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A new paradigm for world agriculture: meeting human needs Productive, sustainable, nutritious

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Abstract

Micronutrient malnutrition ('Hidden Hunger') now afflicts over two billion people worldwide, resulting in poor health, low worker productivity, high rates of mortality and morbidity, increased rates of chronic diseases (coronary heart disease, cancer, stroke, and diabetes), and permanent impairment of cognitive abilities of infants born to micronutrient-deficient mothers. The consequences of food system failures include lethargic national development efforts, continued high population growth rates, and a vicious cycle of poverty for massive numbers of underprivileged people in all nations. Our food systems are failing us globally by not providing enough balanced nutrient output to meet all the nutritional needs of every person, especially resource-poor women, infants and children in developing countries. Agriculture is partly responsible because it has never held nutrient output as an explicit goal of its production systems. Indeed, many agricultural policies have fostered a decline in nutrition and diet diversity for the poor in many countries. Nutrition and health communities are also partly responsible because they have never considered using agriculture as a primary tool in their programs directed at alleviating poor nutrition and ill health globally. Now is the time for a new paradigm for agriculture and nutrition. We must consider ways in which agriculture can contribute to finding sustainable solutions to food system failures through holistic food-based system approaches, thereby closely linking agricultural production to improving human health, livelihood and well being. Such action will stimulate support for agricultural research in many developed countries because it addresses consumer issues as well as agricultural production issues and is, therefore, politically supportable.

Keywords: Sustainable agriculture; Human nutrition; Micronutrients; Malnutrition; Development; Health

1. Introduction

The path set down for world agriculture into the 21st century was defined barely a decade ago, but we already need further change before the millennium to avert global food system failures. This has much to do with the impact of the green revolution and its perceived inadequacies: we have begun to address the environmental concerns about modern, technological agriculture, but evidence is growing that our global food systems are failing to deliver adequate quantities of healthy, nutritionally balanced food especially to underprivileged people globally (Mason and Garcia, 1993; McGuire, 1993). The consequences are affecting human health, well being, productivity, livelihood

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and contributing to stagnating national development efforts in many developing nations.

1.1. The old production paradigm

Science-driven progress in agriculture in the last 100 years has resulted in an increasingly technological operation which has shown itself capable of achieving lifts in productivity needed to provide adequate food energy for the world, and even to provide more calories per person. The technology included new cultivars, chemicals ranging from mineral fertilizers to pesticides to synthetic plant hormones, and machines to supplement and replace the labor force. Many countries benefitted immensely from this agricultural revolution as the problems of inherently infertile soils were resolved by the development of nitrogen, superphosphate and micronutrient fertilizers, creating a surplus of food that has endured since the early 1980s. We call this technological revolution the *Production Paradigm*. It culminated in the green revolution, a series of highly orchestrated, global strategies developed in the face of threatening starvation, to expand the global production of staple food crops, especially cereals. This huge international effort began in the 1960s and achieved adequacy in world food calorie/protein production in just two decades, an effort for which one of the leaders, Dr. N.E. Borlaug, received the Nobel Peace Prize in 1971.

1.2. The current paradigm

Even before this monumental international effort for food security got underway, Rachel Carson had published her famous book, *Silent Spring* (Carson, 1962), depicting the threat to our environment from the indiscriminate use of toxic chemicals, much of it in 'modern' agriculture. There was also concern that the emphasis on agricultural production was threatening the resource base of land, soil, air and water through processes such as loss of soil fertility by erosion, acidification, salinization and desertification.

In the mid-1980s, that approach to agriculture and its research base was largely overrun and a new paradigm installed: high productivity while preserving or improving the resource base of agriculture and the environment – the so-called *Sustainability Paradigm*. Originally, the green revolution failed to place enough emphasis on the sustainability of its increased productivity (though it must be remembered that the initial focus was to avert the then imminent prospect of mass starvation in many countries). It did not, however, link farming-system sustainability to food-system sustainability as a whole.

1.3. A new paradigm is needed

No sooner had the proponents of sustainability been congratulated for getting the philosophy for world agriculture 'right', with a remarkable global consensus (though the objectives still have to be realized), than new concerns have arisen. Like the environmental concerns before them, these have been brewing for some time, but they have been brought into sharp focus by the statistics of the United Nation's World Health Organization and World Bank (Anonymous, 1992a; World Bank, 1994) in the last few years. While the world's food supply has been sufficient (wars, food distribution problems and the like excepted), it is simply not providing adequate, balanced nutrition. Micronutrient malnutrition, often called 'Hidden Hunger', is more conspicuous in many countries since the introduction of green-revolution cropping systems (Fig. 1). Today, micronutrient malnutrition diminishes the health, productivity, and well being of over half of the global community, with impact primarily on women, infants and children from low-income families (Anonymous, 1992b; Mason and Garcia, 1993). The latest figures indicate that 2.15 billion people are deficient in iron, often severely enough to cause anemia (Table 1). This is about 40% of the total population (up from 30% a decade ago), and includes most of the women and children of the developing world, together with a surprisingly large number in developed countries.

Some people question the green revolution's success because productive cereals, the basis of increased food production in poor countries, have displaced other, traditional crops which are higher in iron and other limiting micronutrients needed for healthy lives (see later). In South Asia, where cereal production has increased more than four times since 1970 (while the population has less than doubled), production of pulses actually declined about 20% (Fig. 2). To put this in economic terms, the World Bank and the U.S.

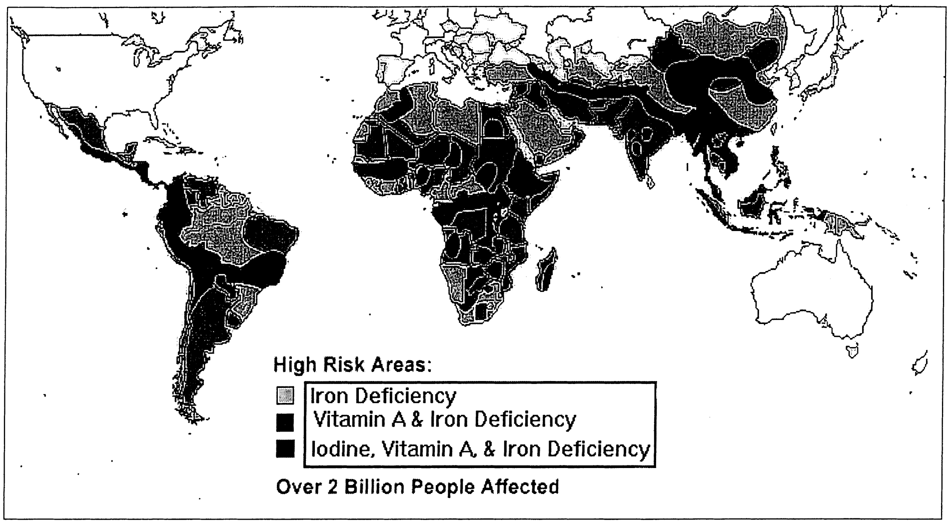

Fig. 1. Prevalence of iron, vitamin A and iodine deficiencies in humans living in developing countries; map modified from Sanghvi (1996).

Table 1
Prevalence of micronutrient malnutrition in human populations by WHO regions (Table modified from World Bank (1994))

Region	Iodine deficiency disorders [a]		Vitamin A deficiency [a]		Iron-deficient or anemic [a]
	at risk	affected (goiter)	at risk	affected (xerophthalmia) [b]	
Africa	150	39	18	1.3	206
Americas	55	30	2	0.1	94
South and Southeast Asia	280	100	138	10.0	616
Europe	82	14	—	—	27
Eastern Mediterranean	33	12	13	1.0	149
Western Pacific and China	405	30	19	1.4	1058
Total	1005	225	190	13.8	2150

[a] Millions of people.
[b] Xerophthalmia (drying of the eyes) is defined as severe vitamin A deficiency resulting in eye damage including irreversible blindness.

Agency for International Development (Sanghvi, 1996) have estimated that iron deficiency costs India and Bangladesh about 5 and 11%, respectively, of their gross national product annually, enough all by itself to prevent these countries rapidly accelerating out of Third World status, a prospect which historically, if achieved, results in lower national birth rates.

During the green revolution's push toward food (i.e. calorie or energy) security, little thought was given to nutritional value and human health, and certainly almost none to the content of iron and other micronutrients in the new cereal cultivars being bred, nor to the micronutrient content of the resultant changing diets. However, the prospect of mass starvation, inevitable without the green revolution, is far worse than the problems we now need to address. In toto, the impact of modern agriculture on improving the lives and well being of billions of people globally is impressive. While the impact of agricultural research has been immense, the outcome of these success stories, however, has created even more daunting challenges for agricultural scientists, nutritionists, health care specialists, policy makers and their institutions.

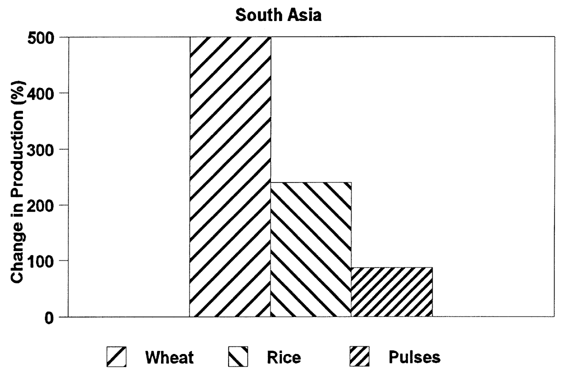

Fig. 2. Percent change in the production of rice, wheat and pulses in South Asia between 1965 to 1995 (data obtained from FAO data base accessed from the internet at address http://apps.fao.org/cgi-bin/nph-db.pl?subset=agriculture).

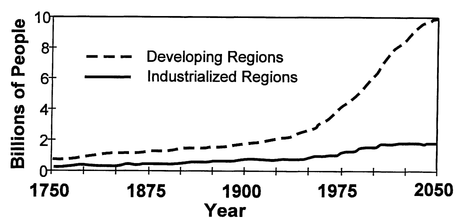

Fig. 3. Trends in global human population growth from 1750 to 2050 (data from World Resources Institute, Washington, D.C.).

1.4. The population explosion

Fig. 3 illustrates the population of the earth for developing and developed countries separately from the year 1750 to the year 2050. The projections to the year 2050 indicate that population stability is expected at that time with numbers in the range of 10 to 12 billion. The population explosion in the developing world is a phenomenon of our own time – post World War II – and a feature of the curve is that we are currently half way through the population bulge, both in time and in numbers. The implications are clear: while the green revolution in food production has kept pace with the population increase to the half way point, a second green revolution of similar magnitude is needed to provide food for another 4–6 billion people still to come. Agricultural scientists in the international arena now talk of the 'first' green revolution (1960–the present) and the 'second' green revolution currently in plan. The achievements of the first were based heavily on increases in productivity of high-yield-potential, irrigated lands, and as their productivity approaches the potential, it is perceived that the second green revolution must be based, in contrast to the first, more on the low-yield, rain-fed environments that are far below their potential. To succeed is essential, if we are to guarantee an acceptable future for our children and grandchildren, no matter what country we now live in. Food security is essential to political stability on which an acceptable future depends. Importantly, among those entrusted with the responsibilities of planning this second green revolution, there is a quiet but total confidence that it can be delivered, and this confidence needs to be conveyed to the next generation and its budding scientists who will join the effort.

2. Identifying the target micronutrients

To a considerable extent, the nutritionists, FAO and WHO have done this already, identifying micronutrient malnutrition as a primary health care issue affecting over two billion people, and as more extensive today than protein-energy deficiency which affects about 800 million people worldwide. The most important, in order of numbers of people known to be affected, are iron, iodine and vitamin A. To this group is added zinc, equally as widespread as the others, and in the opinion of specialists in zinc nutrition, as important as iron deficiency (Gibson, 1994). (There are no good statistics for zinc deficiency as diagnosis is complicated (Shrimpton, 1993).) After these in importance is selenium, effects and functions of which are only now being revealed. Other micronutrient minerals include copper, boron, manganese, chromium, and lithium. In addition, we need to consider vitamins (e.g. vitamin E, folic acid, and vitamin C) and other dietary substances (including promoters and inhibitors of absorption of iron and zinc) that are important factors affecting human health and nutritional status (discussed later).

While the 'big four' micronutrients (iron, iodine, vitamin A and zinc) select themselves by virtue of the numbers of people worldwide whose diet is inadequate in them, they also select themselves in another, rather fundamental way: deficiencies of iron, zinc, vitamin A and iodine not only compromise the immune system, but can irreversibly retard brain development in utero and for up to two years postpartum. This means that deficiency of any of them in a pregnant or lactating woman can result in a mentally and physically handicapped child that will never achieve its genetic potential in cognitive abilities. Such children may be less fit to control their environment and to provide for their own food security in later life; they cannot compete for better education and for higher level jobs within their societies. They are, therefore, more likely to be nutrient deficient too, giving rise to a higher chance of another generation of less fit and less competitive individuals. Poverty and malnutrition thus tend to perpetuate themselves, and the high population growth rate which is associated with poor food security. Thus, deficiencies in micronutrients appear to contribute to the population 'time bomb', and delivering more of these limiting nutrients through the food system will not only improve the health, livelihood, and welfare of the present generation, but may also contribute greatly to solving the population growth conundrum. There is compelling evidence that the kinds of social and economic changes required for major improvements in health and security through improved nutritional status are conducive to later marriage, lower fertility, and successful policies to reduce population growth rates (National Research Council, 1977).

Our ultimate objective is sustainable food systems that provide adequate nutrient output, potentially achievable by an alliance between agricultural, nutritional, and health-related sciences. This is a more aggressive and potentially successful 'bottom up' approach to lowering population growth rates than that promoted by the international population summit held in Cairo, Egypt, in 1995, namely, to rely on 'top down' economic development alone to decrease the birth rate, as has been done in the past, though neither approach precludes the other. Indeed, we argue that they are interrelated. Economic development depends on good nutrition. Hetzel (1989) in his book on iodine deficiency records two separate instances of how treatment of a village with iodine not only eliminated cretinism, goiter and other health manifestations of the deficiency, but it led to improved social and economic development, including the adoption of new agricultural technology, compared to a control village.

Additionally, micronutrient deficiencies are far from eliminated in the developed world. Some 14 million women are anemic, including 41% of all poor, pregnant African–American women in the USA (U.S. Department of Health and Human Services, 1990), and anemia among children is well documented in Australia (Cobiac and Bathurst, 1993). Diet-related diseases (including coronary heart disease, cancer, stroke, and diabetes) cost the U.S. economy about 100 billion dollars annually (Frazao, 1996). Recently, Goldenberg et al. (1995) reported that zinc supplementation of pregnant African–American women (randomized double-blind placebo-controlled trial, n=580) resulted in greater infant birth weights and head circumferences demonstrating zinc deficiency in some low-income gravid women from this population group in the United States. Work at the University of California, Davis, has recently shown serious teratogenic outcomes of pregnancies associated with low blood zinc levels in women in that state (Brown et al., 1996). Iodine deficiency is increasing in Europe even after earlier programs were effective in controlling it. The U.S. Department of Agriculture and the U.S. Department of Health and Human Services, Public Health Service, advocate that people eat more whole grain cereal products, vegetables, and fruit, and less fatty meats, added fats and sugars, using their published Food Guide Pyramid to determine healthy daily food choices in order to realize the benefits in lowering the risk of coronary heart disease, cancer, stroke and diabetes (Kantaor, 1996). Even in the USA, with one of the most abundant and healthy food supplies in the world, its food systems are failing to provide adequate nutrients to insure good health for all. Eating less meat will likely increase the numbers of people deficient in iron and zinc in developed countries because it is the primary source of iron and zinc in diets of developed nations. Therefore, support from developed countries should be available if agriculture chooses to embark on the food systems strategies to sustainable micronutrient nutrition under investigation in this volume.

3. Micronutrients in food systems

Modern agricultural systems are adept at providing calories, but in the process, they have increased 'Hidden Hunger' among the world's poor by displacing acreage allotted to traditional crops such as pulses, making many micronutrient-rich plant foods less

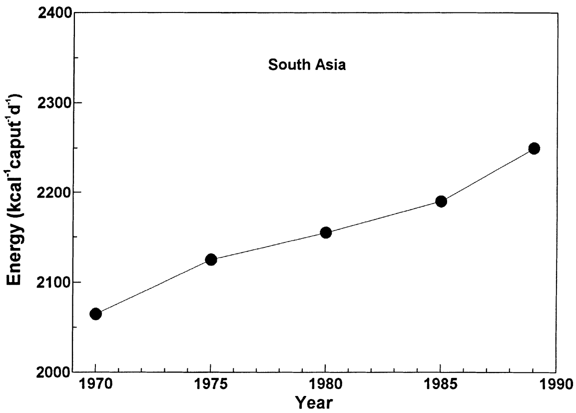

Fig. 4. Trends in dietary energy supply for people in South Asia from 1970 to 1990 (data from Anonymous (1992b)).

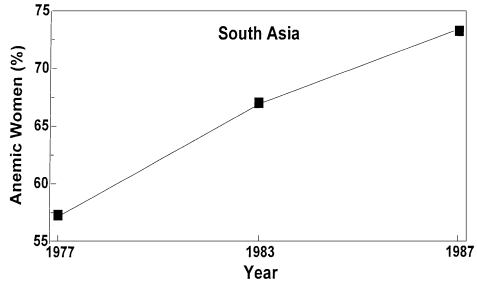

Fig. 6. South Asian trends in iron-deficiency anemia (<12 g hemoglobin per dl blood) from 1977 to 1987 among nonpregnant adult women between the ages of 15 and 49 year (data from Anonymous (1992b)).

available and more expensive to low-income families (Combs et al., 1996). This is no more evident than in South Asia. Fig. 4 depicts the effect of the introduction of the green revolution crops (i.e. rice/wheat cropping systems) on the per capita availability of food energy in South Asia, proof that agriculture has been successful at finding ways to increase the caloric output to meet the demands of this region's population that almost doubled in the two decades represented. Fig. 5 depicts the change in iron density of the diets consumed by people in this region. The introduction of green revolution cropping systems was associated with a decline in the density of iron in the diets of people in South Asia and the incidence of iron-deficiency anemia has increased in pre-menopausal women in South Asia as illustrated in Fig. 6.

The cereals, rice in particular, that have displaced traditional micronutrient-rich crops of pulses, vegetables and fruits, contain inherently lower amounts of micronutrients (Table 2) and are eaten primarily after milling while pulses are normally consumed whole after cooking; milling removes most of the micronutrients cereals contain (Table 3). Furthermore, whole cereal grains contain relatively high levels of antinutrients (substances that reduce the absorption and/or utilization, i.e. bioavailability, of micronutrient metals to humans) and lower levels of substances that promote the bioavailability of these nutrients, further reducing the nutritional value of cereal products with respect to micronutrients (Graham and Welch, 1996; Welch and House, 1984). Table 4 lists some important antinutrients found in food products from many plants.

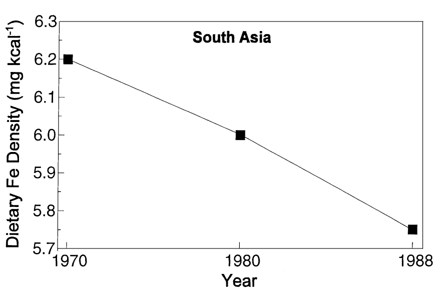

Fig. 5. Trends in dietary iron density for people in South Asia from 1970 to 1989 (data from Anonymous (1992b)).

Animal products (beef, pork, lamb, poultry, fish) and many fruits and vegetables contain high levels of micronutrient metals, such as iron and zinc. Meats are also rich sources of substances ('meat factors') that counteract the negative effects of antinutrients found in many staple plant foods, thereby promoting the bioavailability of iron, zinc and other micronutrients in mixed diets (Graham and Welch, 1996; Welch and House, 1995). Table 5 lists some promoter substances found in abundance in animal protein sources.

In many developing nations, animal meats, fruits, and vegetables are not continually available throughout the year (especially to low-income families). Therefore, they contribute little to meeting the continuous nutritional needs of gravid women, infants and children because these foods are either seasonal and/or relatively expensive. For example, Fig. 7 shows that many developing nations do not produce

Table 2
Median concentration and range of Fe, Zn, and Cu in rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), field corn (*Zea mays* L.), and soybean (*Glycine max* L.) grain/seeds from major agricultural production regions within the conterminous United States and range of Fe, Zn and Cu concentrations in commercial bean (*Phaseolus vulgaris* L.) seeds

Mature grain/seed	Fe		Zn		Cu	
	median ($\mu g\ g^{-1}$ dry wt)	range	median	range	median	range
Rice [a]	3	2–10	16	10–22	2	1–5
Wheat [a]	37	24–61	31	13–68	4	2–9
Field corn [a]	20	16–30	21	15–34	1	1–4
Soybean [a]	70	48–110	45	36–70	13	4–29
Bean [b]	—	33–80	—	19–65	—	5–14

[a] Source of data: Wolnik et al. (1983); Wolnik et al. (1985)).
[b] Source of data: Augustin et al. (1981).

Table 3
The influence of milling on the iron and zinc concentrations in seed/grain of rice, wheat (*Triticum aestivum* L.), corn (*Zea mays* L.) and sorghum (*Sorghum bicolor* Moench); sources of data: Pedersen and Eggum (1983a); Pedersen and Eggum (1983b, b); Resurreccion et al. (1979); Widdowson (1975)

Crop	Milling fraction	Fe ($\mu g\ g^{-1}$ dry wt)	Zn
Corn	whole grain	23	21
	degermed	11	4
Sorghum	whole grain	179	36
	64% extraction	54	10
Rice	brown rice	16	28
	90% extraction	5	17
Wheat	whole grain	38	37
	70% extraction	22	12

enough fruits and vegetables to meet the recommended level of consumption of fruits and vegetables of 73 kg $year^{-1}$ per person. Thus, greatly increasing small animal, fruits, and vegetable production and the infrastructure to process and provide these foods on a continuing basis to those most in need would have a significant effect in improving the micronutrient status of people in many regions of the world (Combs et al., 1996).

What are the ramifications of micronutrient malnutrition to human health, livelihood, well being, fertility, and, ultimately, the sustainability of national development efforts in Third World countries? ‘Hidden Hunger’ results in huge costs to society that greatly impair national development efforts, reducing labor productivity, lowering educational attainments in children, reducing school enrolments and attendance, increasing mortality and morbidity rates, and increasing health care costs (Sanghvi, 1996).

Commonly, policy makers have viewed malnutrition, including micronutrient malnutrition, as a disease that must be ‘treated’. Accordingly, many nations have adopted the strategy of supplementation that stresses only food fortification intervention programs

Table 4
Important ‘antinutrient’ substances in plant foods reported to reduce the bioavailability of Fe and/or Zn to humans under most, but not necessarily all, circumstances (modified from Graham and Welch (1996))

Antinutrient	Examples of major dietary source
Phytic acid or phytin	whole legume seeds and cereal grains
Fiber (e.g. cellulose, hemicellulose, lignin, cutin, suberin, etc.)	whole cereal grain products (e.g. wheat, rice, maize, oat, barley)
Tannins and polyphenolics	tea, coffee, beans, sorghum, etc.
Hemagglutinins (e.g. lectins)	most legumes and wheat
Heavy metals (e.g. Cd, Hg, Pb, Ag)	plant foods obtained from crops grown on metal polluted soils (e.g. Cd in rice)

Table 5
Promoter substances in plant foods reported to enhance the bioavailability of iron, zinc, and/or vitamin a to humans eating meals containing complex diets under some, but not necessarily all circumstances (modified from Graham and Welch (1996)). Garcia-Casal et al. (1998)*

Substance	Micronutrient	Major dietary sources
Certain organic acids (e.g. ascorbic acid or vitamin C, fumarate, malate, citrate)	Fe and/or Zn	fresh fruits and vegetables
Phytoferritin (plant ferritin)	Fe	legume seeds and leafy vegetables
Certain amino acids (e.g. methionine, cysteine, histidine, and lysine)	Fe and/or Zn	animal meats (e.g. beef, pork, and fish)
Long-chain fatty acids (e.g. palmitic acid)	Zn	human breast milk
Fats and lipids	vitamin A	animal fats, vegetable oils
	vitamin E	animal fats, vegetable oils
beta-carotene	Fe, Zn	green and yellow vegetables*
Se	I	Sea foods, tropical nuts
Zn	vitamin A	Animal meats
Vitamin E	vitamin A	Vegetable oils, green leafy vegetables

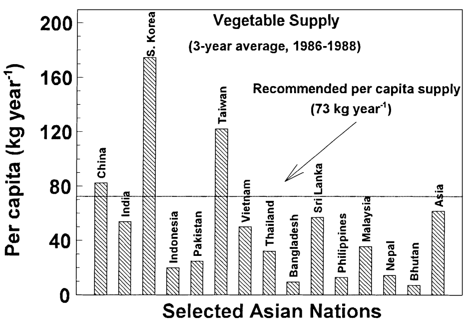

Fig. 7. Per person vegetable supply for selected nations (three year average; 1986–1988). Recommenced per caput vegetable consumption is estimated to be 73 kg year^{-1} to prevent micronutrient malnutrition and is depicted as a dashed line on the graph (graph modified from a personal communication from M. Ali, T. Samson, and H.P. Janson, Asian Vegetable Research and Development Center, Taiwan, 1995).

(Maberly et al., 1994). While many of these programs have been successful for those individuals treated, they are all too often unsustainable because of economic, political, and logistic reasons (McGuire, 1993). The International Conference on Nutrition, held in Rome, Italy, in December of 1992 (Anonymous, 1992a) recognized the urgent need to find sustainable solutions to micronutrient malnutrition. Indeed, the Conference called for ensuring that sustainable food-based strategies be given *first* priority by national policy makers, asking that their policies be directed at additional investment in agricultural research, where necessary, to promote improved micronutrient output of agricultural systems. Dr. Barbara Underwood, World Health Organization, emphasized ''that food, nutrition and health programs should not exist as vertical programs within the health ministry, nor should agricultural programs be solely production-oriented, ignoring consumption issues, household food security, and community nutritional needs. Indeed . . . health, nutrition, and food security are inextricably interrelated and must become explicit objectives of development policies, particularly agricultural development policy'' (Underwood, 1992). There is now a distinct message from the nutrition community to the agricultural community seeking to forge closer linkages between agricultural production and human nutrition and health in ways that will insure adequate, balanced and enduring nutriment for everyone (Buyckx, 1993).

In developed nations, agricultural science provided tools that dramatically increased food crop yields and food abundance while reducing the cost of food to consumers. Food surpluses also accumulated. This success has led to substantially larger but fewer farms and fewer farm families in developed countries. Now, farmers no longer comprise a significant proportion of the voting public within most intranational political boundaries in developed nations. (e.g. today, <2% of the USA population produces the food needed to nourish its citizens). Consequently, there is much less public concern for agriculture and farming issues than there was a century ago. Public support for agricultural research has been eroded, making government-sponsored funding of agricultural research more difficult to obtain. Currently, leading agricultural institutions in developed nations are faced with expanding their missions to service the concerns of new clients (not just farmers) to justify their existence and glean political support to maintain their agricultural programs. As a result of national and international movements to redress environmental concerns, many agricultural institutions have initiated environmental research programs to gain more public support. Importantly, the world community has now given agriculture a new global agenda that will help generate new public support for agricultural research because nutrition and health issues are of growing concern to the public at large and are, therefore, politically supportable. The time has come to seize this opportunity and begin to form collaborations between agricultural and health scientists to eradicate 'Hidden Hunger'. Unquestionably, agriculture must address this quandary if we are to find sustainable solutions to micronutrient malnutrition that degrades human health, productivity and well being.

4. The food systems paradigm for sustainable production of nutritious food

Insecurity for food and shelter is considered to be causally related to the high birth rate in poor countries (Combs et al., 1996). Consequently, the stakes in any attempt to eliminate these deficiencies are of the highest order. Forging research linkages between agriculture, nutrition and health overcomes the adverse effects of past policies for global agriculture, nutrition, and national development that have fostered only short-term, unsustainable, solutions to starvation, malnutrition, underdevelopment, and high human fertility rates. Food systems approaches (directed at empowering people and insuring balanced and adequate nutrition and improved health for all in sustainable ways) hold much promise in providing the methods needed for agricultural research to insure sustainable agricultural systems. To do so would be to support a new paradigm for agriculture – the *food systems paradigm* – an agriculture which aims not only at productivity and sustainability, but also at better nutrition, compelling objectives for the entire human race.

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