Is Variety More than the Spice of Life? Diversity, Stability and Sustainable Agriculture

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Who does not delight in the multitude of different kinds of beetles or wildflowers, in heaps of many colored potatoes, beans or corn cobs at harvest, or in the costumes, rituals or farming techniques of different ethnic groups? Many of us find the rich variety of life on this planet, the result of biological and cultural evolution over aeons, emotionally and intellectually exciting. However, at this point in time, when we face potentially catastrophic environmental degradation, a huge and growing human population, and widespread human conflict and malnutrition, is diversity really useful?

A consensus seems to be emerging which recognizes that biological diversity is essential for the continued functioning of the planet as we know it (i.e., in maintaining the composition of the atmosphere or the generation and maintenance of soils [e.g., Ehrlich and Wilson 1991; NRC 1992:12-18]). Ethical and aesthetic reasons and direct economic benefits are also widely accepted as arguments for conserving biodiversity. In many cases, such concerns underlie the alarm over the increasing rate of destruction of biodiversity (Ehrlich and Wilson 1991; NRC 1992:31-34). They also suggest that there is a direct relationship between diversity and stability. Put simply from a human-centered perspective, we don't want the world to change too much, or we won't be able to live here any longer.

Many ecologically- and socially-oriented scientists also claim that a direct relationship exists between stability and diversity in agriculture, and they contend that the conservation of this diversity is essential for our future (e.g., Cooper et al. 1992; Pimentel et al. 1992). Small-scale, low-input, indigenously-based agriculture is usually more ecologically, biologically and culturally diverse than large-scale, high-input industrial agriculture (Cleveland and Soleri 1991:286-293). The diversity present in indigenous agriculture at crop, field and regional levels offers greater yield stability than does the less diverse industrial-style agriculture. While it may offer higher levels of production under certain conditions, the latter has only been in existence for one century. Indeed, an inverse relationship may exist between diversity and stability on the one hand, and production maximization on the other. This means that optimal diversity, not maximum production, is the key to sustainable agriculture. More conventional, production-oriented agricultural scientists, however, disagree with this assertion. Although they recognize trade-offs among diversity, stability and production, they argue that the increased production made possible through industrial agriculture, even with the subsequent loss of diversity, is the only possible route to agricultural development (e.g., Anderson and Hazell 1989a).

> *"What role do biological and cultural diversity play in agricultural stability and in the development of sustainable agriculture?"*

In this article I examine the following questions. What role do biological and cultural diversity play in agricultural stability and in the development of sustainable agriculture? Is the conservation of this diversity really essential for our future?

Diversity and Stability in Ecology and Agriculture

Because both social and natural agricultural scientists often borrow ecological concepts, I begin with a brief consideration of the relevance of ecology for understanding the relationship between stability and diversity in agriculture.

The idea that diversity begets stability became widespread in ecology in the 1950s. In addition, "the notion that greater community diversity is associated with increased stability was among the most influential beliefs in ecology from the 1960s until the mid 1970s, reaching the status, in some cases, of a 'core principle' (McNaughton 1988:204; also see Pimm 1991:6-9)." This belief came under attack in the early 1970s. May's mathematical models showed that growing complexity augments fluctuation and hence increases community instability (see McNaughton 1988; Pimm 1991). However, May made the point that his models applied to random complexity. He suggested that real-world natural ecosystems might be mathematically atypical, an assertion which has stimulated much subsequent research supporting a direct relationship between diversity and stability (McNaughton 1988:204; Pimm 1991:9-11).

The discussion of stability and diversity in ecology is often confusing. This confusion stems in part from the difficulty of comparing results on different temporal and spatial scales, and in part because there are many possible definitions of the concepts involved. For example, Pimm has identified five definitions of stability, three definitions of complexity (diversity) and three definitions of levels of organization used by ecologists—for a total of 45 "possible questions about the relationships between community complexity and stability (Pimm 1991:15)."

Although at some level, these ecological concepts of diversity and stability are relevant to ecological systems that exist in agriculture, there are some important differences that need to be taken into account when considering agricultural systems. First, the subject of study in ecology is natural biophysical ecosystems. In agriculture, however, the focus extends beyond biophysical components to include social, cultural, economic and institutional factors as well. Thus, agriculture is qualitatively different and more complex than are natural ecosystems. In addition, the biophysical ecosystem in agriculture is managed by humans to meet human goals. This usually results in less biophysical complexity than that found in the natural ecosystems.

Second, definitions of stability and diversity in agriculture are relative and are based on subjective judgments of the perceived utility for meeting human goals. Assertions concerning the relationship between diversity, stability and production which are subject to formulation as hypotheses capable of being tested with empirical data need to be kept separate from subjective assertions that are not amenable to such tests. An example of the former is the hypothesis that genetic diversity in crops is related to yield fluctuations under environmental stress while an example of the latter is the assertion that agricultural stability is good because it supports equity.

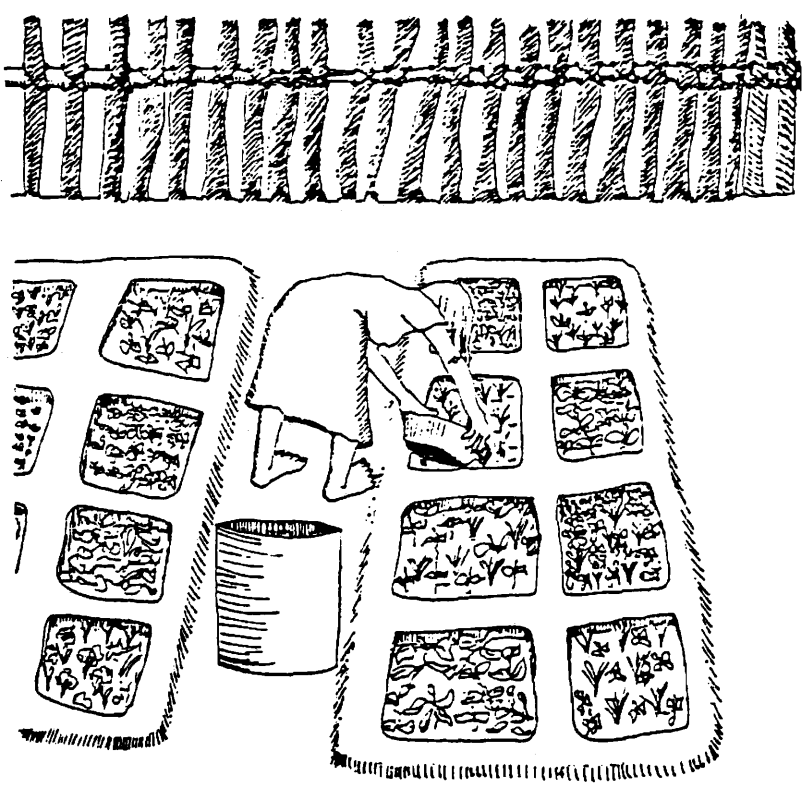
Production, Diversity and Stability

Evidence of a direct relationship exists between diversity and stability at various levels of organization within agriculture. There is also indication of an inverse relationship between stability and diversity on the one hand and yield or production on the other. This latter relationship is most evident at the crop variety and crop species levels. At the more inclusive levels of the farm, region or globe, relationships become more complex, interactions between variables increase, and value-based goals and definitions make associations more difficult to decipher.

Although a complex continuum exists between more diverse indigenous and less diverse industrial agriculture, for the purposes of this discussion, a contrast will be drawn between the two extremes. As is the case in ecology, the temporal and spatial scales and the definitions of stability and diversity used by agricultural researchers affect their conclusions about the relationship between diversity, stability and production. Variation in yield is frequently used as an indicator of stability in agriculture at all levels. This is commonly measured as absolute variability by variance (s^2) or as relative variability by coefficient of variation (cv $= s/\bar{x}$). Among the several major definitions of stability employed by agronomists and plant breeders (e.g., Lin et al. 1986), the most appropriate for this discussion is what I term environmental stability (also known as biological or vertical stability). Environmental stability is a measure of yield variation in time and/or space. For example, using this definition, a stable variety is one whose yield varies relatively little between locations and years.

Yield stability at the crop level obviously affects yield stability at the farm and field levels, and yield stability at the farm level has a strong effect on farmers' risk. At national, regional and global levels, through its effects on food supplies and prices, yield variability influences government stabilization schemes and food consumption, especially of the poor (Anderson and Hazell 1989b). Yield stability is also effected by the means farmers, national governments or international development organizations use to manage the risks resulting from yield instability.

Folk varieties (FVs), also known as landraces, traditional or primitive varieties, are a key component of the diversity in indigenous agriculture. These crop varieties, developed by farmers in their role as plant breeders, are adapted to locally diverse biophysical and sociocultural environments. Industrial agriculture, in contrast, relies on modern varieties (MVs), also called high-yielding varieties, developed for production over widespread areas and uniform environments. In comparison with industrial agriculture, there are more varieties of crops and these varieties are often more genetically diverse in indigenous agri-



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culture (Cleveland and Soleri 1991:286-293; Frankel and Soulé 1981, 178-179).

Plant breeders are aware of the tradeoff that exists between yield and stability in response to environmental stress (e.g., Blum 1988). This tradeoff results from the greater genetic diversity found in heterozygous or heterogeneous FVs compared with the homozygous or homogeneous modern varieties (MVs) (Borojevic 1990:332-334). MVs have high yields in optimal environments characterized by good soils, a favorable climate and the provision of optimum levels of nutrients, water and pest management. In marginal environments, however, these varieties generally have lower yields. FVs, in contrast, have relatively low yields in optimal environments compared with MVs, but higher yields in marginal environments to which they are specifically adapted (e.g., Weltzien and Fischbeck 1990). The yield of FVs is affected relatively less by genotype x environment interactions than is the yield of MVs. Thus, within their area of adaptation, yields of FVs have less variability and are more stable from season to season than are the yields of MVs.

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The rich genetic diversity of indigenous agriculture extends beyond the level of single crops to encompass the species, field and regional levels. At the species level, greater numbers of FVs are planted in indigenous agriculture than is the case in industrial agriculture. At the field level, more species and varieties are sown together in indigenous agriculture, and, at the regional level, there are more varieties of more species planted in more diverse environments in indigenous than in industrial agriculture. For example, Richards (1986:131-146) reported that Mende farmers in Sierra Leone grew 70 varieties of rice in one area. In 1989, Soleri and I found that a sample of 50 Hopi farmers grew 18 FVs and four other varieties of corn. They also planted 16 FVs and four additional varieties of beans (Soleri and Cleveland n.d.).

Farmers are aware of the relationship between diversity and stability. In fact, stability is often an important criterion in their varietal selection. Haugerud and Collinson (1990:343) report that African farmers "often favor yield stability...more than maximum yields." Ferguson and Sprecher (1987) report that women farmers in Malawi are aware of the yield stability that results from growing mixtures of different bean varieties in the same field. Women stated that planting numerous varieties of common bean reduces the likelihood of crop failure. While Hopi farmers avidly experiment with varieties from any source, they nonetheless continue to plant primarily Hopi FVs. The major reasons they give for their choice are the importance of FVs in Hopi religion and culture and the adaptedness of these varieties to their arid environment (Soleri and Cleveland n.d.).

In economic terms, indigenous farmers often invest in production at levels where their marginal factor cost (MFC) is significantly less than the marginal value of their product (MVP). Such risk-adverse farmers forgo potential profit for security of food supply even in bad years. Profit-maximizing farmers who invest in production closer to the level where MVP=MFC gamble that, on average, good years will balance bad years. This strategy may push them into borrowing against the future to mitigate current losses.

In some indigenous farming systems, a lack of diversity at one level may be compensated for by a large amount of diversity at another level. For example, Boster (1983) reports that in Jivaroan forest fields in Peru, where 80% of the plants are manioc, a relative lack of diversity exists at the crop species level. Using Shannon's measure of uncertainty (scale of 0-1), species diversity here is 0.15 compared with 0.53 for the forest. For manioc, however, varietal diversity is 0.39, reflecting the fact that many different manioc varieties are planted. Morren and Hyndman (1987) suggest that in the case of taro monocultures in central New Guinea, the lack of diversity at the crop species level is compensated for in three ways. First, farmers plant a large number of taro varieties. Second, their monoculture fields are surrounded by a diverse forest. Third, they exploit a wide range of wild and domestic foods.

The degree of diversity at crop varietal, crop species, field and farm levels affects the degree of stability at regional or global levels. For yield, this is commonly measured as covariation. Breeding MVs for increased responsiveness to inputs increases yields without appearing to increase instability when grown under trial conditions. As a result, however, farmers growing these varieties become dependent both on purchased inputs and on the capital-intensive infrastructure necessary to deliver these inputs.

Although their maximum yields may be lower, FVs are not dependent on such inputs or infrastructure. Consequently, farmers growing these varieties are less likely to experience a decline in yields when a breakdown occurs in input supply due to resource shortages, drought, conflict or other factors. Therefore, covariation in yields between regions and nations both within and between years tends to increase as industrial agriculture and MVs replace indigenous agriculture and FVs. This is brought about by the greater homogeneity of plants, "modern" production techniques and input supply sources over larger and larger geographical areas. All of these factors contribute to increasing covariation of yields between fields and regions, thus increasing overall yield instability. Anderson and Hazell (1989b:32) note that "the phenomenon is perhaps an inevitable consequence of the modernization of agriculture" (see also Barker et al. 1981). Hazell's (1989) analysis of world cereal production shows that both absolute and relative production variability have increased since the early 1960s.

It is often asserted that biophysical and sociocultural diversity are interdependent (e.g., NRC 1992:93-94), and that the diversity of management strategies practiced by local farmers is the best way to conserve crop genetic resources and maintain stability (e.g., Cooper et al. 1992). However, it is much more difficult to test the stability-diversity relationship at this level. A key factor may be the growing centralization at the farm, national and global levels. This characteristic of industrial society is evidenced both through the integration of markets under capitalistic governments and through centralized planning under socialistic ones (e.g., Stone and Zhong 1989). A reduction in the diversity of local interactions with local conditions often accompanies such centralization. The resulting instability may give rise to increases in central control which in themselves further decrease flexibility and may eventually result in a system collapse (e.g., Merrey 1987).

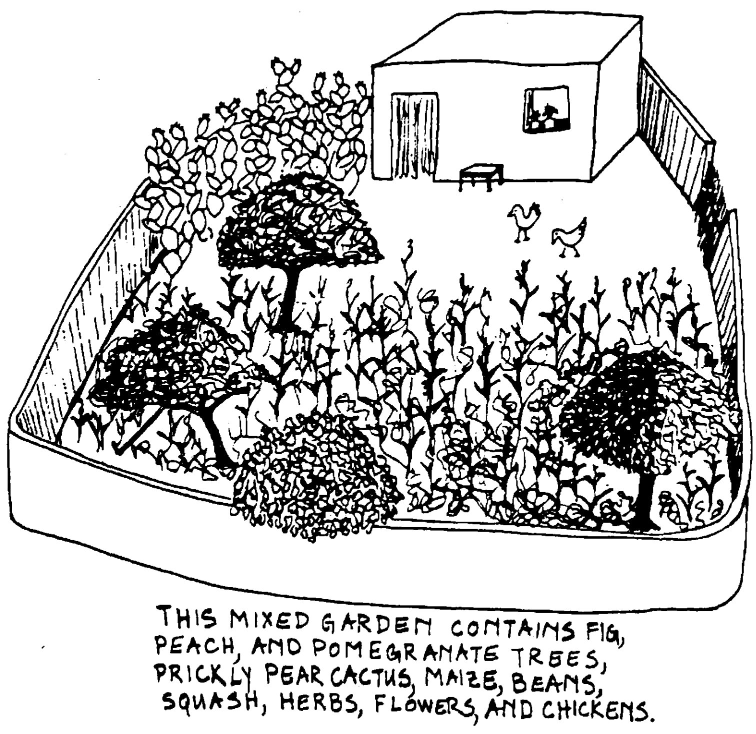
Values and Choices

When stability is defined in terms of crop yield variability, there is general acceptance of the relationship among diversity, stability and production outlined above. The major debate centers around the issue of the appropriate response to yield variability.

The conventional approach is to counter the variability resulting from industrial agriculture with even greater production. Relative stability (cv) is favored as a measure over absolute stability (s^2). This is because if mean yields can be pushed up fast enough, relative stability will not decrease as absolute stability falls with increased production.

Therefore, advocates of this approach contend that production-maximizing agricultural policies do not necessarily result in overall instability. Rather, they assert that "poor countries and poor households are beset with constraints, structural or otherwise, which limit their ability to prevent and cope with increased production variability (Sahn and von Braun 1989:338)." As a solution to instability, they recommend introducing new technology to increase production. They also propose mitigating any resulting yield instability through increased centralization of markets and through government efforts to integrate individual farmers more fully into the world market system (e.g., Anderson and Hazell 1989c).

Such policies would require "sizable increases in public investments in research, extension, credit, and input delivery systems." These, in turn, would necessitate raising "average productivity in order to be justified (Anderson and Hazell 1989c:356)." In other words, not only would mean yields have to increase fast enough to keep ahead of increasing absolute instability, but they would have to grow even faster to pay for the massive infrastructure required to raise yields in the first place.



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The ideology of neoclassical economics that underlies the production-maximizing strategy is based on a number of questionable assumptions. These include a) continually increasing production and yields are essential for agricultural development, b) no natural limits to this growth exist that cannot be overcome by human inventiveness and technology, and c) markets are the best means to distribute resources for optimizing social benefits (Daly and Cobb 1989).

In addition, the production maximizing strategy draws on a unilineal evolutionary model of agricultural development (e.g., Todaro 1985:309) now usually considered obsolete in the natural and social sciences. Adherents of this outdated model assert that "a combination of MVs, improved water control, and fertilizers...is the only game in the countryside (Lipton and Longhurst 1989:359)," suggesting that farmers who are "risk taking profit maximizers (Ellis 1988)," should be the only players in the game.

A strategy emphasizing optimal diversity and stability over the long term is an important alternative to the production maximization model. Supporters of this alternative approach favor s^2, an absolute measure of stability. They reason that an emphasis on production-maximizing strategies and relative stability will only avoid relative instability in the short run, and will actually increase absolute instability in the long run. The destruction of diversity that the production-maximizing approach entails undermines the foundation on which a continual increase (or even maintenance) of yields depends.

Consequently, adoption of the production-maximizing strategy is equivalent to gambling long-term security for short-term riches. While increasing control over the environment can postpone the instability that results from maximizing production, it can only do so for a limited amount of time. When the dip arrives, it often reaches lower levels than would be likely under the diversity/stability optimizing approach (see Ehrenfeld 1987). In this sense, profit maximizing farmers are like MVs. They do very well when conditions are good, but when conditions are bad, risk averse farmers, like FVs, often do better.

Advocates of this alternative approach contend that existing empirical evidence disproves most key assumptions of neoclassical economic ideology. In this regard, they draw attention to the biophysical limits to increased production, and to the destruction of biophysical and sociocultural diversity by market forces (Daly and Cobb 1989). With a world population of 5.5 billion people growing at 1.7% per year, and commandeering 38% of the net terrestrial global photosynthetic product (Vitousek et al. 1986), they suggest that we may already have exceeded our planet's carrying capacity.

The production-maximizing strategists concede that little information exists on the comparative benefit-costs of alternative approaches to dealing with instability. Nonetheless, they conclude that sacrificing yield increases for decreases in instability "could prove costly to society (Anderson and Hazell 1989c:356)." One result of such an approach, they contend, is likely to be widespread starvation. In fact, plant breeders and agricultural development professionals often depict the need to maximize yield as a race to keep up with population growth and with the growing middle-class demand for meat (see for example Anderson and Hazell 1989b:1; Borojevic 1990:16, 188, 216; Lipton and Longhurst 1989:359). Rarely are possible biophysical limits to increasing yield recognized, or is instability considered as an important limiting factor.

In other words, metaphysical values, not tests of hypotheses with empirical data, underpin this approach. Two of the most prominent of these values, mentioned above, are a belief in the inherent ability of human creativity to overcome all physical limits, and the notion that there is only one path to development.

Because advocates of yield maximization assume that human ingenuity will ultimately guarantee that we do not have to pay the price, they would have us trade off long-term stability for short-term yield increases. In essence, they proffer the illusion that their strategy can feed the world while, in reality, it may well undermine the ability of the planet to feed anyone. However, supporters of sustainable agriculture based on optimizing diversity and stability must address the question "How can this kind of farming feed the growing world population?" The answer is that it cannot any more than can production-maximizing industrial agriculture. If we fail to understand the implications of the choice between production maximization and diversity optimization, we may ultimately find we are unable to support the human population at any size.

The evidence provided above for the role of diversity in promoting stability, coupled with the historical relationship between food supply and population, suggests that population growth cannot be halted or reversed by maximizing food supply over the short run. In fact, the breakup of local communities and their integration into world markets in the name of agricultural modernization may be a major cause of high growth rates. It is therefore more probable that population growth rates will decline as a result of biophysical and sociocultural diversity, and the resulting stability of the food supply together with the social organization, resource use and technology such diversity implies. Socially cohesive communities dependent on limited local resources for food production may be most likely to regulate their size over the long term.

Conclusion

Understanding the factual basis for the diversity/stability production relationship and arriving at a consensus about the goals of agricultural development are essential for building a socially and environmentally sustainable agriculture. However, promotion of sustainable agriculture does not imply a return to pristine indigenous agriculture, even if it could somehow be recaptured. Traditional systems themselves may not be well-adapted to present or future conditions because they and their social, biological and physical environments have been transformed by processes such as colonialism, the development of international markets, population growth, environmental degradation, migration to new areas and international conflict. Thus, planning for sustainable agriculture requires not only development of a strategy that is flexible, but also one which adapts to unique local conditions and promotes local diversity and experimentation. It also means making use of the most current information and techniques from Western scientific agriculture, without, of course, adopting the production-maximizing values and overall organization of industrial agriculture.

At the **Center for People, Food and Environment**, we are now putting these ideas into practice in our work with the Zuni Tribe of New Mexico. We are helping the Zuni community to draw up a plan for sustainable agricultural development. It proposes to increase production within the limits set by the Zuni commitment to conserve biological and cultural diversity. It draws on indigenous Zuni farming practices but also incorporates some of the tools of modern industrial agriculture.

Agricultural development policy at all levels is influenced either explicitly or implicitly by which end of the diversity-optimization/production-maximization continuum the decision-maker is closest to. What is involved, however, is not simply a matter of choosing one absolute over another, but of determining where on a complex continuum we as a global society want to be. This is what wrangling over the meaning of the term "sustainable agriculture", — claimed by both ends of the spectrum — is all about.

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