C_2H_4$ production.

### *$C_2H_4$ Distribution in Soil Profile*

On 14 and 16 June, while $C_2H_4$ concentrations were decreasing, we collected gas samples at various depths in the soil using an especially constructed probe. The $C_2H_4$ levels were greatest at the 10-cm depth (Fig. 2). These data may not represent the exact depth at which $C_2H_4$ generation was maximum but they represent a balance between production and diffusion. Maximum generation may have been nearer than 10 cm to the surface because of gaseous diffusion in the surface layer is usually higher than at lower depths within the profile.

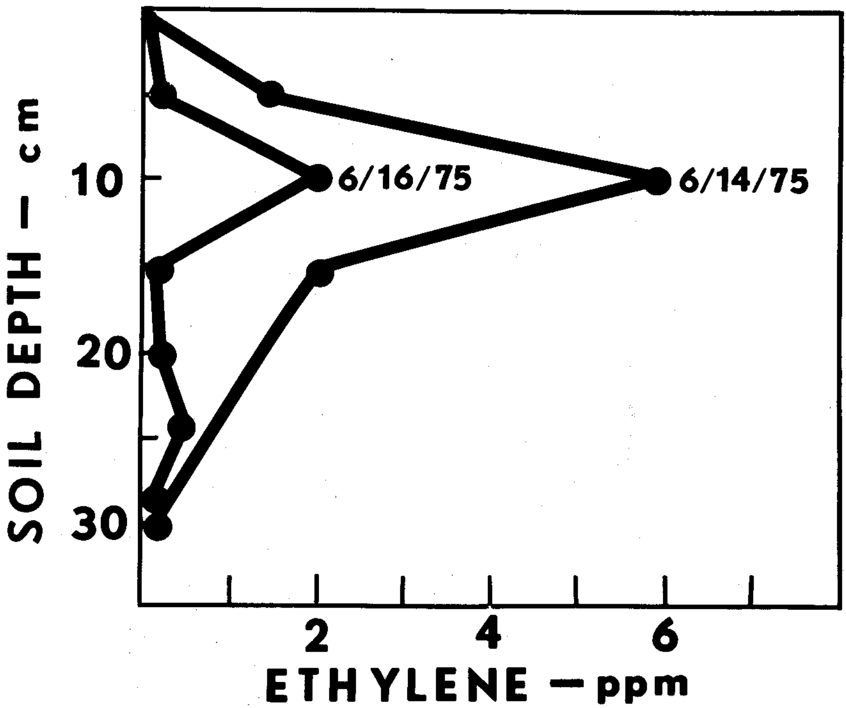


FIG. 2. Ethylene concentration in relation to soil depth on two sampling dates.

*Plant Appearance*

The first symptom of plant stress was leaf wilting on 7 June, the same day that $O_2$ levels were decreasing rapidly and $C_2H_4$ levels increased rapidly. Wilt symptoms continued for 4 days after the first irrigation and after a total of 7.5 cm water had been applied. The potato vines showed severe wilting on 9 June when $C_2H_4$ concentration peaked. At this time, some of the most severely affected leaves began to turn brown, indicating a complete loss of leaf chlorophyll. We observed no leaf stress symptoms in the two plots where no $C_2H_4$ was found, but which had received the same amounts of water.

*Tuber Yield*

Prime tuber yield was highest in the noncompacted-irrigated treatment (Fig. 3). Tuber yields from the two plots with low $O_2$ and high $C_2H_4$ levels were 57 and 63% less than those for the noncompacted-irrigated treatment. The two partially compacted plots in the experiment had $C_2H_4$ concentrations of 7.4 and 18.4 ppm.

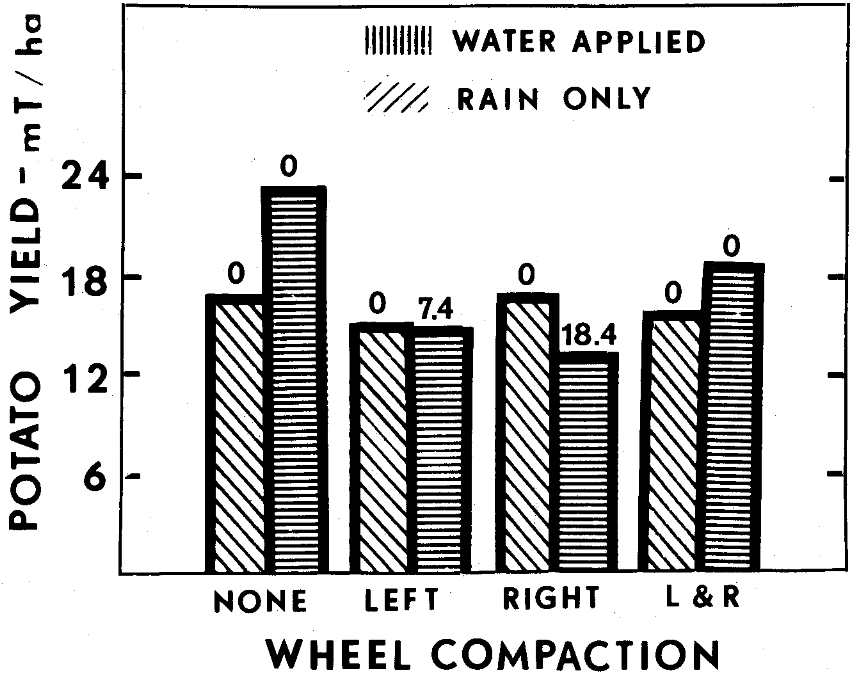


FIG. 3. Potato yield shown in relation to soil compaction, partial flooding and soil generated ethylene. Values above bar indicate $C_2H_4$ concentrations in ppm in the soil atmosphere.

For the nonirrigated treatments, the compacted treatments yielded only 6% less tubers than the noncompacted treatment. Irrigation increased yield from the noncompacted plot by 26% over the yield in the nonirrigated plot. Even the tuber yield of the noncompacted-nonirrigated treatment exceeded by 20% that of the partially compacted-irrigated treatment in which $C_2H_4$ was detected. Tuber yield, Y, expressed as a function of maximum $C_2H_4$ concentration was, X is $Y = 35.68 - 1.95X + .07 X^2$ with an $R^2$ value of 0.81.

Tuber yields were lower on the partially compacted plots (traffic on the left or the right of the row) than on the plot with wheel traffic on both sides of the row. However, we observed greater water infiltration rate on the plot with compaction on both sides of the row which suggests that the plot's previous compaction history may have influenced the total compaction of the chosen plot areas. Since the two lowest yields were associated with high $C_2H_4$ levels, rather than with degree of compaction, $C_2H_4$ evidently played a dominant role in reducing yields.

The distribution of irrigation water applied to plots, in which we found $C_2H_4$ was not as uniform as that on plots with no $C_2H_4$. Water tended to pond at the lower end of the row. The effect of water distribution and possible resultant effects of the soil gaseous environment on the tuber yield showed that ponded water decreased yields when $C_2H_4$ was present and increased yield when $C_2H_4$ was absent (Fig. 4). Tuber yield data showed beneficial effects associated with irrigation without $C_2H_4$ and detrimental effects with $C_2H_4$.

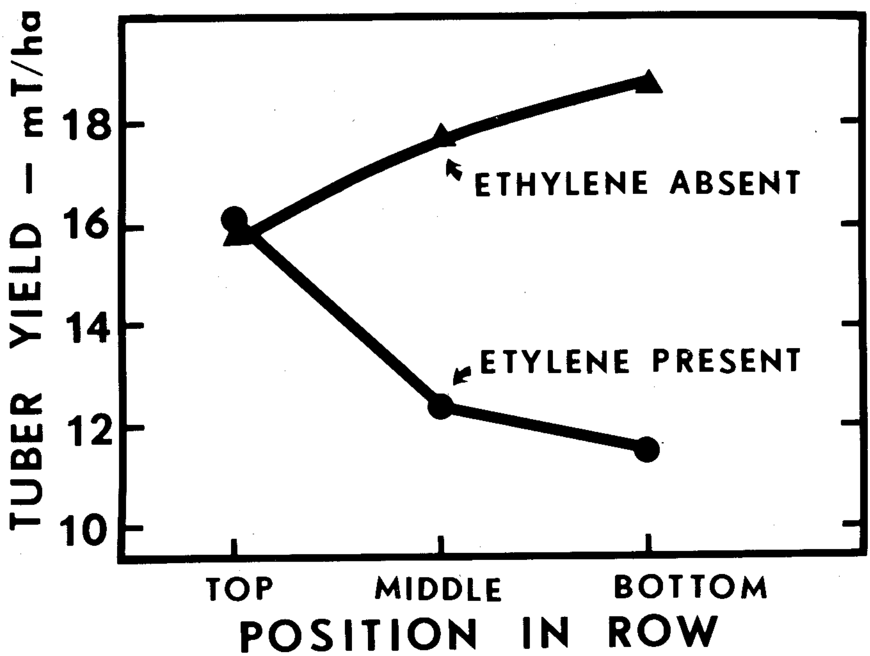


FIG. 4. Tuber yield shown in relation to water distribution in ⅓ increments of the harvested row (top, middle, bottom refer to position in the harvested row). Dots indicate average yield from the two plots in which ethylene was detected under low soil oxygen conditions. Triangles refer irrigated plots with high oxygen levels and undetected levels of ethylene.

Prime tubers varied in size and appearance between treatments. Tubers from the noncompacted-irrigated treatment were moderately free of skin blemishes and were slightly distorted and shaped asymmetrically (Fig. 5). Tubers from the nonirrigated-noncompacted plots were uniform in size with short sprouts as a result of rain after a drought period (Fig. 6). Several tubers with quality defects, which differed from the more normal smooth skin symmetry, were harvested from plots with the higher $C_2H_4$ concentrations. Eye formations at the base of the tuber were not fully developed and were distorted (Fig. 7). The skin of many tubers had a checked appearance, as if their epidermal growth had been stunted for a short time. Many lenticel-like tissues appeared on potatoes harvested from the lower end of

FIG. 5. Prime tubers from noncompacted irrigated treatment (no $C_2H_4$ detected).

the plot, where water tended to concentrate. The yields of prime size tubers were reduced in plots with low $O_2$ levels and high $C_2H_4$ concentrations. More inferior quality potatoes were harvested from plots with low $O_2$-high $C_2H_4$ levels.

## Summary

We found $C_2H_4$ concentrations sufficient to reduce root growth in a compacted sandy loam soil in the southeastern Coastal Plains.

Ethylene initially appeared in the soil at the 10-cm depth after only 5 cm of irrigation water had been applied. Levels of $O_2$ decreased and $C_2H_4$ levels increased rapidly after two daily equal increments of water totalling 5 cm were applied.

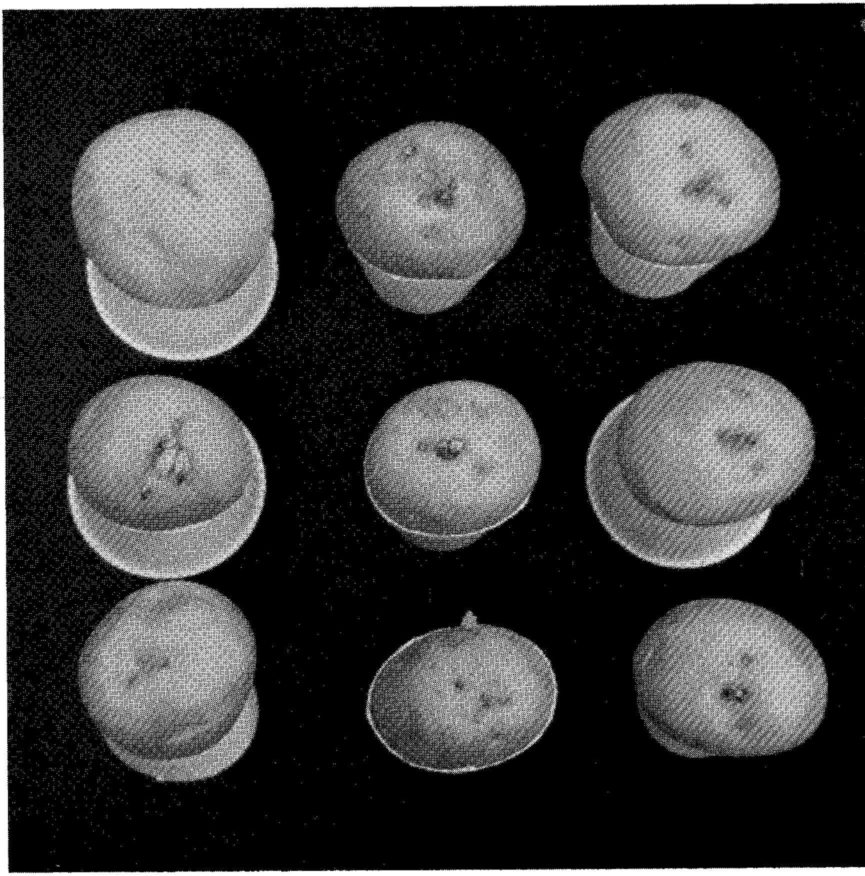

FIG. 6. Prime tubers from noncompacted-nonirrigated treatment (no $C_2H_4$ detected).

Ethylene levels increased to a maximum of 18.4 ppm in an irrigated partially-compacted soil and to a maximum of 7.4 ppm in the second partially compacted plot. These were the highest known concentrations of $C_2H_4$ reported in soil under field conditions. No $C_2H_4$ was found in two other plots — one compacted by wheel traffic and the other uncompacted. Low $O_2$ and high $C_2H_4$ concentrations in the soil atmosphere were associated with leaf injury, lower tuber quality, and lower potato yields.

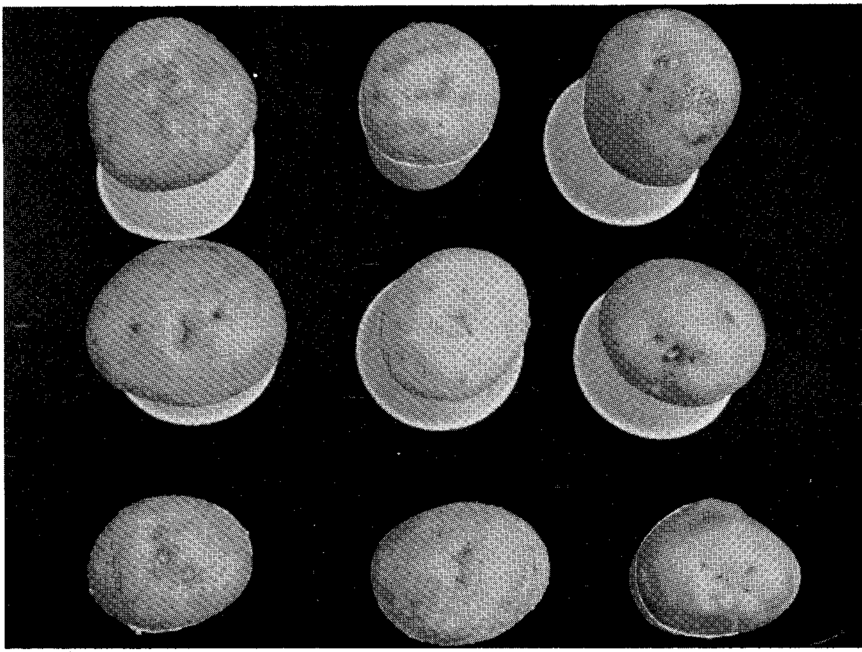

FIG. 7. Prime tubers from compacted-partially flooded treatment showing deformed eyes, lenticel-like tissue, checked skin abrasions, spots of dark skin pigmentation (maximum 18.4 ppm $C_2H_4$ detected).

## Literature Cited

1. Abeles, F.G. 1972. Biosynthesis and mechanism of action of ethylene. Ann Rev Plant Physiol 23: 259-292.

2. Burg, S.P., A. Apelbaum, W. Ersinger, and B.G. Kang. 1971. Physiology and mode of action of ethylene. Hort Science 6: 7-12.

3. Campbell, R.B., D.C. Reicosky, and C.W. Doty. 1974. Physical properties and tillage of paleudults in the southeastern Coastal Plains. J Soil Water Conserv 29: 220-224.

4. Catchpole, A.G. and J. Gillman. 1969. Effect of ethylene on tuber initiation in *Solanum tuberosum* L. Nature 223: 1387.

5. Mingo-Castal, A.M., O.E. Smith, and J. Kumamoto. 1976. Studies on the carbon dioxide promotion and ethylene inhibition of tuberization in potato explants cultured in vitro. Plant Physiol 57: 480-485.

6. Neelson-Jones, W. 1935. Organic soils and epinastic response. Nature 136: 554.

7. Pratt, H.K. and J.D. Goeschl. 1969. Physiological roles of ethylene in plants. Ann Rev Plant Physiol 20: 541-584.

8. Reid, M.S. and H.K. Pratt. 1970. Ethylene and the respiration climacteric. Nature 226: 976-977.

9. Smith, K.A. and R.J. Dowdell. 1974. Field studies of the soil atmosphere. I. Relationships between ethylene, oxygen, soil moisture content, and temperature. J Soil Sci 25: 217-230.

10. Smith, K.A. and S.W.F. Restall. 1971. The occurrence of ethylene in anaerobic soil. J Soil Sci 22: 430-443.

11. Smith, K.A. and R.S. Russell. 1969. Occurrence of ethylene and its significance in anaerobic soil. Nature 222: 769-771.