Climate Change, Plant Biology and Public Health

Impacts of elevated temperature and CO_2 on agriculture and beyond

by Lewis Ziska, Ph.D.

Eds. Note. *The impact of global warming will have consequences that increase the pressure for herbicide use. In his research, Lewis H. Ziska, Ph.D., with USDA's Alternate Crop and Systems Laboratory, finds increased pressure from invasive plant species ("undesirable plants") because of rising carbon dioxide, as well as increases in insect-borne diseases due to rising temperatures.*

Abstract

In addition to being the principle greenhouse gas, carbon dioxide (CO_2) is also the principle source of carbon for photosynthesis. Although the stimulation of plant growth by rising CO_2 is usually viewed as a positive aspect of climate change, the rise in CO_2 is indiscriminate with respect to the stimulation of both anthropogenically important and deleterious plant species. Here we present laboratory and *in situ* data from studies that have examined the response of undesirable plants to CO_2 increases during the 20th century (from 290 to 375 parts per million by volume, ppmv), as well as that projected for the mid-21st century (500-1000 ppmv). Data from these studies indicate a number of potential indirect effects (changes in nutritional content of foods, increased use of herbicides) as well as potential direct effects (increased ragweed pollen) on public health. These initial results regarding CO_2 and/or temperature-induced changes in plant biology suggest a number of potentially unfavorable and some favorable consequences in human systems.

Introduction

Documented and projected changes in the concentration of atmospheric carbon dioxide (CO_2) and other gases suggest potential changes in temperature and global climate that could negatively impact human health. Public health concerns related to climate stability include changes in the range of insect- or rodent-borne diseases (malaria, yellow fever, dengue); changes in waterborne and seafood-borne disease outbreaks; increasing ground-level ozone and respiratory ailments; contamination of drinking water due to increased flooding; and, heat-related deaths (stroke). At present, there is a concerted effort among academic and government institutions to both recognize the degree of health risk and to formulate strategies to minimize adverse impacts.

The implications of a changing climate with respect to floods, storms, range of disease vectors, etc. are well recognized. However, less attention has been given to potential associations between climate, plant biology and human health. Plant biology is directly affected by rising CO_2, since CO_2 is the sole supplier of carbon for photosynthesis. Because 96% of all plant species are deficient in the amount of CO_2 needed to operate at maximum efficiency, recent increases in CO_2 and future projections have already, and will continue, to stimulate plant growth, with the degree of stimulation being at least, potentially, temperature dependent. Critics of the role of carbon dioxide as a greenhouse warming gas have stressed that

CO_2-induced stimulation of plant growth will result in a lush plant environment; indeed, much of the literature has focused on anthropogenically beneficial species. However, it should be emphasized that CO_2 does not discriminate between desirable and undesirable plant species.

Direct Effects of CO_2/Temperature on Plant Biology and Potential Public Health Consequences

While we generally think of plants in positive terms, there are a number of species whose presence is considered undesirable or even dangerous. We call such plants "weeds" as a means to denote their undesirability with respect to human activity. Although weeds are often associated with cultivated situations, they may also impact human health.

Allergies. At present it is estimated that approximately 10% of the U.S. population -or 30 million people- suffer from hay fever or allergenic rhinitis. Symptoms include sneezing, inflammation of nose and eye membranes, and wheezing. Complications such as nasal polyps or secondary infections of the ears, nose and throat may also be common. Severe complications, such as asthma, permanent bronchial obstructions, and damage to the lungs and heart can occur in extreme cases. Although there are over four dozen plant species that produce allergic reactions, common ragweed, a ubiquitous weed, causes more problems than all other allergenic plants combined.

Environmental growth chambers (EGC) studies of common ragweed indicate that exposure to concentrations of current CO_2 (ca 370 ppmv) and that projected for the mid-21st century (ca 600 ppmv) increased ragweed pollen productivity by 131% and 320% respectively, compared to ragweed grown at pre-industrial CO_2 levels (ca 280 ppmv). The finding regarding the response of ragweed pollen to future CO_2 (relative to current levels) was later confirmed by a different group in a greenhouse (GH) study.

A recent two-year transect study of ragweed also found that urbanization-induced increases in CO_2 and temperature are associated with increased ragweed growth, pollen production and pollen allergenicity, suggesting a probable link between rising CO_2 levels, global change and public health. While most of the work regarding weeds, pollen production and climate have focused on common rising CO_2 and/or temperature, these factors would also be expected to influence seasonal pollen production of other allergenic plants, including tree and grass species.


Ragweed pollen, an allergen for millions of people, is expected to thrive in an environment with elevated carbon dioxide.

Poison/Toxicology. Ingestion of poisonous plants can result in serious illness or death. There are over 700 plant species that are known to induce illness in humans. Similar to dermatitis, toxicology is related to specific plant organs (fruit, leaf, stem), as well as stage of growth, soil and eco-type. Both edible and poisonous parts can exist on the same plant (rhubarb, potato). Bracken may represent a toxicological threat due to production of potential carcinogenic spores or exudates. Poison hemlock, oleander, jimsonweed and castor bean (ricin) are so poisonous that tiny amounts can be fatal if eaten. For 2001, approximately 73,000 cases of accidental plant ingestion were reported for children in the U.S. under the age of six.

Although quantification of particular compounds such as ricin have not been determined, the response of a number of poisonous/toxicological plant species to rising CO_2 and/or temperature have been reported. For bracken, GH studies indicate a significant stimulation of photosynthesis with an increase in CO_2 concentration 200 ppmv above current ambient at two levels of nitrogen supply, although, curiously, no significant effect on growth was observed. For castor bean in EGCs, the net gain of carbon per leaf was approximately double at projected CO_2 concentrations of 700 ppmv. For jimsonweed, a 300 ppmv increase in CO_2 resulted in a 2-3x increase in seed capsules and dry weight in GH experiments; and, a CO_2 increase from preindustrial levels (ca 280 ppmv) to 460 ppmv in EGC trials resulted in an approximate doubling of dry mass. Lambsquarters, which produce nitrates and soluble oxalatcs with subsequent photosensitization in humans, has shown a 115% increase in above ground biomass with a 75 ppmv increase in CO_2 and 3.3°C increase in temperature along a rural-urban transect. Overall, it is clear that for both laboratory and field, a number of poisonous species will show significant growth increases in response to CO_2 and temperature.

Unfortuntely for millions of gardeners and hikers, poison ivy is also expected to increase in a high carbon dioxide environment.

Contact Dermatitis. Another common weed-induced health effect is contact dermatitis, which is associated with over 100 plant species. These chemical irritants can be present on all plant parts, including leaves, flowers and roots, or can appear on the plant surface when plant injury occurs. Toxicity may vary with a range of factors including maturity, weather, soil and eco-type. Most reactions caused by these chemicals usually occur within a few minutes of exposure. The type of dermatitis produced is species dependent. For example, the milky sap in spurges can be chemically irritating, whereas some species such as the stinging nettle are both mechanically and chemically irritating. One well-known chemical is urushiol, a mixture of catchol derivatives. This is the compound that induces contact dermatitis in the poison ivy group. Sensitivity to urushiol occurs in about two of every three people, and amounts as small as one nanogram (ng) are sufficient to induce a rash. Over two million people in the U.S. suffer from annual contact with members of the poison ivy group (poison ivy, poison oak, or poison sumac).

Unfortunately, the growth and qualitative response of these species to increasing CO_2 and/or temperature is unknown. Other vines similar in morphology, such as kudzu, have shown relatively strong response to future CO_2 levels in EGC experiments. GH data is available for stinging nettle however, showing a 30% increase in biomass at projected CO_2 levels of 700 ppmv. Data for leafy spurge showed a 85% stimulation of vegetative biomass to past increases in CO_2 (285-380 ppmv) and a smaller increase (32%) to projected CO_2 (380-720 ppmv) in recent EGC studies.

Indirect Effects of CO_2/Temperature on Plant Biology and Potential Public Health Consequences

The direct effect of CO_2/temperature on specific weedy species whose biology directly impacts human health is straightforward. Less evident are the means by which plant biology can indirectly impact public well-being. Overall, indirect effects may include CO_2-induced changes in plant nutrition, plant-derived pharmaceuticals, plants needed for disease vectors, and pesticide use.

Nutrition/food quality. With a global population exceeding 6 billion, people rely on grain cereals as their principle source of calories. Two principle cereals, wheat and rice, supply the bulk of the caloric intake for over 4 billion people. Although wheat and rice have shown a positive growth response to increasing CO_2, yields may actually decline with concurrent increases in both CO_2 and temperature due to greater sensitivity of floral sterility to temperature as CO_2 increases. In addition, increasing CO_2 may also affect food quality. In general, plants are anticipated to become more starchy, but protein-poor, with a subsequent decline in digestibility as CO_2 increases. In rice, percent protein decreases with both increasing air temperature and increasing CO_2 concentration over a two-year period in an open top container (OTC) study conducted for tropical paddy rice in the Philippines. For wheat, increasing CO_2 from pre-industrial to current levels results in decreased protein in both Spring and Winter wheat in a GH experiment. Free Air CO_2 Enrichment (FACE) experiments with wheat in Maricopa, AZ show significant effects on flour protein concentration, optimum mixing time for bread dough and bread loaf volume with increasing CO_2 (550 ppmv), which are exacerbated if nitrogen is limited. Although qualitative changes in rice and wheat have been well-documented, less is known regarding nutritional impacts on other crops. Lu et al. reported decreased protein content in sweet potato in response to CO_2. In contrast, Rogers

Studies show that rice decreases in protein content in environments with elevated carbon dioxide and temperatures.

et al. reported no response in protein content of maize to CO_2 in GH experiments. Recent OTC data for strawberries, which are a good source of natural anti-oxidants, show a positive increase in antioxidant capacity and flavanoid content in response to increased CO_2 (300 and 600 ppmv above current levels). Overall, these data indicate both positive and negative changes in the quality of common food sources in response to CO2/temperature.

Scientists theorize that plant-derived drugs, such as Lapachol - an anti-cancer drug from *Tabebuia spp.* (pictured), may have its pharmacological metabolites impacted by climate change.

Medicine. The use of plants as herbal remedies for human ailments dates to the beginning of civilization. Modern plant biochemists have long recognized that plant species synthesize a wide range of secondary metabolites. One of the most compelling explanations for the degree of chemical diversity is that plants have evolved toxicological strategies to protect themselves from viral diseases, fungal pathogens, and herbivory. Interestingly, a number of these secondary metabolites also constitute a principle source for established medicines and potential new drugs. Although it is estimated that there are roughly 400,000 terrestrial plant species, at present, less than 1% of these species have been examined in-depth for their possible pharmacological use.

An OTC study shows a significant increase in leaf photosynthesis and plant growth in *Brassica nigra L.* with increasing CO_2 (300 ppmv above ambient), but the effect of CO_2 on its secondary metabolite, allyl isothiocyanate, was not determined. Similarly, a doubling of atmospheric CO_2 above current ambient resulted in a doubling of dry weight in *Tabebuia rosea*, but the effect of CO_2 on levels the secondary metabolite lapachol was unknown.

At present, few studies are available which have assessed the quantitative or qualitative CO_2 response of secondary metabolites of pharmacological interest. Most secondary metabolites have been evaluated in terms of plant-insect interactions with projected CO_2 levels either stimulating or decreasing the production of secondary compounds. One exception has been wooly foxglove, which produces digoxin, a pharmaceutical glycoside which helps the heart pump blood. In GH experiments, plant growth and digoxin production are significantly increased at 1000 ppmv relative to ambient CO2 conditions.

Interestingly, while the relative proportion of digioxin among glycosides does not change, the relative amount of digitoxigenin, another glycoside, is considerably reduced in response to CO_2. Similarly to digoxin in *D. Lanats*, projected CO_2 has also been shown to increase the growth of tropical spider lily, a plant whose bulbs may produce secondary compounds with potential anti-cancer and anti-viral activities.

Disease Vectors and Plant Biology. Adult mosquitoes do not feed on blood (although the female requires blood proteins in order to successfully lay eggs); rather, they rely on flower nectar, phloem, and decaying plant matter for flight energy. Rodents also depend in large part on plant material as a principle food source (seed). In general, plant growth and seed production are anticipated to increase in response to rising CO_2. Potentially, because of CO_2-induced increases in their food sources, populations of these disease carrying vectors could be stimulated.

Herbicide Efficacy and Usage. Any resource which affects the growth of an individual alters its ability to compete with individuals of the same or different species. Differential inter- and intra-specific responses to CO_2 have been observed for the increase in atmospheric carbon dioxide which has already occurred during the 20th century and that projected for the end of the 21st century. If differential responses to increasing CO_2 occur between crops and weeds, will crop losses due to weedy competition increase or decrease? This will depend in part on the photosynthetic pathway, but there are a number of GH and OTC experiments indicating a greater response of weeds. Such a response is consistent with the suggestion of Treharne that the physiological plasticity and greater genetic diversity of weed species relative to modern crops would provide a greater competitive advantage as atmospheric CO_2 increases.

But even if CO_2 stimulates the growth of agronomic weeds, won' t we still be able to limit where and when such species grow with herbicides? A single herbicide, glyphosate is so widespread that more than half of the current U.S. soybean and a third of the U.S. corn crop have been genetically modified to be glyphosate resistant.

This assumes however, that increasing CO_2 will not affect herbicide efficacy. Yet, there is increasing evidence from GH and OTC studies that CO_2 decreases chemical efficacy for annual and perennial weeds. It can be argued that CO_2-induced changes in herbicide tolerance are irrelevant given the rate of atmospheric CO_2 increase (other herbicides will be developed in the future). However, herbicides can persist over decades (2,4-D), coinciding with significant increases in atmospheric CO_2 (300-372 ppmv since the introduction of 2,4-D in the 1940's). Given the investment of large companies in genetically modified crops and their associated herbicides, it seems more likely that use of current herbicide will persist for longer periods. Obviously, chemical control can still be obtained if additional sprayings occur, or if concentration increases, but this could potentially, alter the environmental and subsequent health costs associated with pesticide usage.

In addition to any direct effect of CO_2 on efficacy, climatic change *per se* can alter abiotic variables such as temperature, wind speed, soil moisture, and atmospheric humidity. Alteration of such variables can also influence the efficacy of herbicide applications. These same environmental variables can affect crop injury due to herbicide application. A recent economic evaluation based on anticipated climate change suggested that increasing temperature increases pesticide cost variance for corn, potatoes and wheat, while decreasing it for soybean. Overall, existing data suggest that CO_2 and potential changes in climate could reduce efficacy with a subsequent increase in spraying frequency or herbicide concentration. The overall consequences of such an increase have not been specifically evaluated with respect to human health.

Glyphosate Efficacy Under Elevated CO_2

Unwanted Plant	CO_2 (ppmv)	Growth (g/day)
lambsquarters	365	0.09 (death)
	723	1.37
red-root pigweed	365	0.04 (death)
	723	0.18
quackgrass	388	-0.05 (death)
	721	1.14
Canada thistle	421	0.55
	771	1.37

Changes in efficacy determined as changes in growth following glyphosate application for weeds grown at current or projected future levels of carbon dioxide. Plants were followed for 2-4 weeks.

Conclusions

Plant biology impacts every aspect of our lives. As carbon dioxide continues to increase, we can anticipate fundamental changes in plant biology either from anticipated changes in temperature or, directly from CO_2-induced changes in physiology and growth. From the initial studies described here, it is evident that there are a number of potential means by which plant biology will directly or indirectly affect human health. This includes changes in allergenic pollen, contact dermatitis, physical damage, and poisons; as well as potential changes in nutrition, medicines, disease vectors and pesticide usage.

Unfortunately, there is much we still don't know. If CO_2 and/or temperature influence ragweed pollen production, are there qualitative (allergenicity) changes in the pollen? What other allergenic species are affected? Will the level of urishiol, or other chemicals which cause contact dermatitis increase with increasing CO_2? Can we expect toxicological changes in poisonous plants? How will CO_2-induced changes in proteins or antioxidants alter human nutrition? Is the nutrient content of foods increasing or decreasing in response to CO_2? Is the quality of medicines derived from botanical sources improving? If more food is made available, will populations of disease carrying mosquitoes or rodents increase? If weed growth is improved and herbicide usage increases, will the CO_2-induced reductions in efficacy result in increased pesticide use? If so, what are the long-term implications for human health? None of these questions have been addressed in depth. Few, if any field data are available which assess both CO_2 and temperature concurrently in regard to these questions.

The potential consequences of a warmer planet with respect to disease outbreaks, air and water quality, and respiratory disease are well recognized by the health care community. Less recognized or evaluated are the direct and indirect consequences of CO_2 on plant biology and human health. Yet, the environmental and health costs of not understanding these consequences may be substantial. It is hoped that this review will both emphasize the critical nature of this issue and serve as a guide for interested medical researchers and policy makers in assessing the separate importance of atmospheric CO_2 to plant biology and public health.

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