Estimates of Global Food Production in the Year 2050:

Will We Produce Enough to Adequately Feed the World?

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Cover photo: "A Simple Meal – Children sharing a meal of leaves" by Aubrey Wade/Oxfam, as posted to flickr.com. "The villagers of Timbouloulag have been forced by the food shortage to supplement their diet with leaves collected from the bush. The leaves are soaked and cooked for three hours to break the strong fibres and pounded to a flour-like consistency before eating."

Abstract

Global food security is one of the most pressing societal issues of our time. Based on food production databases assembled and maintained by the United Nations, I have identified the specific crops that supply 95% of the food needs of the world, six large regions into which the world may be divided, twenty sub-regions, and twenty-five individual countries of particular interest. I have then projected trends in the productivities of these key crops for each of these geographical areas to the year 2050, finding that expected advances in agricultural technology and expertise will significantly increase the food production potential of many countries and regions, but discovering that these advances will not increase production fast enough to meet the demands of the planet's even faster-growing human population. The positive impact of Earth's rising atmospheric CO_2 concentration on crop yields, however, will considerably lessen the severity of the looming food shortage. In some regions and countries it will mean the difference between being food *secure* or food *insecure*; and it will aid in lifting untold *hundreds of millions of people* out of a state of hunger and malnutrition, thereby preventing widespread starvation and premature death.

The primary implication of the ensuing results is that in order to avoid the unpalatable consequences of unprecedented widespread hunger – and even starvation – in the years and decades ahead, a commitment similar to that which drove the Apollo moon-mission is needed to increase crop yields per unit of land area, per amount of nutrients applied, and per amount of water used. And about the only way of successfully doing so – without taking unconscionable amounts of land and water from nature and thereby driving untold numbers of plant and animal species to extinction in the process – is to invest the time, effort

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and capital that is required to identify, and to then use, the major food crop *genotypes* that respond most strongly to atmospheric CO_2 enrichment, while recognizing that we must not interfere with human enterprises that release CO_2 to the atmosphere; for that course of action will only *exacerbate* the future food problem by reducing the CO_2-induced stimulation of crop productivity that is so desperately needed to meet the future food requirements of humanity.

Prologue

Many people have long believed that the ongoing rise in the air's carbon dioxide or CO_2 content has been causing the world to warm, due to the "greenhouse effect" of this radiatively-active trace gas of the atmosphere; and they believe that the planet will continue to warm for decades -- if not centuries -- to come, based upon economic projections of the amounts of future fossil fuel (coal, gas and oil) usage and climate-model projections of the degree of global warming they expect to be produced by the CO_2 that is emitted to the atmosphere as a result of the burning of these fuels. The same people have also long believed that CO_2-induced global warming will lead to a whole host of climate- and weather-related catastrophes, including more frequent and severe floods, droughts, hurricanes and other storms, rising sea levels that will inundate the planet's coastal lowlands, increased human illness and mortality, the widespread extinction of many plant and animal species, declining agricultural productivity, frequent coral bleaching, and marine life dissolving away in acidified oceans. And because of these theoretical model-based projections, they have lobbied local, regional and national governments for *decades* in an attempt to get the nations of the world to severely reduce the magnitudes of their anthropogenic CO_2 emissions. But are the scenarios painted by these climate alarmists true portrayals of what the future holds for humanity and the rest of the biosphere if their demands are not met?

This is the question recently addressed in our Center's most recent major report: *[Carbon Dioxide and Earth's Future: Pursuing the Prudent Path](#)*. In it, we describe the findings of many hundreds of peer-reviewed scientific studies that analyzed *real-world data* pertaining to the host of climate- and weather-related catastrophes predicted by the world's climate alarmists to result from rising global temperatures. The approach of most of these studies was to determine if there had been any increasing trends in the predicted catastrophic phenomena over the past millennia or two, the course of the 20th century, or the past few decades, when the world's climate alarmists claim that the planet warmed at a rate and to a degree that they contend was *unprecedented* over the past thousand or two years. And the common finding of all of this research was a resounding *No!*

But even this near-universal repudiation of climate-alarmist contentions has not been enough to cause them to alter their overriding goal of reducing anthropogenic CO_2 emissions. Invoking the *precautionary principle*, they essentially say that the potential climatic outcomes they foresee are so catastrophic that we cannot afford to gamble upon them being wrong, evoking the old adage that it is better to be safe than sorry, even if the cost is staggering.

If this were all there were to the story, we all would agree with them. But it is not, for they ignore an even more ominous catastrophe that is rushing towards us like an out-of-control freight train that is only *years* away from occurring. And preventing this ominous future involves letting the air's CO_2 content *continue* its historical upward course, until the age of fossil fuels gradually peaks and then *naturally*, in the course of *unforced innovation*, declines, as other sources of energy gradually become more efficient and less expensive, and *without* the forced intervention of government.

So just what *is* this *other side of the story*? Read on to find out.

Introduction

Global food security is one of the most pressing societal issues of our time. It is presently estimated that more than one billion persons, or one out of every seven people on the planet, is hungry and/or malnourished. Even more troubling is the fact that thousands die daily as a result of diseases from which they likely would have survived had they received adequate food and nutrition. Yet the problem of feeding the planet's population is not one of insufficient food production; for the agriculturalists of the world currently produce more than enough food to feed the globe's entire population. Rather, the problem is one of inadequate *distribution*, with food *insecurity* arising simply because the world's supply of food is not evenly dispensed among the human population, due to what Conway and Toenniessen (1999) have called "notoriously ineffective" world markets. In the near future, however, global food insecurity is expected to develop as a result of the more basic increasing global demand from an expanding and more-highly-developed world populace, which demand will far outstrip global food *supply*. And if left unchecked, this situation is destined to wreak havoc on humanity and nature alike in the years and decades to come.

Agricultural scientists "have a moral obligation to warn political, educational, and religious leaders about the magnitude and seriousness of the arable land, food, and population problems that lie ahead." If we fail to do so, "we will be negligent in our duty and inadvertently may be contributing to the pending chaos of incalculable millions of deaths by starvation."

An early perspective on the looming food shortage was presented more than a decade ago by Norman Borlaug, father of the Green Revolution and 1970 Nobel Laureate for Peace (Borlaug, 2000). In an article on world hunger, he wrote that "it took some 10,000 years to expand food production to the current level of about 5 billion tons per year," and that to meet the needs of the planet's growing population by 2025, "we will have to nearly double current production again." Given this enormous challenge, Dr. Borlaug wrote that agricultural scientists "have a moral obligation to warn political, educational, and religious leaders about the magnitude and seriousness of the arable land, food, and population problems that lie ahead." In fact, "if we fail to do so," he said, "we will be negligent in our duty and inadvertently may be contributing to the pending chaos of incalculable millions of deaths by starvation."

Other researchers have followed in Dr. Borlaug's footsteps, echoing concerns about the coming global food crisis. According to those scientists, global food production must increase by 70 to 100 percent by the year 2050, if we are to adequately feed a global population of nine billion people at that time (Bruinsma, 2009; Parry and Hawkesford, 2010; Zhu *et al*., 2010). So how is it to be done? Or, even more basically, *can* it be done?

Many of the scientists and organizations addressing this problem have concluded that unless there are significant advancements in basic farming techniques and/or reductions in world population, serious food shortages *will occur*. And they conclude they will develop *within a decade*. Other groups are more optimistic; but in nearly all of the analyses of the subject that have been conducted to date, there is one important factor that has typically been overlooked: the ongoing rise in the air's CO_2 concentration and its well-known aerial fertilization and water conservation or anti-transpiration effects.

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To account for this deficiency, I here present realistic estimates of world food supplies derived for the year 2050, both including and not including the direct biological effects of the rise in the atmosphere's CO_2 concentration that is expected to occur over the next half-century; and I then compare these results with the food needs of the human population that is expected to be inhabiting the planet at that future date.

Atmospheric CO_2 Enrichment Effects

At a fundamental level, carbon dioxide is the basis of nearly all life on Earth, as it is the primary raw material or "food" that is utilized by plants to produce the organic matter out of which they construct their tissues, which subsequently become the ultimate source of food for all animals, including humans. Consequently, the more CO_2 there is in the air, the better plants grow, as has been demonstrated in literally *thousands* of laboratory and field experiments (Idso and Singer, 2009). And the better plants grow, the more food there is available to sustain the entire biosphere.

I here present realistic estimates of world food supplies derived for the year 2050, both including and not including the direct biological effects of the rise in the atmosphere's CO_2 concentration that is expected to occur over the next half-century; and I then compare these results with the food needs of the human population that is expected to be inhabiting the planet at that future date.

The idea that an increase in the air's CO_2 content may be of benefit to the biosphere can be traced back in time over 200 years. As early as 1804, for example, de Saussure showed that peas exposed to high CO_2 concentrations grew better than control plants in ambient air; and work conducted in the early 1900s significantly increased the number of species in which this growth-enhancing effect of atmospheric CO_2 enrichment was observed to occur (Demoussy, 1902-1904; Cummings and Jones, 1918). In fact, by the time a group of scientists convened at Duke University in 1977 for a workshop on Anticipated Plant Responses to Global Carbon Dioxide Enrichment, an annotated bibliography of 590 scientific studies dealing with CO_2 effects on vegetation had been prepared (Strain, 1978). This body of research demonstrated that increased levels of atmospheric CO_2 generally produce increases in plant photosynthesis, decreases in plant water loss by transpiration, increases in leaf area, and increases in plant branch and fruit numbers, to name but a few of the most commonly reported benefits. And five years later, at the International Conference on Rising Atmospheric Carbon Dioxide and Plant Productivity, it was concluded that a doubling of the air's CO_2 concentration would likely lead to a 50% increase in photosynthesis in C_3 plants, a doubling of water use efficiency in both C_3 and C_4 plants, significant increases in biological nitrogen fixation in almost all biological systems, and an increase in the ability of plants to adapt to a variety of environmental stresses (Lemon, 1983).

Fast forwarding to the present, studies conducted on hundreds of different plant species testify to the very real and measurable growth-enhancing and water-saving advantages that elevated atmospheric CO_2 concentrations bestow upon Earth's plants (Idso and Singer, 2009; Idso and Idso, 2011). And in commenting on these and many other CO_2-related benefits, Wittwer (1982) wrote that "the 'green revolution' has coincided with the period of recorded rapid increase in concentration of atmospheric carbon dioxide, and it seems likely that some credit for the improved [crop] yields should be laid at the door of the CO_2 buildup." Similarly, Allen *et al*. (1987) concluded that yields of soybeans may have been rising since at least 1800 "due to global carbon dioxide increases," while more recently, Cunniff *et al*. (2008) hypothesized that the rise in atmospheric CO_2 following deglaciation of the most recent planetary ice age, was the trigger that launched the global agricultural enterprise.

This body of research demonstrated that increased levels of atmospheric CO_2 generally produce increases in plant photosynthesis, decreases in plant water loss by transpiration, increases in leaf area, and increases in plant branch and fruit numbers.

In a test of this hypothesis, Cunniff *et al*. designed "a controlled environment experiment using five modern-day representatives of wild C_4 crop progenitors, all 'founder crops' from a variety of independent centers," which were grown individually in growth chambers maintained at atmospheric CO_2 concentrations of 180, 280 and 380 ppm, characteristic of glacial, post-glacial and modern times, respectively. The results revealed that the 100-ppm increase in CO_2 from glacial to postglacial levels (180 to 280 ppm) "caused a significant gain in vegetative biomass of up to 40%," together with "a reduction in the transpiration rate via decreases in stomatal conductance of ~35%," which led to "a 70% increase in water use efficiency, and a much greater productivity potential in water-limited conditions."

In discussing their results, the five researchers concluded that "these key physiological changes could have greatly enhanced the productivity of wild crop progenitors after deglaciation ... improving the productivity and survival of these wild C_4 crop progenitors in early agricultural systems." And in this regard, they note that "the lowered water requirements of C_4 crop progenitors under increased CO_2 would have been particularly beneficial in the arid climatic regions where these plants were domesticated." For comparative purposes, they also included one C_3 species in their study – *Hordeum spontaneum* K. Koch – and they report that it "showed a near-doubling in biomass compared with [the] 40% increase in the C_4 species under growth treatments equivalent to the postglacial CO_2 rise."

Since the ever-present dynamic of supply and demand for food is of critical importance to the human inhabitants of the globe, it seems only prudent to explore the role that the ongoing rise in the air's CO_2 concentration may play in sustaining humanity throughout the 21st century, via the balance that must be struck between the production and consumption of food.

In light of these and other similar findings (Mayeux *et al*., 1997), it can be appreciated that the civilizations of the past, which could not have existed without agriculture, were largely made possible by the increase in the air's CO_2 content that accompanied deglaciation, and that the peoples of the Earth today are likewise indebted to this phenomenon, as well as the *additional* 100 ppm of CO_2 the atmosphere has subsequently acquired. But what about the future, will such benefits continue to accrue?

Because thousands of laboratory and field experiments have demonstrated that atmospheric CO_2 enrichment significantly enhances plant growth and water use efficiency, and because those benefits have positively impacted crop yields in the *past*, there is ample reason to believe that *future* increases in atmospheric CO_2 concentration will produce increases in crop yields in addition to those expected to result from future advancements in agricultural technology and expertise. And since the ever-present dynamic of supply and demand for food is of critical importance to the human inhabitants of the globe, it seems only prudent to explore the role that the ongoing rise in the air's CO_2 concentration may play in sustaining humanity throughout the 21st century, via the balance that must be struck between the production and consumption of food. Hence, it is to this important task that we now turn our attention.

Methods

The ultimate objective of this study is to develop realistic estimates of food production in the year 2050. This will be done for three different levels of spatial organization: the entire world, regions comprising groups of countries, and selected individual countries. The first step in this process is to determine which crops currently provide the bulk of the food produced at each of these levels of geographical complexity. Data to complete this task were obtained from the Food and Agriculture Organization (FAO) of the United Nations, as published in their statistical database FAOSTAT, which covers the period 1961-2009 on a country, regional and worldwide basis. That database is available online at http://faostat.fao.org/site/567/default.aspx#ancor.

For the world as a whole, the FAO database contains agricultural production data for 169 different crops that have been grown and used by man since 1961; but because more than half of these crops each account for less than 0.1% of the world's total food production, it was deemed both prudent and adequate to focus on only those crops that accounted for the top 95% of global food production. This was accomplished by taking the production contribution of the most important crop, adding to that the contribution of the second most important crop, and continuing in like manner until 95% of the world's total food production was reached. In addition, since some of the 169 crops increased in their productive importance over the 48-year period of record, while others declined (and some remained relatively unchanged), this analysis was performed for mean conditions over the most recent 15-year period (1995-2009), which should provide the most accurate assessment of the crops most likely to be providing the top 95% of total world food production in the year 2050, since this latter period is the closest to that future date. The results of these procedures produced a list of 45 crops that account for 95% of world food production (see Table 1).

Table 1. *The forty-five crops that supplied 95% of the total world food production over the period 1995-2009.*

Crop	% of Total Production	Crop	% of Total Production
Sugar cane	21.240	Yams	0.670
Maize	10.283	Rapeseed	0.662
Rice, paddy	9.441	Cucumbers and gherkins	0.563
Wheat	9.372	Groundnuts, with shell	0.531
Potatoes	4.871	Plantains	0.495
Sugar beet	3.877	Millet	0.461
Vegetables fresh nes	3.335	Mangoes, mangosteens, guavas	0.433
Cassava	2.979	Eggplants (aubergines)	0.433
Soybeans	2.836	Sunflower seed	0.423
Oil palm fruit	2.247	Oats	0.408
Barley	2.216	Fruit Fresh Nes	0.367
Sweet potatoes	1.966	Carrots and turnips	0.354
Tomatoes	1.784	Other melons (inc.cantaloupes)	0.351
Watermelons	1.222	Chillies and peppers, green	0.347
Bananas	1.126	Tangerines, mandarins, clem.	0.343
Oranges	0.981	Lettuce and chicory	0.303
Grapes	0.975	Rye	0.297
Seed cotton	0.937	Beans, dry	0.289
Apples	0.936	Pumpkins, squash and gourds	0.287
Sorghum	0.930	Pears	0.267
Cabbages and other brassicas	0.930	Pineapples	0.250
Onions, dry	0.858	Olives	0.248
Coconuts	0.834		
Sum of All Crops = 95.0%			

Identical methods were used to determine which crops supplied 95% of total food production for each of the six regions, the twenty sub-regions, and the twenty-five countries examined in

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this paper. Appendices 1-3 list these geographical entities, explicitly identifying those crops. In all, 92 unique crops were identified in this process; and they are listed in Appendix 4.

To determine the productivity responses of the group of crops listed in Appendix 4 to rising atmospheric CO_2 concentrations, the online Plant Growth Database of *CO_2 Science* was utilized. Located on the Internet at http://www.co2science.org/data/plant_growth/plantgrowth.php, this database lists the results of thousands of CO_2 enrichment experiments conducted on hundreds of different crops growing under varying environmental conditions over the past few decades. This database was used to calculate the mean crop growth response to a 300-ppm increase in atmospheric CO_2 concentration for each crop listed in Appendix 4. For some crops, however, there were no CO_2 enrichment data contained in the database; and in those cases the mean responses of similar plants, or groups of plants, were utilized. Also, there were some instances where the plant category in the FAO database represented more than one plant in the *CO_2 Science* Plant Growth Database. For example, the designation ***Tomatoes*** represents a single FAO crop category in the FAO database, yet there were three different types of tomatoes listed in the *CO_2 Science* database (*Lycopersicon esculentum*, *Lycopersicon lycopersicum*, and *Solanum lycopersicum*). Thus, in order to produce a single number to represent the CO_2-induced growth response for the ***Tomatoes*** category, we calculated a weighted average from the growth responses of all three tomato species listed in the *CO_2 Science* database. This procedure was repeated in other such circumstances; and the final results for all crops are listed in Table 2, which provides the average biomass response by FAO plant category for a 300-ppm increase in the air's CO_2 concentration for all 92 crops listed in Appendix 4, which values are based upon data downloaded from the *CO_2 Science* Plant Growth Database on 1 May 2011.

Table 2. *Mean percentage yield increases produced by a 300-ppm increase in atmospheric CO_2 concentration for all crops accounting for 95% of total food production.*

Crop	% Biomass Change		Crop	% Biomass Change
Apples	44.2%		Natural rubber	44.2%
Apricots	44.2%		Oats	34.8%
Artichokes	43.3%		Oil palm fruit	44.2%
Asparagus	43.3%		Okra	32.0%
Avocados	44.2%		Olives	35.2%
Bananas	44.2%		Onions (inc. shallots), green	135.0%
Barley	38.9%		Onions, dry	20.0%
Beans, dry	61.7%		Oranges	44.1%
Beans, green	57.7%		Other melons (inc.cantaloupes)	4.7%
Broad beans, horse beans, dry	46.3%		Papayas	44.2%
Cabbages and other brassicas	42.0%		Peaches and nectarines	27.8%
Carrots and turnips	77.8%		Pears	44.2%
Cashew nuts, with shell	44.2%		Peas, dry	33.3%
Cassava	13.8%		Peas, green	33.3%
Cauliflowers and broccoli	42.0%		Persimmons	44.2%
Cereals, nes	37.3%		Pigeon peas	109.5%
Cherries	56.2%		Pineapples	5.0%
Chick peas	33.3%		Pistachios	44.2%
Chillies and peppers, green	25.0%		Plantains	44.2%
Citrus fruit, nes	40.5%		Plums and sloes	44.2%
Cocoa beans	44.2%		Potatoes	31.4%
Coconuts	44.2%		Pulses, nes	43.3%
Coffee, green	175.5%		Pumpkins, squash and gourds	41.5%
Cow peas, dry	77.0%		Rapeseed	42.0%
Cucumbers and gherkins	50.2%		Rice, paddy	35.7%
Dates	44.2%		Roots and Tubers, nes	63.1%
Eggplants (aubergines)	41.0%		Rye	37.3%
Figs	44.2%		Seed cotton	60.6%
Fruit Fresh Nes	56.2%		Sesame seed	43.3%
Fruit, tropical fresh nes	56.2%		Sorghum	20.7%
Garlic	54.1%		Soybeans	46.5%
Grapefruit (inc. pomelos)	41.1%		Spinach	24.3%
Grapes	68.2%		Sugar beet	66.3%
Groundnuts, with shell	54.1%		Sugar cane	34.0%
Hazelnuts, with shell	44.2%		Sugar crops, nes	50.2%
Jute	43.3%		Sunflower seed	37.5%
Kiwi fruit	44.2%		Sweet potatoes	33.7%
Lemons and limes	41.1%		Tangerines, mandarins, clem.	29.5%
Lentils	61.7%		Taro (cocoyam)	54.1%
Lettuce and chicory	35.6%		Tea	44.2%
Lupins	22.0%		Tomatoes	37.4%
Maize	21.3%		Triticale	37.3%
Maize, green	21.3%		Vegetables fresh nes	43.3%
Mangoes, mangosteens, guavas	36.0%		Watermelons	23.1%
Millet	13.5%		Wheat	31.9%
Mixed grain	45.1%		Yams	54.1%

Yield Projections

The process of calculating future crop yields was begun by plotting the yield history of each of the crops that accounted for part of the 95% of the total food production in each geographic area under study over the entire time period for which data were available: 1961-2009. The yields of these crops varied over time; most showed increases, some experienced little change, and others actually decreased. And for those crops whose yields *rose* over time, the *rate* of yield increase for a number of them *diminished* toward the latter portion of the data record. Therefore, crop yield projections were based only on data from the latter third of the record (1995-2009), since this is the time period closest to the future and should thus be the most appropriate period to use in any procedure designed to infer future yields.

For all crops listed in Table 2, CO_2-enhanced and non-CO_2-enhanced yield projections were made as follows. First, the 1995-2009 yield data were plotted as a function of time, as shown in Figure 1 for the example of wheat (the solid diamonds). A simple linear regression was then run on these data to obtain the short solid-line relationship of the figure; and based on this relationship, modeled yield values for 1995 and 2009 were obtained and plotted as open circles.

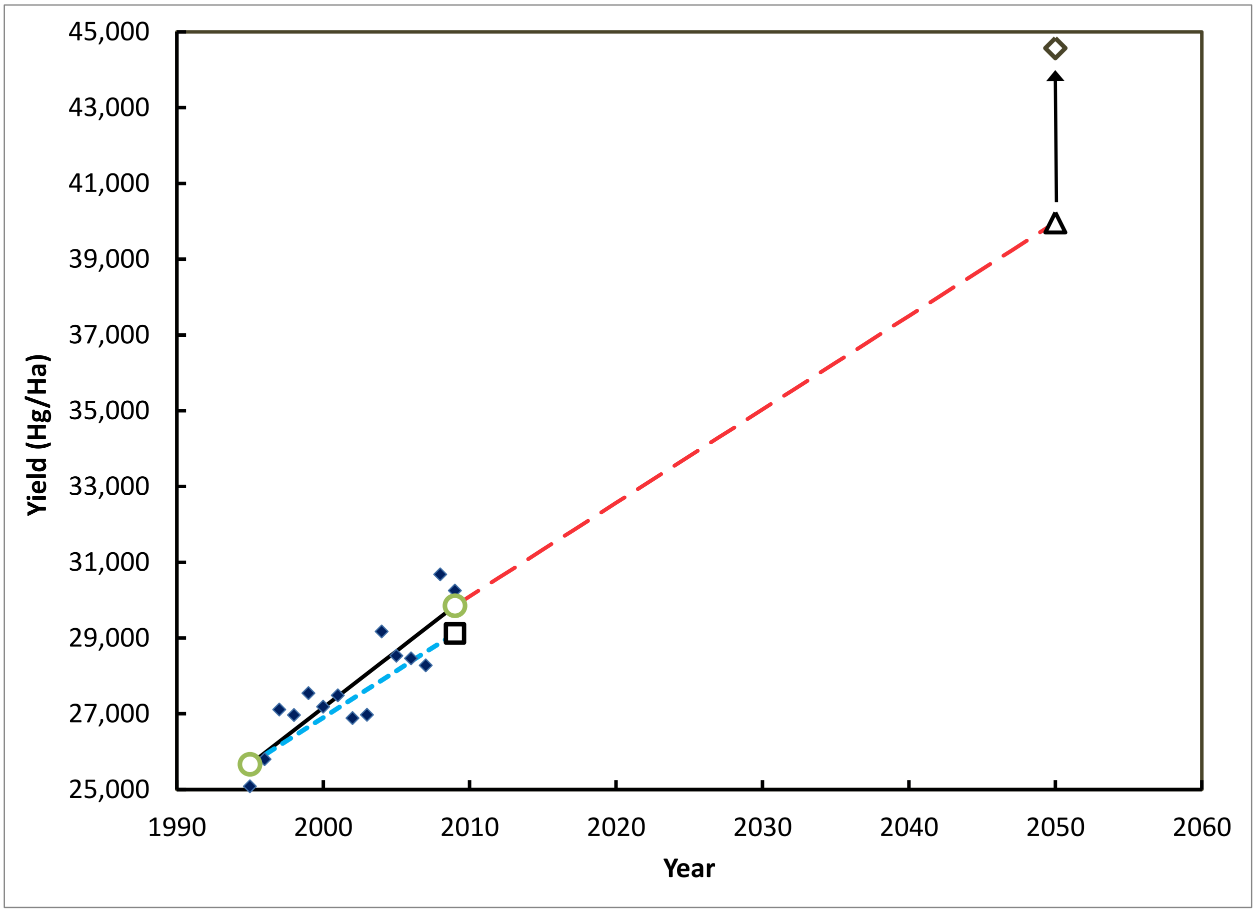
The increase in yield represented by the difference between the 2009 and 1995 endpoints of this relationship can be attributed to two things: the aerial fertilization effect of the increase in the air's CO_2 content that occurred between 1995 and 2009, and the net effect of everything else that tended to influence crop yield over that time period.

The increase in yield represented by the difference between the 2009 and 1995 endpoints of this relationship can be attributed to two things: the aerial fertilization effect of the increase in the air's CO_2 content that occurred between 1995 and 2009, and the net effect of everything else that tended to influence crop yield over that time period. Although many factors play a role in determining the magnitude of this latter effect, I refer to it here as the *techno-intel effect*, as it derives primarily from continuing advancements in agricultural technology and scientific research that expands our knowledge or intelligence base.

To separate the effects of these two phenomena – the rising CO_2 content of Earth's atmosphere and continuing advancements in agricultural technology and expertise – I first multiplied the 1995 modeled yield value by the percent yield increase in wheat due to a 300 ppm increase in atmospheric CO_2 concentration (31.9%, obtained from Table 2, converted to decimal form

0.319). Then, I divided this result by 300 ppm CO_2 and multiplied the quotient by the increase in atmospheric CO_2 concentration actually observed between 1995 and 2009 (26.72 ppm). Last of all, this real-world CO_2-induced yield increase was subtracted from the 2009 modeled yield value to determine what the modeled crop yield would have been in 2009 if the air's CO_2 content had not changed from what it was in 1995, producing the open-square yield value of Figure 1.

Figure 1. *Graphical representation, using wheat as an example, of the methods used to make yield projections for the crops listed in Table 2. See text for explanation.*



Drawing a straight dashed line (light blue in color) between this reconstructed 2009 modeled yield value and the original 1995 modeled yield value, we obtain a relationship whose slope describes the impact of the techno-intel effect over this period (defined as the yield increase per year due to changes in everything of significance except CO_2). Assuming that this same rate of techno-intel-induced yield enhancement will be operative over the next 41 years, I then started at the original 2009 modeled yield value and drew a long dashed line (in red color), of identical slope to the short dashed line of Figure 1, to the year 2050. The open triangle at the end of this line thus becomes our best estimate of what the yield of wheat will likely be in that year if there is no increase in atmospheric CO_2 concentration from 2009 to 2050.

This process was repeated for each crop in each of the six regions, twenty sub-regions, and twenty-five countries examined in this paper.

Last of all, to obtain a 2050 yield estimate that incorporates the aerial fertilization effect of rising atmospheric CO_2 concentrations, we need an estimate of what the atmosphere's CO_2 concentration will likely be in 2050. Based on the Intergovernmental Panel on Climate Change's best median estimate of this number (derived from the A1B scenario, ISAMS, in the IPCC's Fourth Assessment Report, see http://www.ipcc-data.org/ancilliary/tar-isam.txt), we find that we could expect an increase in atmospheric CO_2 concentration of 145 ppm between 2009 and 2050. Thus, by multiplying the original modeled 2009 yield value by the percent yield increase in wheat due to a 300 ppm increase in atmospheric CO_2 concentration (once again, 31.9%, as obtained from Table 2, converted to decimal form 0.319), and dividing this result by 300 ppm and multiplying the quotient by 145 ppm, we obtain the amount by which the yield of wheat is expected to rise over this time interval due to the aerial fertilization effect of the expected rise in the air's CO_2 content. Adding this result to the open-triangle result that contains the techno-intel effect then gives us our final result, which is represented by the open diamond of Figure 1. This process was repeated for each crop in each of the six regions, twenty sub-regions, and twenty-five countries examined in this paper.

Results

The results of the world food supply calculations are contained in Table 3. Column one lists the forty-five crops that provided 95% of the total food production of all the planet's agricultural enterprises over the period 1995-2009, the individual percentage contributions of which (listed in column 2) are assumed will remain constant to the year 2050. The third column lists the linear regression-based modeled production values of these crops in 2009. The fourth column lists the production values of the crops projected for the year 2050 on the basis of techno-intel-induced enhancements of the agricultural enterprise, as calculated in the previous section of this paper; while the fifth column lists the techno-intel production values plus enhancements due to the increase in the air's CO_2 content expected to occur between 2009 and 2050.

Table 3. *Current (2009) and projected (2050) food production values for the forty-five crops that account for 95% of total world food production.*

Crop	% of Total Production	2009 Modeled Production	2050 Modeled Production	
			Techno-Intel	Techno-Intel + CO2
Sugar cane	21.240	1,607,378,474	1,978,906,102	2,243,051,964
Maize	10.283	801,752,947	1,283,289,809	1,365,830,275
Rice, paddy	9.441	667,845,984	866,774,613	982,011,437
Wheat	9.372	649,369,968	869,478,087	969,600,113
Potatoes	4.871	329,396,898	416,075,404	466,066,874
Sugar beet	3.877	233,491,258	440,378,749	515,201,023
Vegetables fresh nes	3.335	260,218,566	254,366,069	308,825,478
Cassava	2.979	235,464,012	396,379,817	412,085,267
Soybeans	2.836	237,132,979	288,918,300	342,213,937
Oil palm fruit	2.247	212,099,048	358,711,133	404,022,560
Barley	2.216	144,083,335	194,375,983	221,466,051
Sweet potatoes	1.966	109,219,121	42,163,460	59,953,435
Tomatoes	1.784	142,498,661	156,637,603	182,396,611
Watermelons	1.222	106,488,725	191,691,235	203,580,701
Bananas	1.126	92,378,755	147,646,972	167,382,154
Oranges	0.981	66,450,407	52,637,647	66,801,551
Grapes	0.975	68,521,127	88,043,769	110,630,617
Seed cotton	0.937	69,531,828	123,476,440	143,842,312
Apples	0.936	68,666,347	150,914,254	165,583,674
Sorghum	0.930	60,671,360	59,638,936	65,709,105
Cabbages and other brassicas	0.930	73,769,952	67,024,271	81,999,571
Onions, dry	0.858	73,732,153	104,747,840	111,875,282
Coconuts	0.834	60,540,736	90,235,617	103,169,136
Yams	0.670	53,970,213	57,120,672	71,232,983
Rapeseed	0.662	55,842,707	97,268,526	108,604,595
Cucumbers and gherkins	0.563	46,890,842	44,624,707	56,001,988
Groundnuts, with shell	0.531	38,060,633	52,944,939	62,897,160
Plantains	0.495	34,956,141	33,785,082	41,252,879
Millet	0.461	33,428,967	54,577,740	56,758,980
Mangoes, mangosteens, guavas	0.433	35,181,749	25,294,793	31,416,417
Eggplants (aubergines)	0.433	36,192,963	38,522,930	45,695,169
Sunflower seed	0.423	31,167,361	37,386,591	43,035,675
Oats	0.408	23,163,973	33,051,978	36,948,158
Fruit Fresh Nes	0.367	27,249,910	22,162,976	29,564,960
Carrots and turnips	0.354	28,554,619	23,701,473	34,438,962
Other melons (inc.cantaloupes)	0.351	29,730,479	47,296,351	47,971,729
Chillies and peppers, green	0.347	29,246,040	49,477,396	53,011,293
Tangerines, mandarins, clem.	0.343	29,348,527	47,668,019	51,852,630
Lettuce and chicory	0.303	24,678,029	24,448,657	28,694,923
Rye	0.297	14,526,084	20,235,083	22,853,894
Beans, dry	0.289	20,828,118	25,779,093	31,990,385
Pumpkins, squash and gourds	0.287	22,302,805	26,846,799	31,320,370
Pears	0.267	21,737,299	42,223,806	46,867,618
Pineapples	0.250	20,016,700	29,110,839	29,594,576
Olives	0.248	18,706,637	18,038,975	21,221,597
Sum	95.0	7,046,483,438	9,474,079,535	10,676,526,068
% Increase Over 2009 Values			**34.5**	**51.5**

Summing the food production contributions reported in columns three, four and five, it can be seen that for the world as a whole, total food production is estimated to increase by 34.5% between 2009 and 2050 due to the techno-intel effect alone, but that it will increase by 51.5% due to the combined consequences of the techno-intel effect and the CO_2 aerial fertilization effect. Both of these percentage increases, however, fall far short of the estimated 70 to 100 percent increase in agricultural production needed to feed the planet's growing population by the year 2050, as per the calculations of Bruinsma (2009), Parry and Hawkesford (2010) and Zhu *et al*. (2010).

Table 4 lists the percentage increases in food production expected to occur between 2009 and 2050 for the world, six world regions and twenty sub-regions due to the techno-intel effect alone (column two) and the combined consequences of the techno-intel effect and the CO_2 aerial fertilization effect (column three). Column four of this table lists the percent population change between 2009 and 2050 for each of these geographic entities based on medium variant population projections of the United Nations. As can be seen from this column, the percent population change varies considerably among the different regions and sub-regions. It is also worth noting that in one region (Europe) and three sub-regions (Eastern, Southern, and Western Europe), the population is actually expected to *decline*.

Determining the food security status of each of the regions and sub-regions of the globe is not as simple as it was to determine the food security status of the world as a whole. One cannot simply look to see if the percent food production change due to the techno-intel and techno-intel plus CO_2 values (columns two and three in Table 4) are greater than 70 to 100 percent (the percent increase range required for the entire planet). Because each region's population change between 2009 and 2050 is different from what is projected for the Earth as a whole, a population-change-weighted value corresponding to the 70 to 100 percent food production increase needed for the globe to be food secure must be calculated. This is accomplished by dividing the percent population change for each region and sub-region by the percent population increase for the world as a whole (32.4 percent) and then multiplying this value by the estimated 70 and 100 percent increases in production that bracket the productivity increase range that researchers have estimated is necessary to meet the global food demand in 2050. The results of these calculations are presented in column 5 for the low end of such food production estimates (70 percent) and in column 6 for the high end of such estimates (100 percent).

In columns seven and eight I list the food security status in 2050 for the world as a whole, the six world regions and the twenty sub-regions for the techno-intel and techno-intel plus CO_2 scenarios, respectively, where a region or sub-region was determined to be food secure if its percent production change value listed in column 2 or 3 was greater than the population change-weighted production values listed in column 6. If it was less than the value in column 6, but greater than the value in column 5, the region or sub-region was deemed to be *possibly* food secure. And if the value in column 2 or 3 was less than the value in both columns 5 and 6, the region or sub-region was determined to be food ***in***secure.

Table 4. *Percentage increases in food production expected to occur between 2009 and 2050 for the world, six world regions and twenty sub-regions due to the techno-intel effect alone (column two) and the combined consequences of the techno-intel effect and the CO_2 aerial fertilization effect (column three). Column four lists the percent population change between 2009 and 2050 based on United Nations medium variant population projections. Columns five and six list the population-adjusted percent change in food production between 2009 and 2050 that is needed for each region/sub-region to be food secure, based on low and high end food production estimates for the globe that indicate a 70 to 100 percent increase is needed for the world to be food secure in 2050. Columns seven and eight list the future food security projections of the various regions under the techno-intel and the techno-intel plus CO_2 scenarios, calculated as explained in the text.*

Region	Percent Production Change		Percent Population Change	Percent Production Change Required to be Food Secure		Food Secure?	
	Techno-Intel	Techno-Intel + CO2		Low End	High End	Techno-Intel	Techno-Intel + CO2
World	34.5	51.5	32.4			No	No
Regions							
Africa	18.0	34.0	93.5	201.9	288.4	No	No
Asia	26.9	44.1	25.6	55.2	78.9	No	No
Europe	50.2	69.8	-5.7	-12.3	-17.6	Yes	Yes
North America	49.2	64.5	27.5	59.5	85.0	No	Maybe
Oceania	-70.2	-52.7	43.3	93.4	133.5	No	No
South America	43.4	60.4	22.8	49.2	70.4	No	Maybe
Sub-Regions							
Africa							
Eastern	-1.3	14.5	117.4	253.7	362.5	No	No
Western	27.3	43.5	104.4	225.6	322.2	No	No
Middle	28.0	40.4	111.8	241.4	344.9	No	No
North	33.0	50.5	50.8	109.7	156.8	No	No
South	34.7	50.8	16.3	35.1	50.2	No	Yes
Americas							
Central America	15.6	31.6	28.6	61.7	88.1	No	No
Caribbean	64.3	81.6	17.0	36.7	52.4	Yes	Yes
Asia							
Eastern	17.1	34.2	2.3	5.0	7.1	Yes	Yes
Southern	17.8	34.9	40.1	86.5	123.6	No	No
Central	114.6	132.7	40.1	86.5	123.6	Yes	Yes
Southeastern	45.1	62.5	29.9	64.6	92.3	No	No
Western	33.3	52.5	59.8	129.2	184.5	No	No
Europe							
Eastern	74.2	92.9	-17.7	-38.2	-54.6	Yes	Yes
Northern	18.2	38.0	13.8	29.7	42.5	No	Maybe
Southern	31.2	50.4	-0.1	-0.2	-0.2	Yes	Yes
Western	23.4	44.4	-2.0	-4.2	-6.0	Yes	Yes
Oceania							
Australia	-80.0	-63.0	32.0	69.1	98.7	No	No
Melanesia	-26.6	-5.9	78.1	168.7	241.0	No	No
Micronesia	46.7	69.2	40.0	86.3	123.3	No	No
Polynesia	-10.3	12.2	23.7	51.1	73.0	No	No

In viewing the results presented in columns 7 and 8 from Table 4, it can be seen that only one of the six world regions (Europe) is expected to be food secure based on the techno-intel scenario of future food production. All other regions fall within the food *insecure* category. However, when the yield-enhancing effects of atmospheric CO_2 enrichment are added to the techno-intel scenario, two additional regions (North America and South America) become *possibly* food secure. No matter which estimates are used for future food production needed to be food secure (the low or high end of scientific projections), however, and no matter which of the two food production scenarios is used (techno-intel or techno-intel plus CO_2), Africa, Asia and Oceania are expected to be food insecure by 2050 or earlier.

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However, when the yield-enhancing effects of atmospheric CO_2 enrichment are added to the techno-intel scenario, two additional regions (North America and South America) become *possibly* food secure.

Examining the 20 sub-regions, it can be seen that six of them should be food secure in 2050 based on the techno-intel scenario alone (Caribbean, Eastern Asia, Central Asia, Eastern Europe, Southern Europe, and Western Europe); but this number rises to seven to include South Africa, and possibly Northern Europe when the effects of rising CO_2 are added. Locations *lacking* in food production and security include most of Africa and Oceania, as well as parts of Asia. In Africa, production is expected to increase in most all regions between now and 2050, but production gains are outpaced by massive increases in population (less so for Asia). In Oceania, expected population increases are similar to those of other world regions; but production values decline. Projections such as these latter two, however, may not be realistic, especially in situations such as that experienced by Australia, where a recent multi-year drought has taken a huge toll on agricultural production and has likely skewed production estimates downward. It is also interesting to note that Europe is the only one of the six regions projected to experience a population decline between 2009 and 2050; which decline tremendously aids Europe's ability to be food secure under both the techno-intel and techno-intel plus CO_2 scenarios.

Table 5 was produced in a similar manner to Table 4 and presents food production and security data for the top twenty-five most populous world countries. In viewing Table 5, it may be seen that under the techno-intel scenario, nine of these countries are expected to be food secure in 2050, three possibly secure, and thirteen insecure. Adding the beneficial impacts of rising atmospheric CO_2, the numbers change to eleven food secure countries, four possibly secure, and ten insecure. The ten insecure countries in this latter scenario (with their global population rank in parentheses) include India (2), Pakistan (6), Nigeria (7), Philippines (12), Egypt (15), Ethiopia (16), Iran (17), Turkey (18), the Congo (19) and the United Kingdom (22). The four possibly secure countries with their population rank (also in parentheses) include the United States (3), Indonesia (4), Bangladesh (8) and Mexico (11).

Table 5. *Percentage increases in food production expected to occur between 2009 and 2050 for the top 25 populated world countries due to the techno-intel effect alone (column three) and the combined consequences of the techno-intel effect and the CO_2 aerial fertilization effect (column four). Column five lists the percent population change between 2009 and 2050 based on United Nations medium variant population projections. Column six was calculated as the ratio of the percent change in production between 2009 and 2050 for the techno-intel effect and percent population change. Columns six and seven list the population-adjusted percent change in food production between 2009 and 2050 that is needed for each country to be food secure, based on low and high end food production estimates for the globe that indicate a 70 to 100 percent increase is needed for the world to be food secure in 2050. Columns eight and nine list the future food security projections of the various regions under the techno-intel and the techno-intel plus CO_2 scenarios, calculated as explained in the text.*

Popultion Rank	Individual Countries	Percent Production Increase		Percent Population Change	Percent Production Change Required to be Food Secure		Food Secure?	
		Techno-Intel	Techno-Intel + CO2		Low End	High End	Techno-Intel	Techno-Intel + CO2
1	China	19.3	36.3	4.6	10.0	14.3	Yes	Yes
2	India	6.0	23.0	32.9	71.0	101.5	No	No
3	USA	50.1	65.4	27.2	58.7	83.8	No	Maybe
4	Indonesia	36.4	54.4	23.9	51.7	73.8	No	Maybe
5	Brazil	46.5	62.9	11.8	25.5	36.5	Yes	Yes
6	Pakistan	37.6	54.6	81.4	175.9	251.3	No	No
7	Nigeria	26.9	43.3	82.7	178.6	255.1	No	No
8	Bangladesh	80.3	97.4	35.3	76.3	109.0	Maybe	Maybe
9	Russia	106.6	125.6	-17.3	-37.4	-53.4	Yes	Yes
10	Japan	0.8	21.2	-20.0	-43.1	-61.6	Yes	Yes
11	Mexico	30.8	46.1	16.6	35.8	51.1	No	Maybe
12	Philippines	31.1	48.7	56.1	121.2	173.2	No	No
13	Vietnam	83.1	100.6	25.4	54.9	78.5	Yes	Yes
14	Germany	27.3	48.1	-14.1	-30.4	-43.5	Yes	Yes
15	Egypt	5.1	22.7	53.3	115.2	164.6	No	No
16	Ethiopia	47.0	66.0	104.5	225.9	322.7	No	No
17	Iran	36.0	54.3	29.2	63.0	90.0	No	No
18	Turkey	33.6	53.4	28.6	61.9	88.4	No	No
19	Congo	4.3	17.2	117.5	253.8	362.6	No	No
20	Thailand	58.8	73.9	7.7	16.6	23.7	Yes	Yes
21	France	18.3	39.1	8.0	17.4	24.8	Maybe	Yes
22	United Kingdom	9.1	29.0	16.9	36.5	52.2	No	No
23	Italy	17.0	36.7	-5.0	-10.9	-15.6	Yes	Yes
24	Myanmar	59.9	78.6	25.5	55.1	78.7	Maybe	Yes
25	South Africa	41.1	57.0	12.5	27.0	38.6	Yes	Yes

Discussion

It is clear from the results obtained above that a global food security crisis is indeed looming on the horizon. If population projections and estimates of the amounts of additional food needed to feed the rising population of the planet prove correct, humanity will *still* fall short of being able to adequately feed the 9.1 billion persons expected to be inhabiting the Earth in the year 2050, even utilizing all yield-enhancing benefits associated with technological and intelligence advancements *plus* the aerial fertilization effect of Earth's rising atmospheric CO_2 content.

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So what can be done to deal with the projected food production shortfall? Based on the results described above, there are only three possible avenues to achieving food security in the future: (1) greater gains must be achieved in the techno-intel sector than presently forecasted, (2) benefits from atmospheric CO_2 enrichment must be increased, or (3) world population growth must be slowed to reach a lesser value by 2050.

Slowing World Population

Of each of the three possibilities listed above, a smaller global population in 2050 is probably the most difficult to achieve, because interventionist actions in this very personal area of human behavior would likely be met with great resistance on many fronts. A less intrusive tactic might be to lobby for dietary shifts among the population designed to obtain "more bang for the bushel," especially in countries that are food sufficient and use much of their grain to produce meat products for their consumption. Such actions would free up more grain to help meet the basic food needs of other countries experiencing food shortages. Increases in the efficiency and effectiveness of food transport, packaging, and preservation could also help by reducing avoidable waste.

Another concern with respect to future population is whether or not the use of medium variant data from the United Nations is too *conservative*. Indeed, the medium variant population estimate for the year 2050 has recently been revised upward from 8.9 to 9.2 billion persons. A more realistic estimate of future population may be to use the *constant* fertility variant, which is weighted more heavily on current population trends and which foresees a global population of 11 billion in 2050. If that is the case, global food security will become an even *greater* issue in the years and decades ahead. And, to make matters even more challenging, what happens if and when global population continues to grow beyond 2050?

Based on the results described above, there are only three possible avenues to achieving food security in the future: (1) greater gains must be achieved in the techno-intel sector than presently forecasted, (2) benefits from atmospheric CO_2 enrichment must be increased, or (3) world population growth must be slowed to reach a lesser value by 2050.

Improving the Techno-intel Effect

In the techno-intel sector, a simple solution would seem to be to increase the amount of land that is presently farmed so as to raise production. However, bringing new land into agricultural cultivation is a knotty issue in and of itself, as pointed out by Waggoner (1995) in an insightful essay on the subject in which he inquired "*How much land can ten billion people spare for nature?*"

In answering this provocative question, Waggoner explored the dynamic tension that exists between the need for land to support the agricultural enterprises that sustain mankind, and the need for land to support the natural ecosystems that sustain all other creatures. This challenge of meeting our future food needs – and not decimating the rest of the biosphere in the process – was stressed even more strongly by Huang *et al*. (2002), who wrote that humans "have encroached on almost all of the world's frontiers, leaving little new land that is cultivatable." And in consequence of humanity's usurpation of this most basic of natural resources, Raven (2002) stated in his Presidential Address to the American Association for the Advancement of Science that "species-area relationships, taken worldwide in relation to habitat destruction, lead to projections of the loss of fully two-thirds of all species on Earth by the end of this century."

In a more detailed analysis of the nature and implications of this impending "global land-grab" – which moved it closer to the present by a full half-century – Tilman *et al*. (2001) concluded that the task of meeting the doubled world food demand, which they calculated would exist in the year 2050, would likely exact a toll that "may rival climate change in environmental and societal impacts." Specifically, Tilman and his nine collaborators noted that at the end of the 20th century mankind was already appropriating "more than a third of the production of terrestrial ecosystems and about half of usable freshwaters." And enlarging upon those figures, in order to meet the doubled global food demand that Tilman *et al*. predict for the year 2050, humanity may well need to appropriate as much as *two thirds* of terrestrial ecosystem production and *all of Earth's remaining usable freshwater*, as has also been discussed by Wallace (2000).

In terms of *land* devoted to agriculture, Tilman *et al*. calculate a much less ominous 18% increase by the year 2050. However, because most developed countries are projected to withdraw large areas of land from farming over the next fifty years, the loss of natural ecosystems to crops and pastures in developing countries will amount to about half of their remaining suitable land, which would, in the words of the Tilman team, "represent the worldwide loss of natural ecosystems larger than the United States." What is more, they say that these land usurpations "could lead to the loss of about a third of remaining tropical and temperate forests, savannas, and grasslands." And in a worrisome reflection upon the consequences of these land-use changes, they remind us that "species extinction is an irreversible impact of habitat destruction."

What can be done to avoid this horrific situation? In a subsequent analysis, Tilman *et al*. (2002) introduced a few more facts before suggesting some solutions. First of all, they noted that by 2050 the human population of the globe is projected to be 50% larger than it was just prior to the writing of their paper, and that global grain demand by 2050 could well double, due to expected increases in per capita real income and dietary shifts toward a higher proportion of meat. Hence, they but stated the obvious when they concluded that "raising yields on existing farmland is essential for 'saving land for nature'."

So how can this readily-defined but Herculean task be accomplished? Tilman *et al*. proposed a strategy that focuses on three essential efforts: (1) increasing crop yield per unit of *land area*, (2) increasing crop yield per unit of *nutrients applied*, and (3) increasing crop yield per unit of *water used*.

Dynamic tension exists between the need for land to support the agricultural enterprises that sustain mankind, and the need for land to support the natural ecosystems that sustain all other creatures.

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Raising yields on existing farmland is essential for 'saving land for nature'.

With respect to the first of these efforts, increasing crop yield per unit of land area, the researchers note that in many parts of the world the historical rate-of-increase in crop yield is declining, as the genetic ceiling for maximal yield potential is being approached. This observation, in their estimation, "highlights the need for efforts to steadily increase the yield potential ceiling." Much more research can and should be conducted in this area, some of which is highlighted in the next section of this paper.

With respect to the second effort, increasing crop yield per unit of nutrients applied, Tilman *et al*. say that "without the use of synthetic fertilizers, world food production could not have increased at the rate [that it did in the past] and more natural ecosystems would have been converted to agriculture." Hence, they say that the ultimate solution "will require significant increases in nutrient use efficiency, that is, in cereal production per unit of added nitrogen."

Finally, with respect to the third effort, increasing crop yield per unit of water used, Tilman *et al*. note that "water is regionally scarce," and that "many countries in a band from China through India and Pakistan, and the Middle East to North Africa either currently or will soon fail to have adequate water to maintain per capita food production from irrigated land." Similar conclusions were reported more recently by Hanjra and Qureshi (2010), who say that "irrigation will be the first sector to lose water, as water competition by non-agricultural uses increases and water scarcity intensifies." Furthermore, these two researchers say that "increasing water scarcity will have implications for food security, hunger, poverty, and ecosystem health and services," where "feeding the 2050 population will require some 12,400 km^3 of water, up from 6800 km^3 used today." This huge increase, in their words, "will leave a water gap of about 3300 km^3 even after improving efficiency in irrigated agriculture, improving water management, and upgrading of rainfed agriculture," as per the findings of de Fraiture *et al*. (2007), Molden (2007) and Molden *et al*. (2010).

Some researchers have begun to explore ways in which to maximize the influence of atmospheric CO_2 on crop yields even more. Much of these efforts are devoted to identifying "super" hybrid cultivars that can "further break the yield ceiling" presently observed in many crops.

In an effort to alleviate the significant and forthcoming water deficiency noted above, Hanjra and Qureshi propose renewed efforts to conserve water and energy resources, develop and adopt climate-resilient crop varieties, modernize irrigation, shore up domestic food supplies, reengage in agriculture for further development, and reform the global food and trade market. And to achieve these goals, they say that "unprecedented global cooperation is required." However, reaching such unprecedented cooperation is doubtful, especially since the world presently fails in its cooperative ability to feed our current population, albeit there is enough food to do so (Conway and Toenniessen, 1999). Increasing crop water use efficiency, therefore, is also a must.

Maximizing the Benefits of Atmospheric CO_2 Enrichment

In our efforts to meet the three tasks set forth by Tilman *et al*. (2002) to (1) increase crop yield per unit of land area, (2) increase crop yield per unit of nutrients applied, and (3) increase crop yield per unit of water used, humanity is fortunate to have a powerful ally in the ongoing rise in the air's CO_2 content.

Since atmospheric CO_2 is the basic "food" of nearly all plants, the more of it there is in the air, the better they function and the more productive they become. For a 300-ppm increase in the atmosphere's CO_2 concentration above the planet's current base level of slightly less than 400 ppm, for example, the productivity of Earth's herbaceous plants rises by something on the order of 30 to 50% (Kimball, 1983; Idso and Idso, 1994), while the productivity of its woody plants rises by something on the order of 50 to 80% (Saxe *et al*., 1998; Idso and Kimball, 2001). Thus, as the air's CO_2 content continues to rise, so too will the productive capacity or *land-use efficiency* of the planet continue to rise, as the aerial fertilization effect of the upward-trending atmospheric CO_2 concentration boosts the growth rates and biomass production of nearly all plants in nearly all places. In addition, elevated atmospheric CO_2 concentrations typically increase plant *nutrient-use efficiency* in general – and *nitrogen-use efficiency* in particular – as well as plant *water-use efficiency*. Consequently, with respect to fostering *all three* of the plant physiological phenomena Tilman *et al*. (2002) contend are needed to prevent the catastrophic consequences they foresee for the planet just a few short decades from now, a continuation of the current upward trend in the atmosphere's CO_2 concentration as projected by the IPCC would appear to be *essential*.

Recognizing these benefits, some researchers have begun to explore ways in which to maximize the influence of atmospheric CO_2 on crop yields even more. Much of these efforts are devoted to identifying "super" hybrid cultivars that can "further break the yield ceiling" presently observed in many crops (Yang *et al*., 2009). De Costa *et al*. (2007), for example, grew 16 genotypes of rice (*Oryza sativa* L.) under standard lowland paddy culture with adequate water and nutrients within open-top chambers maintained at either the ambient atmospheric CO_2 concentration (370 ppm) or at an elevated CO_2 concentration (570 ppm). Results indicated that the CO_2-induced enhancement of the light-saturated net photosynthetic rates of the 16 different genotypes during the grain-filling period of growth ranged from +2% to +185% in the yala season (May to August) and from +22% to +320% in the maha season (November to March). Likewise, they found that the CO_2-induced enhancement of the *grain yields* of the 16 different genotypes ranged from +4% to +175% in the yala season and from -5% to +64% in the maha season.

Genotypes that are highly responsive to elevated CO_2 may be selected and incorporated into breeding programs to produce new rice varieties which would be higher yielding in a future high CO_2 climate.

In commenting on their findings, the five Sri Lanka researchers say their results "demonstrate the significant genotypic variation that exists within the rice germplasm, in the response to increased atmospheric CO_2 of yield and its correlated physiological parameters," and they go on to suggest that "the significant genotypic variation in this response means that genotypes that are highly responsive to elevated CO_2 may be selected and incorporated into breeding programs to produce new rice varieties which would be higher yielding in a future high CO_2 climate."

Atmospheric CO_2 enrichment also tends to enhance growth and improve plant functions in the face of environmental constraints. Conway and Toenniessen (2003), for example, describe how ameliorating four such impediments to plant productivity – soil infertility, weeds, insects and diseases, and drought – significantly boosts crop yields. Therefore, reducing the negative consequences of each of these yield-reducing factors via *human ingenuity* should boost crop productivity in an additive manner. And a continuation of the historical increase in the air's CO_2 content should boost crop productivity even more.

Atmospheric CO_2 enrichment also tends to enhance growth and improve plant functions in the face of environmental constraints.

In the case of soil infertility, many experiments have demonstrated that even when important nutrients are present in the soil in less than optimal amounts, enriching the air with CO_2 still boosts crop yields. With respect to the soil of an African farm where their "genetic and agro-ecological technologies" have been applied, for example, Conway and Toenniessen speak of "a severe lack of phosphorus and shortages of nitrogen." Yet even in such adverse situations, atmospheric CO_2 enrichment has been reported to enhance plant growth (Barrett *et al*., 1998; Niklaus *et al*., 1998; Kim *et al*., 2003; Rogers *et al*., 2006). And if supplemental fertilization is provided as described by Conway and Toenniessen, even *larger* CO_2-induced benefits above and beyond those provided by the extra nitrogen and phosphorus applied to the soil would likely be realized.

In the case of weeds, Conway and Toenniessen speak of one of Africa's staple crops, maize, being "attacked by the parasitic weed Striga (*Striga hermonthica*), which sucks nutrients from roots." This weed also infects many other C_4 crops of the semi-arid tropics, such as sorghum, sugar cane and millet, as well as the C_3 crop rice, particularly throughout much of Africa, where it is currently one of the region's most economically important parasitic weeds. Here, too, studies have shown that atmospheric CO_2 enrichment greatly reduces the damage done by this devastating weed (Watling and Press, 1997; Watling and Press, 2000).

In the case of insects and plant diseases, atmospheric CO_2 enrichment also helps prevent crop losses. In a study of diseased tomato plants infected with the fungal pathogen *Phytophthora parasitica*, which attacks plant roots inducing water stress that decreases yields, for example, the growth-promoting effect of a doubling of the air's CO_2 content *completely counterbalanced* the yield-reducing effect of the pathogen (Jwa and Walling, 2001). Likewise, in a review of impacts and responses of herbivorous insects maintained for relatively long periods of time in CO_2-enriched environments, as described in some 30-plus different studies, Whittaker (1999) noted that insect populations, on average, have been unaffected by the extra CO_2. And since plant growth is nearly universally *stimulated* in air of elevated CO_2 concentration, Earth's crops should therefore gain a relative advantage over herbivorous insects in a high-CO_2 world of the future.

In the case of insects and plant diseases, atmospheric CO_2 enrichment also helps prevent crop losses.

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In the case of drought, we again have the nearly universal bettering of plant water use efficiency that is induced by atmospheric CO_2 enrichment.

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The same situation exists with respect to excessive heat, ozone pollution, light stress, soil toxicity and most any other environmental constraint. Atmospheric CO_2 enrichment generally tends to enhance growth and improve plant functions to minimize or overcome such challenges.

Lastly, in the case of drought, we again have the nearly universal bettering of plant water use efficiency that is induced by atmospheric CO_2 enrichment. Fleisher *et al*. (2008), for example, grew potato plants (*Solanum tuberosum* cv. Kennebec) from "seed tubers" in soil-plant-atmosphere research chambers maintained at daytime atmospheric CO_2 concentrations of either 370 or 740 ppm under well-watered and progressively water-stressed conditions. And in doing so, they found that "total biomass, yield and water use efficiency increased under elevated CO_2, with the largest percent increases occurring at irrigations that induced the most water stress." In addition, they report that "water use efficiency was nearly doubled under enriched CO_2 when expressed on a tuber fresh weight basis." These results indicate, in the words of the three researchers, that "increases in potato gas exchange, dry matter production and yield with elevated CO_2 are consistent at various levels of water stress as compared with ambient CO_2," providing what we so desperately need in today's world, and what we will need even more as the world's population continues to grow: significantly enhanced food production per unit of water used. And there are many other studies that have produced similar results (De Luis *et al*., 1999; Kyei-Boahen *et al*., 2003; Kim *et al*., 2006).

The same situation exists with respect to excessive heat, ozone pollution, light stress, soil toxicity and most any other environmental constraint. Atmospheric CO_2 enrichment generally tends to enhance growth and improve plant functions to minimize or overcome such challenges (Idso and Singer, 2009; Idso and Idso, 2011). As researchers continue to explore these benefits and farmers select cultivars to maximize them, the chances of the world becoming food secure by 2050 increase. Without these benefits, however, there is little chance we will be able to adequately feed the global population a few short decades from now. What is more, without these CO_2-induced benefits of (1) increasing plant land-use efficiency, (2) increasing plant water-use efficiency, and (3) increasing plant nutrient-use efficiency, more and more land and freshwater resources would need to be taken from "wild nature" in order to sustain humanity's growing population, which unprecedented land and water usurpation would likely lead to the extinction of numerous plant and animal species. Clearly, therefore, humanity and nature alike are dependent upon rising atmospheric CO_2 concentrations to continue to improve all three of the yield-enhancing requirements set forth by Tillman *et al*. (2002).

As researchers continue to explore these benefits and farmers select cultivars to maximize them, the chances of the world becoming food secure by 2050 increase.

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Without these benefits, however, there is little chance we will be able to adequately feed the global population a few short decades from now.

Biofuels

Producing energy from biofuels represents an additional, but very important, consideration impacting future global food security, *since*, in the words of Spiertz and Ewert (2009), "biomass production will compete with food crops for arable land and scarce fresh water resources," which will only worsen the food security problem and further decimate what yet remains of wild nature.

In an article published in the *Journal of Plant Nutrition and Soil Science*, Rattan Lal (2010) of the Carbon Management and Sequestration Center of Ohio State University (USA) commented on this concern by writing that (1) "there still are more than one billion food-insecure people in the world (FAO, 2009a,b)," (2) "the world food supply will have to be doubled between 2005 and 2050 (Borlaug, 2009) because of the increase in population and change in dietary preferences," and (3) "the world energy demand is also increasing rapidly and is projected to increase by 84%

by 2050 compared with 2005." And what makes the problem even worse is the fact that in an attempt to meet the anticipated increase in the global demand for energy, "the emphasis on biofuels is strongly impacting the availability of grains for food and soil resources for grain production."

Producing energy from biofuels will compete with food crops for arable land and scarce fresh water resources, which will only worsen the food security problem and further decimate what yet remains of wild nature.

As many people have begun to realize the significance of this latter problem, Lal indicates that crop residues are being "widely considered as a source of lignocellulosic biomass." However, he says that removal of crop *residues* for this purpose "is not an option (Lal, 2007) because of the negative impacts of removal on soil quality, and increase in soil erosion (Lal, 1995)," as well as the loss of the residue's "positive impacts" on "numerous ecosystem services." Therefore, in yet another shift in tactics, Lal reports that degraded soils are being considered as possible sites for establishing energy plantations. However, Lal (2010) notes that with their extremely low capacity for biomass production, the amount of biofuel produced on globally-abandoned agricultural land cannot even meet 10% of the energy needs of North America, Europe and Asia, citing the work of Campbell *et al*. (2009) in this regard. Yet even these considerations are only half the problem.

In addition to the need for considerable land, Lal writes that the "successful establishment of energy plantations also needs plant nutrients," as well as an "adequate supply of water." And since an adequate supply of water is something on the order of 1000-3500 liters per liter of biofuel produced, it is, as he puts it, "an important factor." And he notes that this strategy will also "increase competition for limited land and water resources thereby increasing food crop and livestock prices (Wise *et al*., 2009)."

Lal closes his review by writing that society should not take its precious resource base for granted, stating that "if soils are not restored, crops will fail even if rains do not; hunger will perpetuate even with emphasis on biotechnology and genetically modified crops; civil strife and political instability will plague the developing world even with sermons on human rights and democratic ideals; and humanity will suffer even with great scientific strides."

Conclusions

As indicated in the material above, a very real and devastating food crisis is looming on the horizon, and continuing advancements in agricultural technology and expertise will most likely not be able to bridge the gap between global food supply and global food demand just a few short years from now. However, the positive impact of Earth's rising atmospheric CO_2 concentration on crop yields will considerably lessen the severity of the coming food shortage. In some regions and countries it will mean the difference between being food secure or food insecure; and it will aid in lifting untold *hundreds of millions* out of a state of hunger and malnutrition, preventing starvation and premature death.

If countries learned to identify which genotypes provided the largest yield increases per unit of CO_2 rise, and then grew those genotypes, it is quite possible that the world could collectively produce enough food to supply the needs of all of its inhabitants.

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But since rising CO_2 concentrations are considered by many people to be the primary cause of global warming, we are faced with a dilemma of major proportions.

For those regions of the globe where neither enhancements in the techno-intel effect nor the rise in CO_2 are projected to foster food security, an Apollo moon-mission-like commitment is needed by governments and researchers to *further* increase crop yields per unit of land area planted, nutrients applied, and water used. And about the only truly viable option for doing so (without taking enormous amounts of land and water from nature and driving untold numbers of plant and animal species to extinction) is to have researchers and governments invest the time, effort and capital needed to identify and to prepare for production the plant genotypes that are most capable of maximizing CO_2 benefits for important food crops.

Rice, for example, is the third most important global food crop, accounting for 9.4% of global food production. Based upon data presented in the *CO_2 Science* Plant Growth Database, the average growth response of rice to a 300-ppm increase in the air's CO_2 concentration is 35.7%. However, data obtained from De Costa *et al*. (2007), who studied the growth responses of 16 different rice genotypes, revealed CO_2-induced productivity increases ranging from -7% to +263%. Therefore, if countries learned to identify which genotypes provided the largest yield increases per unit of CO_2 rise, and then grew those genotypes, it is quite possible that the world could collectively produce enough food to supply the needs of all of its inhabitants. But since rising CO_2 concentrations are considered by many people to be the primary cause of global warming, we are faced with a dilemma of major proportions.

About the only option for avoiding the food crisis, and its negative ramifications for humanity and nature alike, is to allow the atmospheric CO_2 concentration to continue to rise as predicted (no CO_2 emission restrictions), and then to learn to maximize those benefits through the growing of CO_2-loving cultivars.

If proposed regulations restricting anthropogenic CO_2 emissions (which are designed to remedy the potential global warming problem) are enacted, they will greatly exacerbate future food problems by reducing the CO_2-induced yield enhancements that are needed to supplement increases provided by advances in agricultural technology and expertise. And as a result of such CO_2 emissions regulations, hundreds of millions of the world's population will be subjected to hunger and malnutrition. Even more troubling is the fact that thousands would die daily as a result of health problems they likely would have survived had they received adequate food and nutrition. About the only option for avoiding the food crisis, and its negative ramifications for humanity and nature alike, is to allow the atmospheric CO_2 concentration to continue to rise as predicted (no CO_2 emission restrictions), and then to learn to maximize those benefits through the growing of CO_2-loving cultivars.

Epilogue

In light of the host of real-world research findings discussed in the body of this report, it should be evident to all that the looming food shortage facing humanity mere years to decades from now is far more significant than the theoretical and largely unproven catastrophic climate- and weather-related projections of the world's climate alarmists. And it should also be clear that the factor that figures most prominently in both scenarios is the air's CO_2 content. The *theorists* proclaim that we must drastically reduce anthropogenic CO_2 emissions by whatever means possible, including drastic government interventions in free-market enterprise systems. The *realists* suggest that letting economic progress take its natural unimpeded course is the only way to enable the air's CO_2 content to reach a level that will provide the aerial fertilization effect of atmospheric CO_2 enrichment that will be needed to provide the extra food production that will be required to forestall massive human starvation and all the social unrest and warfare that will unavoidably accompany it, as well as humanity's decimation of what little yet remains of pristine nature, which will include the driving to extinction of untold numbers of both plant and animal species.

Climate alarmists *totally misuse* the precautionary principle when they ignore the reality of the approaching lack-of-food-induced crisis that would decimate the *entire biosphere*, and when they claim instead that the catastrophic projections of their climate models are so horrendous that anthropogenic CO_2 emissions must be reduced at all costs. Such actions should not even be *contemplated* without first acknowledging the fact that *none* of the catastrophic consequences of rising global temperatures have yet been conclusively documented, as well as the much greater likelihood of the horrendous global food crisis that would follow such actions. The *two* potential futures must be *weighed in the balance*, and very carefully, before any such actions are taken.

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Appendix 1

List of the crops that provide 95% of the food production of the six world regions, obtained from the United Nations FAOSTAT database. The numbers in parentheses that follow each crop represent the percentage of each geographical entity's total food production that is supplied by that particular crop.

Region

Africa: Cassava (17.8), Sugar cane (15.1), Maize (7.9), Yams (7.2), Plantains (3.9), Sorghum (3.8), Wheat (3.3), Rice, paddy (3.2), Oil palm fruit (2.7), Millet (2.6), Potatoes (2.5), Tomatoes (2.4), Vegetables fresh other (2.2), Sweet potatoes (2.0), Bananas (1.6), Groundnuts, with shell (1.5), Taro (1.3), Sugar beet (1.0), Oranges (0.9), Roots and Tubers, other (0.9), Barley (0.8), Onions, dry (0.8), Seed cotton (0.8), Fruit Fresh Other (0.7), Watermelons (0.7), Cow peas, dry (0.7), Citrus fruit, other (0.7), Grapes (0.6), Beans, dry (0.5), Mangoes, mangosteens, guavas (0.5), Pineapples (0.4), Cocoa beans (0.4), Cereals, other (0.4), Chilies and peppers, green (0.4), Olives (0.4), Dates (0.4), Cabbages and brassicas (0.3), Coconuts (0.3), Apples (0.3), Pumpkins, squash and gourds (0.3), Okra (0.3), Maize, green (0.3)

Asia: Sugar cane (18.8), Rice, paddy (18.0), Wheat (8.5), Vegetables fresh other (6.0), Maize (5.9), Potatoes (3.9), Oil palm fruit (3.9), Sweet potatoes (3.6), Watermelons (2.1), Cassava (1.9), Tomatoes (1.8), Coconuts (1.5), Cabbages and brassicas (1.4), Seed cotton (1.3), Bananas (1.2), Sugar beet (1.2), Onions, dry (1.1), Apples (1.1), Cucumbers and gherkins (0.9), Eggplants (aubergiother) (0.8), Soybeans (0.8), Groundnuts, with shell (0.8), Barley (0.7), Mangoes, mangosteens, guavas (0.7), Rapeseed (0.6), Fruit Fresh Other (0.6), melons (inc. cantaloupes) (0.5), Grapes (0.5), Tangerines other, mandarins, clem. (0.5), Chilies and peppers, green (0.5), Oranges (0.5), Millet (0.4), Fruit, tropical fresh other (0.4), Cauliflowers and broccoli (0.4), Sorghum (0.4), Pears (0.4), Pumpkins, squash and gourds (0.4), Lettuce and chicory (0.4), Garlic (0.4), Carrots and turnips (0.3), Spinach (0.3)

Europe: Wheat (20.6), Sugar beet (18.4), Potatoes (14.4), Barley (9.4), Maize (8.0), Grapes (3.1), Tomatoes (2.2), Rye (1.8), Oats (1.8), Apples (1.7), Sunflower seed (1.6), Rapeseed (1.6), Cabbages and brassicas (1.3), Vegetables fresh other (1.2), Olives (1.2), Triticale (1.0), Carrots and turnips (0.8), Onions, dry (0.8), Oranges (0.6), Peas, dry (0.5), Cucumbers and gherkins (0.5), Watermelons (0.5), Mixed grain (0.5), Peaches and nectarines other (0.4), Lettuce and chicory (0.4), Rice, paddy (0.3), Pears (0.3)

North America: Maize (40.8), Wheat (12.6), Soybeans (11.8), Sugar cane (4.5), Sugar beet (4.4), Potatoes (3.8), Barley (2.7), Tomatoes (2.0), Sorghum (1.8), Oranges (1.5), Seed cotton (1.5), Rice, paddy (1.4), Rapeseed (1.3), Grapes (0.9), Oats (0.8), Apples (0.8), Maize, green (0.7), Lettuce and chicory (0.7), Onions, dry (0.5), Peas, dry (0.4), Carrots and turnips (0.3)

Oceania: Sugar cane (41.7), Wheat (21.7), Barley (7.8), Coconuts (2.2), Sorghum (2.0), Potatoes (1.9), Grapes (1.6), Oats (1.5), Rapeseed (1.5), Oil palm fruit (1.4), Seed cotton (1.3), Lupins (1.2), Bananas (1.2), Rice, paddy (0.9), Fruit Fresh Other (0.9), Apples (0.8), Sweet potatoes (0.7), Triticale (0.6), Maize (0.6), Tomatoes (0.5), Vegetables fresh other (0.5), Oranges (0.5), Peas, dry (0.4), Maize, green (0.4), Roots and Tubers, other (0.4), Taro (cocoyam) (0.4), Carrots and turnips (0.4)

South America: Sugar cane (58.8), Soybeans (8.7), Maize (7.4), Cassava (3.6), Oranges (2.5), Rice, paddy (2.4), Wheat (2.3), Bananas (1.8), Potatoes (1.5), Tomatoes (0.7), Plantains (0.7), Grapes (0.7), Oil palm fruit (0.6), Sunflower seed (0.6), Sorghum (0.6), Beans, dry (0.4), Seed cotton (0.4), Apples (0.4), Vegetables fresh other (0.4), Onions, dry (0.4), Coffee, green (0.4)

Appendix 2

List of the crops that provide 95% of the food production of the twenty sub-regions, obtained from the United Nations FAOSTAT database. The numbers in parentheses that follow each crop represent the percentage of each geographical entity's total food production that is supplied by that particular crop.

Sub-Region

Africa

Eastern: Sugar cane (20.7), Cassava (16.3), Maize (11.4), Plantains (9.3), Sweet potatoes (5.0), Bananas (3.9), Potatoes (3.8), Rice, paddy (3.1), Roots and Tubers, other (3.0), Sorghum (2.7), Vegetables fresh other (2.6), Wheat (1.7), Beans, dry (1.5), Cereals, other (1.5), Millet (1.0), Barley (0.9), Fruit Fresh Other (0.8), Coconuts (0.7), Seed cotton (0.7), Groundnuts, with shell (0.6), Mangoes, mangosteens, guavas (0.6), Cabbages and brassicas (0.6), Tomatoes (0.5), Pineapples (0.5), Coffee, green (0.5), Onions, dry (0.4), Broad beans, horse beans, dry (0.3), Tea (0.3)

Western: Cassava (25.1), Yams (18.9), Oil palm fruit (5.9), Millet (5.8), Sorghum (5.7), Maize (5.1), Rice, paddy (3.7), Plantains (3.2), Vegetables fresh other (2.7), Taro (2.7), Groundnuts, with shell (2.5), Sugar cane (2.3), Citrus fruit, other (1.7), Cow peas, dry (1.7), Sweet potatoes (1.5), Cocoa beans (1.1), Seed cotton (1.0), Fruit Fresh Other (0.8), Tomatoes (0.7), Pineapples (0.6), Okra (0.5), Maize, green (0.5), Mangoes, mangosteens, guavas (0.5), Chilies and peppers, green (0.5), Onions, dry (0.5)

Middle: Cassava (48.1), Sugar cane (8.3), Plantains (5.4), Maize (5.3), Oil palm fruit (5.0), Bananas (3.0), Taro (2.4), Vegetables fresh other (2.3), Groundnuts, with shell (2.1), Yams (2.1), Sorghum (1.9), Sweet potatoes (1.9), Millet (1.1), Rice, paddy (1.0), Potatoes (0.9), Beans, dry (0.9), Seed cotton (0.8), Tomatoes (0.7), Pineapples (0.6), Fruit Fresh Other (0.6), Mangoes, mangosteens, guavas (0.5), Cereals, other (0.5)

North: Sugar cane (19.2), Wheat (11.9), Tomatoes (8.9), Maize (5.4), Potatoes (5.1), Rice, paddy (5.1), Sugar beet (5.0), Sorghum (3.9), Watermelons (2.8), Oranges (2.7), Barley (2.6), Onions, dry (2.1), Olives (1.9), Dates (1.8), Grapes (1.6), Vegetables fresh other (1.5), melons (Inc. Cantaloupes) (1.1), Tangerines other, mandarins, clem. (1.0), Chilies and peppers, green (0.9), Eggplants (aubergiother) (0.9), Apples (0.9), Groundnuts, with shell (0.9), Pumpkins, squash and gourds (0.9), Bananas (0.9), Fruit Fresh Other (0.8), Seed cotton (0.7), Cucumbers and gherkins (0.7), Carrots and turnips (0.5), Broad beans, horse beans, dry (0.5), Cabbages and brassicas (0.5), Millet (0.5), Peaches and nectarines other (0.5), Mangoes, mangosteens, guavas (0.5), Lemons and limes (0.4), Peas, green (0.3), Figs (0.3)

South: Sugar cane (51.7), Maize (19.5), Wheat (4.3), Potatoes (3.7), Grapes (3.2), Oranges (2.5), Sunflower seed (1.4), Apples (1.3), Tomatoes (0.9), Roots and Tubers, other (0.9), Onions, dry (0.8), Sorghum (0.7), Vegetables fresh other (0.7), Grapefruit (inc. pomelos) (0.7), Bananas (0.6), Maize, green (0.6), Pears (0.6), Pumpkins, squash and gourds (0.5), Soybeans (0.5)

Americas

Central America: Sugar cane (51.7), Maize (13.5), Bananas (4.0), Sorghum (3.8), Oranges (2.9), Wheat (2.0), Tomatoes (1.9), Oil palm fruit (1.4), Pineapples (1.2), Potatoes (1.2), Mangoes, mangosteens, guavas (1.1), Lemons and limes (1.1), Chilies and peppers, green (1.0), Beans, dry (0.9), Coconuts (0.8), Watermelons (0.7), Onions, dry (0.7), melons (Inc. Cantaloupes) (0.7), Rice, paddy (0.7), Coffee, green (0.6), Avocados (0.6), Papayas (0.5), Vegetables fresh other (0.4), Fruit Fresh Other (0.4), Barley (0.4), Plantains (0.4), Cassava (0.3)

Caribbean: Sugar cane (71.4), Bananas (3.3), Plantains (2.4), Rice, paddy (2.4), Vegetables fresh other (2.4), Cassava (1.8), Tomatoes (1.5), Mangoes, mangosteens, guavas (1.4), Oranges (1.3), Sweet potatoes (1.2), Coconuts (1.0), Maize (1.0), Yams (1.0), Pumpkins, squash and gourds (0.8), Potatoes (0.7), Grapefruit (inc. pomelos) (0.7), Avocados (0.4), Cucumbers and gherkins (0.4), Cabbages and brassicas (0.4)

Asia

Eastern: Rice, paddy (16.2), Vegetables fresh other (10.4), Maize (10.3), Sweet potatoes (8.3), Wheat (8.2), Sugar cane (7.1), Potatoes (5.3), Watermelons (4.1), Cabbages and brassicas (2.6), Tomatoes (2.1), Apples (1.9), Cucumbers and gherkins (1.8), Onions, dry (1.4), Seed cotton (1.3), Soybeans (1.2), Eggplants (aubergiother)

(1.2), Sugar beet (1.1), Groundnuts, with shell (1.0), Tangerines other, mandarins, clem. (0.9), Rapeseed (0.9), Chilies and peppers, green (0.9), melons (Inc. Cantaloupes) (0.8), Pears (0.8), Lettuce and chicory (0.7), Garlic (0.7), Spinach (0.7), Carrots and turnips (0.6), Cauliflowers and broccoli (0.5), Peaches and nectarines other (0.5), Bananas (0.4), Pumpkins, squash and gourds (0.4), Grapes (0.4), Asparagus (0.4)

Southern: Sugar cane (35.8), Rice, paddy (18.7), Wheat (11.0), Potatoes (3.7), Vegetables fresh other (3.3), Maize (2.0), Bananas (1.8), Seed cotton (1.4), Mangoes, mangosteens, guavas (1.4), Tomatoes (1.3), Coconuts (1.2), Millet (1.1), Onions, dry (1.1), Fruit Fresh Other (0.9), Eggplants (aubergiother) (0.9), Sorghum (0.8), Soybeans (0.8), Groundnuts, with shell (0.7), Cassava (0.7), Rapeseed (0.7), Oranges (0.7), Chick peas (0.7), Cabbages and brassicas (0.6), Cauliflowers and broccoli (0.5), Sugar beet (0.5), Barley (0.5), Pumpkins, squash and gourds (0.5), Apples (0.4), Fruit, tropical fresh other (0.4), Grapes (0.4), Okra (0.4), Beans, dry (0.4)

Central: Wheat (42.2), Seed cotton (11.3), Potatoes (9.9), Barley (5.5), Tomatoes (4.9), Watermelons (3.3), Onions, dry (2.6), Vegetables fresh other (2.4), Maize (2.1), Grapes (2.0), Carrots and turnips (1.9), Sugar beet (1.8), Apples (1.7), Cabbages and brassicas (1.6), Rice, paddy (1.4), Cucumbers and gherkins (1.0)

Southeastern: Rice, paddy (26.0), Sugar cane (21.9), Oil palm fruit (19.5), Cassava (7.5), Coconuts (5.5), Maize (4.0), Vegetables fresh other (2.5), Bananas (2.3), Natural rubber (1.0), Fruit, tropical fresh other (1.0), Pineapples (0.9), Fruit Fresh Other (0.8), Sweet potatoes (0.7), Mangoes, mangosteens, guavas (0.7), Groundnuts, with shell (0.4), Cabbages and brassicas (0.4)

Western: Wheat (20.1), Sugar beet (11.7), Tomatoes (9.7), Barley (7.3), Potatoes (6.4), Watermelons (4.4), Grapes (3.8), Maize (2.8), Apples (2.3), Seed cotton (2.3), Cucumbers and gherkins (2.2), Onions, dry (2.1), Oranges (1.8), Dates (1.7), melons (Inc. Cantaloupes) (1.7), Olives (1.6), Vegetables fresh other (1.3), Chilies and peppers, green (1.3), Eggplants (aubergiother) (1.2), Cabbages and brassicas (0.9), Sunflower seed (0.7), Tangerines other, mandarins, clem. (0.7), Lemons and limes (0.6), Pumpkins, squash and gourds (0.6), Chick peas (0.5), Fruit Fresh Other (0.5), Rice, paddy (0.5), Apricots (0.5), Peaches and Nectarines other (0.5), Sorghum (0.4), Carrots and turnips (0.4), Lentils (0.4), Beans, green (0.4), Hazelnuts, with shell (0.4), Pears (0.4), Lettuce and chicory (0.4), Grapefruit (inc. pomelos) (0.4), Bananas (0.3), Cherries (0.3)

Europe

Eastern: Wheat (22.0), Potatoes (21.1), Sugar beet (15.1), Barley (9.1), Maize (7.2), Rye (3.0), Sunflower seed (2.9), Oats (2.4), Cabbages and brassicas (2.0), Apples (1.6), Tomatoes (1.3), Vegetables fresh other (1.1), Triticale (1.1), Mixed grain (1.0), Rapeseed (0.9), Carrots and turnips (0.9), Grapes (0.9), Onions, dry (0.9), Cucumbers and gherkins (0.7)

Northern: Wheat (29.1), Sugar beet (20.1), Barley (19.3), Potatoes (14.7), Oats (4.4), Rapeseed (3.0), Carrots and turnips (1.3), Rye (1.1), Cabbages and brassicas (0.8), Triticale (0.8), Vegetables fresh other (0.7)

Southern: Maize (13.6), Sugar beet (12.1), Wheat (10.3), Grapes (9.2), Tomatoes (7.3), Olives (5.9), Barley (5.8), Potatoes (4.8), Oranges (3.1), Apples (2.1), Vegetables fresh other (2.1), Peaches and Nectarines other (1.9), Tangerines other, mandarins, clem. (1.5), Watermelons (1.4), Rice, paddy (1.3), Lettuce and chicory (1.1), Onions, dry (1.1), Chilies and peppers, green (1.0), Pears (1.0), melons (Inc. Cantaloupes) (0.9), Cabbages and brassicas (0.9), Sunflower seed (0.9), Oats (0.8), Lemons and limes (0.8), Seed cotton (0.8), Carrots and turnips (0.7), Soybeans (0.6), Cauliflowers and broccoli (0.5), Plums and sloes (0.5), Pumpkins, squash and gourds (0.5), Cucumbers and gherkins (0.5), Artichokes (0.4)

Western: Sugar beet (27.3), Wheat (23.2), Potatoes (11.0), Barley (9.0), Maize (7.9), Grapes (3.3), Rapeseed (3.1), Apples (2.0), Triticale (1.6), Rye (1.6), Vegetables fresh other (0.9), Peas, dry (0.8), Oats (0.7), Sunflower seed (0.7), Carrots and turnips (0.7), Tomatoes (0.7), Onions, dry (0.6), Cabbages and brassicas (0.6)

Oceania

Australia: Sugar cane (43.3), Wheat (24.7), Barley (8.8), Sorghum (2.3), Potatoes (2.1), Grapes (2.0), Oats (1.7), Rapeseed (1.7), Seed cotton (1.5), Lupins (1.4), Rice, paddy (1.1), Apples (0.9), Triticale (0.7), Maize (0.7), Tomatoes (0.6), Oranges (0.6), Peas, dry (0.5), Carrots and turnips (0.4), Kiwi fruit (0.3)

Melanesia: Sugar cane (32.7), Coconuts (14.2), Oil palm fruit (12.8), Bananas (8.2), Fruit Fresh Other (7.8), Sweet potatoes (5.7), Roots and Tubers, other (3.2), Taro (cocoyam) (3.0), Yams (2.9), Vegetables fresh other (2.6), Maize, green (2.1)

Micronesia: Coconuts (81.3), Cassava (4.2), Vegetables fresh other (3.9), Roots and Tubers, other (3.3), Bananas (2.6)

Polynesia: Coconuts (59.7), Taro (cocoyam) (6.0), Bananas (5.2), Cassava (4.7), Pumpkins, squash and gourds (3.4), Fruit, tropical fresh other (3.3), Roots and Tubers, other (2.7), Vegetables fresh other (1.9), Yams (1.7), Pineapples (1.6), Sweet potatoes (1.4), Fruit Fresh Other (1.3), Mangoes, mangosteens, guavas (1.1), Papayas (0.9)

Appendix 3

List of the crops that provide 95% of the food production of the twenty-five most populous world countries, obtained from the United Nations FAOSTAT database. The numbers in parentheses that follow each crop represent the percentage of each geographical entity's total food production that is supplied by that particular crop.

Country

China:	Rice, paddy (15.5), Maize (10.8), Vegetables fresh other (10.3), Sweet potatoes (8.6), Wheat (8.6), Sugar cane (7.4), Potatoes (5.2), Watermelons (4.2), Cabbages and brassicas (2.2), Tomatoes (2.1), Apples (1.8), Cucumbers and gherkins (1.8), Seed cotton (1.4), Onions, dry (1.3), Soybeans (1.2), Eggplants (aubergiother) (1.2), Groundnuts, with shell (1.1), Rapeseed (0.9), Sugar beet (0.9), Chilies and peppers, green (0.9), Tangerines other, mandarins, clem. (0.8), melons (Inc. Cantaloupes) (0.8), Pears (0.8), Garlic (0.7), Lettuce and chicory (0.7), Spinach (0.7), Carrots and turnips (0.6), Cauliflowers and broccoli (0.5), Bananas (0.5), Peaches and Nectarines other (0.5), Pumpkins, squash and gourds (0.4), Asparagus (0.4), Grapes (0.4)
India:	Sugar cane (39.1), Rice, paddy (17.6), Wheat (9.6), Vegetables fresh other (3.5), Potatoes (3.4), Bananas (2.2), Maize (1.9), Mangoes, mangosteens, guavas (1.5), Millet (1.4), Coconuts (1.3), Eggplants (aubergiother) (1.1), Tomatoes (1.1), Seed cotton (1.1), Sorghum (1.1), Soybeans (1.0), Groundnuts, with shell (0.9), Onions, dry (0.9), Cassava (0.9), Fruit Fresh Other (0.8), Rapeseed (0.8), Chick peas (0.8), Cabbages and brassicas (0.7), Cauliflowers and broccoli (0.7), Okra (0.5), Pumpkins, squash and gourds (0.5), Fruit, tropical fresh other (0.4), Beans, dry (0.4)
USA:	Maize (44.3), Soybeans (12.8), Wheat (10.0), Sugar cane (5.1), Sugar beet (4.8), Potatoes (3.5), Tomatoes (2.1), Sorghum (2.1), Oranges (1.7), Seed cotton (1.7), Rice, paddy (1.5), Grapes (1.0), Barley (1.0), Apples (0.8), Lettuce and chicory (0.7), Maize, green (0.7), Onions, dry (0.6), Grapefruit (inc. pomelos) (0.3), Oats (0.3)
Indootheria:	Rice, paddy (25.9), Oil palm fruit (25.0), Sugar cane (12.9), Cassava (8.7), Coconuts (7.8), Maize (5.4), Bananas (2.1), Fruit, tropical fresh other (1.0), Natural rubber (0.9), Sweet potatoes (0.9), Cabbages and brassicas (0.7), Oranges (0.7), Mangoes, mangosteens, guavas (0.6), Groundnuts, with shell (0.6), Fruit Fresh Other (0.5), Soybeans (0.5), Potatoes (0.5), Chilies and peppers, green (0.5)
Brazil:	Sugar cane (69.5), Soybeans (7.0), Maize (6.7), Cassava (3.9), Oranges (3.2), Rice, paddy (1.8), Bananas (1.0), Wheat (0.6), Tomatoes (0.5), Potatoes (0.5), Beans, dry (0.5)
Pakistan:	Sugar cane (49.6), Wheat (19.6), Rice, paddy (7.6), Seed cotton (5.6), Maize (2.3), Potatoes (1.8), Onions, dry (1.5), Oranges (1.4), Mangoes, mangosteens, guavas (1.2), Vegetables fresh other (1.0), Chick peas (0.6), Dates (0.6), Tangerines other, mandarins, clem. (0.5), Fruit, tropical fresh other (0.5), Apples (0.4), Roots and Tubers, other (0.4), Watermelons (0.4)
Nigeria:	Cassava (27.9), Yams (21.9), Oil palm fruit (6.3), Sorghum (6.2), Millet (5.0), Maize (4.4), Vegetables fresh other (3.3), Taro (cocoyam) (3.0), Rice, paddy (2.5), Citrus fruit, other (2.4), Groundnuts, with shell (2.3), Sweet potatoes (1.9), Cow peas, dry (1.8), Plantains (1.7), Fruit Fresh Other (1.0), Tomatoes (0.7), Pineapples (0.7), Sugar cane (0.7), Okra (0.6), Papayas (0.6), Mangoes, mangosteens, guavas (0.5)
Bangladesh:	Rice, paddy (66.4), Sugar cane (12.0), Potatoes (6.1), Wheat (2.4), Vegetables fresh other (1.6), Jute (1.5), Bananas (1.3), Fruit, tropical fresh other (0.8), Sweet potatoes (0.7), Mangoes, mangosteens, guavas (0.6), Onions, dry (0.6), Sugar crops, other (0.6), Maize (0.5)
Russia:	Wheat (27.7), Potatoes (23.3), Sugar beet (12.6), Barley (10.8), Oats (4.0), Rye (3.2), Sunflower seed (3.0), Cabbages and brassicas (2.3), Maize (1.6), Vegetables fresh other (1.4), Tomatoes (1.3), Apples (1.1), Carrots and turnips (1.0), Onions, dry (0.9), Peas, dry (0.7), Cucumbers and gherkins (0.7)
Japan:	Rice, paddy (29.3), Sugar beet (10.1), Potatoes (7.6), Vegetables fresh other (7.5), Cabbages and brassicas (5.7), Sugar cane (3.7), Onions, dry (3.1), Tangerines other, mandarins, clem. (3.0), Sweet potatoes (2.7), Apples (2.2), Tomatoes (2.0), Wheat (1.8), Cucumbers and gherkins (1.8), Carrots and turnips (1.8), Onions (inc. shallots), green (1.4), Lettuce and chicory (1.4), Watermelons (1.3), Eggplants (aubergiother) (1.1), Pears (0.9), Spinach (0.8), melons (Inc. Cantaloupes) (0.7), Maize, green (0.7), Persimmons (0.7), Pumpkins, squash and gourds (0.6), Grapes (0.6), Citrus fruit, other (0.6), Taro (cocoyam) (0.6), Soybeans (0.5), Barley (0.5)
Mexico:	Sugar cane (44.0), Maize (18.4), Sorghum (5.5), Oranges (3.6), Wheat (3.0), Tomatoes (2.5), Bananas (1.8), Chilies and peppers, green (1.5), Lemons and limes (1.5), Mangoes, mangosteens, guavas (1.5), Potatoes (1.4), Coconuts (1.1), Beans, dry (1.1), Onions, dry (1.0), Avocados (0.9), Watermelons (0.8), Papayas (0.7), Barley (0.6), Pineapples (0.5), melons (Inc. Cantaloupes) (0.5), Pumpkins, squash and gourds (0.5), Apples (0.5), Cucumbers and gherkins (0.4), Vegetables fresh other (0.4), Maize, green (0.4), Seed cotton (0.4), Grapes (0.4), Tangerines other, mandarins, clem. (0.3)

Philippiother: Sugar cane (33.9), Coconuts (17.3), Rice, paddy (16.6), Bananas (7.2), Maize (6.4), Vegetables fresh other (5.0), Fruit, tropical fresh other (3.9), Cassava (2.3), Pineapples (2.2), Mangoes, mangosteens, guavas (1.1)

Vietnam: Rice, paddy (45.0), Sugar cane (20.5), Vegetables fresh other (7.8), Cassava (6.6), Maize (3.8), Fruit Fresh Other (3.2), Sweet potatoes (2.2), Bananas (1.7), Coconuts (1.4), Coffee, green (1.0), Cashew nuts, with shell (0.8), Cabbages and brassicas (0.7), Oranges (0.7)

Germany: Sugar beet (27.0), Wheat (23.0), Barley (12.8), Potatoes (12.5), Rapeseed (4.5), Rye (4.0), Maize (3.8), Triticale (2.7), Apples (1.6), Grapes (1.5), Oats (1.2), Vegetables fresh other (1.1)

Egypt: Sugar cane (23.6), Tomatoes (10.8), Wheat (10.4), Maize (9.3), Rice, paddy (9.0), Sugar beet (4.5), Potatoes (3.7), Oranges (2.7), Watermelons (2.4), Grapes (1.8), Dates (1.6), Onions, dry (1.4), Eggplants (aubergiother) (1.3), Sorghum (1.3), Bananas (1.2), Seed cotton (1.0), Pumpkins, squash and gourds (1.0), melons (Inc. Cantaloupes) (0.9), Tangerines other, mandarins, clem. (0.9), Vegetables fresh other (0.9), Cabbages and brassicas (0.8), Cucumbers and gherkins (0.8), Apples (0.7), Chilies and peppers, green (0.7), Broad beans, horse beans, dry (0.5), Peaches and Nectarines other (0.5), Mangoes, mangosteens, guavas (0.5), Fruit Fresh Other (0.5), Olives (0.5)

Ethiopia: Roots and Tubers, other (18.6), Maize (15.2), Cereals, other (9.9), Sugar cane (9.7), Sorghum (8.7), Wheat (8.3), Barley (5.7), Potatoes (2.1), Broad beans, horse beans, dry (2.1), Vegetables fresh other (2.0), Millet (1.7), Sweet potatoes (1.5), Coffee, green (1.2), Yams (1.0), Chick peas (0.9), Peas, dry (0.8), Papayas (0.8), Cabbages and brassicas (0.7), Beans, dry (0.7), Bananas (0.7), Onions, dry (0.7), Mangoes, mangosteens, guavas (0.6), Fruit Fresh Other (0.6), Oilseeds, Other (0.5), Chilies and peppers, dry (0.5)

Iran: Wheat (20.3), Sugar beet (8.2), Tomatoes (6.8), Potatoes (6.6), Sugar cane (6.0), Barley (4.7), Rice, paddy (4.3), Grapes (4.1), Watermelons (4.0), Apples (4.0), Oranges (3.4), Vegetables fresh other (2.7), Onions, dry (2.6), Cucumbers and gherkins (2.5), Maize (2.5), Fruit Fresh Other (2.4), melons (Inc. Cantaloupes) (1.9), Dates (1.6), Lemons and limes (1.4), Tangerines other, mandarins, clem. (1.2), Pumpkins, squash and gourds (0.9), Seed cotton (0.7), Peaches and Nectarines other (0.6), Apricots (0.5), Chick peas (0.5), Pistachios (0.4), Cabbages and brassicas (0.4)

Turkey: Wheat (20.5), Sugar beet (16.4), Tomatoes (9.6), Barley (8.5), Potatoes (5.1), Watermelons (4.2), Grapes (3.9), Maize (3.0), Apples (2.5), Seed cotton (2.3), Onions, dry (2.2), melons (Inc. Cantaloupes) (1.9), Cucumbers and gherkins (1.7), Chilies and peppers, green (1.7), Olives (1.3), Oranges (1.3), Sunflower seed (0.9), Eggplants (aubergiother) (0.9), Cabbages and brassicas (0.7), Chick peas (0.6), Tangerines other, mandarins, clem. (0.6), Lemons and limes (0.6), Hazelnuts, with shell (0.6), Beans, green (0.5), Lentils (0.5), Apricots (0.5), Rice, paddy (0.5), Peaches and Nectarines other (0.5), Pears (0.4), Pumpkins, squash and gourds (0.4), Carrots and turnips (0.4), Lettuce and chicory (0.4)

Congo: Cassava (46.9), Sugar cane (27.3), Oil palm fruit (4.8), Bananas (4.1), Plantains (3.7), Roots and Tubers, other (2.1), Vegetables fresh other (1.9), Mangoes, mangosteens, guavas (1.3), Groundnuts, with shell (1.3), Fruit Fresh Other (1.3), Yams (0.6)

Thailand: Sugar cane (44.1), Rice, paddy (20.6), Cassava (15.3), Oil palm fruit (3.6), Maize (3.2), Natural rubber (2.0), Pineapples (1.6), Bananas (1.4), Mangoes, mangosteens, guavas (1.3), Coconuts (1.2), Vegetables fresh other (0.8)

France: Wheat (28.4), Sugar beet (24.9), Maize (11.8), Barley (8.1), Grapes (5.5), Potatoes (5.2), Rapeseed (3.1), Apples (1.8), Peas, dry (1.5), Sunflower seed (1.3), Triticale (1.1), Tomatoes (0.6), Carrots and turnips (0.5), Oats (0.5), Vegetables fresh other (0.4), Maize, green (0.4), Lettuce and chicory (0.4)

United Kingdom: Wheat (34.6), Sugar beet (20.8), Potatoes (14.9), Barley (14.8), Rapeseed (3.8), Carrots and turnips (1.7), Oats (1.5), Pulses, other (0.9), Peas, green (0.9), Onions, dry (0.8), Cabbages and brassicas (0.8)

Italy: Sugar beet (14.3), Maize (14.0), Grapes (12.1), Wheat (10.8), Tomatoes (9.3), Olives (4.8), Vegetables fresh other (3.3), Apples (3.1), Oranges (2.8), Potatoes (2.7), Peaches and Nectarines other (2.3), Rice, paddy (2.0), Barley (1.8), Lettuce and chicory (1.3), Pears (1.2), Soybeans (1.0), Tangerines other, mandarins, clem. (0.8), Lemons and limes (0.8), melons (Inc. Cantaloupes) (0.8), Carrots and turnips (0.8), Watermelons (0.7), Artichokes (0.7), Cauliflowers and broccoli (0.7), Pumpkins, squash and gourds (0.6), Cabbages and brassicas (0.6), Onions, dry (0.6), Sunflower seed (0.5), Kiwi fruit (0.5), Oats (0.5)

Myanmar: Rice, paddy (57.1), Sugar cane (14.9), Vegetables fresh other (7.0), Beans, dry (4.0), Fruit Fresh Other (2.6), Groundnuts, with shell (1.9), Maize (1.5), Onions, dry (1.3), Plantains (1.2), Sesame seed (1.0), Pigeon peas (0.9), Potatoes (0.8), Sugar crops, other (0.8)

South Africa: Sugar cane (48.2), Maize (21.5), Wheat (4.8), Potatoes (4.0), Grapes (3.6), Oranges (2.8), Sunflower seed (1.6), Apples (1.5), Tomatoes (1.0), Onions, dry (0.9), Bananas (0.7), Maize, green (0.7), Pears (0.7), Sorghum (0.7), Vegetables fresh other (0.7), Grapefruit (inc. pomelos) (0.7), Pumpkins, squash and gourds (0.6), Soybeans (0.5), Peaches and Nectarines other (0.5)

Appendix 4

List of all 92 unique crops supplying 95% of total food production for each of the six regions, the twenty sub-regions, and the twenty-five countries examined in this paper.

Master List of All Crops, All Regions, All Countries			
Apples	Cow peas, dry	Natural rubber	Rapeseed
Apricots	Cucumbers and gherkins	Oats	Rice, paddy
Artichokes	Dates	Oil palm fruit	Roots and Tubers, nes
Asparagus	Eggplants (aubergines)	Okra	Rye
Avocados	Figs	Olives	Seed cotton
Bananas	Fruit Fresh Nes	Onions (inc. shallots), green	Sesame seed
Barley	Fruit, tropical fresh nes	Onions, dry	Sorghum
Beans, dry	Garlic	Oranges	Soybeans
Beans, green	Grapefruit (inc. pomelos)	Other melons (inc.cantaloupes)	Spinach
Broad beans, horse beans, dry	Grapes	Papayas	Sugar beet
Cabbages and other brassicas	Groundnuts, with shell	Peaches and nectarines	Sugar cane
Carrots and turnips	Hazelnuts, with shell	Pears	Sugar crops, nes
Cashew nuts, with shell	Jute	Peas, dry	Sunflower seed
Cassava	Kiwi fruit	Peas, green	Sweet potatoes
Cauliflowers and broccoli	Lemons and limes	Persimmons	Tangerines, mandarins, clem.
Cereals, nes	Lentils	Pigeon peas	Taro (cocoyam)
Cherries	Lettuce and chicory	Pineapples	Tea
Chick peas	Lupins	Pistachios	Tomatoes
Chillies and peppers, green	Maize	Plantains	Triticale
Citrus fruit, nes	Maize, green	Plums and sloes	Vegetables fresh nes
Cocoa beans	Mangoes, mangosteens, guavas	Potatoes	Watermelons
Coconuts	Millet	Pulses, nes	Wheat
Coffee, green	Mixed grain	Pumpkins, squash and gourds	Yams

About the Author

CRAIG D. IDSO is the founder and former President of the Center for the Study of Carbon Dioxide and Global Change and currently serves as Chairman of the Center's board of directors. Dr. Idso received his B.S. in Geography from Arizona State University, his M.S. in Agronomy from the University of Nebraska - Lincoln, and his Ph.D. in Geography from Arizona State University, where he studied as one of a small group of University Graduate Scholars.

Dr. Idso has been involved in the global warming debate for many years and has published peer-reviewed scientific articles on issues related to data quality, the growing season, the seasonal cycle of atmospheric CO_2, world food supplies, coral reefs, and urban CO_2 concentrations, the latter of which he investigated via a National Science Foundation grant as a faculty researcher in the Office of Climatology at Arizona State University. Since 1998, he has been the editor and a chief contributor to the online magazine *CO_2 Science*.

Dr Idso is the author of several books, the most recent of which, *The Many Benefits of Atmospheric CO_2 Enrichment*, details 55 ways in which the modern rise in atmospheric CO_2 is benefiting Earth's biosphere. Dr. Idso has also produced three video documentaries, *Carbon Dioxide and the Climate Crisis: Reality or Illusion?*, *Carbon Dioxide and the Climate Crisis: Avoiding Plant and Animal Extinctions*, and *Carbon Dioxide and the Climate Crisis: Doing the Right Thing*, and he has lectured in Meteorology at Arizona State University and in Physical Geography at Mesa and Chandler-Gilbert Community Colleges.

Dr. Idso is a member of the American Association for the Advancement of Science, American Geophysical Union, American Meteorological Society, Association of American Geographers, Ecological Society of America, and The Honor Society of Phi Kappa Phi. He also serves as co-editor of the Assement Reports for the Nongovernmental International Panel on Climate Change (NIPCC) and he is the former Director of Environmental Science at Peabody Energy in St. Louis, Missouri.

About the Center

The *Center for the Study of Carbon Dioxide and Global Change* was founded as a non-profit organization in 1998 to provide regular reviews and commentary on new developments in the world-wide scientific quest to determine the climatic and biological consequences of the ongoing rise in the air's CO_2 content. It achieves this objective primarily through the weekly online publication of '*CO_2 Science*,' which is freely available on the Internet at **www.co2science.org**, and contains reviews of recently published peer-reviewed scientific journal articles, original research, and other educational materials germane to the debate over carbon dioxide and global change.

The Center's main focus is to separate reality from rhetoric in the emotionally-charged debate that swirls around the subject of carbon dioxide and global change and to avoid the stigma of biased advocacy by utilizing sound science. It has a stated commitment to empirical evidence and its position on global warming may be summarized as follows. There is little doubt the carbon dioxide concentration of the atmosphere has risen significantly over the past 100 to 150 years from humanity's use of fossil fuels and that the Earth has warmed slightly over the same period; but there is no compelling reason to believe that the rise in temperature was caused primarily by the rise in carbon dioxide. Moreover, real world data provide no compelling evidence to suggest that the ongoing rise in the carbon dioxide concentration of the atmosphere will lead to significant global warming or changes in Earth's climate.

In the 14-year period since its creation, the Center has published over 4000 timely and objective reviews of scientific research reports on both the biological and climatological effects of atmospheric CO_2 enrichment. Accompanying each review is the full peer-reviewed scientific journal reference from which the review was derived, so that patrons may independently obtain the original journal articles and verify the information for themselves.