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PROJECT TITLE: Monitoring Ethylene Emissions from Plants Cultured for a Controlled Ecological Life Support System

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Emission of hydrocarbons and other volatile compounds by materials and organisms in closed environments will be a major concern in the design and management of advanced life support systems with a bioregenerative component. Ethylene, a simple hydrocarbon synthesized by plants, is involved in the elicitation of a wide range of physiological responses. In closed environments, ethylene may build up to levels which become physiologically active. In several growouts of 'Yecora Rojo' wheat in Kennedy Space Center's Biomass Production Chamber (BPC), it was observed that leaf flecking and rolling occurred in the sealed environment and was virtually eliminated when potassium permanganate was used to scrub the atmospheric environment. It was suggested that ethylene, which accumulated to about 60 ppb in the chamber and which was effectively absorbed by potassium permanganate, was responsible for the symptoms. The objectives of this work were to: 1) determine rates of ethylene evolution from lettuce (Lactuca sativa cultivar Waldemann's Green) and wheat (Triticum aestivum cultivar Yecora Rojo) plants during growth and development, 2) determine the effects of exposure of whole, vegetative stage plants to exogenous ethylene concentrations in the range of what would develop in closed environment growth chambers, and 3) develop predictive functions for changes in ethylene concentration that would develop under different cropping and closed environment configurations. Results will lead to the development of management strategies for ethylene in bioregenerative life support systems.

Plants were grown in a glasshouse using complete nutrient solutions (modified Hoagland's). Plants from different stages of development were sealed in bell jars for several hours, gas samples taken from the head space and the ethylene concentration measured using a gas chromatograph fitted with a flame ionization detector. In two experiments with lettuce, the rate of ethylene production was highest during early vegetative growth (200 to 220 nl/g/hr) and declined sharply during later growth (20 nl/g/hr). Ethylene evolution from wheat also was highest during early vegetative growth with a sharp decline at 18 to 22 days from planting. In a repeat of the experiment, a similar trend was measured with an additional decline occurring after anthesis and extending through grain fill and senescence. Absolute rates of ethylene evolution from wheat (range of 5 to 30 nl/g/hr) were only a fraction of those measured for lettuce.

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Seed germination and seedling development studies were conducted with lettuce. Germination was unaffected (97 to 100 %) by ethylene exposures in the range of 0 to 100 ppm suggesting the absence of phytotoxic effects of ethylene during this brief stage of development. However, when cobalt was supplied as CoCl_2 , ethylene evolution, radicle elongation, and hypocotyl elongation were all inhibited with increasing cobalt concentration in the range of 0.1 to 50 mM. Respiration was unaffected by cobalt. These results suggest that ethylene may be necessary for normal seedling development.

In ethylene exposure studies, germinating wheat seeds were exposed to 0, 0.1, 1.0, and 10.0 ppm ethylene. The angle between the first two leaves on 9-day old seedlings increased in a log linear fashion, indicating a strong epinastic response. For whole plant exposure studies, ethylene was metered into glass bell jars at 0, 0.05, 0.1, 0.25, 0.5, and 1.0 ppm (lettuce only). Controls consisted of ethylene-free air achieved by potassium permanganate scrubbing and activated carbon-filtered air. No effects on rate of photosynthesis, chlorophyll content, or appearance were measured on wheat plants exposed to ethylene for 9 days at 0.1 ppm, a concentration comparable to what has been measured to accumulate in the biomass production chamber. At 0.25 ppm, dry matter was higher, photosynthesis the same, and chlorophyll content 16 % lower than the controls. At 0.5 ppm, the rate of photosynthesis was 70 % and the chlorophyll content 66 % of the KMnO_4 -filtered control. With lettuce, photosynthesis and chlorophyll content were unaffected at 0.1 and 0.25 ppm, but were reduced to 62 % and 52%, respectively, of the KMnO_4 -filtered control. In these studies, we observed chlorosis at the higher concentrations, but did not observe the leaf flecking and rolling symptoms that occurred during the KSC biomass production chamber tests. Perhaps these differences may be explained by the different exposure regimes (chronic vs. acute). However, effects do demonstrate the importance of ethylene in the physiology, growth, and development of plants in closed environments and the need to develop ethylene management strategies for a closed, bioregenerative life support system.

Ethylene evolution data and a range of crop growth rates were used to develop families of curves illustrating predicted changes in ambient ethylene concentration for different combinations of plant growth rate, ethylene evolution rate, and volume to area ratio of a closed system containing plants. These predictions will be useful in understanding ethylene exposure studies and the expected physiological effects. Concentrations which have developed in Kennedy Space Center's Biomass Production Chamber (100 ppb) are on the low end of potential exposure ranges due to frequent openings for sampling and maintenance, leakage, and a relatively high volume to plant growth area ratio (about 5.5). Such concentrations however are physiologically important

and represent chronic low concentration exposures to crops. Chambers with relatively low volume to crop surface area ratios (e.g. 2.5) and tight closure such as the Variable Pressure Growth Chamber at Johnson Space Center are predicted to have substantially higher ethylene concentrations (750 to 1000 ppb) and may represent extreme exposure scenarios. Crop performance under such extremes would be expected to be severely affected. Whether exposures are acute or chronic, it appears that ethylene concentrations should be controlled at the 50 ppb or lower in order to avoid physiological effects. More refined definition of this critical concentration threshold will be needed for other crops at different stages of development and recommendations developed for a variety of closed environment cropping situations.