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Some unorthodox perspectives on agricultural biodiversity. The case of legume cultivation

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Abstract

In spite of their well known nutritional, agronomic and agroecosystemic advantages legumes are unlikely to regain their traditional share of agricultural production. Nevertheless, sustainable cropping is hard to imagine without their proven benefits in crop rotations and their contributions to benign nitrogen supply and to the maintenance of soil microorganisms. © 1997 Elsevier Science B.V.

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1. Introduction

Wider perspectives are essential in order to assess the potentials and limitations of major choices related to the maintenance of agricultural diversity. Maintenance of agricultural diversity whose promotion has environmental, economic, social and nutritional implications whose combined consequences and requirements will decide the long-term success or failure of diversification. An excellent insight into these challenges is offered by a closer look at legumes. If maximization of cropping diversity is seen as a desirable goal – not only as a preferable agronomic practice but as a significant contribution to socio-economic well-being – then the promotion of leguminous species should follow. These crops have many well-known advantages, and no intensive traditional agroecosystem could work without relying on them.

Why is it then that legumes have been in a virtually global retreat? That even China, the home of soybean and beancurd, is now producing less than two generations ago, indeed less than the peak output during the 1930s? Has this largely been a matter of avoidable neglect – or a consequence of unavoidable developmental trends? Answering these questions should help in appraising realistic limits to increased agricultural biodiversity through leguminous cultivation, and to design effective approaches to the promotion of this goal.

2. Recounting the benefits

Both the agroecosystemic and nutritional advantages of leguminous crops have been appreciated for centuries in convincing qualitative terms. They have been researched and described in much quantitative detail since the closing decades of the nineteenth century after the demonstration of nitrogen-fixing capabilities of symbiotic bacteria and the almost concurrent emergence of modern nutritional understanding, including the critical role of food proteins.

To begin with, food legumes come in a wide variety of species, including such worldwide choices

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as ordinary (kidney, French or haricot) beans (*Phaseolus*) and peas (*Pisum*) to plants largely unknown beyond their limited tropical or subtropical homes. This category includes such diverse crops as West African bambara groundnuts (*Voandzeia subterranea*) and Southeast Asian rice beans (*Vigna umbellata*). This variety means that there is no agroclimatic zone, from the wettest tropics to Canadian prairies, which could not support at least a few legume cultivars.

The principal agronomic advantage of legumes is, of course, the ability of symbiotic *Rhizobium* bacteria to fix substantial amounts of nitrogen, and thus either almost entirely eliminate, or greatly reduce, the need for any supplemental supply of that critical macronutrient. In addition, legumes are generally more drought-tolerant than cereals, require less irrigation in arid environments, and are also fairly pest-resistant. And leguminous cover crops – alfalfa, clovers and vetches being the most important by far – provide outstanding anti-erosion protection, fix much more nitrogen than edible species, and they are also the richest source of new organic soil matter in agroecosystems when plowed under as green manures.

The nutritional appeal of legumes rests on their unusually high protein content, and on the fact that their amino acid make-up complements that of staple cereals. While protein levels in wheat, rice and corn range between 7% and 14%, most legumes contain between 20% and 25%, and soybeans around 40%. These proteins are deficient in sulfur-containing amino acids (methionine and cystine), but have abundant lysine, the pattern exactly opposite to the amino acid make-up of staple cereals. The nutritional quality of legumes is further enhanced by their relatively high levels of riboflavin, thiamine, calcium and iron, and by the provision of excellent dietary roughage by mature seeds: diets containing cooked pulses require no fanciful bran supplements. And, of course, several leguminous seeds, above all soybeans and peanuts, are rich sources of plant oils high in polyunsaturated fatty acids.

Finally, legumes offer impressive culinary flexibility. They can be eaten as vegetables, either as immature pods or seeds, most commonly those of peas, or as sprouted seeds. Uncooked mature dry or roasted seeds make good snacks (peanuts are a global favorite). Cooked dry seeds, including virtually all varieties of pulses, are universal staples, and there is an array of fermented foodstuffs, ranging from Indian *idli* to Indonesian *tempeh* and to now almost global soy sauce, and of milled and coagulated products, most notably the Chinese *doufu* and slightly different Japanese *tofu*.

Not surprisingly, every traditional society planted food legumes in often complex rotations with staple cereal, root, oil and sugar species. Dominant food species differed – soybeans and beans in East Asia, lentils and chickpeas in the Indian subcontinent and throughout the Middle East, peas and beans in Europe, groundnuts in West Africa, beans in the Americas – but the basic pattern of rotations or intercropping was universal. And as their productivity of agroecosystems increased, both Asian and Western farming also begun to rely more on legumes as green manures.

Given this combination of agronomic, dietary and culinary virtues one might expect that plantings of all leguminous varieties – be it for food, feed or as green manures – should be on the rise in all highly productive agricultural regions, combining to produce a clear upward global trend. In reality, just the opposite has been true. Although a few food legumes have been holding their relative position in some regions, overall cultivation of pulses has been in unmistakable global decline. And although plantings of soybeans for feed have risen to record levels, the increase has been concentrated in a small number of countries, and cultivation of other leguminous feeds has been in decline.

3. Global retreat

The clearest nutritional evidence for this trend comes from basic accounts of food availability. Food balance sheets, be they prepared by national statistical offices or calculated in the FAO's Rome headquarters, do not tell us how much, on average, people actually eat. There is a gap, often surprisingly large, between aggregates of energy and nutrient availability derived from food balance sheets and actual intakes measured by much more expensive, and hence much rarer consumption surveys (Smil, 1994). But these accounts are good enough to assess long-term changes in nutritional patterns and to appraise approximate contributions of individual foodstuffs to overall energy, carbohydrate, protein, lipid and micronutrient supply.

Food balance sheets available for the period before the Second World War for a small number of non-Western countries reflect traditional patterns of legume consumption, with annual per capita intakes as high as about 25 kg per year in India and well over 10 kg in most of Latin America. Such intakes provided between 5% and 15% of all food energy supply – and 15% to almost 30% of all protein consumed.

In contrast, in industrialized countries the pre-1939 supply of legumes already slipped to a marginal position, with annual per capita availabilities ranging from just 2–3 kg in the Netherlands to about 7 kg in France and in North America, totals equivalent to just 0.5%–2% of available food energy and 1%–5% of all protein (Den Hartog, 1992; Dupin et al., 1984; USDA, 1920–1995).

After 1945 there had been some temporary increases in a few Asian and African countries, but the global trend has been unmistakable as absolute intakes of legumes fell on every continent. Given the much higher increases of other staple crop yields and rising availability of animal foods, the relative importance of leguminous foodstuffs has fallen even more rapidly

Current average per capita supplies are just above 1 kg per year in the European Union, below 3 kg in North America and Japan, below 10 kg throughout Latin America and less than 15 kg in India. Consequently, even in India legumes provide only about 5% of all food energy and 15% of all protein.

In many Latin American and African countries the importance of legumes has been reduced to levels prevailing in pre Second World War Europe, and throughout the industrialized world the intake of pulses has sunk to a marginal category that includes the disparate worlds of underclass poverty (canned beans) and voguish vegetarian experimentations (bacon-flavored beancurd). In sum, in terms of large-scale averages, legumes hold their own as staple foods only on the Indian subcontinent; they are becoming marginal in their traditional Latin American stronghold; and their nutritional contribution is inconsequential throughout the Western world.

This decline appears to be part of a almost universal dietary change accompanying improvements in the average standard of living. The other key ingredients are declining intakes of whole grain cereals and tubers, and higher consumption of animal foods, refined sugar and fresh fruits. Affluence tends to bring a more expensive diet lower in carbohydrates and higher in lipids and animal protein shares.

The decline in the consumption of legumes has not been limited to food crops. Of course, soybean cultivation has expanded enormously outside its East Asian core – but the bulk of the gain has been in just two countries. American plantings, which amounted to a few thousand hectares in the early 1930s, have been above 20 million hectares since the early 1970s, producing more than 50 million tonnes a year. The increase in the Brazilian soybean production has been even faster, from a negligible harvest in the early 1960s to more than 20 million tonnes in the early 1990s. These two countries now produce two-thirds of the global soybean harvest, virtually all of it for cattle and pig feed.

In contrast, the cultivation of leguminous forages has been declining or stagnating. Alfalfa (*Medicago sativa*), grown mostly in Europe and in the Americas, is still the world's largest forage crop (with a total of about 30 million hectares), but its worldwide plantings have recently been shrinking by about one million hectares a year. Global plantings of clover and vetches have been also decreasing. This retreat has paralleled the steady increase in applications of inexpensive synthetic nitrogenous fertilizers and the expanding production of high-protein soybean-based feeds.

4. China's experience

The best available information on typical rates of traditional Chinese food consumption comes from extensive surveys conducted by John L. Buck during the 1920s (Buck, 1937), and from figures gathered by the Department of Agricultural Economics of the National Agricultural Research Bureau during the 1930s (Shen, 1951). These data show legume intakes which were both widespread and important.

Nationwide, one-fifth of all families regularly consumed broad beans, one-quarter green beans, one-third field peas and two-fifths soybeans, with regional rates rising to as high as 70% for soybeans in the Southwest, and 75% for peas in the area of double-cropped rice. Average per capita legume consumption during the years 1931–1937 reached just over 25 kg per year, equal to India's mean and hence just about the highest recorded. Soybeans, beans and peas supplied about 7% of all food energy and 16% of all protein during the 1930s, with the latter share as high as 25% in the winter-wheat region.

Soybeans, whose cultivation dates as far back as the 11th century BC, were the leading pulse, with an average pre-1937 harvest of about 6 million tonnes a year, and an annual per capita supply amounting to almost exactly 8 kg. Broad beans, with less than 6 kg, were second. Post-1949 soybean plantings increased slowly but steadily during the early 1950s, peaking at 12.8 million hectares in 1957. The subsequent decline, to the low of 6.7 million hectares in 1976, was reversed with the beginning of radical agricultural reforms in 1979. A new high of 8.44 million hectares was reached in 1987, but this was still one-third below the 1957 peak (State Statistical Bureau, 1994). Even more significantly, it was also below the record pre Second World War extent of 11.9 million hectares planted in 1933.

Higher average yields (national mean of 1470 kg per hectare in 1987 vs. 795 kg in 1957) were not able to compensate for the combination of reduced plantings and growing population. While the 1957 harvest prorated to 15.5 kg per capita, the 1987 rate was only 11.4 kg per capita. Since 1987 both the total sown area and average yields have stagnated or declined, while China's population increased by just over 100 million people by the end of 1994. Consequently, the average per capita availability of soybeans in the mid-1990s is only about three-fifths of the rate prevailing two generations ago (in the mid-1950s), and less than half of the supply reached during the best harvest years of the 1930s.

The current low status of other food legumes in China (broad, red, mung and kidney beans, and peas) is perhaps best illustrated by the fact that – unlike for soybeans and for cereal, oil and sugar crops – the State Statistical Bureau offers no nationwide data on their planted area and annual harvests, and that on the provincial levels such figures were available in the early 1990s only for Yunnan, Sichuan and Anhui (Hornbein, 1991).

Recent changes in the cultivation of green manures show even faster decline trends. Complex rotations, including a variety of green manures – most commonly the Chinese vetch (*Astragalus sinensis*), common vetch (*Vicia sativa*) and lucerne (*Medicago denticulata*) – used to be one of the characteristic features of traditional Chinese farming. In 1952 green manures were planted on about 2.3 million hectares and their area kept expanding during the years of limited availability of synthetic fertilizers to a peak of 9.9 million hectares in 1975.

Subsequent expansion of large-scale synthesis of urea (produced by more than a dozen large modern plants ordered from the US and the Netherlands after 1972) brought a steady decline in green manure plantings to only about 4 million hectares by 1989. Moreover, recent cultivation of green manures has been extremely uneven: in the early 1990s Hunan accounted for more than 20% of all such plantings – but intensively cropped Guangdong contributed less than 3% of the national total (Smil, 1993).

The reason for abandoning green manure cultivation is clearly the higher pressure to produce more food on limited land. To return to the peak plantings of the 1970s would mean to forgo grain harvest on some 6 million hectares, or roughly 20 million tonnes of food cereals, equivalent to about 5% of China's total output and sufficient to feed some 75 million people. These grains, and their residues, will incorporate about 600,000 tonnes of nitrogen derived largely from chemical fertilizers, a mass equivalent to less than 5% of China's recent application of synthetic nitrogenous compounds.

5. What is wrong with legumes?

Certainly the most obvious disadvantage of pulses in modern agriculture are their relatively low yields, inherently lower than those of staple cereal crops. While the recent global means for wheat and rice are, respectively, about 2500 and 3600 kg per hectare, those for pulses rose from around 500 kg in the early 1960s to less than 900 kg per hectare in the early 1990s (FAO, 1994).

More importantly, typical yields of many traditional varieties remain so low that there is no incentive to expand their cultivation in areas of inadequate or marginal food supply. Even a rather poor cereal crop in the arid Sahelian zone of Africa will yield 1–1.5 tonnes per hectare – while traditional legumes may bring less than 500 kg.

But low yields of legumes are just one, and I believe not even the most important, factor. The lowered desirability of legumes in changing diets and their less needed contribution to nitrogen balances in intensive agroecosystems, whose nutrient supply is dominated by synthetic fertilizers, matter more.

6. Nutritional drawbacks

Some of these detractions, above all complications in cooking and digesting many legumes, have been known since antiquity. Minimum cooking times for many mature seeds are much longer than those for cereal seeds and flours, on the order of two hours if the seeds were not presoaked. Although the food energy content of legumes is nearly identical to that of cereal grains, their different composition (above all the absence of gluten complex) makes it difficult, or outright impossible, to process them into such staples as bread and noodles.

Increased flatulence following higher intakes of legumes is due to the presence of indigestible oligosaccharides. Because the human digestive tract lacks the requisite enzyme (α-galactosidase), these sugars can become subject to anaerobic microbial fermentation, resulting in an excessive gas production (Augustin and Klein, 1989).

Modern biochemistry has added a long list of other objectionable, and often unique, ingredients (Ferrando, 1981; Matthews, 1989; Jones, 1992). All food legumes contain at least one, and most of them several, antinutritive factors. Enzyme inhibitors, mostly those interfering with the functioning of proteases (above all with trypsin and chymotrypsin), are especially common. Ironically, protease inhibitors make it more difficult for our bodies to use the proteins present in food legumes which may be eaten specifically for their high amino acid content!

Concentrations of lectins (seed toxins agglutinating red blood cells) are relatively high in virtually all legumes, while goitrogens, cyanogens (glycosides releasing HCN), estrogens, antivitamin factors (most notably those causing rachitis and vitamin E antagonists) and toxic amino acids are less widespread, but prominent in some species.

Species-specific antinutritive factors include vicine and covicine in faba beans, which may cause hemolytic anemia and hematuria in genetically sensitive individuals, and monoamine oxidase inhibitors, also in faba beans, engendering headaches and palpitations. Common, and not infrequently perilous, allergies to peanuts are well documented, as is the risk from aflatoxins not only in unprocessed whole seeds but also in peanut butter.

Of course, many traditional cultures learned to live with the poorer digestibility of legumes, and they also discovered how to destroy, or at least substantially eliminate, many antinutritive factors by prolonged cooking and by specific processing. But the resulting inconvenience, and the remaining risks accompanying insufficiently modified foodstuffs, do not add to the mass appeal of legumes. Consequently, it is hardly surprising that the foods not requiring such elaborate preparation yet providing equal, or better, nutritional value, will be preferable.

As soon as modernizing societies get richer and increased purchasing power enables people to buy more convenient and less risky foodstuffs, they follow one of the most notable universal nutritional shifts and begin reducing their consumption of legumes. Although the initial stages of incipient affluence may be accompanied by a slight increase in demand for pulses (a similar upturn is also often noticed for staple cereals), later developmental stages bring a sustained decline in the eating of traditional pulses.

7. Legumes as the sources of nitrogen

While the nutritional drawbacks of pulses have been appreciated for a long time, it was only during the last two decades when a better understanding of symbiotic nitrogen fixation, the first detailed studies of nitrogen balances in agroecosystems, and a greater appreciation of the complex dynamics of the biospheric nitrogen cycle revealed some surprisingly limited contributions of common leguminous crops to the supply of the critical macronutrient.

These findings challenge the traditional agronomic notion that nitrogen-fixing legumes can be relied on to contribute substantial quantities of nitrogen to be used by subsequent crops. The reality is far more complex: not only is the contributed amount so highly variable that it may often account for less than one-fifth of all nitrogen requirements, but not infrequently there may be no net gain at all.

The first reason for such relatively low contributions is the enormous variability of actual field fixation rates and inherent difficulties of their accurate appraisal. In spite of extensive research devoted to the study of symbiotic fixation, there is not even a single crop for which we would have reliable estimates of annual fixation rates. Published extreme rates for most common leguminous species show five- to six-fold differences (Table 1). And although they contribute less in absolute terms, measured outputs of nitrogen fixation by cyanobacteria span more than two orders of magnitude.

Similarly, totals of nitrogen removed by leguminous crops cannot be estimated with precision by using simple averages for nitrogen tissue contents and crop residue multipliers. Nitrogen content of both seeds and crop residues can commonly vary by up to 25%, and the amount of stalks and vines can differ by as much as two-fold.

An example of three realistic field outcomes summarized in Table 2 shows that a planting of leguminous grain crop may result in substantial nitrogen gain – or in an appreciable loss.

Nitrogen loss can become much larger when most of the crop residues are not recycled, the norm in many traditional settings, and still a common practice in many parts of Asia and Africa. The Chinese situation, both traditional and modern, is a perfect illustration of this reality. The relatively high protein content of leguminous straws, stalks and vines makes them good fodder, and Buck's extensive surveys showed that during the 1920s 25%–50% of all peanut vines and bean and pea residues were fed to animals (Buck, 1937).

Table 1
Ranges of published estimates for nitrogen fixation by legumes (all value are in kg N/ha·year)

Food legumes		Forages	
Beans	2–120	Alfalfa	120–600
Peas	10–70	Red clover	150–300
Lentils	30–120	Sweet clover	110–140
Soybeans	15–330	Egyptian clover	60–240
Peanuts	70–240	Vetch	110–180

Based on data in Smil (1985), Dixon and Wheeler (1986) and Heichel (1987).

Table 2
Examples of possible nitrogen additions and withdrawals in legume cultivation (all values are in kg N/ha)

	A	B	C
Nitrogen fixation	150	80	40
Symbiotic nitrogen fixation	130	65	30
Free living fixers	20	15	10
Nitrogen removal	70	70	70
Seeds	55	52	50
Crop residues	15	18	20
Balance	+80	+10	−40

All cases assume harvest of 1500 kg/ha and complete recycling of all residues. Case A assumes 3.7% N in seeds, crop residue multiplier of 0.8 and 1.25% nitrogen in stalks. Analogous figures for cases B are 3.5%, 1.0 and 1.2%, and for case C 3.3%, 1.3 and 1.1%. All other nitrogen inputs and outputs are assumed to be equal in all three cases.

In deforested lowland regions leguminous crop residues were also commonly used as fuel. A classical Chinese poem by Cao Zhi (quoted here in an admirable translation by A.H. Giles) attests to this reality in whimsical lines:

With a view to a good mess of pottage, all hot,The beanstalks, aflame, a fierce heat were begetting.The beans in the pot were all fuming and fretting.Yet the beans and the stalks were not born to be foes;Oh, why should these hurry to finish off those?

During the 1920s China's farmers typically burned 50%–75% of all soybean straw and broad bean and bean stalks (Buck, 1937).

Both of these practices are still very much in evidence. In spite of massive increases in coal consumption and rural electrification, Chinese peasants continue to burn substantial shares of crop residues in household stoves (Smil, 1993). Depending on climate and on access to alternative energy sources, these shares vary from less than 10% to more than

80%, and the nationwide mean was close to 50% in the early 1990s. Traditional feeding of all available phytomass to pigs is also still widespread (Colby, 1991; Smil, 1995). Even when assuming that these claims would remove no more than half of all leguminous residues, scenario B would result in no nitrogen gain, and scenario C would produce a 25% higher deficiency.

The first convincing quantitative evidence of the often limited contributions made by leguminous crops to soil nitrogen levels came from a series of experiments in the US Midwest which began in the late 1970s and used labelled nitrogen (Heichel and Barnes, 1984). Rotating non-leguminous crops had no smaller benefits on crop yields than rotating legumes and non-legumes; wheat and corn did as well as soybeans and corn.

Detailed nitrogen budgets prepared for soybeans, now by far the most important grain legume both in US and in China, showed that when the crop yielding about 2400 kg per hectare derives 40% of its nitrogen from symbiosis, then it causes, even with complete residue recycling, net nitrogen loss amounting to more than 80 kg per hectare (Heichel, 1987). Only when soybeans can derive more than about 80% of their nitrogen need from symbiosis, or when they are planted as green manures, do they bring a major nutritional benefit for the subsequent crop: they can add up to 90 kg of nitrogen per hectare, the enrichment surpassed only by plowing-in good stands of clover or alfalfa.

Prorating these findings to the typical Chinese crop would mean that 1500 kg of soybeans harvested per hectare would remove about 105 kg of nitrogen in seeds, and 27 kg of nitrogen in pods, leaves, stems, roots and nodules. Even if two-thirds of all nitrogen were derived from symbiosis and all residues were recycled, the crop would still cause a nitrogen deficit of almost 20 kg per hectare.

Moreover, in many densely populated regions (including Western Europe, Eastern North America, and parts of East Asia) increased atmospheric deposition of nitrate and ammonia resulting from higher anthropogenic emissions now adds 10–20 kg of nitrogen per hectare a year, an input which may equal net gains from poorly nodulated legumes, and which (if it is largely in the form of nitrates) tends to lower the rate of symbiotic fixation.

Obviously, the possibility of such outcomes greatly reduces the appeal of legumes as providers of nitrogen for subsequent crops. Instead, non-leguminous crops fertilized with synthetic compounds may be chosen for rotations with cereal staples or, indeed, rotations of two staples (in large parts of China commonly wheat and rice) may be more appealing, a choice which would further strengthen the already high reliance on staple cereals.

And although green manures may supply substantial amounts of rather rapidly available nitrogen, their declining cultivation is easily explained by the quest for overall maximization of food harvests. As their population densities increase, countries with a limited amount of arable land cannot afford to use that space for a green-manure leguminous fixer whose growth would preempt the cultivation of a food crop – and must turn to synthetic nitrogen fertilizers.

8. Looking ahead

Putting intensive agricultures on a more sustainable basis is unimaginable without reversing the worldwide trend toward monocultures. Rational cropping must include rotations: they have been the mainstay of all sustainable traditional agroecosystems and their rapid decline, and sometimes outright abandonment, during the past two generations should be seen as an undesirable aberration. The environmental advantages of rotations have been well documented by long-term field experiments (Higgs et al., 1990). They include, above all, reduced soil erosion and water run-off, nutritional benefits of symbiotic nitrogen production by legumes, better soil tilth (largely because of the forage crops used in rotations), and interruption of weed, insect and crop disease cycles.

Will food, feed and forage legumes continue to have an essential place in future rotations – or will they matter only in a few areas specialized in the cultivation of a single species? Legumes will be a widely sought part of rotations only when they will provide a number of clearly demonstrable benefits. Only a multipronged strategy can achieve this goal.

To begin with, much more attention should be paid to the productivity of established edible varieties. An outstanding recent example of this approach is the release of an improved strain of mung bean by the Asian Vegetable Research and Development Center. Between 1985 and 1990 this cultivar was planted on over 360,000 hectares in China, outyielding local varieties by about 50% and bringing a major economic benefit (Harris, 1991).

An enormous global potential of similar improvements is illustrated by the fact that the differences between average global yields and the lowest regional performances are much larger for pulses than for cereals. Taking peas as an example, the global mean is now 1500 kg per hectare (both the US and Japanese averages are over 2000 kg per hectare) – but the rates are commonly below 500 kg per hectare in many Latin American and African countries (FAO, 1994).

Substantial gains can be also made in maximizing the protein content of commonly cultivated legumes. While doubling of the overall protein level is not out of the question for some species – for example, protein content of pea cultivars ranges from just 15% to well over 30 % – a more realistic goal would be to increase the shares by 25%–35%.

Increasing the nutritional appeal of legumes throughout the rich world does not appear to be very promising. There has been no shortage of innovative, especially soybean-based, processed foods, and many of them are now regularly available in Western supermarkets. In addition, a growing appeal of non-European cuisines has created new openings for many old foodstuffs. However, these two changes have led at best to marginal increases in Western demand for food legumes. Perhaps the most realistic expectation would be to maintain a modest per capita level of pulse consumption (on the order of at least 5 kg per year in industrialized countries, and 10 kg elsewhere), which would guarantee their continuing importance in all intensive agroecosystems.

The growing demand for meat in industrializing countries should mean good prospects for planting of soybeans needed to contribute protein to mixed feeds. Again, China exemplifies this universal dietary trend and the need for better feeds. In fact, China's meat consumption has been rising faster than anticipated, almost tripling between 1978 and 1994, and already reaching the target for the year 2000 envisaged by the Chinese Academy of Agricultural Sciences in 1982 and reconfirmed in 1993 (Food Development Research Group, 1993). In order to meet this demand, the country's mixed feed industry has grown rapidly, but it still provides only a small share of total nutrients (Colby, 1991).

While it is unlikely that there will be yet another explosion of soybean cultivation akin to the Brazilian experience, soybean cultivars can be grown in a variety of soil types, and they also have a wide range of photoperiodic responses. Consequently, it is almost inevitable that in the long run the strong trend toward higher meat consumption in industrializing countries will be tied to more frequent soybean planting.

Although many leguminous crops may not supply as much nitrogen as formerly believed, and although rhizobia may have a more modest role in biospheric nitrogen cycle, their contribution can be maximized by insuring good nodulation and by complete recycling of crop residues. Such recycling would also maximize the supply of desirable organic matter. In the long run, two strategic changes could lead toward greater cultivation of leguminous forages. The first would be a more realistic, that is substantially higher, pricing of synthetic fertilizers, a change arising from the eventual incorporation of true costs associated with production and conversion of fossil fuels and with ecosystemic effects of nitrogen losses following field applications of ammonia and urea.

The second would be a gradual shift toward more sustainable ways of farming, a change which would have to include a higher reliance on dairy foodstuffs whose production is both energetically more efficient and ecosystemically less taxing than the raising of animals for meat. The potential for such a dietary change in traditionally non-dairy countries is illustrated by Japan's rising consumption of milk, yoghurt and cheeses.

From virtually nothing in 1945, Japanese annual per capita intake of milk rose to about 35 kg in the early 1970s, and to almost 50 kg in the early 1990s (Statistics Bureau, 1995). The latter figure equals about two-fifths of North America's high mean. China's average intake is also slowly increasing, from close to zero in the early 1950s to about 5 kg a year in the early 1990s (State Statistical Bureau, 1994).

Of course, given Japan's land constraints, this output rests overwhelmingly on imported American feed, but a large share of higher dairy production in many other countries could be supported by a greater reliance on forage legumes. This is true not only in the case of countries with a temperate and tropical climate, but also in arid environments where field crops can be augmented by protein-rich forage tree legumes (National Academy of Sciences, 1979).

I hope that the outlined combination of higher pulse yields, higher protein contents, better nutritional awareness, new conveniently processed foodstuffs, more realistic fertilizer pricing, and a greater embrace of dairy production will be able at least to maintain the current extent of leguminous cropping. I do not expect that the trends in legume cultivation during the next 50 years will resemble those evident during the past half a century. If they were to, food pulses would be reduced to dietary oddities, leguminous forages would be marginalized. This shift could make no difference to the overall supply of food energy and it could have a minimal impact on the quality of average diets – but it would have an appreciable effect on the world's agricultural biodiversity.

Virtually eliminating or marginalizing more than a dozen common leguminous grain, forage and green manure crops – which still account for about one-tenth of the world's planted area – would further restrict the choice of cultivars suitable for sustainable rotations and strengthen the trend toward oligocropping agroecosystems. The agronomic consequences of this loss would extend beyond the narrowed cultivar base.

Achieving recently proposed targets for the reduced use of nitrogen fertilizers (maxima of 170 kg N/ha in the European Union) would be much more difficult without the inclusion of legumes in regular rotations. Forage legumes may not be the most efficient source of animal feed, and green manures are clearly a more cumbersome, and usually less effective, way of nitrogen supply than synthetic fertilizers – but their cultivation makes an unequalled contribution toward preventing further declines in soil organic matter and restoring it to higher levels in many improperly farmed areas. This is of critical importance for maintaining high biodiversity of soil microorganisms.

Legumes are unlikely to reclaim their traditional share in the diets of modern societies. Nevertheless, they should remain an important part of today's agroecosystems because of their proven benefits in crop rotations, their environmentally benign contributions to nitrogen supply, and their value for the maintenance of soil organic matter and microbial diversity. Sustainable agriculture is hard to imagine without these contributions.

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