Nutrient Decline in Vegetables

The Evidence

History of Concern About Nutrient Decline

The next two slides show data collected by Alex Jack. He is a member of the Preventive Medicine Center, and a writer, and has published quite a bit in the field of nutrition and healthy diets. Before the observations I am about to show you, Jack had published earlier glimpses of the same data, which caused quite a furor.

In the course of his writing, he has consulted the USDA's Food Composition Tables many times over the decades, and he noticed that the nutrient data in the composition tables has been changing significantly over the years. While researching for a recent book, he has compiled USDA data on food composition from 1975 to 1997.

The following two slides illustrate the changes shown in the USDA tables. His paper containing these tables includes several other charts addressing other vegetables and including fruits, all showing the same trend.

(https://www.betterbones.com/wp-content/uploads/2016/03/Americas-vanishing-nutrients-Decline-in-fruit-and-vegetable-quality-poses-serious-health-and-environmental-risks.pdf)

Selected Nutrients in Broccoli			
	1975	1997	% Change
Calcium	103 mg	48 mg	Down 53.4%
Iron	1.1mg	0.88 mg	Down 20%
Vitamin A	2500 IU	1542 IU	Down 38.3%
Vitamin C	113 mg	93.2 mg	Down 17.5%
Thiamin	0.10 mg	0.07 mg	Down 35%
Riboflavin	0.23 mg	0.12 mg	Down 47.8%
Niacin	0.9 mg	0.64 mg	Down 28.0%
Based on 100 grams, Edible Portion. *Source: USDA food composition tables*			

Calcium in Selected Garden Vegetables			
	1975	1997	% Change
Broccoli	103 mg	48 mg	Down 53.4%
Cabbage	49 mg	47 mg	Down 4.1%
Carrots	37 mg	27mg	Down 27%
Cauliflower	25 mg	22 mg	Down 12%
Collard Greens	203 mg	145 mg	Down 28.6%
Daikon	35 mg	27 mg	Down 22.9%
Kale	179 mg	135 mg	Down 24.6%
Mustard Greens	103 mg	83 mg	Down 43.7%
Onion	27 mg	20 mg	Down 25.9%
Parsley	203 mg	138 mg	Down 32%
Turnip Greens	246 mg	190 mg	Down 22.8%
Watercress	151 mg	120 mg	Down 20.5%
Overall Change			Down 26.5%
Based on 100 grams, edible portion. *Source: USDA food composition tables.*			

What would the effect be on us if this decline is real?

Take calcium for example.

In the US the recommended daily intakes for calcium vary, but take 1000 mg as an average. (Nearly all the rest of the world sets the requirement lower. The WHO recommends 500 mg, and the UK 700 mg.) (https://www.health.harvard.edu/staying-healthy/how-much-calcium-do-you-really-need)

To put nutrient density into practical context, consider that to get 1000 mg of calcium from broccoli in 1975, when there were apparently 103 mg/100g, you would need to consume (1000/103)100 = 970 grams, or about 34 ounces (2.13 lbs), of broccoli per day.

In 1997, when Ca concentration apparently was 48 mg per 100 g, you would have to consume (1000/48)100 = 2,080 grams (4.6 lbs) of broccoli per day to get your calcium.

That is, you would need to consume 2.14 times as much in 1997 as in 1975 to get your required micronutrients.

Supplement Facts

Serving Size 2 Gummy Vitamins
Servings Per Bottle 50

Amount Per Serving		% Daily Value
Calories	30	
Total Carbohydrate	7 g	3% †
Total Sugars	6 g	**
Includes 6 g Added Sugars		12% †
Vitamin D (as cholecalciferol)	25 mcg (1000 IU)	125%
Calcium (as tricalcium phosphate)	500 mg	38%
Phosphorus (as tricalcium phosphate)	200 mg	16%
Sodium	10 mg	< 1%

† Percent Daily Values are based on a 2,000 calorie diet.
** Daily Value not established.

Other ingredients: Sugar, glucose syrup, water, gelatin; less than 2% of: canola lecithin, citric acid, colors (annatto extract, blueberry and carrot concentrates, purple carrot juice concentrate), lactic acid, medium chain triglycerides, natural flavors, and pectin.

Processed in a facility with products that contain egg, fish, shellfish, soy and tree nuts.

The original observation sparked quite a sensation!

Rodale, Inc, publishers of Organic Gardening magazine, wrote an open letter to the U.S. Secretary of Agriculture demanding to know what was being done to protect the American food supply.

The USDA subsequently confirmed the apparent loss of nutrients revealed in the original study, but questioned the idea that it was the result of the environmental crisis or soil depletion.

Instead, the agency contended that changed testing methods and uncontrolled comparisons may be responsible for the discrepancies.

In other words, the UDSA suggested that these apparent declines do not reflect real changes in nutrient density, but are artifacts of measurement methods.

Following on Jack's early observations, Mayer (1997) wrote an article (British Food Journal 99: 207-211) assessing whether the same declines could be seen in Britain. They could.

A comparison of the mineral content of 20 fruits and 20 vegetables grown in the 1930s and the 1980s (published in the UK Government's Composition of Foods tables) shows several marked reductions in mineral content.

There were statistically significant reductions in the levels of Ca, Mg, Cu and Na in vegetables and Mg, Fe, Cu and K in fruit. The only mineral that showed no significant differences over the 50 year period was P.

So, we are left with questions. Is the apparent nutrient decline real? If so, why is it happening, and what can we do about it?

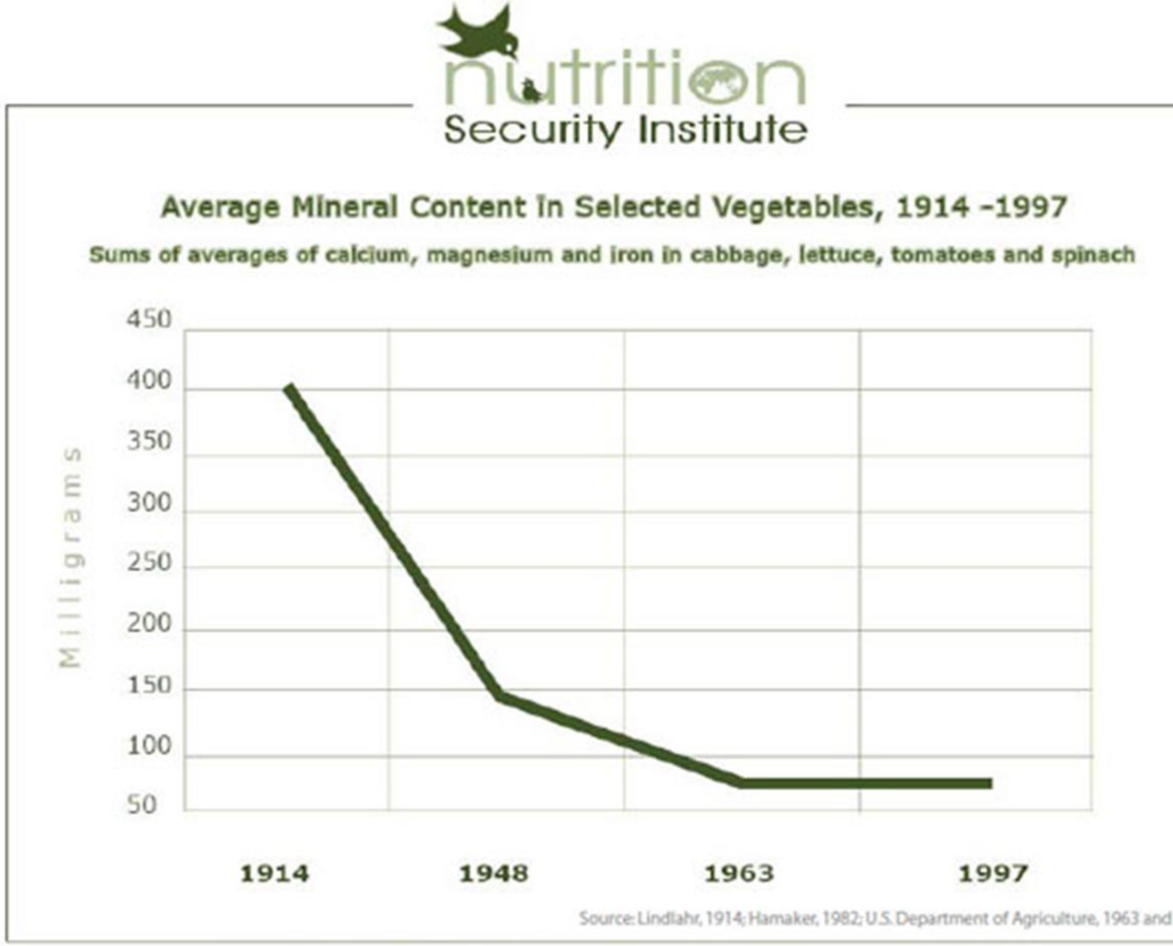


Photo credit:
www.truefoodsnutrition.com.au

Is it real? I found only one recent peer-reviewed paper that seemed to suggest the decline is not real. (Marles, RJ. 2016. Journal of Food Composition and Analysis. http://dx.doi.org/10.1016/j.jfca.2016.11.012)

Marles argues against what I think is a 'straw man,' the notion that apparent nutrient decline is caused by a decline in soil quality. Although this was suggested as a possibility by Alex Jack when he published his earliest observations, evidence for this is lacking, and it has not been put forth as the basis of the apparent decline for many years.

As one reads through this review, one finds that Marles does indeed admit that there has been a decline in nutrient density, although not caused by soil depletion, but argues that this is not a cause for concern, and that the food composition tables can still be a useful guide to an adequate diet.

Note that the food intake amount required for an adequate diet would have to increase to provide adequate nutrients.

It is true that measurement techniques and equipment have changed greatly in the past century. Therefore there is some merit to the criticism that the apparent declines seen in comparisons of old data to new, as when we compare old UDSA tables to new ones, might be artifacts of measurement.

So lets leave those behind, just with the observation that there were a lot of such measurements, all with the same basic conclusion, and they were responsible for bringing the issue to our attention.

Instead we will look for evidence of nutrient decline in situations where all the measurements are done with modern techniques.

Evidence Independent of Time Gap

What might have happened in the last century that could account for this apparent decline in nutrient density?

One thing that happened was the "Green Revolution," introducing chemical pesticides, synthetic fertilizers and hybrid plants. In 1926 a commercial seed company called Pioneer Hi-Bred introduced hybrid corn seeds.

Hybrid seeds offered advantages to both sellers and buyers, and soon replaced more traditional OP varieties. For growers, hybrid plants often grew more rapidly and gave greater yields. For sellers, advantages were that the hybrids were not true-breeding, and so seeds had to be purchased annually, rather than being saved.

So, it could be thought that the apparent nutrient decline in food plants might be explained if the older OP plants were more nutrient-dense than the new hybrid varieties. Or perhaps the introduction of synthetic fertilizers or other chemicals led to the decline.

PIONEER HI-BRED INTERNATIONAL, INC.

PIONEER®
A DUPONT BUSINESS

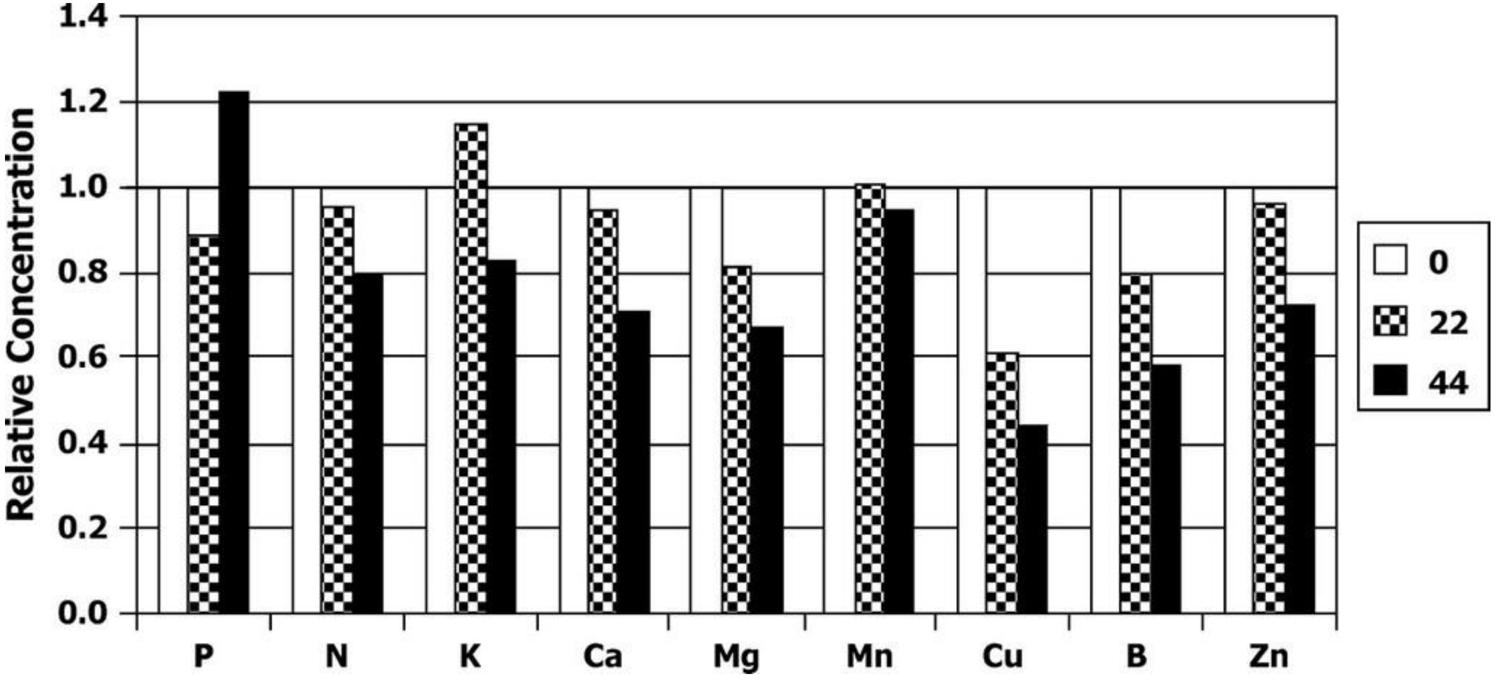
Science with Service Delivering Success™

One of the prominent investigators of the nutrient decline phenomenon is Donald R. Davis, PhD, a biochemist at the University of Texas. In 2009 he published a review (in the reference list) of studies, both observational and experimental, related to nutrient decline. He divided the evidence in the literature into three sorts.

One category included several repetitions of comparisons of nutrient densities in vegetables now versus decades ago. These data all found declines over periods ranging from 100 years to 30 years. I’ll take this as given, and go on to the other sections.

A second category included studies on the effect of chemical fertilization on nutrient density.

The final category involved comparisons of nutrient density in side-by-side plantings of lower and higher yield varieties of the same crop.



This graph shows the effect on nutrient density in red raspberry plants grown in soil containing 12 ppm phosphorus, and given an additional dose of P to raise the concentration to 22 or 44 ppm P. The dry matter of the plants more than doubled with the increase to 44 ppm P. Measuring mineral concentrations per gram of dry matter revealed an increase in P, but declines in the concentrations of all other nutrients measured. (Hughes et al., 1979, *HortScience* 14 521 523)

What was observed in these raspberry plants is a phenomenon often referred to as “the dilution effect.”

The idea is that the extra biomass that the plants developed in the supplemented P situation was predominantly carbohydrates, including starch and cellulose.

The plants that received the additional 44 ppm of P did incorporate somewhat more mineral nutrients than the unsupplemented plants, but the amount taken up was not in proportion to the amount of extra bulk. Thus the concentration in minerals per gram was “diluted” compared to the unsupplemented plants.

The dilution effect has been observed with a great many growth-promoting additions, including increasing available water, increased levels of various sorts of fertilizers, increased temperature, addition of mycorrhizal fungi, addition of rhizobia, and others. Essentially adding any rate-limiting substance.

Observations of this sort are referred to as “chemical dilution.”

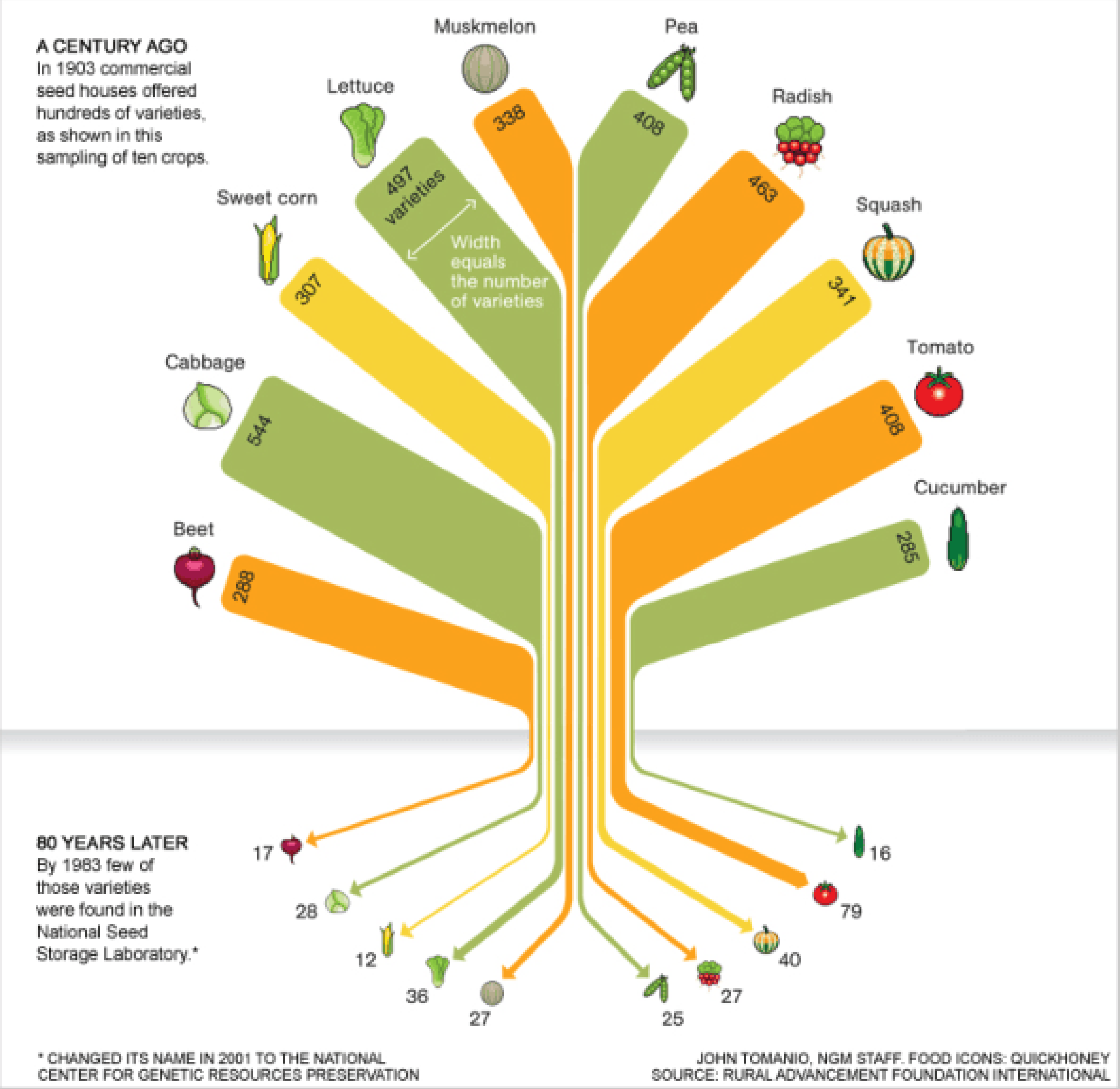
Farnham, Grusak & Wang (2000) looked at broccoli head weight compared to mineral density during two seasons, using several cultivars, and found yield and mineral density to be negatively correlated.

Garvin, Welch & Finley (2006) found winter wheat yield to be negatively correlated with seed mineral content, using several cultivars.

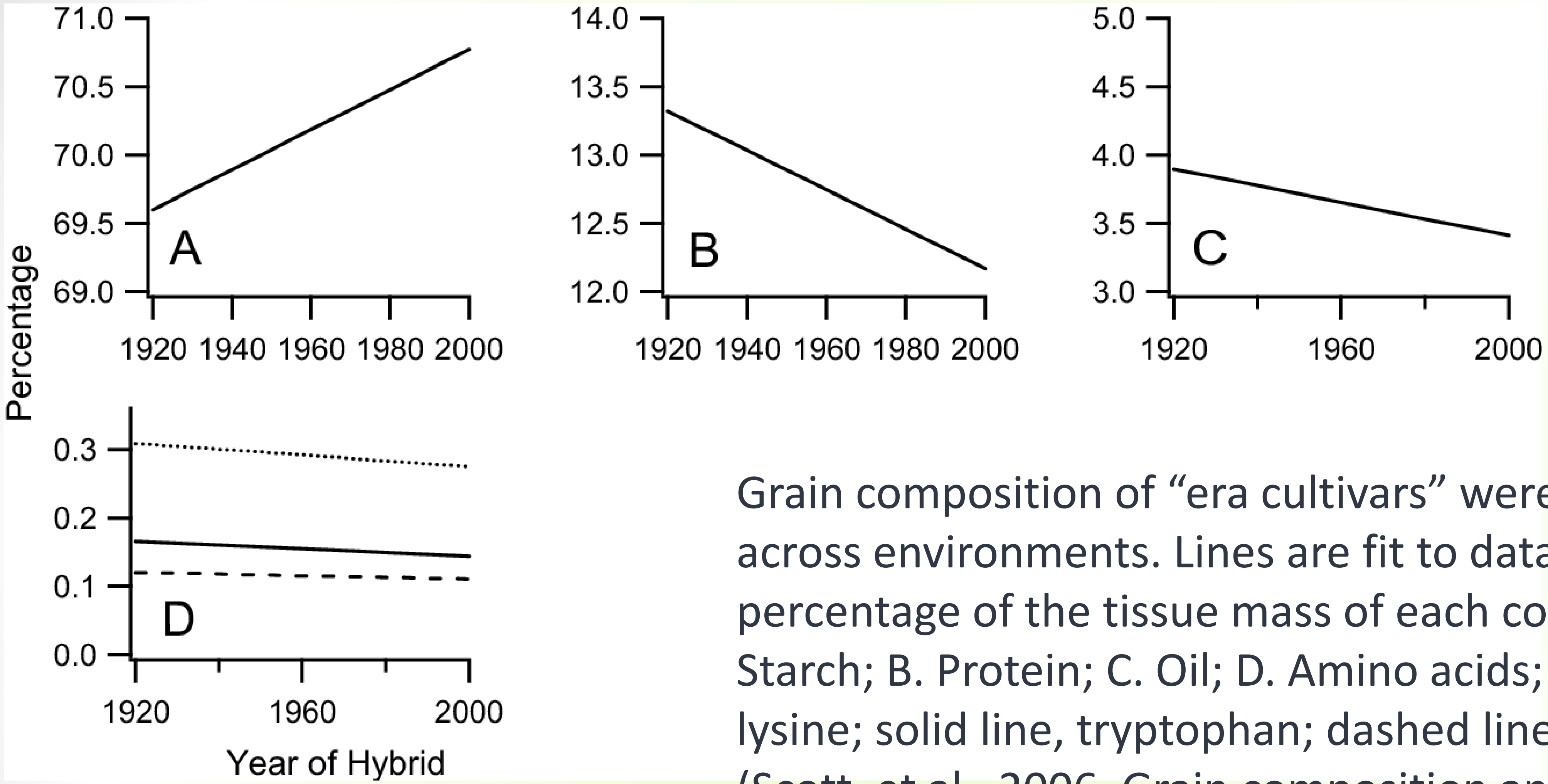
Murphy, Reeves & Jones (2008) did an outstanding study with many replications and several varieties of wheat grown in Washington. Some of the varieties were “historical,” and others were modern hybrids. The modern varieties all produced higher yields, and the historical varieties all produced higher nutrient densities.

These studies and many others suggest that indeed the Green Revolution with its high yielding plants and yield enhancing fertilizers have contributed to a decline in nutrient density.

Differences between old and new varieties, grown side-by-side, reflect genetic differences, so this effect could be called genetic dilution.



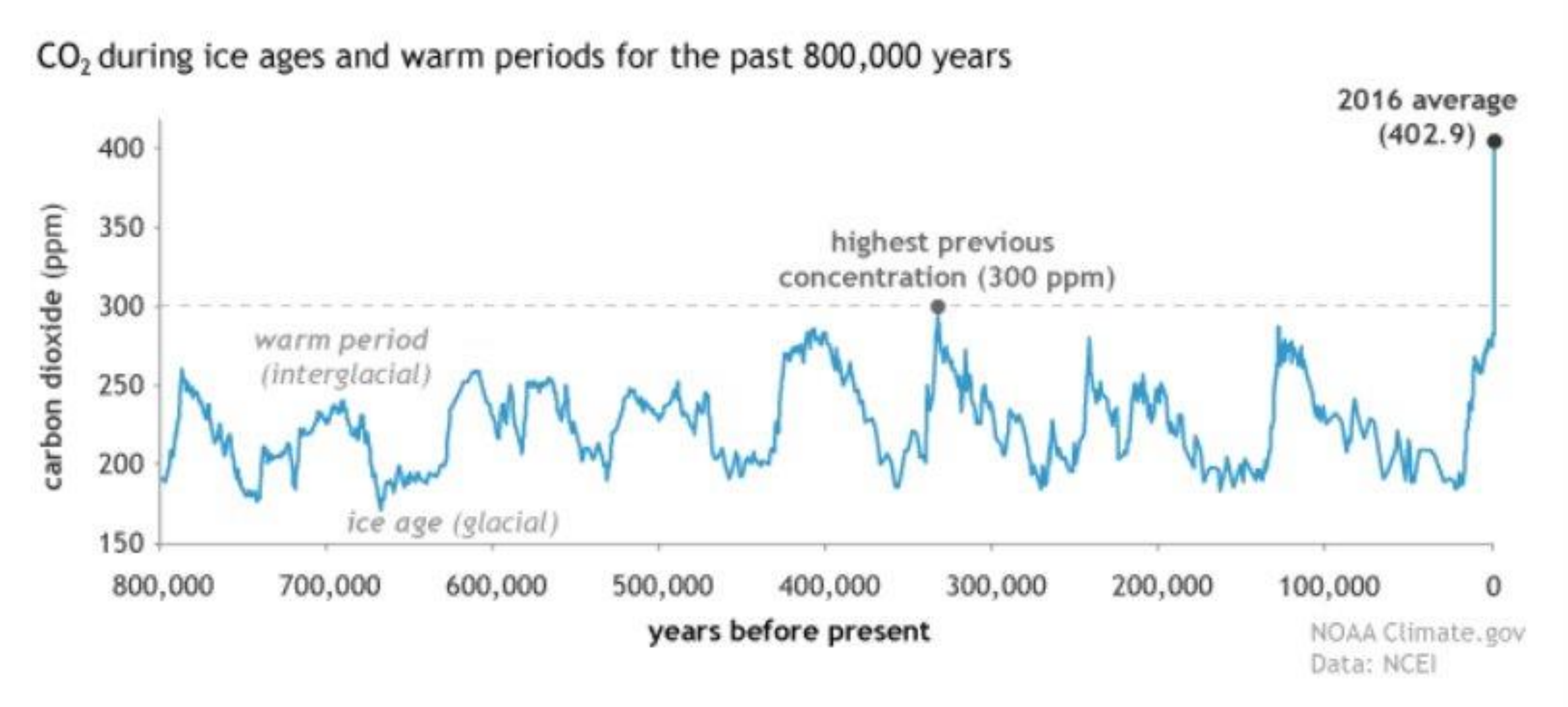
A CENTURY AGO
In 1903 commercial seed houses offered hundreds of varieties, as shown in this sampling of ten crops.
Muskmelon
338
Pea
408
Lettuce
497 varieties
Width equals the number of varieties
Radish
463
Sweet corn
307
Squash
341
Tomato
408
Cabbage
544
Cucumber
285
Beet
288
80 YEARS LATER
By 1983 few of those varieties were found in the National Seed Storage Laboratory.*
17
28
12
36
27
25
27
40
79
16
* CHANGED ITS NAME IN 2001 TO THE NATIONAL CENTER FOR GENETIC RESOURCES PRESERVATION
JOHN TOMANIO, NGM STAFF. FOOD ICONS: QUICKHONEY
SOURCE: RURAL ADVANCEMENT FOUNDATION INTERNATIONAL



Grain composition of "era cultivars" were averaged across environments. Lines are fit to data plotted as percentage of the tissue mass of each component. A. Starch; B. Protein; C. Oil; D. Amino acids; dotted line, lysine; solid line, tryptophan; dashed line, methionine. (Scott, et al., 2006. Grain composition and amino acid content in maize cultivars representing 80 years of commercial maize varieties.)

What About Carbon Dioxide?

Another change that has occurred in the last decades is a huge and ongoing increase in atmospheric carbon dioxide.



Since CO_2 is an essential part of photosynthesis, it would be reasonable to expect increased CO_2 to increase photosynthesis, thus increasing carbohydrates and increasing nutrient dilution.

But is that what happens to plants as CO_2 rises? And what else happens? And what happens to plants after long term exposure to high CO_2 levels?

There are many ways to expose plants to elevated CO_2. They can be grown in a bell jar with introduced gas, or in a greenhouse with a block of dry ice, or on a lab bench. These methods share the drawback of changing the environment in additional ways.

For this reason, several dozen FACE (free air carbon dioxide enhancement) centers have been constructed around the globe, and affecting various kinds of plants.

CO_2 mixed with air is pumped into the area from surrounding sources, and a CO_2 monitor exists at leaf level. Rain, wind, sunshine, insects, etc go on undisturbed. Effects on plants are observed.

Following is a description of one built in India (Maini, et al., 2002, Environmental Science).

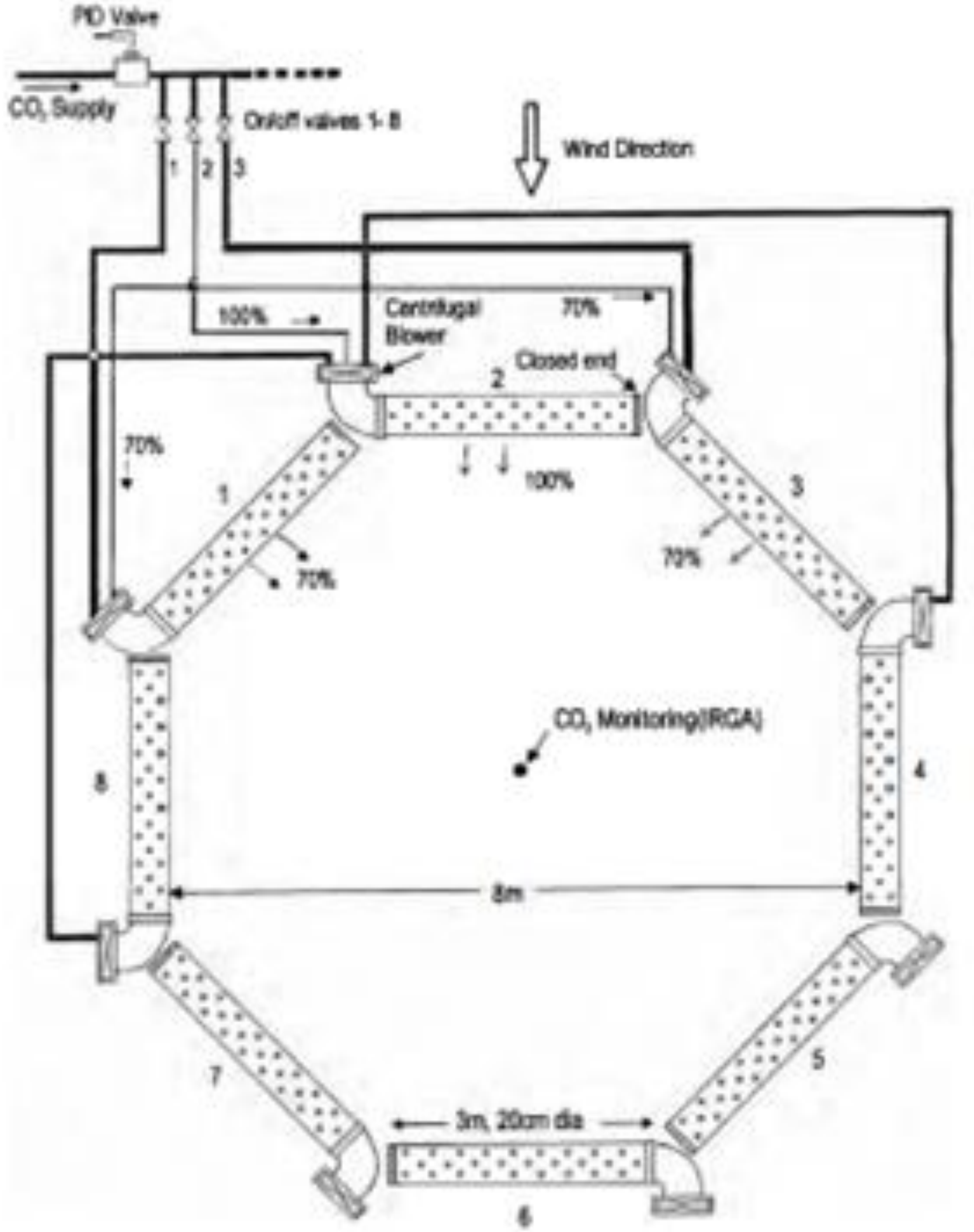


Fig. 1—Layout schematic of Mid-FACE facility

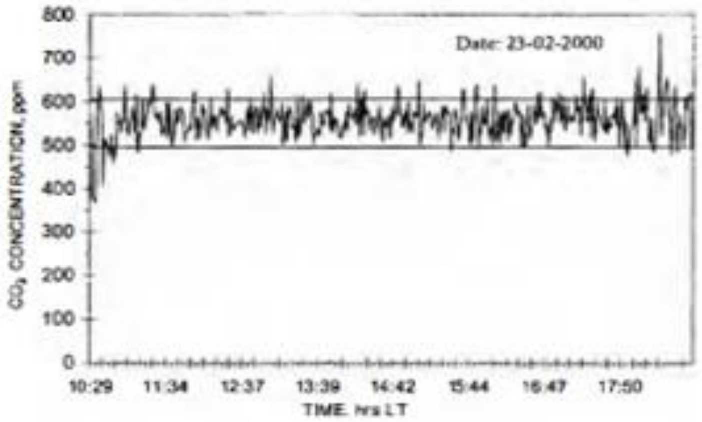
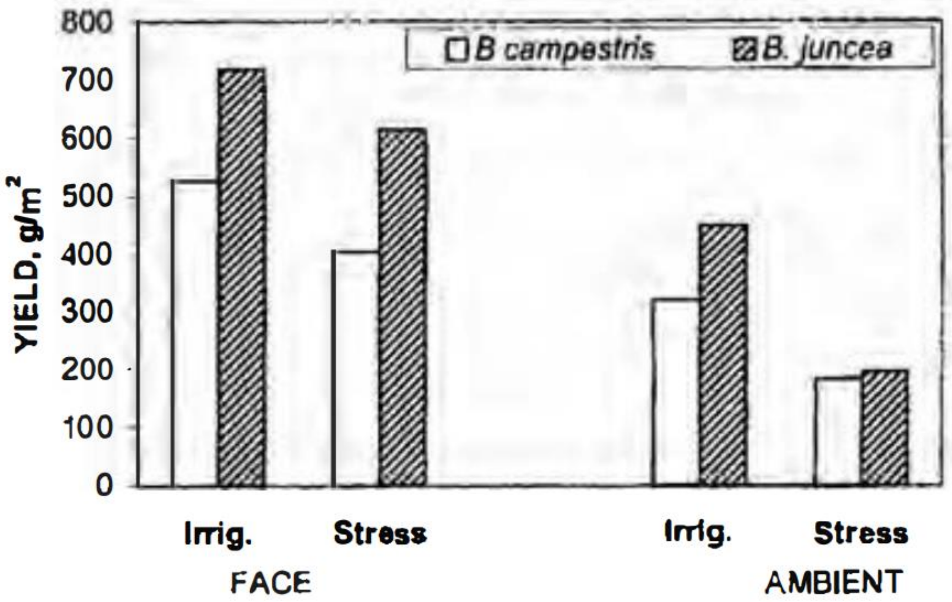


Fig. 4—Daylong CO_2 concentration at the center of the Mid-FACE



I studied two meta-analyses on the topic of rising CO_2 and nutrient density in FACE experiments: Ainsworth & Long (2005) and Loladze (2014).

Ainsworth & Long meta-analysed data from 124 publications on over 40 species from 12 FACE facilities ranging in e[CO_2] from 475 to 600 ppm.

The data showed, among other things, that exposure to elevated [CO_2] resulted in a 31% increase in the light-saturated leaf photosynthetic rate and a 28% increase in photosynthetic carbon assimilation when averaged across all FACE experiments and species. Apparent maximum yield increased by 12%.

Carbohydrate levels in leaves accumulated, and leaves thickened and became fewer, and stomata were fewer and open less often.

Stomatal conductance was reduced by 20% with growth at elevated [CO_2] when averaged for 40 species grown at all 12 FACE experiments.

Ainsworth & Long related the reduced stomatal opening and conductance to “more efficient water use,” and indeed the soil was moister in the FACE areas.

Reduced rates of transpiration and more efficient water use have been noted by many (2022, Center for the Study of Carbon dioxide and Global Change).

Water use efficiency is of course to be desired, but reduction of transpiration has a downside.

Transpiration powers the xylem system, which is responsible for carrying water and dissolved mineral nutrients up from the roots and around the plant. So reduced transpiration should mean less uptake of mineral nutrients.

Dugas, et al. found that the transpiration rate dropped by about one-half upon transfer of plants from ambient CO_2 to air containing 980 ppm CO_2. In addition, plants grown for a year at 980 ppm CO_2 and measured at that same concentration exhibited transpiration rates that were only one-fourth of those of control plants grown and measured at 385 ppm CO_2. (Dugas, Polley, Mayeux & Johnson, 2001. Tree Physiology 21: 771-3)

Loladze (2014) meta-analysed 7761 observations, including 2264 observations at state of the art FACE centers, covering 130 species/cultivars. The attained statistical power is huge.

He divides his discussion of the effects of elevated [CO_2] into effects on plant quantity (yield) and effects on plant quality (nutrient content).

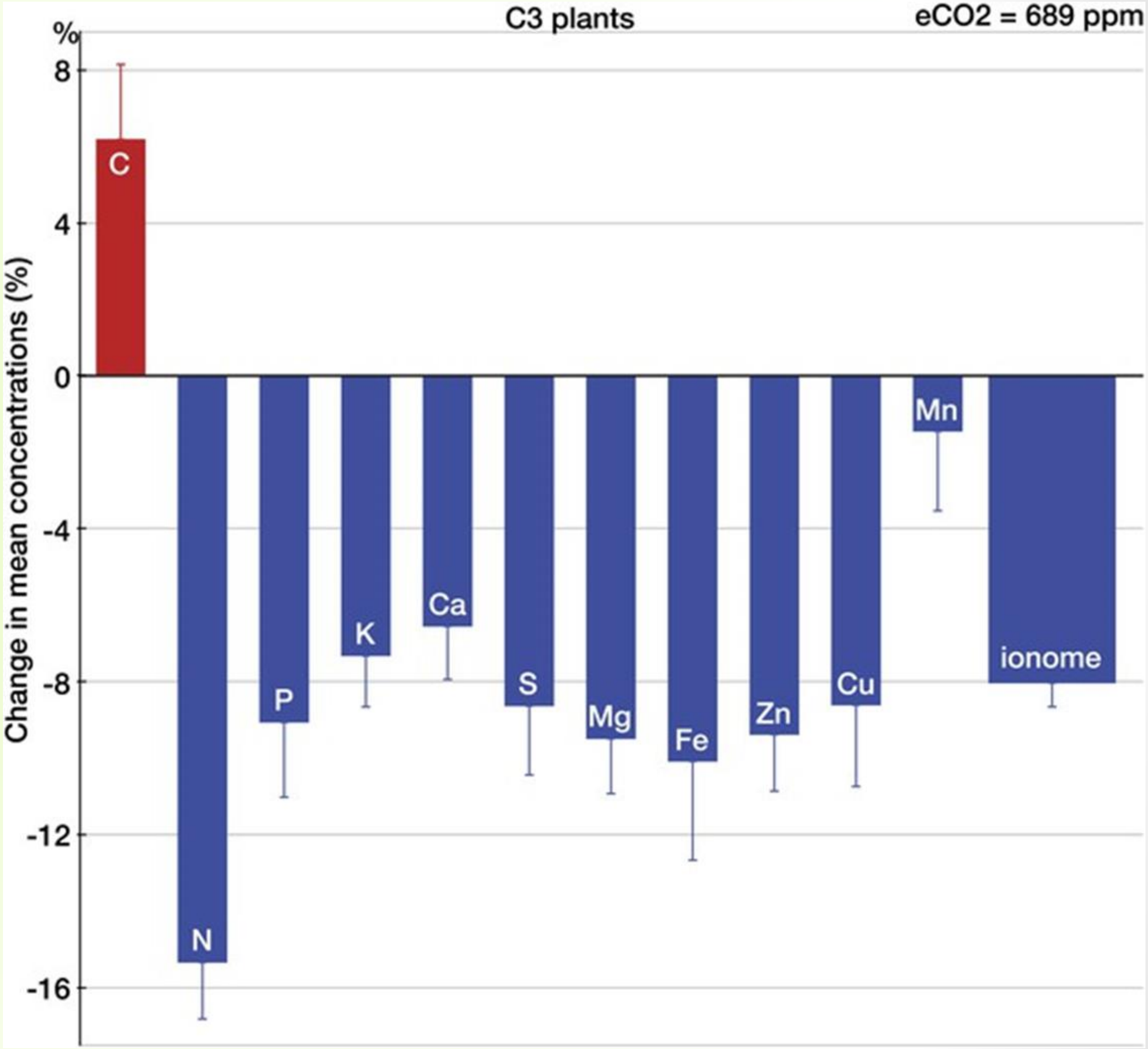
He points out that effects on quantity have been widely studied, and increased yields attributable to elevated CO_2 have been welcomed by some, given that there will be a lot more people to feed in another generation or so. Plant quality, on the other hand, has not been as widely discussed in connection with climate change.

“A higher concentration of carbon dioxide in our atmosphere would aid photosynthesis, which in turn contributes to increased plant growth,” Rep. Lamar Smith (R–Texas) wrote in an op-ed last year. “This correlates to a greater volume of food production and better quality food.” Scientists and others calling for emission cuts are being hysterical, he contends. (https://www.scientificamerican.com/article/ask-the-experts-does-rising-co2-benefit-plants1/)

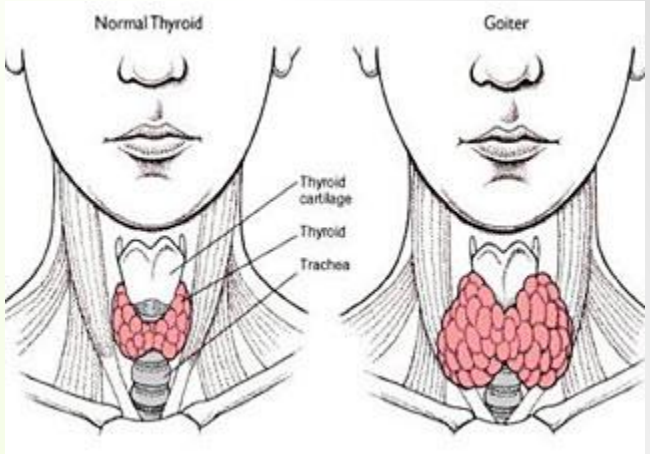
Loladze was able to show that, when averaged across very different plant and tissue types, experimental approaches and locations, elevated CO_2 reduced the overall mineral content of plants by about 8%.

At the same time, elevated CO_2 was shown to strongly increase the ratio of soluble carbohydrates (starch and sugars) to proteins.

For the future, it would be useful to measure nutrients as mgs per calorie, rather than mg/gm, as calories (carbs)/gm are increasing.



Some of the mineral nutrients play very important roles in maintaining our health and functioning, such as Fe, Mg, Zn and Ca. Deficiencies in these lead to multiple and potentially even lethal consequences.



But deficiencies in minerals with more limited functions can also be devastating. Let iodine (I) be an example.

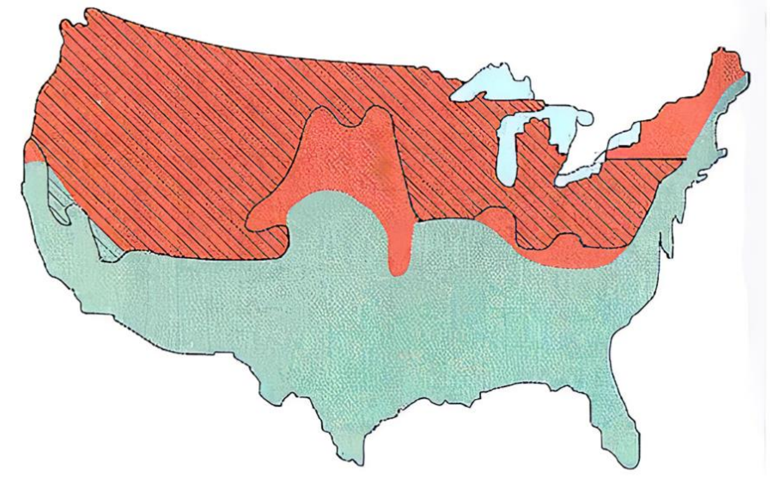
In the 1800s a disease was common in Switzerland which involved enlarged thyroid (goiter) and cases of cretinism.

Consumption of seaweed was found to reduce goiters, so goiters came to be treated by adding seaweed to the diet. Then it was discovered that seaweed contains iodine, and iodine itself was found to be a more effective treatment.

In due course iodine was added to salt as a preventive treatment, and goiter and cretinism vanished from all places with enough organization and means to produce iodized salt.

The US added iodine to salt in 1924 to combat iodine deficiency diseases

A paradoxical aspect of 'hidden hunger' is that only minuscule amounts of minerals are required and could be provided easily – in theory - to everyone, by fortifying foods with minerals. However, this does not happen for large parts of the world's community.



Map showing spatial correlation between the former "Goiter Belt" in the northern U.S. and areas where the iodine content of drinking water is naturally low.

The case of iodine is a good example: although iodized table salt has wiped out iodine deficiency in the industrialized world, a billion people still have no regular access to it, making iodine deficiency the leading cause of preventable brain damage, cretinism, and lower IQ in children, as well as goiter (Welch and Graham, 1999; WHO, 2002).

Micronutrient inadequacies other than iodine are common in Americans (Drake, VJ, 2017, https://lpi.oregonstate.edu/mic/micronutrient-inadequacies/overview)

There is an additional issue concerning the ongoing changes in plants. Recall that now we need to consume more carbohydrates in order to get our mineral requirements.

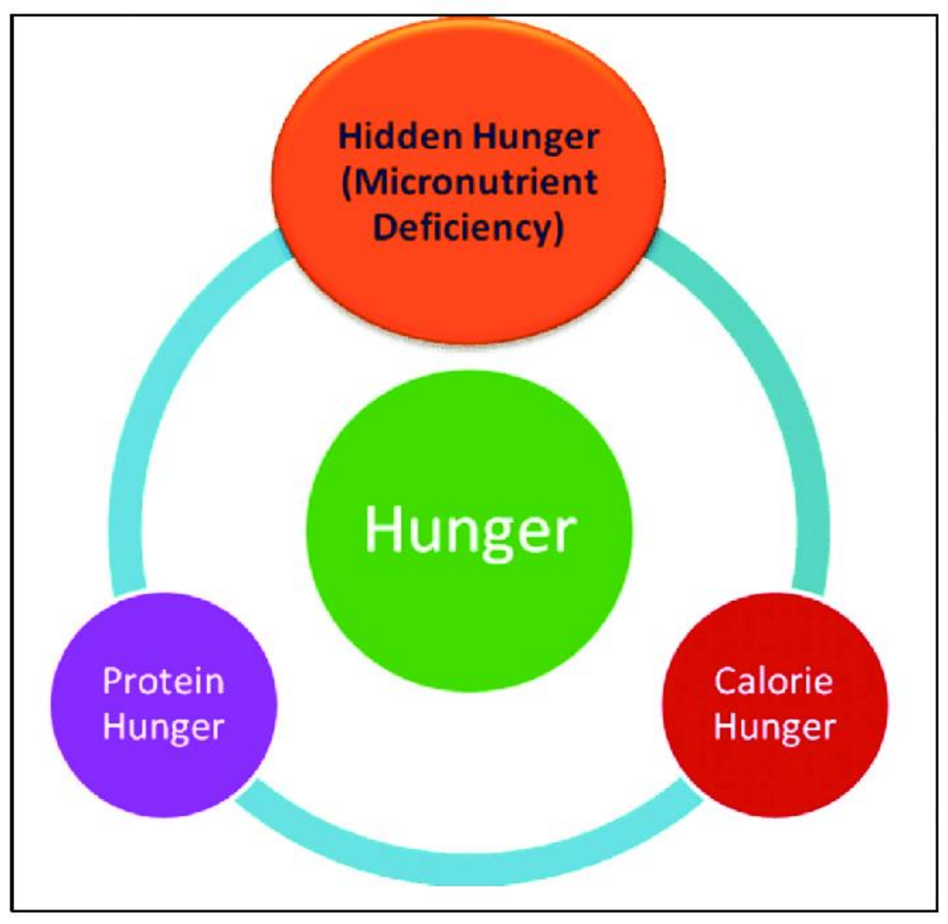
To summarize, there is good evidence that the vegetables we depend on for our mineral nutrients are becoming less able to provide them. Of course, the animals we use for food are also dependent on plant mineral nutrients, and we should expect reductions in these nutrients in meat, eggs, and milk as well as in our vegetables.

In fact, articles in Mother Earth News (2009, 2011 & 2013) claim exactly that.

The same factors that contribute to reduction in mineral density at the same time lead to increase in carbohydrates.

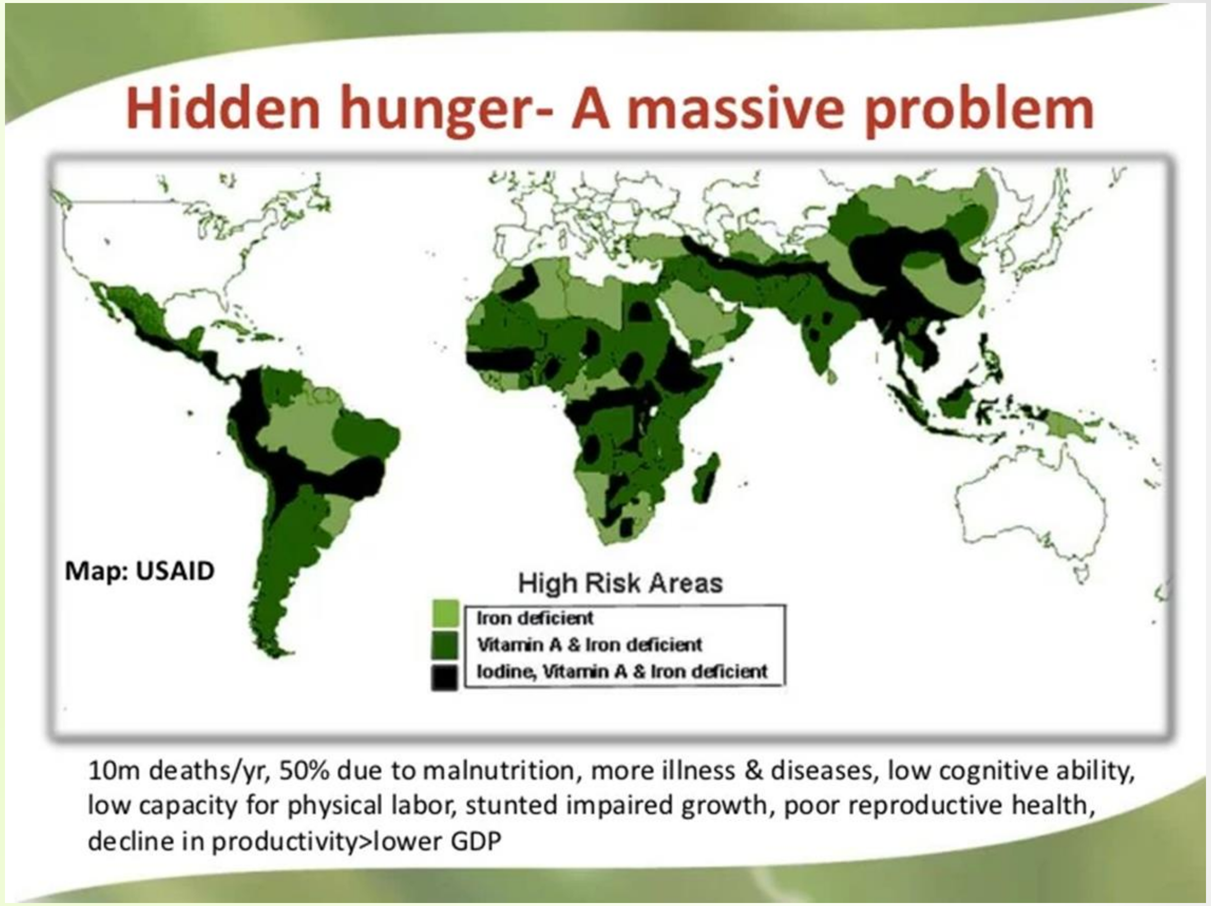
Does this matter?

Loladze relates his findings of the connection of rising [CO_2] to decreasing nutrients to what is known as “Hidden Hunger,” which does matter.



Bimal Prasanna Mohanty, PhD
Indian Council of Agricultural Research

There are different kinds of hunger, but if any kind affects a person for an extended period, physical harm and mental disability will follow.



Calorie hunger happens when one has not taken in a sufficient amount of food that can be broken down to provide energy (carbs, protein, fat).

Protein hunger when we haven't eaten enough protein or amino acids to support tissue growth and repair.

Hidden hunger is when one has adequate protein and energy, but lacks one or more minerals or vitamins. This is the crux of the problem with the decline in nutrient density in vegetables.

(Bradley, KL What is Hidden Hunger and Why Good Nutrition Is Essential to Fight It, https://iamherbalifenutrition.com/global-responsibility/hidden-hunger/)

https://www.sdg2advocacyhub.org/news/hunger-obesity-paradoxes-our-food-system

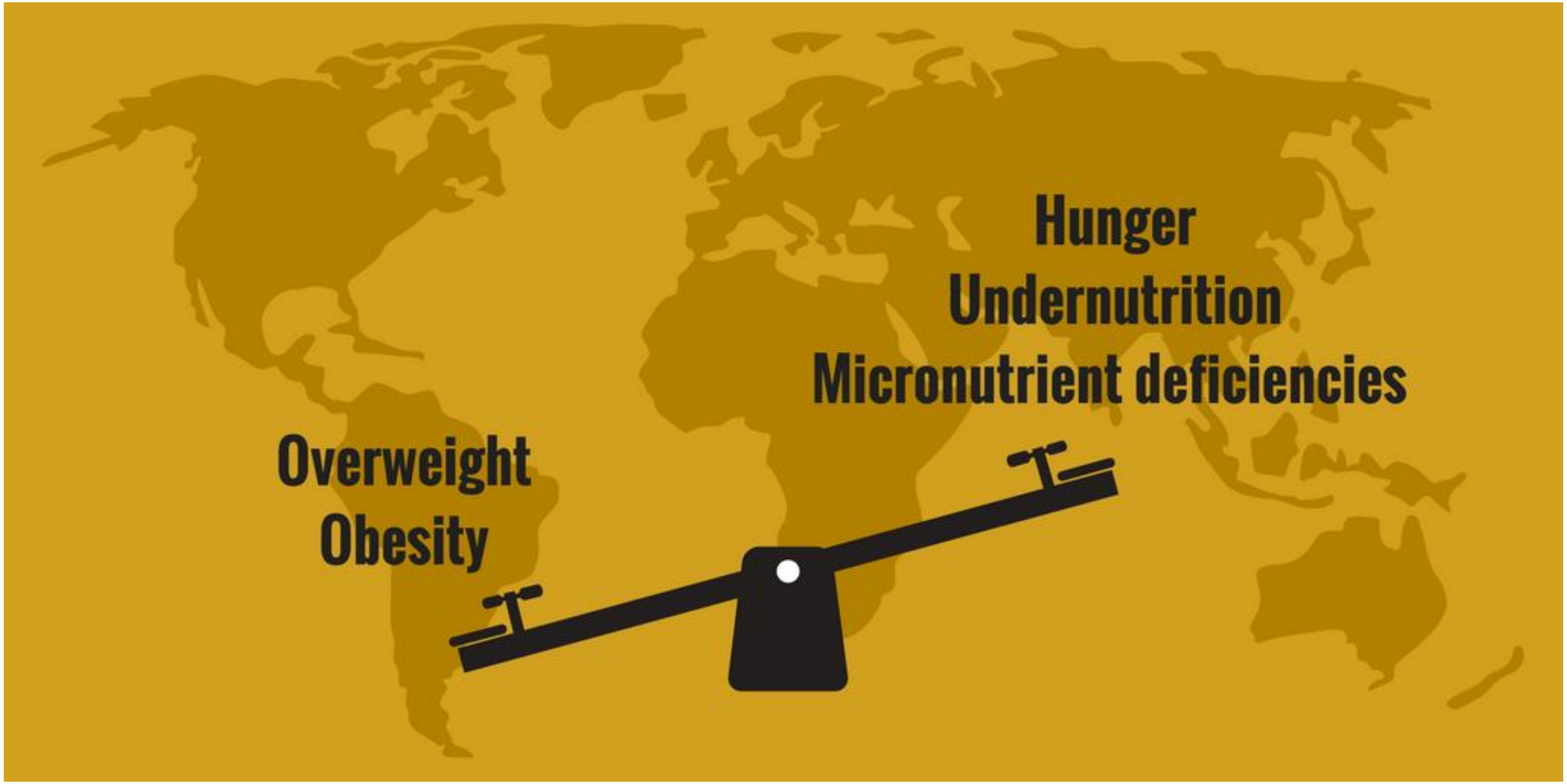
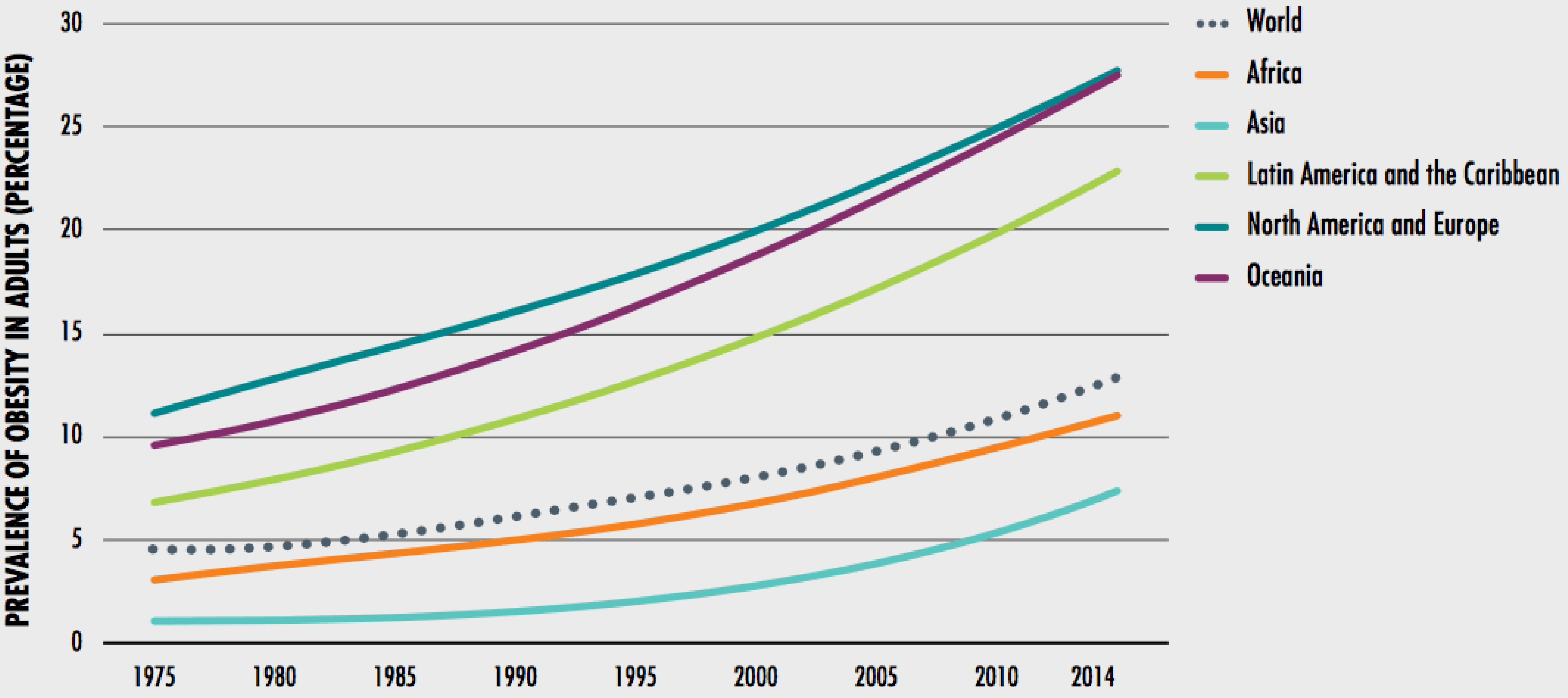


FIGURE 7
ADULT OBESITY IS RISING EVERYWHERE AT AN ACCELERATING PACE



NOTES: Prevalence of obesity in adults 18 years and over, 1975–2014.
SOURCE: WHO/NCD-RisC and WHO Global Health Observatory Data Repository, 2017.

Those are the problems. Are there any solutions?

Perhaps the most hopeful thing about the future of food that can be gleaned from what I have said can be found in the comparisons of different cultivars in the studies on “genetic dilution.”

Wide variation in nutrient contents within species have been observed, there are many underutilized species and cultivars. Such information should be sought out and publicized, both so that we can choose to eat more nutritious cultivars and so that plant breeders can use them for breeding programs aimed at increasing the nutrient content of more commonly used varieties. (https://www.intechopen.com/chapters/75589)

Gene forms leading to enhanced nutrient density, once identified, can be used for within-species breeding projects, or for gene transplant projects like the one that created “golden rice.”

Gene modification or editing via CRISPR can be used to improve nutrient density. For example, Diaz de la Garza et al. (2004) developed folate-rich tomatoes by engineering over expression of two enzymes that catalyze initial steps in the biosynthesis of folic acid (vitamin B9). Vine ripened fruits contained on average 25 fold more folate than controls.

There is also a need for breeding for CO_2 tolerance. Can plants be bred or engineered that do not reduce transpiration at elevated [CO_2] and therefore continue to take up soil minerals at a good rate?

From the point of view of a consumer of commercially grown food, the bottom line of these studies would seem to be that yes, you can get your required nutrients from vegetables under today's conditions, but in order to do so you must consume more carbohydrates.

This will be ever more true as [CO_2] increases.

From the point of view of the home gardener who wants to rely on garden produce for meeting nutritional needs, it would help to seek out and grow heirloom varieties, and avoid modern hybrids.

Unfortunately, though, data show that old varieties, like high-yielding hybrids, also respond to rising [CO_2] by reducing transpiration and mineral uptake.

References

Davis, DR (2009). Declining fruit and vegetable composition: What is the evidence? (https://doi.org/10.21273/HORTSCI.44.1.15)

Diaz de la Garza, R., Quinlivan, E.P., Klaus, S.M., Basset, G.J. and Gregory, F. F, 2004. Folate biofortification in tomatoes by engineering the pteridine branch of folate synthesis. Proc. Nat. Acad. Sci. 101: 13720-13725.

Keily, Lynn (2013). Overfed and Undernourished: Nutrient Deficiency in Our Modern Diet. https://www.motherearthnews.com/natural-health/nutrient-deficiency-zm0z13jjzmat/

Loladze, I. (2014) Hidden Shift of the Ionome of Plants Exposed to Elevated CO2 Depletes Minerals at the Base of Human Nutrition. eLife, 3, e02245. https://doi.org/10.7554/eLife.02245

Weigel, H-J (2014). Plant quality declines as CO2 levels rise. DOI: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4036122/