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.

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

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

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.

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.

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.

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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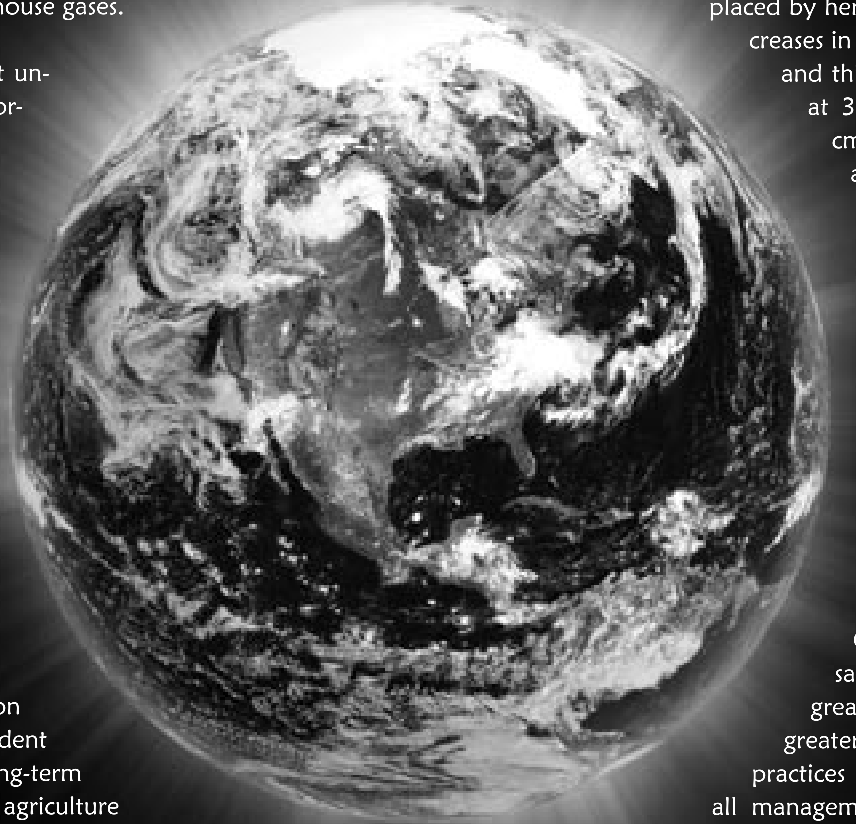
The Organic Farming Response to Climate Change

One of the most powerful tools in fighting global warming sequesters atmospheric carbon, data suggests a new worldwide urgency for the transition from chemical to organic agriculture

by Paul Hepperly, Ph.D.

Organic farming may be one of the most powerful tools in the fight against global warming. Findings from The Rodale Institute's Farming Systems Trial® (FST), which began in 1981 as the longest running agronomic experiment designed to compare organic and conventional cropping systems, show that organic/regenerative agriculture systems reduce carbon dioxide, a major greenhouse gas. This data positions organic farming as a major player in efforts to slow climate change from increases in runaway greenhouse gases.



Besides being a significant underutilized carbon sink, organic systems use about one-third less fossil fuel energy than that used in the conventional corn/soybean cropping systems. According to studies of the FST in collaboration with David Pimentel, Ph.D. of Cornell University, this translates to less greenhouse gases emissions as farmers shift to organic production. The ability of organic agriculture to be both a significant carbon sink and to be less dependent on fossil fuel inputs has long-term implications for global agriculture and its role in air quality policies and programs. The Rodale Institute drew these conclusions in a white paper that was released in 2003.

Organic shows dramatic increases in carbon sequestration

Since 1981, data from the FST has revealed that soil under organic agriculture management can accumulate about 1,000 pounds of carbon per acre foot of soil each year (1,123 kg/ha/yr metric). This accumulation is equal to about 3,500 pounds of carbon dioxide per acre taken from the air and sequestered into soil organic matter. When multiplied over the 160 million acres of corn and soybeans grown nationally, a potential for 580 billion pounds of excess carbon dioxide per year can be sequestered when farmers transition to organic grain systems.

Since the release of this data in 2003, there are new more dramatic findings. Figure 1 shows a more complete assessment of greenhouse gas sequestration in our long-term trial. In our comparison of soil in organic and conventional systems, we found greater levels of soil carbon in organic systems to a depth of two feet, about 60 cm. Conventional no till (or no tillage where plowing is replaced by herbicides) soil carbon increases in just the first few inches and this effect is extinguished at 3 to 6 inches (5 to 10 cm) or before this level, according to published results from several authors doing long-term trials. Organic no till is typically incorporated into organic agriculture production as a supplementary practice to cover cropping, rotation and organic amendment or fertilization.

Our take home message is: (i) non till is great, (ii) cover crops are greater, and (iii) combined practices offer the best overall management systems but need greater verification for their interaction. The data demonstrates that organic farming methods increase stored carbon and retain other nutrients and organically improved soils better hold these nutrients in place for uptake by plants. In the process, organic methods reduce nitrate and other nutrient runoff into streams and water aquifers. These findings can be beneficial to all farmers by helping them to increase crop yields while decreasing energy, fuel and irrigation costs.

The 1995 Kyoto Protocol references the potential of soil to sequester carbon without emphasizing its capacity nor the importance of organic agriculture management for this purpose. Since then, researchers have moved forward strongly with investigations to support agriculture's real potential to sequester carbon. The Rodale Institute's farm manager, Jeff Moyer, has invented and developed an innovative planter and roller for use in an organic no till system. (See at www.newfarm.org and Google "No Till Plus.")

Now in its 27th season, The Rodale Institute Farming Systems Trial® is the longest running comparison of conventional corn and soybean row crop farming to organic production systems of corn and soybean.

In 2003, The Rodale Institute's findings show that organic grain production systems increase soil carbon 15% to 28%. Moreover, soil nitrogen in the organic systems increases 8% to 15%. Our 2006 deep profile carbon readings on soils receiving compost raises the carbon bar to 40% improvement. The conventional system shows no significant increases in either soil carbon or nitrogen in the same time period. Soil carbon and nitrogen are major determinants of soil productivity.

Why the increase in soil carbon in organic systems?

Why does the soil carbon level increase in organic systems but not in conventional systems when crop biomass is so similar? We believe the answer lies in the different decay rates of soil organic matter under different management systems. In the conventional system the application of soluble nitrogen fertilizers stimulates more rapid and complete decay of organic matter, sending carbon into the atmosphere instead of retaining it in the soil as the organic systems do.

Additionally, soil microbial activity, specifically the work of mychorrhiza fungi, plays an important role in helping conserve and slow down the decay of organic matter. Collaborative studies in our FST with the United States Department of Agriculture (USDA) Research Service (ARS) researchers, led by David Douds, Ph.D., show that mychorriza fungi are more prevalent in the FST organic systems. These fungi work to conserve organic matter by aggregating organic matter with clay and minerals. In soil aggregates, carbon is more resistant to degradation than in free form and therefore more likely to be conserved. Support for this work comes from USDA researchers at the Eastern Regional Research Center and Sustainable Agriculture Research Laboratory in Wyndmoor, Pennsylvania and Beltsville, Maryland. Their findings demonstrate that mychorrizal fungi produce a potent glue-like substance called glomalin that is crucial for maximizing soil aggregation. We believe that glomalin is an important component for carbon soil retention and encourage increased investigation of this mechanism in carbon sequestration. In addition, in organic production systems, increased mycorrhiza fungal activity allows plants to increase their access to soil resources, thereby stimulating plants to increase their nutrient uptake, water absorption, and their ability to suppress certain

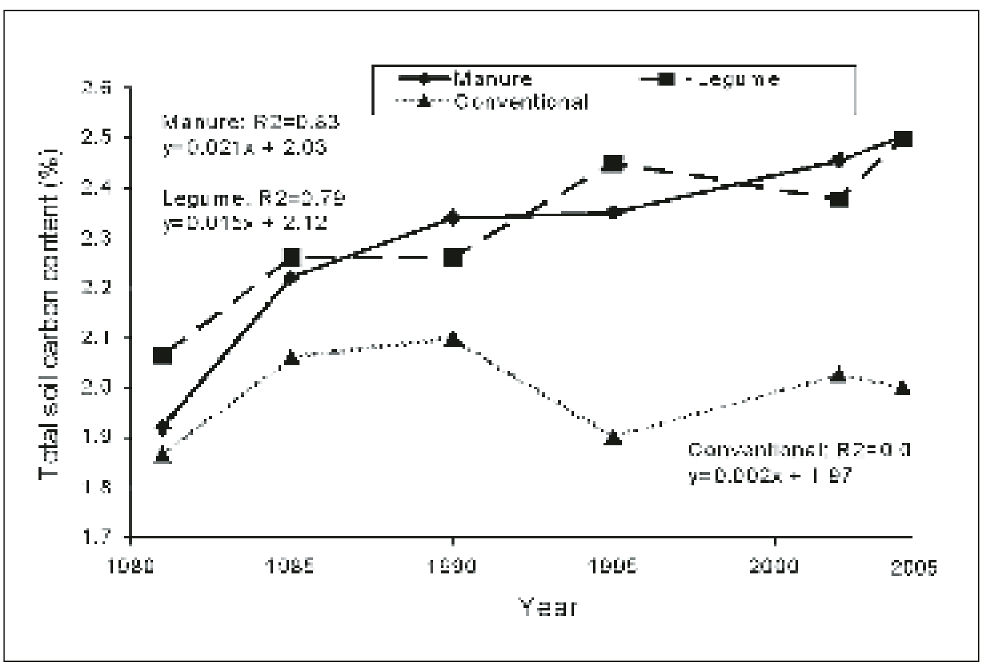


Figure 1: Linear regression of soil carbon rise with time in both organic treatments; while, no increase is found in the conventional system.

plant pathogens. Research shows 12% of the carbon captured in photosynthesis can be shunted to soil mycorrhizae. Synthetic chemical fertilizers and pesticides inhibit mycorrhizae and turn off a key mechanism by which plants naturally feed the soil through their support of beneficial fungi.

Increasing soil organic matter for the soil's carbon bank is a principle goal of organic agriculture. Organic agriculture relies on the carbon bank and stimulated soil microbial communities to increase soil fertility, improve plant health, and support competitive crop yields. This approach utilizes the natural carbon cycle to reduce the use of purchased synthetic inputs, increase energy resource efficiency, improve economic returns for farmers, and reduce toxic effects of fertilizers and pesticides on human health and the environment.

Former U.S. Secretary of Agriculture, Ann Veneman, put it this way: "The technologies and practices that reduce greenhouse gases emissions and increase carbon sequestration also address conservation objectives, such as improving water and air quality and enhancing wildlife habitat. This is good for the environment and good for agriculture."

Background and impact

In 1938, G. Callendar published findings suggesting that the burning of fossil fuels, such as coal, oil and natural gases, would likely increase world temperatures. Since 1958, continuous carbon dioxide measurements on Mount Mauna Loa in Hawaii confirm that carbon dioxide is increasing in the atmosphere at a rate of about 1.3 parts per million (ppm) per year. Atmospheric scientists believe that although several other gases contribute to the greenhouse effect in the Earth's atmosphere, carbon dioxide is responsible for over 80% of potential warming. NASA scientist James Hansen, Ph.D. tracked temperature changes in relation to past carbon dioxide levels and he correlated the 25% increase in carbon dioxide over the last 100 years with a 0.7° C warming of the atmosphere. A number of models have predicted that at current rates of carbon dioxide emission the Earth will warm 2.5° C in the next 100 years.

According to climatic change models, agriculture could be seriously affected by global warming. It is estimated that 20% of potential food crop production is lost each year due to unfavorable weather patterns (drought, flood, severe heat and cold, strong storms, etc.). The deterioration of weather patterns in North America could have devastating effects on world supplies of basic food grains such as wheat and corn. Climate change modelers predict that higher temperatures will generate more extreme weather events, such as severe

Answering The Critics

Upon the release of our original findings, a challenge immediately arose from Rattan Lal, Ph.D. in Ohio and Goro Uehara, Ph.D. in Hawaii (see Lewerenz, 2004). These scientists suggested that our estimates for carbon sequestration were too high, based on their personal research experience on conventional no till and reports in the literature showing conventional no till practice might sequester in soil a maximum of only about 200 to 500 pounds of carbon per year.

Conventional no till emphasizes tillage elimination. It does not, however, generally use live cover crops between cash crops. Under the organic farming systems, however, tillage is commonly used but live cover crops are normally established as the key biological drivers of the organic system. These drivers are what account for the 2 to 4 times greater carbon sequestration than that determined in conventional no till without cover crops as practiced by the critics. In conventional no till the ground can be covered with dead decaying crop residue for 4 to 8 months, while in organic farming cover crops provide live growing plants on the ground virtually all year long.

Veenstra, Ph.D. and co-workers (2006) at the University of California have reported on an experiment in the San Joaquin Valley that evaluated the levels of tillage vs. no tillage and cover cropping vs. without in cotton and tomato cropping systems. This work confirmed our 1,000 pounds of carbon per year soil sequestration level that we obtained under their very different California environment. Moreover, it also confirmed that tillage was of less importance compared to cover crop use in terms of improving soil and increasing carbon sequestration.

sequestration and reduce carbon emissions. While carbon can cycle in and out of soil or biomass material, there are methods for building up what are called soil "humic" substances (also known as organic matter) that can remain as stable carbon compounds for thousands of years.

Before forests and grasslands were converted to field agriculture, soil organic matter generally composed 6 to 10% of the soil mass, well over the 1 to 3% levels typical of today's agricultural field systems. The conversion of natural grasslands and forests around the globe works to elevate atmospheric carbon dioxide levels significantly. Building soil organic matter by better nurturing of our forest and agricultural lands can capture this excess atmospheric carbon dioxide, and preserve more natural landscapes.

droughts and torrential rains. A shift of 1 to 2° C in summer temperatures at pollination season can cause a loss of pollen viability, resulting in male sterility of many plant species such as oats and tomatoes.

As global temperatures rise, the glaciers and polar icecaps will melt, leading to major island- and coastal-flooding. About 50% of the United States population lives within 50 miles of a coastline. As coastlines move inland, uncontrolled carbon dioxide levels will directly affect coastal dwellers. If greenhouse gases continue to increase in the next several hundred years, the rise of global temperature is estimated at 7° C, or almost 15° F, and the sea level would rise over 2 meters, or in excess of 6 feet.

Soil organic matter is the key to sequestration

Agricultural and forest carbon sequestration will reduce the dangers that carbon dioxide currently presents to our atmosphere and world climatic patterns. These benefits will complement energy conservation and emission control efforts.

Normal seasonal carbon dioxide fluctuations in the atmosphere demonstrate that plant growth governs major amounts of carbon dioxide, enough to change atmospheric concentration by up to 10 ppm. By increasing plant production, we can reduce carbon dioxide concentrations in the atmosphere. Carbon dioxide levels are minimized in summer when vegetation is lush, and maximized in winter when plants die or go dormant. The fluctuation of carbon dioxide from season to season is about 7 times greater than the yearly average increase in atmospheric carbon from fossil fuel burning and deforestation (1.3 ppm). Plants serve as sinks for atmospheric carbon dioxide. Carbon stored in vegetation, soil, or the ocean, which is not readily released as carbon dioxide, is said to be sequestered. To balance the global carbon budget, we need to increase carbon

Soil, agriculture, and forests are essential natural resources for sequestering runaway greenhouse gases, helping to derail drastic climate changes. The amount of carbon in forests (610 gigatons) is about 85% of the amount in the atmosphere.

Less energy use and consistent yields

With the Institute's organic no till system, we have shown that diesel fuel needs can be reduced by about 75%, as trips through the field are reduced from 9 to 2. We have shown that high consistent yields are possible for corn, soybean, and pumpkins without chemical inputs.

In addition to capturing more carbon as soil organic matter, organic agricultural production methods also emit less greenhouse gases through more efficient use of fuels. Energy analysis of the FST by Dr. Pimentel show that organic systems use only 63% of the energy input used by the conventional corn

Notice the difference in the richness of the soil at 1% (left) and 5% (right) carbon.

In addition to capturing less carbon in soil, conventional agricultural production methods also emit greater greenhouse gases and require the hazardous use of chemical fertilizers and pesticides.

and soybean production system. Dr. David Pimentel's findings show that the biggest energy input, by far, in the conventional corn and soybean system is nitrogen fertilizer for corn, followed by herbicides for both corn and soybean production. In our organic approach, winter annual legumes provide the nitrogen naturally at a small fraction of the chemical cost in all its facets -economically, environmentally and to our health.

Organic systems are economically viable

Organic farming also makes economic sense. In addition to reducing input costs, economic analysis by James Hanson, Ph.D. of the University of Maryland has shown that organic systems in the FST are competitive in returns with conventional corn and soybean farming, even without organic price premiums. Numerous studies point to long term organic corn yield surpassing conventional ones. Perhaps just as important, all our yields have exceeded the country conventional farmer average.

International and state response

Calls for an African Green Revolution based on conventional farming methods will only make matters worse. We are losing ground as the Sahara Desert continues to expand southward because of misdirected land management and it is time to shift the chemical paradigm. In Zimbabwe, the droughts that cause famine are clearly associated with El Nino effects. Unfortunately, problems which are rooted in the soil are now being attributed to lack of synthetic fertilizer, insufficient genetically modified food crop varieties, and lack of pesticide availability. The call for a Green Revolution must be rooted in the soil and not in false hopes and promises based on magical potions with their proven history of health and environmental destruction. We can, and indeed we must, do better.

However, in Europe, scientist consultant groups from Netherlands and Germany have reviewed our findings and use them to incorporate organic farming targets as a part of their greenhouse gas targets for their roadmap and strategies.

In addition, we have been actively involved with Pennsylvania, New Mexico, and Northeast Regional Greenhouse Gas Working Groups. We intend to be at the table to have a positive impact on agriculture and food policies in relation to greenhouse gas issues. This is particularly important because business as usual will not resolve the challenges we have ahead of us.

Conclusion

The presence of sequestered carbon in FST organic field trials is an indicator of healthy soil that has an abundance of carbonaceous matter, in particular the organic material humus. It is humus that enables healthy soils to retain water during periods of drought. Each pound or kilogram of dry soil organic matter can absorb 20 times its weight in water. It is humus that retains mobile nutrients found in soils such as phosphates and nitrates, that would otherwise be lost as runoff to streams and aquifers.

These trials illustrate that economic benefit as well as environmental protection can and should work together hand in hand. The economic benefits are realized by farmers and landowners who see reduced costs for fertilizer, energy and fuels requirement, irrigation needs, and increased crop yields and quality at the same time. It is also economically beneficial to the agricultural business economy, and an environmental benefit to all of us, that specific soil management and tillage practices can help to sequester or retain carbon in the soil – carbon that would otherwise be lost to the atmosphere as a component of the growing greenhouse gas menace.

In conclusion, organic farming can reduce the output of carbon dioxide by 37-50%, reduce costs for the farmer, and increase our planet's ability to positively absorb and utilize greenhouse gases. These methods maximize benefits for the individual farmer as well as for society as a whole. It is a winning strategy with multiple benefits and low comparative risk. These proven approaches mitigate current environmental damages and promote a cleaner and safer world for future generations.

Creating incentives and taking action

While credits for no till farming are now fully established, to elevate the response to climate change we must extend those credits to organic practices, including cover cropping, compost addition, rotation and other methods. There is a continuing need to develop verified methods and real time estimation of sequestration rates. We believe that this can be achieved by utilizing a combination of process- and performance-based standards as a way of confirming and conferring greenhouse gas credits.

Each and every one of us needs to look ourselves in the mirror and ask, "How can I contribute to easing the burden of our collective planetary debt?" In terms of the food system, it can start with consumers consciously eating local organic, producing their own food wherever possible, and even reducing feedlot beef consumption. As individuals, let us start this journey to the future by dedicating ourselves to doing the small things we can do. Then, as a collective, let us work together to do the rest of the job. We can and we must.

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Local Organic: The Best Approach

Part of the problem in our present food system is its centralized nature. Spinach can grow fine in Pennsylvania, but it usually is shipped from California where it is grown on subsidized water shipped hundreds of miles from its source. In the transformation of this inefficient and often unhealthy system of food, we need to engage consumers in the values local organic food resources represent. Combining organic and local is the strongest tandem concept for improving the food system, people's health, and the health of the air, water, and soil.

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