# F.A.S. *PUBLIC INTEREST REPORT*

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## Sustainable Agriculture Through Plant Nutrition and Biodiversity

This newsletter provides background on two new FAS projects arising from truly innovative approaches to food-security.

**Fortify Plants Rather Than People**

Literally billions of people suffer from deficiences in iron, iodine, zinc, vitamin A and other micronutrients. As a consequence, they suffer from anemia (especially serious for no less than 50 percent of the Third World's women), from mental retardation and eye damage and, probably, from a great deal more that is not yet recognized.

Especially in developing countries, it is no easy task to "fortify" goods in the marketplace, to provide vitamin and mineral "supplements" or to organize nutrition education. What to do?

The best, and most cost-effective, solution—if it can be done—would be to breed plants that provide the micronutrients directly; this could build a solution to nutrient deficiencies right into the agricultural system itself. There is evidence, gathered by Howarth Bouis and his associates at the International Food Policy Research Institute, that this can be done.

The FAS Micronutrient Project, which will be chaired by Bouis, will produce a small publication, beginning in the Fall, which will be sent to specialists and interested public policy experts in such a way as to draw attention to what needs to be done to resolve the obstacles to the success of the research.

**Exploiting Biodiversity To Fill World Needs**

Without any further plant breeding, there is much the world could do to use nature's bounty—if it only wished. In fact, while many champion "biodiversity" few try to mine, milk or utilize all that has been provided to us. Only a tiny fraction of the food

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## Breeding for Nutrition

*by Howarth E. Bouis*

Taken together, mineral and vitamin deficiencies affect a far greater number of people in the world than protein-energy malnutrition. Can commonly-eaten food staple crops be developed which fortify their seeds with essential minerals and vitamins? Can farmers be induced to grow such varieties? If so, would this result in a significant improvement in human nutrition at a lower cost than existing nutrition interventions?

Having concluded that the available scientific evidence indicates positive answers to all three of the above questions, four of the eighteen international agricultural research centers supported by the Consultative Group on International Agricultural Research (CGIAR) recently have embarked on an interdisciplinary effort, with collaborators in developed and developing countries, to produce mineral and vitamin enriched varieties of rice, wheat, maize, beans and cassava. Not only does plant breeding hold great promise

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## Applying Biodiversity

*by Noel Vietmeyer*

The number of species that now sustain humanity is very small. Of the 3500 mammals, only cattle, sheep, pigs and goats are globally employed as livestock. Of the 9000 birds, only the chicken is a true global contributor. And of the 20,000 food plants, a mere dozen or so have been raised to the top rank of global resources and hardly more than 100 have been properly domesticated at all. Obviously, there is a vast undeveloped frontier of science—the frontier of natural resources.

Development of this frontier is among the most vital of scientific endeavors. More crops, more trees and more animals are needed to counter the increasing stresses brought about by human population growth, land degradation, deforestation, soil erosion, soil infertility, desertification, and other difficulties. Put another way, we need an additional set of resources better fitted to meeting and even reversing the harshness that is rising around the earth.

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and plants that could be useful to man have been commercialized.

The world's most indefatigable leader in the effort to "apply" biodiversity—a modern-day informational Johnny Appleseed—is Noel Vietmeyer. For the last 20 years, operating out of the National Academy of Sciences and supported, until recently, by grants mainly from the Agency for International Development, he has investigated, reported on and disseminated these reports world wide, on "new" (i.e., "old") plants (and animals) that could be far more useful if their virtues were more widely known.

Some of these plants have food advantages either for the consumer or for the developing country producer. Some are very fast growing trees. Some are grasses very useful for halting erosion. In his report below, you will see the fascinating promise that existing biodiversity provides.

Vietmeyer will be chairing a small FAS advisory committee on Applied Biodiversity that will, in a variety of ways, seek to advance public understanding, and worldwide use, of under-utilized plants.

—*Jeremy J. Stone*

■

## Project Cusp

As part of its Project Cusp, FAS is organizing small groups of specialists in various relevant fields of global security who work, without compensation, through FAS but from their own places of employment—in effect using FAS as a staging base.

This issue of the ***P.I.R.*** contains background on two such projects—both related to food security. The next issue will report on the goals and formation of some other new projects, including international health activities, systemic risk (which includes risks of economic collapses), and scientific advice to local, state and federal governments. The largest amount of FAS funding and activity continues, as before, to be in peace and disarmament issues. ■

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# FAS



The Federation of American Scientists (FAS), founded October 31, 1945 as the Federation of Atomic Scientists by Manhattan Project scientists, engages in research and advocacy on science-and-society issues, especially global security.

Current war and peace issues range from nuclear war to ethnic conflict and from nuclear disarmament to arms sales; sustainable development issues include disease surveillance, climate modification, poverty, food security and environment. FAS also works on human rights of scientists and on reductions in secrecy.

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BOARD OF TRUSTEES

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The good thing is that these potentially vital species do exist. Among *unsupported* species are:

•**2000 food plants native to Africa** (only sorghum gets research, and even it doesn't get much);

•**3000 tropical fruits** (only banana and pineapple are truly international resources);

•**1000 tropical vegetables** (none in widespread use, despite the prevalence of malnutrition);

•**20,000 tropical trees** (almost no tropical tree is yet intensively used for reforestation);

•18,000 legumes that pump nitrogen into worn-out soil (only 6 legumes are reasonably well employed);

•**4000 plants used as contraceptives** (this number is said to be used, although none is formally authorized for use);

•**1000 useful drought resistant plants** (few are used for fighting desertification); and

•**1000 useful shrubs** (almost all overlooked: too big for agriculture; too small for forestry).

The bad thing is that no one is exploring this vast frontier with any vigor or vision.

### Biodiversifying The Future

That mankind is sustained as well as it is is thanks to the success of wheat, rice, corn, potatoes, cattle, chickens, and the few others. That is well and good, and it might be thought that these superstars are the world's best; that the thousands of unused species failed to make the cut in some ancient competition. But such is not the case. Temperate-zone species and European resources dominate the world mainly through the success of Western technology, culture, and activism during the past several centuries. A few others (rice, for instance) sneaked into the upper echelons of world resources through historical happenstance.

Now, however, the outer envelope of those great global resources is becoming apparent. Yields are topping out, certain pests and diseases are threatening devastation, and it is getting harder and harder to find more sites for the irrigated production that provides the ultimate in yields.

Some great new initiative is now required. It must be more than just a traditional agricultural diversification. Rather, it must be what might be called a "biodiversification." The whole underpinnings of renewable resources need to be put on a broader and therefore sounder footing across the board: more erosion control species, more tree crops, more desert-defying shrubs, more ground-covers, more soil regenerators, more pest-control plants, and more organisms to cultivate in the forest understory. Additionally, we need more combinations of tree crops with farm crops, as well as aquatic plants for water treatment, and species for infertile soils, saline soils, acid soils high in soluble aluminum (the barren red laterite so prevalent in the tropics), and other soils that are toxic to today's crops.

That may sound like a utopian dream. But the amazing thing is that species for all the above purposes do indeed exist, and in spades. Looking out across the frontier of natural resources one can spot hundreds of candidates with high promise not only for improving harsh and degraded environments, but at the same time boosting the world's basic food supplies, fighting malnutrition, and advancing the poor nations' economies.

### Crop Champions Are Among Us

People who know such promising species are legion. Many researchers, commercial horticulturists, and everyday plant-lovers have seen the light, at least in part. Usually, these visionaries have been attracted to the possibilities of a single species. Some devote their lives, risk their reputations, and even hazard their fortunes in the furtherance of their favorite. I have called them "crop champions," although a better word is needed because some of the species they champion are trees or animals.

Many crop champions have participated in my program at the National Research Council. Indeed, I've been able to help certain of them get their species into greater use. It was not hard. Merely informing the public in a bright and upbeat way has been enough to spark activities worldwide.

During its 25-year history, my program produced nearly 40 books on biodiversity. Not one was the normal scientific tome. The texts were thoroughly reviewed for accuracy and balance, and were of course backed by the credibility of the National Research Council, but each also carried a subtly inspirational message on promising but underexploited plants and animals. They were also written for a mass readership. This combination proved highly successful at getting certain biodiversity applied.

Thousands of readers responded by putting in trial plantings, gathering germplasm, undertaking detailed research, and other activities. In this way dozens of formerly unknown, or at least overlooked, natural resources were literally "brought to life." We expended so much effort in ensuring that the science was sound and the presentation responsible that, I'm glad to say, none of the species has proved unworthy under the scrutiny of real-life practice.

*Noel Vietmeyer*

The plants and animals dealt with in this NRC program were mostly native to the tropics and to the arid lands. Although their names may sound strange to Americans, many are no longer strange to the peoples of the hot latitudes. Indeed, there's hardly a country in the Third World

*A stand of leucaena near Poona, India, only four and a half years after it was planted on severely degraded land.*

that doesn't have more than one of them now in production. Among formerly obscure crops this project boosted into widespread application were:

• **Winged Bean.** This climbing bean provides high-protein foods from seeds, leaves, pods, flowers, tendrils, and roots. As a source of nutritious food for tropical villages, this productive and heat-tolerant "supermarket on a stalk," is ideal. Tested in more than 70 nations, it is now in everyday use in many.

• **Amaranth.** Once used by the Aztecs, this grain and vegetable crop was suppressed by the Conquistadors and sank from sight for 450 years. Since the NRC published on amaranth in the 1970s and 1980s, it has come to be planted in a dozen or so nations, including our own. An outstandingly nutritious crop, it has been adopted so quickly in China that perhaps 1 million farmers now have amaranth plants in their dooryards.

• **Leucaena.** This previously obscure tree has proven one of the world's fastest growing. It is now well known to millions in Southeast Asia and is being taken up in Africa as well. Indeed, it is probably the major species now being planted in the tropics, with an estimated 1 billion in the ground. It is more a poor-person's tree than a forester's one, and is spreading mainly from village to village. In a new twist, ranchers in Texas and Australia have found leucaena to be their most productive forage. Grown as a shrub, it is now starting a second diaspora in which the foliage is more valued than the wood, shade, and shelter it provides when allowed to grow tall.

• **Neem.** Seeds of this Indian tree yield non-toxic insecticides that are increasingly used worldwide against pests such as locusts, potato beetles, and earworms. Extracts from neem seeds are being shipped to the United States and the resulting insecticides are sold coast to coast. Neem is now planted in dozens of tropical nations and is shaping up as a major tropical cash crop. Research has shown that it is also a potential source of fungicides, antibiotics, and even of natural contraceptives. One intriguing feature is that the more these products are used, the more trees the world will have to have, which is a blessing in itself.

• **Lost Crops of The Incas.** In the Andes can be found a wealth of roots, fruits, grains, vegetables and legumes that have been languishing in obscurity since the Conquistadors unjustly spurned them as a way to break the influence of the Incas. Thanks largely to our NRC project, these ancient food plants are now being rescued from oblivion and brought to the attention of the world. They are also being brought to the attention of the locals, most of whom never took the crops seriously before outsiders showed such an interest.

• **Jojoba.** This wild desert plant of the Southwest produces a unique and valuable oil that is a superb lubricant for machinery and also does wonders for the human skin. Now grown on a small scale in several arid regions, this crop seems poised for a major breakout. It has an especially promising future as a cash crop to "anchor" anti-desertification agriculture.

### One Crop Champion's Frustration

Through getting such obscure species into expanded use, the NRC program has certainly contributed to biodiversification. But that is just a beginning. Hundreds more species await recognition and the need to put them to use is greater than ever. These days, however, anyone wanting to champion unused biodiversity has a near impossible task. No matter how potentially useful your crop, there seems no way to raise the funds to give it the needed momentum. Support for applying biodiversity (never very substantial) has virtually dried up.

I know this from painful personal experience. Despite its previous successes, my little NRC program is now lost in limbo. For more than a year there's been no funding, while proposal after proposal was rejected, mostly on the grounds that, "There's no funds to support anything like that." Yet each proposed activity would have (in one way or another) highlighted a possible key to solving a seemingly intractable problem. Consider the following topics, all of which were turned down by funding organizations in the last year.

• **Peach Palm (Pejibaye).** This tree's nutlike fruit is probably the most balanced of all tropical foods; its levels of carbohydrate, protein, fat, vitamins, and minerals are perfect for human consumption. It can provide more carbohydrate and protein per hectare than corn. One type is extremely rich in vitamin A, a lack of which causes a million children in the developing world to go blind each year. The plant's multiple stems also make it promising for producing "hearts of palm" in a sustainable manner, which would be a first. Peach Palm is known only to a small part of tropical America, but it could be made a major resource around the tropics.

• **Vetiver.** Hedges of this tall grass create "living walls" strong enough to block rocks and soil from passing. When grown across slopes they even retard rushing runoff after rainstorms. Vetiver hedges therefore keep both soil and moisture on the land, helping both the farmer and the environment. Between the hedges, trees and crops grow better and the aquifers fill up as they did in the days before deforestation. Vetiver is sterile and does not spread, so the benefit is essentially permanent. Vetiver hedges will almost certainly stop the mudslides that devastate Southern California, keep farm runoff out of the Everglades, and reinforce levees in the lower Mississippi. However, although it is already in many states and is cleared for planting, it remains unknown to those who face these natural disasters.

• **Mangium.** This Australian rainforest tree (*Acacia mangium*) can grow ten feet a year. More importantly, it is a nitrogen-fixing legume that improves impoverished soils so that within five years they can be returned to farming. Moreover, mangium suppresses light-demanding plants and is so good at knocking out weeds that people in the Dominican Republic have dubbed it the "green machete." Mangium also acts as a nursemaid to the shade-tolerant species and, thus, by fostering natural understory regrowth it literally restarts rainforests and could help existing rainforests expand. Yet it is not being used for this.

• **Vetch.** A U.S. Department of Agriculture researcher has perfected a system of farming that uses no plowing, no fertilizer, and few pesticides. This is no flaky claim -its development during the past six years having been monitored with controlled experiments by up to 13 researchers. The process employs hairy vetch as a cover crop and mowing rather than plowing. As a result, the soil is always covered and does not erode. This ingenious system is good not only for the farmer but also for the environment. It coopts natural processes and works along with them in the way they want to go. In principle, any such farming that produces high yields with few inputs and little environmental damage should be a vital contributor to the tropics, if not the world. Yet today it is all but unknown outside Beltsville, Maryland.

• **Tropical Fruits.** While millions of children die of malnutrition, the wealth of tropical fruits, which includes dozens of species filled with vitamins and other nutrients, remains undeveloped. Moreover, starchy fruits such as breadfruit and high-energy fruits such as avocado could be staples but are overlooked. And while the tropics is increasingly denuded of trees, hundreds of fruit species are never considered for reforestation purposes -a tragedy because people love to plant fruit trees and a possibility of attacking both hunger and deforestation is being lost.

• **Moringa.** As in the case of tropical fruits, hundreds of tropical vegetables remain undeveloped. Moringa exemplifies the power and potential to be found among these overlooked veggies. An extremely fast growing tree, it produces leaves like spinach and pods that look like giant green beans and taste like asparagus. Its seeds yield an excellent cooking oil. The seeds are also good for clarifying turbidity and making water fit for drinking. All in all, moringa is one of the most exciting little-known plants. With it, the tropics would have a tool "in-one" for reforestation and food production. That it is almost unknown in Africa, for instance, is an in indication of how damaging the neglect of biodiversity can be.

• **Lost Crops of Africa.** Many observers see Africa's future as one with hunger, malnutrition, drought, deforestation, environmental destruction, and other calamities all chasing each other in a sort of death spiral. But at least 2000 indigenous food plants are lying unappreciated in scattered areas between Mauritania and Mauritius. Most of these native foods have fed Africans for tens of thousands of years. Some are wild; many are domesticated. A few have the promise to become major world crops. However, their modern potential has never been seriously assessed, much less studied, developed or promoted. Through such neglect, some are being abandoned and are dwindling into commercial disuse, or even actual extinction. A number are "life-support plants," that the poor rely on to keep themselves alive during times of drought or other hardship. Their loss could mean unnecessary

*Mangium can help recover rainforests, even on acid soil. The trees in this photo taken in Sabah, Borneo, are four years and five months old.*

deaths from the droughts the future will bring.

• **Quality-Protein Maize.** Today's corn is poor in protein quality and the fact that corn is the staple of much of Africa and Latin America is having grave consequences on health, especially children's health. But a newly perfected type of corn has protein approaching that found in milk. This so-called quality-protein maize could be outstanding. High-yielding varieties are already being grown in Ghana, South Africa, China and Brazil, but the world at large is unaware of QPM's true potential. Even Nobel Prizewinner Norman Borlaug and former President Jimmy Carter, main organizers of this effort, are having trouble attracting the interest needed to boost this new corn into global use.

• **Wetland Wastewater Treatment.** Mishandled sewage creates one of the developing world's worst underlying problems. It leads to death and disease, contamination of land and water, and chronically unsanitary conditions for millions. However, there is a new and unsophisticated sewage treatment which seems ideal for the needs of the Third World. This simple and inexpensive approach employs various aquatic plants grown in artificial wetlands. Wastewaters merely trickle through man-made watery gardens in which living plants clarify the waste stream to the point where it is safe for people, animals, and the environment at large. In principle, this low-tech process should be ideal for the world's poor countries. Plants grow extremely well in the heat of tropics. In fact, because there are no winter seasons, the wetland systems should work better there than here. Yet it is unknown.

• **Trees for Absorbing $CO_2$.** Rising levels of atmospheric $CO_2$ make lower are creating concerns over possible global warming. Many different approaches will be needed to overcome this threat, but one is to grow more trees (especially trees people won't cut down). Without a doubt, the tropics is the place for this; trees grow year-round there and absorb much more carbon dioxide than those in the temperate zones. Among the 20,000 tropical trees are some obvious candidates for planting on the massive scale needed to have any effect on the atmosphere. The problem is, the executives and other authorities dealing with the global warming issue are unaware of them. This is truly unfortunate because trees are so good for the people of the tropics, providing shade, shelter, reforestation, cash (witness the above sale of neem seeds), and even food. (In this regard it is noteworthy that people hate to cut down fruit trees, even old apple orchards in the U.S.)

• **Malted Barley.** Each day 40,000 children die of the consequences of malnutrition. Part of the problem—probably a major part is that mothers have no liquid foods for use in weaning their babies. Yet at the NRC we have found that staples are easily turned into liquids. The simple process uses the starch-digesting enzymes found in food-grade malted barley. Stirring a little of this inexpensive flour into hot cooked staples, such as boiled corn, rice, potatoes, or sorghum, produces instant liquids babies can drink from a bottle or a cup.

*One of these twin piglets was fed regular corn; the other was fed Quality Protein Maize. (Photo by Ted Spiegel, courtesy of The Rockefeller Foundation).*

**Questions and Answers**

Naturally, I'm biased in my appraisal, but it seems that these are the type of projects that should be able to find a source of support, somewhere. The problem is an attitudinal one. Those who hold the purse-strings have their minds closed to the importance of applying biodiversity. How to bring about a consciousness raising is much on my mind these days, and has made me think of a host of questions about the whole issue of our natural resources and the future of humanity. Here are some samples, and my answers of the moment.

***Why aren't we applying the myriad under-exploited species against the global problems?***

Basically, the problem is that no one wants to support plants with strange-sounding names that occur on the other side of the world and that may have little direct benefit to the United States itself.

At yet another level, there is these days no governmental agency for applying biodiversity. The U.S. Department of Agriculture, Environmental Protection Agency, and Department of Energy deal with agricultural and environmental issues but concern themselves primarily with domestic interests. The National Science Foundation is mandated to develop new knowledge and (the staff of the international division at least) considers the application of biodiversity to be too far from basic science to qualify.

The Agency for International Development (AID) is the obvious organization to spearhead a Third-World biodiversification, but it is currently so beleaguered it is almost out of science and agriculture altogether. Any relevant funds are almost all spoken for by the International Agricultural Research Centers, which work on the major crops, and by private and local-government organizations protecting biodiversity in such locations as rainforests. Both groups are understandably loath to share whatever little largess they can land. Besides, few of the AID staff seem to care anything for little-known crops anyway; it was mostly they who turned down my myriad proposals during the last year.

***Which crops would be chosen?***

Of the thousands of neglected species listed at the top of this article, the majority are unworthy of much attention; indeed, are hardly worth a researcher's second glance. The key is to locate those "cinderella species" that could rise from the hearth of neglect and take a place in the diversified balance of the world. No giant study is needed here; several hundred are easy to spot. Were funds available, crop champions would vie for the chance to advance their favorite species. In fact, this competition between crop champions would create one of the most interesting and newsworthy areas in all of science.

***Specifically, what research should be done?***

Each crop has its own needs; there is no universal pattern. Some are already both productive and palatable. Others need their productivity or palatability raised but have some special characteristic such as high nutritive value to make the effort worthwhile. Some just need documentation and publicity, and then will take off without scientific support. A common need is the propagation of superior types. All the kiwifruits in our stores, for instance, are cloned from a single plant noticed in New Zealand in the 1920s; one observant nurseryman literally created that crop. A hundred tropical fruits have the potential to rise in the same way. The right specimens for the job are out there just waiting.

***What is needed?***

Massive research efforts are not critical for the development of little-known crops. These plants are mostly in use already. They just need to be nudged into greater use and prepared for the big time to follow. Large expenditures can actually be counterproductive, especially if a plant is not quite ready. Once a species performs economically and provides products people want, businesses, development banks, private voluntary organizations, local governments, students and others will likely take up the cause.

Even now entrepreneurs and businesses should take up certain crops of the kind I'm talking about. Indeed, there is potential to raise up a whole biodiversity industry -one like biotechnology but without the need to splice any genes.

Nature already provides a plethora of good genes, and it's amazing that we haven't begun to employ them. Needed now is a new and separate funding initiative to explore and apply the resources containing such genetic treasures. It could be housed in AID, the U.S. Department of Agriculture, the World Bank, U.N. Development Programme, or perhaps all four.

Foundations and individual philanthropists should get involved. In fact, they could play a vital part in getting the new initiative rolling. They could fund activities such as identification of elite plants, domestications, cultivation trials, market trials, promotions, and, hopefully, my kind of all-round advocacy for the underdogs of natural resources.

***Won't it take huge sums to develop new crops?***

Mindboggling amounts of megabucks are unnecessary. For half a million dollars a year my project could be fully funded (as it presently is not) to evaluate and give worldwide recognition, credibility, and publicity to two topics (like the powerful ones mentioned above). A few million a year would launch a multi-prong, international effort on several topics. $15 million a year would ripen a whole new discipline; Applied Biodiversity would likely become a hot new arena of intellectual and practical endeavor.

***Can the little-known crops compete?***

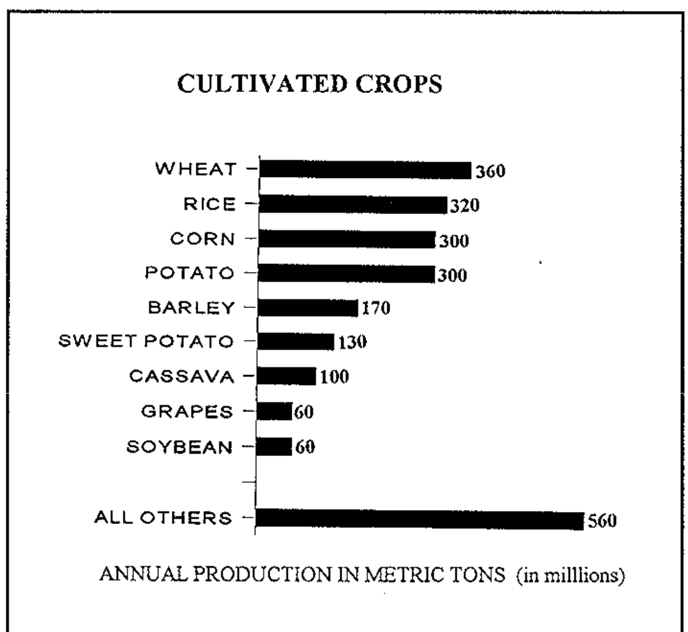
Today's highly developed resources, such as wheat and rice, produce spectacular yields but usually only under the best of conditions. In the vicious competition of the tropical subsistence farm they often perform badly. The little-known plants, on the other hand, tend to be adapted to harshness and neglect. When the going gets tough, they often out yield their more pampered counterparts. And today the going is getting tougher.

***Will the plants become like kudzu and just cause more problems?***

Most plants of promise are already in cultivation of one sort or another. These cultivated forms are unlikely to be pests. Besides, it is one of the sillinesses of our times that people equate "exotic" with badness and apply geographical origin as the litmus test of a plant's value. Those critics have usually just dined on bread, potatoes, corn, orange juice, bacon, beef, or chicken, which, like most everything Americans put in their mouths, are all of foreign provenance.

## The Ultimate Prize

It is not yet widely appreciated that the so-called global problems are, at bottom, natural-resource problems.




*Out of 20,000 known edible plants, only 30 are cultivated to any significant extent. And, as this chart shows, annual production of the top nine crops (1800 million metric tons) is more than three times that of the remaining 23.*

Hunger, malnutrition, deforestation, desertification, soil loss, and soil degradation, for instance, all have to do with plants and animals and soils, as well as with their individual and collective relationships with humanity's needs and interests and capabilities.

Neither is it yet widely appreciated that these problems that threaten everyone's future are, strictly speaking, not global: their primary locus is in the hot regions of Africa, Asia, and Latin America.

The amazing thing is that these very same hot regions are the repository of most of the unsupported plants. In other words, between the tropics of Cancer and Capricorn can be found most of the unused biodiversity as well as most of the unsolved humanitarian and environmental problems.

In this convergence of plants and problems is a vital hope for the future. When you know something about the tropic's unsung and unsupported species, the problems suddenly don't seem intractable any more. Indeed, some of the now undeployed species are superbly suited as weapons for combating hunger, malnutrition, deforestation and the rest.

This provides a new and real world argument for foreign assistance. Indeed, it provides a new paradigm for foreign assistance activities in general. Helping apply tropical biodiversity is a form of aid that benefits everybody. It gives impoverished nations the central role in their own recoveries, using species adapted to their own conditions. And by helping overcome the global problems we are helping ourselves.

Now is the moment of opportunity to step boldly forward and start bringing about this true biodiversification. The new system would complement the superstar resources of today. It would introduce a resource continuum employing both old and new. That combination would be better balanced for handling the good times and bad, good conditions and bad, good soils and marginal. It would also provide a wider range of foods and farming systems as called for by both nutritionists and agricultural visionaries. And it would at the same time lessen reliance on chemical inputs, expensive imports, and ever scarcer irrigation water.

All in all, putting the available biodiversity to work and thereby diversifying the resource base will produce a world that is better balanced for a long, steady, and reliable future. To achieve this will be challenging, but it will also be gratifying. It's exciting to be a crop champion, and in this case there will also be the added impetus of doing something to help everyone. If there is any one way to "save our world" this is it!

—N.V.

*Editor's Note: Noel Vietmeyer is a senior program officer of the Board on Science and Technology for International Development, National Academy of Sciences. With a Ph.D. in organic chemistry from the University of California, Berkeley, he works on innovations in science and technology that are important for the future of developing countries.*

**Breeding** *(continued from page 1)*

for making a significant, low-cost, and sustainable contribution to reducing micronutrient, particularly mineral, deficiencies in humans, it also may well have important spinoff effects for increasing farm productivity in developing countries in an environmentally-beneficial way.

*Howarth Bouis*

Any intervention to improve micronutrient status targets women and children because of their elevated needs for minerals and vitamins. The specific strategy of breeding for mineral and vitamin enhancement of staple foods has several complementary advantages. After the one-time investment is made to develop seeds that fortify themselves, there are no recurrent costs, as with supplementation, fortification, and nutrition education programs. No behavioral change on the part of consumers is required. Indeed the strategy seeks to take advantage of the consistent daily consumption of large amounts of food staples by all family members.

Mineral-packed seeds sell themselves to farmers because, as recent research has shown, these trace minerals are essential in helping plants resist disease. More seedlings survive and initial growth is more rapid. Ultimately, yields are higher, particularly in trace mineral "deficient" soils in arid regions. Because roots extend more deeply into the soil and so can tap more subsoil moisture and nutrients, the mineral-efficient varieties are more drought resistant and so require less irrigation. And because of their more efficient uptake of existing trace minerals, these varieties require fewer chemical inputs. Thus, the new seeds can be expected to be environmentally beneficial as well.

### Historical Focus On Yield, Marketability

The primary objective of plant breeding at agricultural research stations all over the world, in rich and poor countries alike, is to improve farm productivity, usually by developing crops with higher yields. In crossing varieties with various traits, scientists also monitor and attempt to maintain consumer characteristics such as taste, cooking qualities, and appearance. This is because such characteristics have a bearing on market price and so on profitability, which motivates farmers to adopt improved varieties.

Enhanced nutrient content has almost never been a breeding objective. During the breeding process, the nutritional qualities for human consumption (which, unnoticed, may improve, worsen, or change little) of improved crops are ignored for the most part. This is because it is presumed (i) that nutrient-enhanced crops will be lower yielding and so must command a higher price to be profitable—in any event, an additional breeding objective of higher nutrient content will slow down the development of varieties with higher yields—and (ii) that consumers for the most part are unwilling to pay a premium for higher nutrient content of a specific food, even if the problem of reliably marketing the product as nutrient-enhanced could be solved.

However, as science makes new advances—in this case as more is learned about the substantial costs of micronutrient deficiencies in humans, particularly in developing countries; as more is discovered about some similarities between trace mineral requirements for human nutrition and plant nutrition; and as plant breeding techniques improve—conventional wisdom requires rethinking.

**The range in yield of a selection of rice lines from the world collection, varying in tolerance to soil stresses**

**(Ponnamperuma, 1982)**

| Stress | Total Number | | | Mean yield (t/ha) | | |
|---|---|---|---|---|---|---|
| | Tests | Sites | Races | Min. | Max. | Increase |
| Iron toxicity | 14 | 4 | 58 | 2.1 | 4.7 | 2.6 |
| Al/Mn | 4 | 1 | 36 | 1.8 | 3.6 | 1.8 |
| P deficiency | 14 | 2 | 118 | 1.9 | 4.3 | 2.4 |
| Zinc deficiency | 31 | 10 | 107 | 0.8 | 2.9 | 2.1 |
| Iron deficiency | 9 | 3 | 69 | 0.8 | 2.7 | 1.9 |

That this strategy could benefit farm productivity in addition to improving human nutrition—that there are complements rather than tradeoffs between the objectives of higher farm profits and better nutrition—was very much unexpected when the idea of breeding for micronutrient-dense seeds was first broached in informal discussions with plant breeders at several CGIAR centers in 1993. It is useful first to provide some background on the problem of micronutrient deficiencies in developing countries before discussing how the discovery of a connection between plant nutrition and human nutrition came about.

### The Hidden Hunger: Micronutrient Deficiencies

As dismaying as the consequences of famines are, it is only relatively recently that nutritionists working in developing countries have been able to demonstrate conclusively that many more children and adults, particularly women in their childbearing years, die and suffer during times of relative economic and political stability due to a lack of essential vitamins and minerals in their diets, than due to a lack of calories. Because people for the most part are not aware that their diets are lacking in these trace nutrients and hence do not associate these deficiencies with listlessness, poor eyesight, impaired cognitive development and physical growth, and more severe bouts of illness (sometimes leading to death), this general problem of poor dietary quality has been dubbed "hidden hunger."

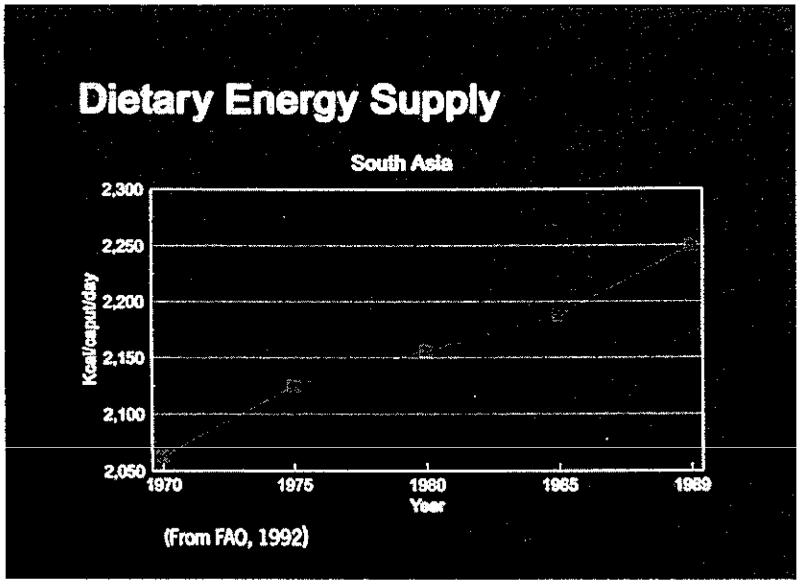
**Percentage of nutrient-deficient soils among 190 soils in a global survey across 25 countries by Sillanpaa (1990)**

| Deficiency Level | Nutrient N | P | K | B | Cu | Fe | Mn | Mo | Zn |
|---|---|---|---|---|---|---|---|---|---|
| Acute | 71 | 55 | 36 | 10 | 4 | 0 | 1 | 3 | 25 |
| Latent | 14 | 18 | 19 | 21 | 10 | 3 | 9 | 12 | 24 |
| Total | 85 | 73 | 55 | 31 | 14 | 3 | 10 | 15 | 49 |

For example, it has been known for several decades that severe vitamin A deficiency can lead to blindness in children. Surveys conducted by the World Health Organization in the 1960s established vitamin A-deficiency-related blindness as a serious public health problem in a large number of developing countries. In the early 1970s, through experiments conducted in India and Indonesia, it was discovered that such blindness could be prevented safely by administering capsules or syrup containing massive doses of vitamin A once every six months. (Vitamin A, which is fat soluble, is stored in the liver).

Later, in an observational study, researchers based at Johns Hopkins University and working in Indonesia, showed that there was a correlation between progressively serious eye damage in children and increased child mortality rates. This was empirical information that was consistent with a long suspected link between vitamin A deficiency and the high child mortality rates common in developing countries. To test this hypothesis more rigorously, 10,000 Indonesian children were given high-dose vitamin A capsules (VAC) and 10,000 children were given a placebo (a low percentage of these children, no more than one percent, had clinically visible eye damage). Mortality rates were found to be 34 percent lower for children who received VAC.

Such a large reduction in mortality was so




startling and unexpected only a decade ago that eventually it was necessary to conduct seven similar experiments in other countries in Africa and Asia (with similar results on average) before there was widespread acceptance in the international nutrition community by the late 1980s that widespread distribution of VAC could significantly reduce child mortality and should be given high priority for government intervention. These dramatic, new research findings in the area of vitamin A deficiency, in turn, helped to focus more attention and spur further research related to other micronutrient deficiencies as well, in particular iron and iodine deficiencies.

### Iodine Deficiency In Children

Statistics now compiled by the World Health Organization (WHO) on a regular basis on the extent of micronutrient deficiencies demonstrate the enormous magnitude of the problem. WHO reported in 1994 that 3.1 million pre-school age children had eye damage due to a vitamin A deficiency and another 227.5 million are subclinically affected at a severe or moderate level. Annually, an estimated 250,000 and 500,000 pre-school children go blind from this deficiency and *about two-thirds of these children die within months of going blind.*

It is estimated that 2.1 billion people globally are iron-deficient and that this problem is severe enough to cause anemia in 1.2 billion people. The problem for women and children is more severe because of their greater physiological need for iron. Worldwide, roughly 50 percent of non-pregnant women and 60 percent of pregnant women have anemia. Of the approximately 500,000 maternal deaths that occur each year due to childbirth, mostly in developing countries, anemia is the major contributor or sole cause in 20 to 40 percent of such deaths. Iron deficiencies during childhood and adolescence impair physical growth and mental development and learning capacity. In adults, iron deficiency reduces the capacity to do physical labor.

Iodine deficiency is the greatest single cause of preventable brain damage and mental retardation in the world. WHO estimates that around 1.5 billion people or one third of the world's population live in iodine deficient environments. Deficiencies in iodine that occur in late infancy and childhood have been shown to cause mental retardation, delayed motor development, growth failure and stunting, neuromuscular disorders, and speech and hearing defects. Even mild iodine deficiency has been reported to reduce intelligence quotients by 10-15 points.

Deficiencies in several other micronutrients, zinc in particular, may be similarly widespread with equally serious consequences for health. However, because there are no specific indicators to screen for deficiencies in these nutrients (other than a positive health response to supplementation), they have not received as much attention.

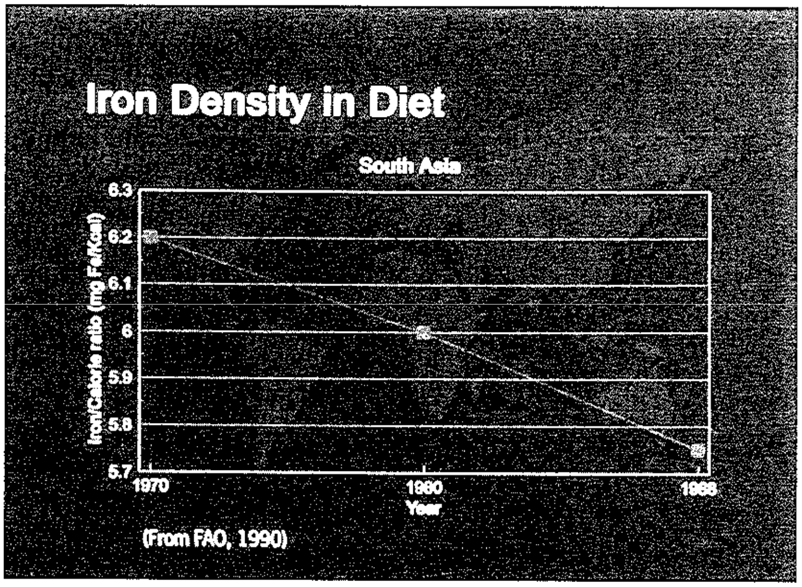
### Conferences Lead To Action

Three worldwide conferences sponsored by a number of international and bilateral agencies held in the late 1980s and the early 1990s spurred the international community and country governments to greater action. Substantially more money was made available for combatting micronutrient deficiencies. Ambitious goals were set for the virtual elimination of vitamin A and iodine deficiency and the significant reduction in iron deficiency in developing countries by the year 2000.

Initially there was some optimism that supplementation programs could solve much of the micronutrient deficiency problem quickly and easily, but this turned out not be to the case. Universal supplementation is an expensive and difficult task logistically. Targeted supplementation involves the costs and associated logistical problems of identifying those in need. In both regimes, compliance can be a problem. For example, in the case of iron deficiency, although capsules need to be taken frequently, there is some risk of toxicity if they are taken too often.

Fortification is an alternative approach which has been used successfully in developed countries. However, since markets for foods are not well developed in Third World identifying appropriate food "vehicles," processed by a relatively small number of manufacturers, is sometimes impossible. Where "vehicles" are available and fortification statutes have been put into law, there have been problems with ensuring that manufacturers comply with these laws.

To provide some sense of the magnitude of the *recurrent annual* costs involved in fortification and supple-




mentation, a lower-bound estimate of the cost of iron supplementation is $2.65 per person per year when all administrative costs are taken into account. A lower-bound estimate for iron fortification is 10 cents per person per year.

In a populous country such as India (total population 880 million) there may be as many as 28 million anemic pregnant women in any given year. The estimates imply that treating *only half* of those women in any one year through a well-targeted supplementation program could cost as much as $37 million per year. A fortification program reaching only half of the women could cost $1.4 million per year. Iron fortification of half the entire population could cost $44 million per year.

### Benefits Accrue With Proper Management

Notwithstanding these cost estimates, the benefits of properly managed interventions can be quite significant. The World Bank's World Development Report 1993 found micronutrient programs to be among the most cost-effective of all health interventions. A World Bank document estimates that deficiencies of just vitamin A, iodine, and iron alone could waste as much as five percent of gross domestic product (GDP) in developing countries, but addressing them comprehensively and sustainably would cost less than one-third of a percent of GDP. Nevertheless, it is difficult for governments and international agencies to mobilize resources of the magnitude implied above, which are needed to address such a pervasive problem through existing strategies.

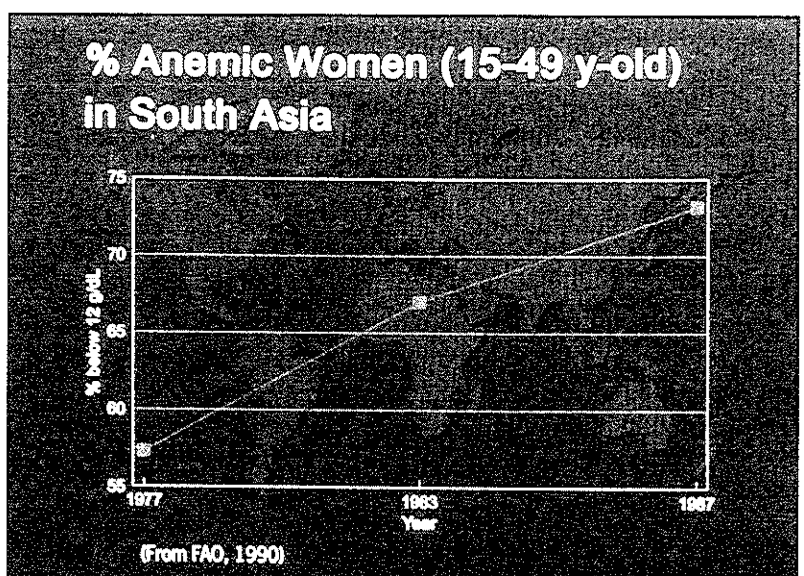
Supplementation and fortification have the advantage that their successful implementation does not require a substantial change in individual behavior, but these interventions treat the symptoms rather than the underlying causes of micronutrient deficiencies. This has led many to advocate the use of "food-based" interventions, such as nutrition education and promotion of home vegetable gardens, which address the underlying cause—poor quality diets. This approach, however, involves motivating substantial changes in human behavior which can be both expensive and difficult.

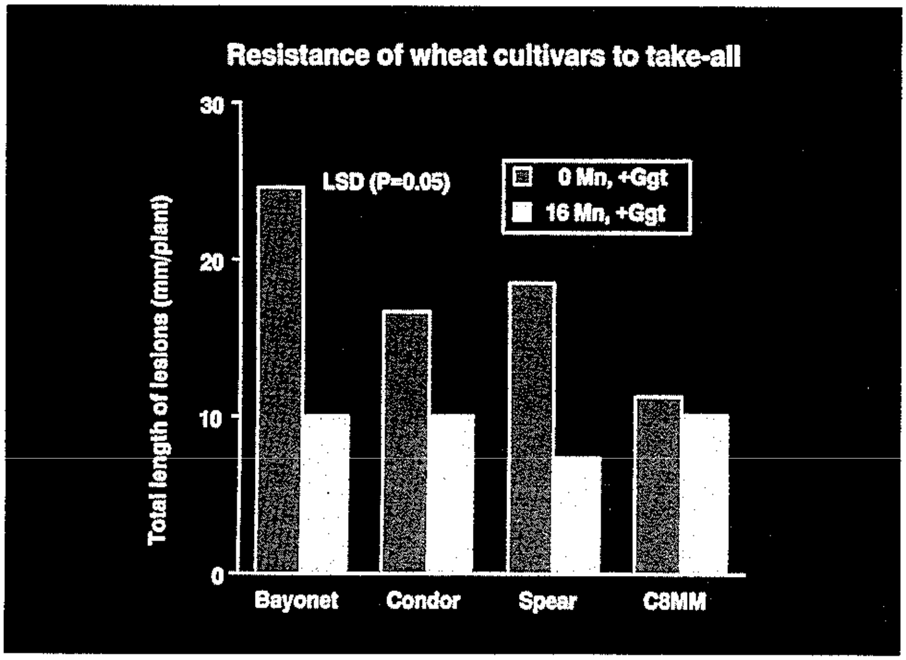
Given the high payoffs to reducing micronutrient deficiencies and the initial disappointment with supplementation and fortification programs as ways to solve the problem quickly and completely, several nutrition education and home gardening projects have been implemented. Only in a few cases has their effectiveness been carefully evaluated. There is now some consensus that in any one country a mix of several approaches is required—supplementation, fortification, promotion of breastfeeding, nutrition education, home gardening, and disease reduction—but little agreement on how best to allocate scarce funds among these strategies in specific settings.

In summary, nutritionists perceive an enormous opportunity, for which new and compelling scientific evidence is rapidly accumulating, for improving nutrition and health in developing countries. Nevertheless, there is some frustration at not having well-developed tools appropriate for developing country contexts with which to solve the problem of micronutrient deficiencies quickly at reasonable cost.

### The CGIAR Response

In 1993, the International Food Policy Research Institute (IFPRI) was commissioned to take the lead in identifying activities which the CGIAR might undertake to join other international and national organizations in the fight against micronutrient malnutrition. IFPRI, a CGIAR center based in Washington, D.C. and staffed primarily by economists, undertakes research to examine alternative government policies for increasing food production and improving food consumption and






nutrition among the poor in developing countries.

Perhaps the two best known centers within the CGIAR are the International Rice Research Institute (IRRI) located in the Philippines and the Maize and Wheat Improvement Center (with the Spanish acronym of CIMMYT) located in Mexico, both of which were established in the 1960s.

High-yielding varieties of rice, wheat and maize developed at these two centers now are grown widely in developing countries, where over the past three decades cereal production has grown faster than demand. These developments, dubbed the "Green Revolution," and the resulting lower food prices and higher farm incomes, have up to now been viewed as the primary contribution of the CGIAR to improved nutrition.

There is previous experience within the CGIAR in breeding for improved nutritional characteristics. In the early 1970s, a major breeding program was begun at CIMMYT to produce a high-quality protein maize (QPM). At the time, nutritionists had identified quality protein (lysine) as a key limiting nutrient to better nutrition in developing countries.

Although there is now new interest in QPM varieties, particularly in Brazil, China, Ghana and South Africa, the QPM breeding project is considered by many scientists within the CGIAR to have been a major misallocation of resources. A primary problem was that the original genetic material that contained high concentrations of lysine was low-yielding. It took some time to develop varieties that were both high-lysine and high-yielding. However, the high-lysine, high-yielding varieties never matched the best-yielding, highest-profit maize varieties, so that farmer adoption was a major constraint. Moreover, because most nutritionists have long since concluded that quality protein is not a key limiting nutrient to better nutrition, impetus to further breeding for nutritional objectives was diminished.

Therefore, when the idea of breeding for micronutrient content was first broached with individual scientists within the CGIAR in visits to Colombia, Ethiopia, India, Mexico, Peru, the Philippines, Syria and Taiwan in 1993, the suggestion was generally met with skepticism, although with a few exceptions. Notwithstanding the fact that there was virtually no institutional knowledge of genotype variation in micronutrient content of crop varieties developed by the CGIAR centers, the presumption among most of those scientists was either that there again would be a trade-off between plant yield and nutritional value or that, at best, there would be no correlation with yield and that adding an additional breeding objective (nutritional quality) would slow down the overriding breeding objectives of higher and more stable crop yields. It probably did not help matters that the subject was introduced by an economist (the author) with little knowledge of plant physiology and plant breeding and no formal training in human nutrition.

In the course of these discussions, one scientist recommended a visit to the Plant, Soil, and Nutrition Laboratory (PSNL), run by the USDA-ARS and located on the Cornell University campus, a visit which was to fundamentally change the direction of the CGIAR micronutrients project. The PSNL, established in the 1930s, has been charged with looking at the linkages between minerals in soils and the nutrition of plants, animals, and humans in the United States.

During that initial visit, Ross Welch of PSNL (who, in keeping with the mandate of PSNL, has published extensively in the separate literatures on soils, plant nutrition and human nutrition) provided information about research conducted by Robin Graham of the Waite Agricultural Research Institute at the University of Adelaide in Australia to improve *plant nutrition* by breeding for crops that have improved efficiency in the

### *Corrections*

In the May/June issue the Harvard economist Amartya Sen was referred to as "she." We regret the error—an undetected typo not in the text submitted by Nathan Keyfitz, who knows the correct gender.

Also in that issue, the middle initial of one of our new sponsors, Stephen S. Morse, was incorrectly stated.

uptake of trace minerals from "deficient" soils, and which load high amounts of these minerals into plant seeds. Varieties of wheat had already been released for commercial production.

The basic reasons for the agronomic advantages of mineral-dense seeds may be stated in a simple way. Plant nutrition may suffer from mineral deficiencies in a number of ways (for example, zinc and manganese play key roles in preventing root disease in wheat). These "deficiencies" are caused not by the physical absence of trace minerals in the soil, but by the fact that these minerals are bound chemically to other elements that make them "unavailable" to plants.

While the Waite Institute work was aimed primarily at improving wheat yields in Australian soils, which are among the most trace mineral "deficient" in the world, such soil "deficiencies" are widespread in developing countries.

**Efficiency Characteristics Key To Success**

Certain plant genotypes, however, are more efficient than others in the uptake of trace minerals from soils (their roots exude substances that chemically "unbind" minerals in the soil, resulting in their becoming available to plants). Plant breeding may select for such "efficiency" characteristics, including the characteristic of translocating high amounts of trace minerals to the plant seeds. When replanted in "deficient" soils, such mineral-dense seeds have been shown to be more vigorous and disease-resistant, which, in turn, leads to higher plant yields, even though fewer chemical inputs and less irrigation are required.

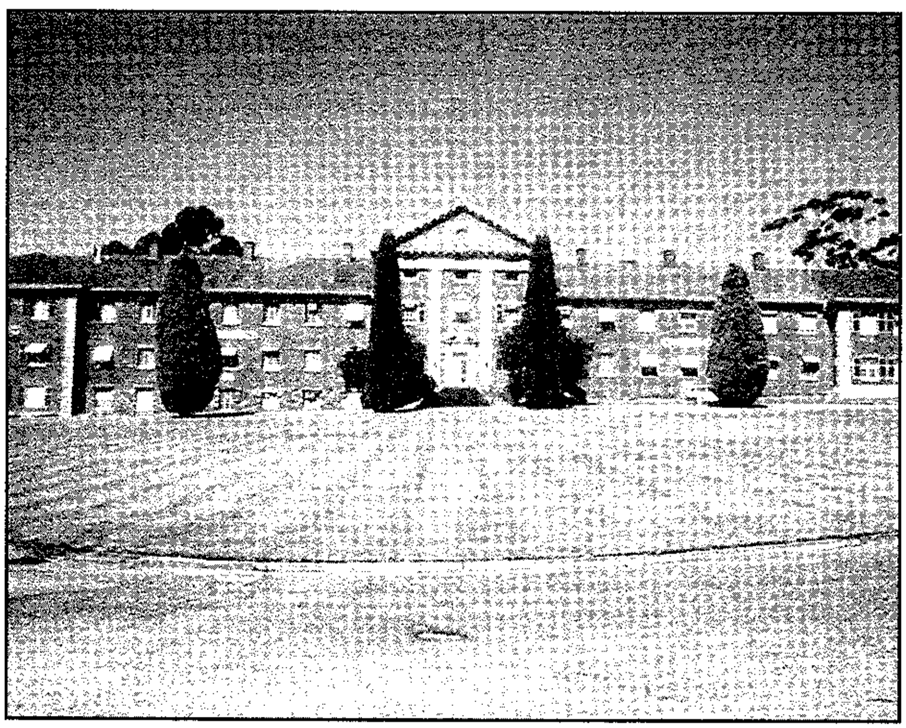
With regard to the potential of this strategy for improving human nutrition, part of the long-standing collaboration between Robin Graham and Ross Welch was motivated by a concern for improving the intake of trace minerals with the US population. Animal products are the most bioavailable sources of trace minerals in the diet. There is a concern that the prevalence of mineral deficiencies in the United States (although obviously lower than those found in developing countries) may be exacerbated by the decline of meat consumption.

From the point of view of the Waite-PSNL collaboration, the CGIAR project became the occasion for the possible application of this work to the much more serious mineral deficiency problems found in developing countries. From the point of view of the CGIAR centers, the Waite-PSNL collaboration represents a wealth of scientific information previously untapped for possibly improving the productivity of CGIAR-released crop varieties, in addition to potential benefits for human nutrition.

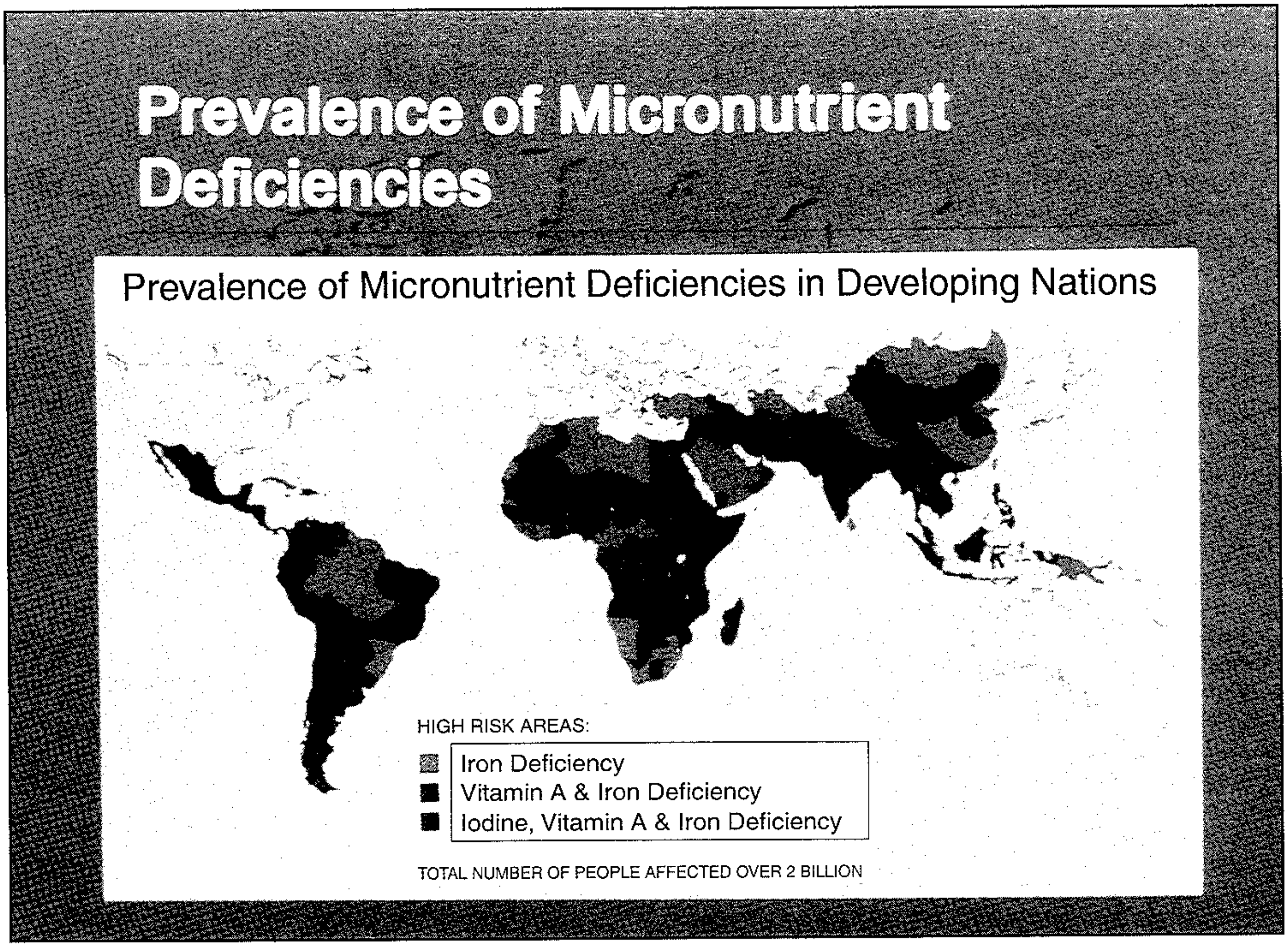
After subsequent lectures by Robin Graham at CIMMYT, IRRI, and a fourth CGIAR center, based in Colombia, the International Center for Tropical Agriculture (with the Spanish acronym of CIAT), attitudes toward the micronutrient-dense-seed plant breeding strategy among a core group of CGIAR plant breeders changed dramatically. In January 1994 an organizational workshop was held, bringing together scientists from many disciplines from inside and outside the CGIAR, and practitioners from several organizations involved in combatting micronutrient malnutrition in developing countries.

A great deal of enthusiasm was generated at the meeting for the plant breeding strategy. For example, in 1993 a CIMMYT wheat breeder based in Turkey, where soils are particularly zinc-deficient, went to Australia, where growing conditions and soil constraints to improved productivity are similar to those in Turkey. He gave a presentation at the workshop in which he estimated that, if the Australian zinc-dense seed varieties were adapted to growing conditions in Turkey, Turkish wheat farmers would save $100 million *annually* in reduced seeding rates alone. (Seeding rates could be reduced from an average of 250 to 150 kilograms per hectare on 5 million hectares; a ton of wheat sells for about US$200 on the world market). This does not count the benefit to yield, or the potential benefit of improved zinc levels in humans.

A major outcome of that workshop was the development and endorsement of a coordinated five-year plan to develop the genetic material and breeding tools necessary for release to national breeding programs. Since



*Waite Institute, one of 16 international agricultural research centers, is in Australia.*




the organizational workshop, the research strategy has been presented, discussed, and received enthusiastically at two 1994 international meetings ( "Food-Based Approaches to Eliminating Hidden Hunger," organized by the Program Against Micronutrient Malnutrition, held in Papendaal, Netherlands in June; The Fifth International Symposium on Genetics and Molecular Biology of Plant Mineral Nutrition held in Davis, California in July), and at an inter-disciplinary seminar held at the World Bank in August of last year. Germplasm screening has already commenced with some promising early results.

**Concerns: Consumers, Bioavailability, Costs**

While the apparent agronomic advantages of mineral-dense seeds has provided much of the momentum for the plant breeding strategy within the CGIAR, four core questions with respect to consumer characteristics, effects on human nutrition, and costs of breeding have also been addressed.

**1. Will breeding for micronutrient-dense seeds change processing or consumer characteristics of staple foods?**

Mineral micronutrients comprise a tiny fraction of the physical mass of a seed, ordinarily as little as ten parts per million. Dense seeds may contain perhaps as many as fifty parts per million. It is not expected that such small amounts will alter the appearance, taste, texture, or cooking quality of foods.

Betacarotene, which is converted to useable vitamin A after ingestion, is associated with an orange or yellow color. Increasing the content of betacarotene in the seed will alter its color. While it might initially reduce consumer preference, a deep orange or yellow color clearly denoting a nutrient-dense product could be turned into an advantage through nutrition education .

Three distinct plant breeding strategies may accomplish the goal of commercial profitability of the new varieties, so that farmer adoption will not be a constraint. It is anticipated that the optimal strategy will vary by nutrient and by crop as indicated below:

• Strategy 1: The new varieties must either out-yield present varieties, use fewer inputs (e.g.,fertilizers, irrigation) or both (e.g., zinc-efficient wheat varieties, grown on zinc-deficient soils, that load high amounts of zinc into the seed).

• Strategy 2: The characteristic of having mineral-dense seeds may be added transparently to the most profitable varieties being released with no yield penalty (e.g. iron-dense rice varieties grown under irrigated conditions).

• Strategy 3: The nutrient-dense seeds must be easily identifiable (e.g., a deep orange or yellow color associated with high levels of betacarotene), so that when consumers are educated to buy such varieties, a premium may be charged for these nutrient-enhanced varieties.

**2. Will micronutrient intakes be increased to a significant degree? To what extent will the extra micronutrients in staple foods consumed be bioavailable?**

An underlying cause and fundamental constraint to solving the micronutrient problem is that non-staple foods, particularly animal products, tend to be the foods richest in bioavailable micronutrients, foods that the poor cannot afford. Their diets consist mostly of staple foods, primarily cereals; in fact, per capita direct consumption of staple foods in the aggregate varies little by income level. For the poor, these staple foods already provide the bulk of the micronutrients consumed, particularly minerals.

Data on staple and non-staple foods consumed by the poor suggest that if the presently low iron content of food staples could be increased by a factor of three or four (say from 15 to 50 parts per million), this would roughly double their iron intakes.

The optimal breeding strategy from the point of view of bioavailability may be to increase levels of promotor compounds. Certain amino acids (such as cysteine and lysine, but particularly methionine) enhance iron and/or zinc bioavailability. These amino acids occur in many staple foods, but their concentrations are lower than those found in meat products. A modest increase in the concentrations of these amino acids in plant foods may have a positive effect on iron and zinc bioavailability in humans. Iron and zinc occur only in micromolar amounts in plant foods, so only micromolar increases in the amounts of these amino acids may be required to compensate for the negative effects of antinutrients on iron and zinc bioavailability. These amino acids are essential nutrients for plants as well as for humans, so relatively small increases of their concentrations in plant tissues should not have adverse consequences on plant growth.

*A close-up view of plants grown side by side in "deficient" soil—trace mineral efficient variety florishing, non-efficient variety stunted.*

**3. Are there other lower-cost, more easily sustainable strategies for reducing micronutrient malnutrition?**

A plant breeding strategy, even if successful, will not eliminate the need for supplementation, fortification, dietary diversification, and disease reduction programs in the future. Nevertheless, this strategy does hold promise for significantly reducing recurrent expenditures required for these higher-cost, short-run programs by significantly reducing the numbers of people requiring treatment.

**4. What is the cost of plant breeding as compared with fortification and supplementation programs?**

The plant breeding effort can be thought of as a two-stage process. The first, five-year, phase will involve research primarily (but not exclusively) at CIAT, CIMMYT, IRRI, PSNL, and Waite. The cost has been estimated at about $2 million per year for research on five crops. During this initial phase, promising germplasm will be identified and the general breeding techniques will be developed for adapting nutrient-rich, high-yielding varieties produced at these international agricultural research centers to specific growing environments in developing countries.

During the second phase, the locus of the research will shift to national agricultural research centers and the focus will shift to adaptive breeding. Total second-phase costs are difficult to estimate, but will depend on the number of countries involved and the number of crops worked on in each country. Certainly, the annual costs for an individual country should not be more than the annual costs incurred by the five core agricultural research centers during phase one. After release of the successfully adapted, nutrient-rich varieties for commercial production, some maintenance breeding will be necessary.

Thus, the projected costs of a plant breeding strategy are relatively low as compared with the costs of supplementation and fortification cited earlier. The major part of the cost is the initial one-time cost of development.

One can imagine that there will be unforeseen problems and costs associated with plant breeding not mentioned here. Daily doses of iron from supplementation and fortification programs may be higher than the additional iron likely to be added to the food staples through plant breeding. Nevertheless, whatever refinements are necessary to these comparative cost estimates, there is no arguing the fact that the base, fixed costs of plant breeding are sufficiently low, that cost considerations are overwhelmingly on the side of a plant breeding strategy as compared with supplementation and fortification. Moreover, these comparative costs do not take into account the potential of improved agricultural productivity.

### Conclusion

Because of the comparatively long lead times involved in bringing the results of plant breeding research to bear on the mineral deficiency problem in humans, these efforts will not contribute to meeting the end-of-decade goals for reducing micronutrient malnutrition set out in the World Declaration on Nutrition and endorsed by 158 countries at the International Conference on Nutrition held in 1992.

However, the timing of the CGIAR project is such that the mineral-dense seed technologies could come "on-line" just after the major push to meet the end-of-decade goals through higher-cost interventions has run its course. By investing now in a plant breeding strategy to sustain the gains made by the end of the decade, the momentum for further reductions in iron and other mineral deficiencies can be maintained.

Very significant progress has been made in terms of (i) putting much of the requisite network of people and institutions in touch with one another, (ii)obtaining consensus among an interdisciplinary group of scientists that this research strategy looks promising in terms of its scientific feasibility and potential for improving human nutrition in developing countries, (iii) obtaining agreement on specific activities that scientists and institutions must undertake in coordination to make this happen, and (iv) initiating the research activities.

The key issues are not those of cost, or whether plant breeders eventually will be successful in developing micronutrient dense seeds if the relatively modest resources required are found to develop them. Rather the two key issues are:

**1.** Will the agronomic advantages of the mineral-dense seeds be sufficiently strong that they will be widely adopted by farmers in developing countries?

**2.** Will the additional nutrients contained in the seeds be of a sufficient magnitude and sufficiently bioavailable so as to have an appreciable impact on micronutrient status?

There is much scientific evidence to be optimistic, even excited, on the first count. There are good reasons to be optimistic on the second count as well.

—*H.E.B.*

*Editor's note: Howarth Bouis, an economist, has undertaken research related to food comsumption and nutrition issues in developing countries at the International Food Policy Research Institute since 1983.*

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