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CLIMATE CHANGE, PLANT BIOLOGY AND PUBLIC HEALTH

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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 (weedy) plants to CO_2 increases during the 20th century (i.e., 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 indicated a number of potential indirect effects (e.g., changes in nutritional content of foods, increased use of herbicides) as well as potential direct effects (e.g., 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. However, these results are based on a small number of experiments and additional data are crucial to reduce the biological and economic uncertainties associated with CO_2-induced changes in plant biology and human health.

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, (e.g., malaria, yellow fever, dengue) (Gubler et al., 2001); changes in waterborne and seafood-borne disease outbreaks (Rose et al., 2001); increasing ground-level ozone and respiratory ailments (Cifuentes et al., 2001, Bransford and Lai, 2002); contamination of drinking water due to increased flooding (Schelling, 1995); and, heat-related deaths (e.g., stroke) (McGeehin and Mirabilli, 2001). 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 (for reviews see Burns, 2002; Epstein, 2000; Patz and Kovats, 2002).

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 (e.g., Poorter, 1993), with the degree of stimulation being at least, potentially, temperature dependent (Long, 1991). 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 (Idso and Idso, 1994); indeed, much of the literature has focused on anthropogenically beneficial species (see Ainsworth et al., 2002; Curtis and Wang, 1998; Kimball, 1993, *inter alia*). However, it should be emphasized that CO_2 does not discriminate between desirable (e.g., wheat, rice) and undesirable (e.g., ragweed, poison ivy) plant species (Patterson, 1995).

How would changes in plant biology impact public health? How have past or projected atmospheric CO_2 levels mediated such changes? In this paper we will provide a number of specific examples of potential direct and indirect effects on public health associated with CO_2-induced changes in plant biology. While these initial examples are limited, we hope to emphasize the potential scope and impact of such effects and to highlight areas where additional data are needed.

SIMULATION OF PAST AND FUTURE CLIMATES

Applicability of data regarding plant biology and potential health effects to a larger population is determined in part by the experimental techniques used to obtain plant responses to past and projected atmospheric carbon dioxide. Simulation of changing CO_2 and/or temperature utilizes a wide range of indoor and outdoor methodologies. Here we provide a brief overview of the means by which plant responses to CO_2 and/or temperature are assessed (for a detailed review, see Moya et al. ,1997).

- *Environmental Growth Chambers* (EGCs). Although outdoor *in situ* systems are almost always preferred, such systems cannot simulate pre-industrial atmospheric carbon dioxide levels over a 24 hour period (e.g., Mayeux et al., 1993). Rather, closed growth chamber systems with high CO_2 scrubbing capacity must be utilized. Such systems allow precise control of edaphic factors, humidity, light, CO_2, temperature, nutrients, pest control, etc. However, because of space considerations, the response of individual plants is usually evaluated.
- *Greenhouses* (GHs). Similar to growth chambers with respect to control of micro-climate and CO_2. However, larger space may allow multi-species comparisons; in addition, natural light can be utilized or supplemented with an artificial light source for greater control.
- *Open-top chambers* (OTCs). Usually field-based plexiglass chambers enclosing a small (2-6 m^2) area. This method does allow species comparison of growth and physiology under *in situ* conditions of soil, water, light, etc. while simulating future (but not past) levels of atmospheric CO_2. However, most OTCs modify the abiotic micro environment around the plant community with a subsequent effect on energy flow, bioprocesses and plant growth, although the degree of modification depends on the system used.
- *Free-Air CO_2 Enrichment* (FACE). It was partly to negate the induced micro-climatic changes of OTCs that the FACE system was introduced in the early 90s (Hendrey and Kimball, 1994). FACE is an *in situ* system consisting of a large metal ring surrounding an

experimental plot. The ring allows injection of CO_2 at high velocities into the center of large plots (100-500 m^2) in order to simulate future CO_2 values. FACE reduces micro-climate effects and provides the most realistic assessment of future CO_2 levels. However, operating costs for FACE systems can be high. In addition, only CO_2 can be supplemented in a FACE system, simultaneous increases in CO_2 and temperature over large areas are not possible.

- *Rural-Urban Transects* (RUTS). It is clear that the two principle environmental parameters expected to increase with global climate, ambient air temperature and CO_2, also increase in response to urbanization (Idso et al., 1998; 2001; Ziska, 2000). Experimental plots which are located within urban, suburban and rural areas have recently been used as an *in situ* means to simulate future climates (e.g., Ziska et al., 2003). Although this transect does not allow separation of CO_2 from temperature effects, it would provide a means to assess concurrent increases in CO_2 and temperature over large areas.

DIRECT EFFECTS OF CO_2 AND TEMPERATURE ON PLANT BIOLOGY AND POTENTIAL CONSEQUENCES FOR PUBLIC HEALTH

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 (gardens, farms), they may also impact human health. Weeds are generally recognized as affecting human health in one of four ways: through allergenic reactions, skin irritations (contact dermatitis), mechanical injury, or internal poisoning.

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 (Gergen et al., 1987). 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 (*Ambrosia artemisiifolia* L.), a ubiquitous weed, causes more problems than all other allergenic plants combined (Wodehouse, 1971).

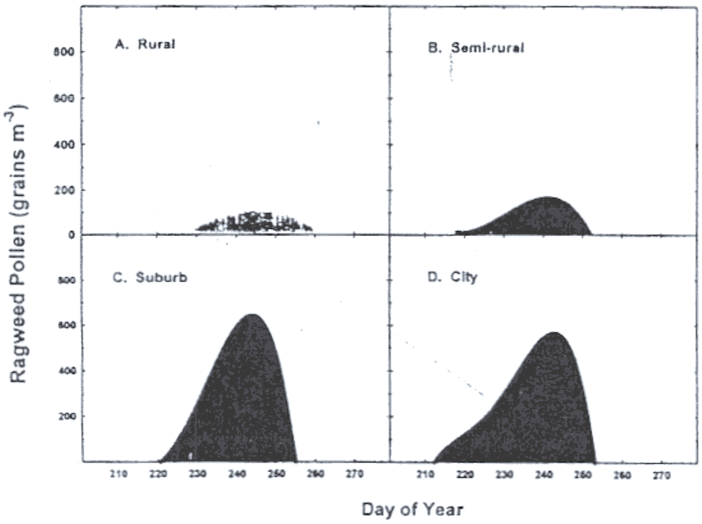

Figure 1 Seasonal changes in ragweed pollen production in 2001along an urban-rural transect. Soil and seed source were the same at each site. Average daily CO_2 concentrations were +10, +112 and +122 ppmv and average daily air temperatures were +0.6, +1.1 and +1.9°C for the semi-rural, suburban and urban locations relative to the rural control. No other measured climatic or air quality characteristic differed along the transect. Pollen counts were determined by roto-rod sampling. Data were regressed by "best-fit" quadratic equation. Additional details are given in Ziska et al., 2003.

EGC studies of common ragweed indicated 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) (Ziska and Caulfield, 2000). 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 GH study (Wayne et al., 2002).

While intriguing, do these laboratory results have meaning under realistic conditions? A recent two-year transect study of ragweed did, in fact, find that urbanization-induced increases in CO_2 and temperature were associated with increased ragweed growth, pollen production and pollen allergenicity (Ziska et al., 2003), suggesting a probable link between rising CO_2 levels, global change and public health (Figure 1). While most of the work regarding weeds, pollen production and climate have focused on common ragweed, rising CO_2 and/or temperature would also be expected to influence seasonal pollen production of other allergenic plants, including tree and grass species.

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 (*Urtica dioica* L.) 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 (*Toxicodendron/Rhus* spp.). Sensitivity to urushiol occurs in about two of every three people, and amounts as small as 1 ng are sufficient to induce a rash. Over two million people in the United States suffer from annual contact with members of the poison ivy group: poison ivy (*T. Toxicodendron* (L.) Ktze.), poison oak (*T. Toxicarium* (Salisb.) Gillis), or poison sumac (*T. vernix* (L.) Ktze) (Resnick 1986)

Unfortunately, the growth and qualitative response of *Toxicodendron* species to increasing CO_2 and/or temperature is unknown. Other vines similar in morphology such as kudzu (*Pueraria lobata*, Ohwi), have shown relatively strong response to future CO_2 levels in EGC experiments (Sasek and Strain, 1990). GH data is available for stinging nettle however, showing a 30% increase in biomass at projected CO_2 levels of 700 ppmv (Hunt et al., 1991). 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 (Ziska, 2003).

Physical Contact. Many weeds may also cause physical injury. Spines, or other sharp appendages can puncture the skin. For the unwary, removing common garden weeds such as Canada thistle (*Cirsium arvense* (l.) Scop.) by hand can be particularly painful. Physical wounding by thorns or spines can be painful, and care must be taken in utilizing the proper protective gear to avoid injury.

As with contact dermatitis, few studies have quantified changes in physical appendages as a function of CO_2 and/or temperatures. One exception is recent EGC data for Canada thistle showing an increase in the number and length of leaf spines as CO_2 increased from 285 to 382 ppmv and from 382 to 721 ppmv (Figure 2)(Ziska, 2002).

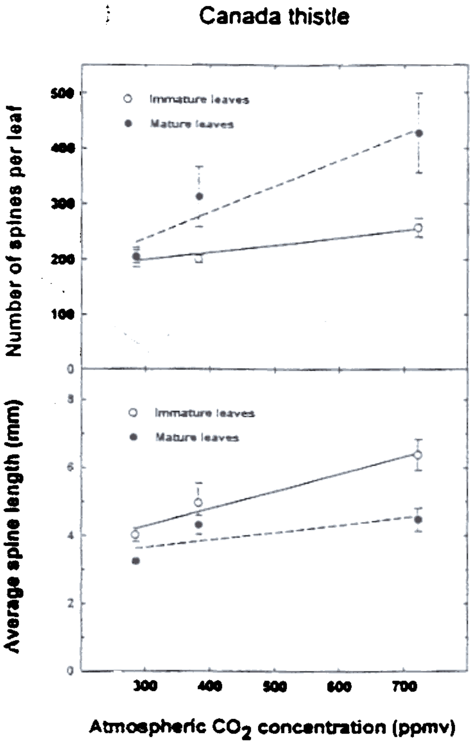

Figure 2 Change in the number and length (mm) of leaf spines determined for mature and immature leaves of Canada thistle grown at 285, 382, and 721 ppmv carbon dioxide. These levels of carbon dioxide approximate those present at the beginning of the 20th century, the current concentration, and that projected for the end of the 21st century. * indicates a significant difference at the $P<0.05$ level between CO_2 treatments for a given measurement date. Bars are ±SE. See Ziska, 2002, for a complete description of the experimental details.

Poison/Toxicology. While physical injury can be annoying, 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 (e.g. rhubarb (*Rheum rhabarbarum* L., potato *Solanum tuberosa* L.). Bracken, (*Pteridium aquilinum* (L.) Kuhn) may represent a toxicological threat due to production of potential carcinogenic spores or exudates (Trotter 1990). Poison hemlock (*Conium maculatum* L.), oleander (*Nerium oleander* L.), jimsonweed (*Datura stramonium* L.) and castor bean (*Ricinus communis* L.) are so poisonous that tiny amounts can be fatal if eaten (e.g., ricin in castor bean has a greater potency than cyanide). For 2001, approximately 73,000 cases of accidental plant ingestion were reported for children in the U.S. under the age of six (Personal Communication, Dr. Rose Anne Soloway, American Association of Poison Control Centers).

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 indicated 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 (Caporn et al., 1999). For castor bean in EGCs, the net gain of carbon per leaf was approximately double at projected CO_2 concentrations of 700 ppmv (Grimmer and Komor, 1999). For jimsonweed, a 300 ppmv increase in CO_2 resulted in a 2-3x increase in seed capsules and dry weight in GH experiments (Garbutt and Bazzaz, 1984); and a CO_2 increase from pre-industrial levels (~280 ppmv) to 460 ppmv in EGC trials resulted in an approximate doubling of dry mass (Bunce, 2001). Lambsquarters (*Chenopodium album*) which produces nitrates and soluble oxalates, with subsequent photosensitization in humans, has shown an 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 (Ziska, unpublished data). 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.

INDIRECT EFFECTS OF CO_2/TEMPERATURE ON PLANT BIOLOGY AND POTENTIAL CONSEQUENCES FOR PUBLIC HEALTH

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, agriculture relies 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 (e.g., Matsui et al., 1997). 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 (Hesman, 2000). In rice, percent protein decreased with both increasing air temperature and increasing CO_2 concentration over a two year period in an OTC study conducted for tropical paddy rice in the Philippines (Ziska et al., 1997). For wheat, increasing CO_2 from pre-industrial to current levels resulted in decreased protein in both Spring and Winter wheat (Rogers et al., 1998) in a GH experiment. FACE experiments with wheat in Maricopa, Arizona showed significant effects on flour protein concentration, optimum mixing time for bread dough and bread loaf volume with increasing CO_2 (550 ppmv) which were exacerbated if nitrogen was limiting (Kimball et al., 2001). Although qualitative changes in rice and wheat have been well documented, less is known regarding nutritional impacts on other crops. Lu et al. (1986) reported decreased protein content in sweet potato (*Ipomoea batatas* L.) in response to CO_2. In contrast, Rogers et al. (1983) reported no response of protein content of maize (Zea mays L.) to CO_2 in GH experiments . Recent OTC data for strawberries, which are a good source of natural anti-oxidants, showed a positive increase in antioxidant capacity and flavanoid content in response to increased CO_2 (300 and 600 ppmv above current levels) (Jim Bunce, personal communication). Overall, these data indicate both positive and negative changes in the quality of common food sources in response to CO_2/temperature.

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 (Table 1). 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 (Pitman and Jorgensen, 2002).

Table 1 A partial list of plant-derived drugs, their chemical structure, action or clinical use and botanical source.

Drug	Action/Clinical Use	Species
Acetyldigoxin	Cardiotonic	Digitalis lanata
Allyl isothiocyanate	Rubefacient	Brassica nigra
Atropine	Antichotinergic	Atropa belladonna
Berberine	Bacillary dysentery	Berberis vulgaris
Codeine	Analgesic, antitussive	Papaver somniferum
Danthron	Laxative	Cassia spp.
L-Dopa	Anti-Parkinson	Mucuna spp.
Digitoxin	Cardiotonic	Digitalis purpurea
Ephedrine	Antihistamine	Ephedra sinica
Galanthamine	Cholinesterase inhibitor	Lycoris squamigera
Kawain	Tranquilizer	Piper methysticum
Lapachol	Anti-cancer, anti-tumor	Tabebuia spp.
Ouabain	Cardiotonic	Strophanthus gratus
Quinine	Anti-malarial	Cinchona ledgeriana
Salicin	Analgesic	Salix alba
Taxol	Anti-tumor	Podophyllum peltatum
Vasicine	Cerebral stimulant	Vinca minor
Vincristine	Anti-leukemic agent	Catharanthus roseus

How then has rising CO_2 and/or temperature altered the growth of medicinal plant species? A OTC study showed 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 allyl isothiocyanate was not determined (Mishra et al., 1999). 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 of lapachol was unknown (Ziska et al., 1991).

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 (e.g., Julkunen-Titto et al., 1993; Lincoln, 1993) or decreasing the production of secondary compounds (e.g., Williams et al., 1994). One exception has been wooly foxglove (*Digitalis lanata* Ehrh.), which produces digoxin, a pharmaceutical glycoside which helps the heart pump blood. In GH experiments, plant growth and digoxin production were significantly increased at 1000 ppmv relative to ambient CO_2 conditions (Stuhlfauth and Fock, 1990).

Interestingly, while the relative proportion of digioxin among glycosides did not change, the relative amount of digitoxigenin, another glycoside, was considerably reduced in response to CO_2 (Stuhlfauth et al., 1987). Similarly to digoxin in *D. Lanata*, projected CO_2 has also been shown to increase the growth of tropical spider lily (*Hymenocallis littoralis* (Jacq.), a plant whose bulbs may produce secondary compounds with potential anti-cancer and anti-viral activities (Idso et al., 2000). Although production of these pharmaceutical compounds may be positively effected by CO_2, CO_2 or temperature-induced changes in the synthesis of narcotic compounds whose abuse constitutes a significant health problem in North America and Europe (e.g., Nicotine in tobacco, Tetrahydrocannabinol (THC) in *Cannabis* spp., Cocaine Chlorohydrate in *Erythroxylum coca*) have not been reported in the scientific literature.

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 (e.g., seed). In general, plant growth and seed production are anticipated to increase in response to rising CO_2 (e.g., Kimball, 1993). 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 (Patterson and Flint, 1990). 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 (Sage, 1995) and that projected for the end of the 21st century (e.g., Poorter, 1993). 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 photosynthetic pathway, but there are a number of GH and OTC experiments indicating a greater response of weeds (see Bunce and Ziska, 2000 for a review). Such a response is consistent with the suggestion of Treharne (1989) 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 (or any of the undesirable species mentioned earlier), won't we still be able to limit where and when such species grow? Current availability of chemical methodologies allow for cheap, effective control in agronomic production. Actually, a single herbicide, glyphosate is so wide-spread and effective that more than half of the current U.S. soybean and a third of the US corn crop have been genetically modified to be glyphosate resistant (Gaskell et al., 1999).

Table 2 Changes in efficacy determined as changes in growth (g day^{-1}) following herbicide application for weeds grown at either current or projected future levels of carbon dioxide. Plants were followed for a 2-4 week period. Data for Canada thistle is based on top (shoot) growth only. All weeds were sprayed with manufacturer recommended levels of the herbicide.

Species (Common name)	CO_2 p.p.m.v.	Environment	Herbicide	Growth g day-1
lambsquarters	365	GH	glyphosate	0.09 (death)
	723	GH	glyphosate	1.37
red-root pigweed	365	GH	glyphosate	0.04 (death)
	723	GH	glyphosate	0.18
quackgrass	388	GH	glyphosate	-0.05 (death)
	721	GH	glyphosate	1.14
Canada thistle	421	OTC	glyphosate	0.55
	771	OTC	glyphosate	1.37
Canada thistle	421	OTC	glufosinate	0.52
	771	OTC	glufosinate	1.14

This assumes however, that increasing CO_2 will not effect herbicide efficacy. Yet, there is increasing evidence from GH and OTC studies that CO_2 decreases chemical efficacy for annual and perennial weeds (Table 2). It can be argued that CO_2-induced changes in herbicide tolerance are irrelevant given the rate of atmospheric CO_2 increase (i.e., other herbicides will be developed in the future). However, herbicide use can persist over decades (e.g., 2-4D) coinciding with significant increases in atmospheric CO_2 (e.g., 300-372 ppmv since the introduction of 2-4 D in the 1940s). Given the investment of large companies in genetically modified crops and their associated herbicides, it seems more likely that use of current herbicides 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 (reviewed in Muzik, 1976). 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 increased pesticide cost variance for corn, potatoes and wheat, while decreasing it for soybean (Chen and McCarl, 2001). 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.

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 anti-oxidants 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? What will be the impact of CO_2/temperature on the production of narcotic plants? 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 (e.g., Patz and Kovatz, 2002). 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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