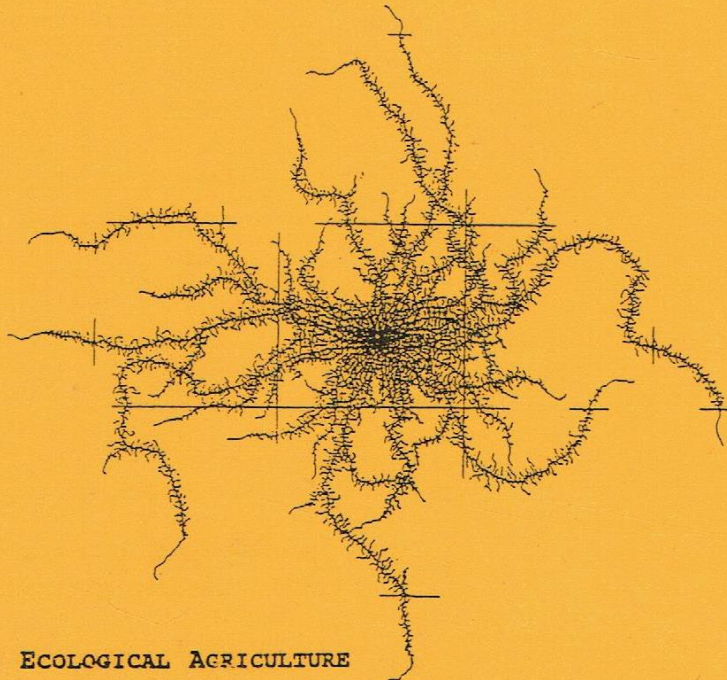
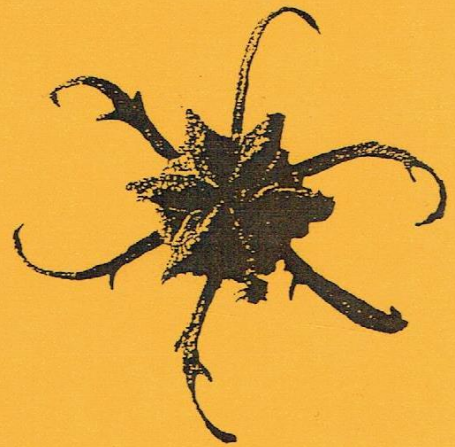
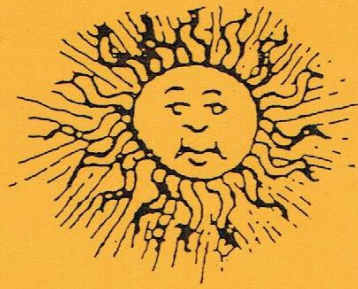


REDESIGNING A VEGETABLE FARM IN PERÚ TO CONVERT IT  
TO ECOLOGICAL AGRICULTURE



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*Our presence in our own knowledge is  
not contamination, but the very  
condition for the generation of that  
knowledge.*

*Susan Oyama*

*...y es que la ciencia no funciona,  
sólo tus besos vida mía.*

*Juan Luis Guerra*

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*to Wageningen and the people I knew in these two years, to the friends that will always be;*

*a la gente de -casi- toda la vida.*

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## INTRODUCTION

Intensification of production practices in the periurban vegetable sector in the central coast of Perú is a cause of concern because of the threats to sustainable development and the conflicting interactions with the cities, in particular Lima, a megalopolis of 7 million inhabitants. Integrated and ecological farming systems appear as alternatives, stressing the need to integrate biological, economic and social criteria into the design of sustainable farming systems. To achieve this, research needs to be focused on local characteristics and be based on coherent methodological approaches to design systems technically, ecologically and socially acceptable.

In this paper, the conversion to ecological agriculture of an experimental vegetable farm in Lima is presented as a response to the current situation in which institutional research needs to be integrated into interdisciplinary schemes, the only way to grasp the meaning and find the way to sustainability. After a discussion of the general situation in Latin America, a literature search provides insight into the experiences on ecological agriculture, at the experimental level and in actual farming systems. Agroecosystem analysis is used as a starting point in a methodic way to more sustainable farming systems, and the first steps in design are proposed. In the end, this paper provides an action plan that may lead Universidad Nacional Agraria La Molina (UNALM) into more effective and longer-lasting research in ecological agriculture.



## I PROBLEM STATEMENT

Human beings used to live in harmony with the land and the changing seasons, with none of the aggressiveness and greed that the domestication of plants and animals, with its illusion of security and permanence, brought to mankind (Matthiessen, 1972). Plants were domesticated in the 'neolithic revolution' and since then we have increased control on crops to the extent that they cannot survive without us and a steady influx of inputs. The tyranny of the overbred crop is obvious in the US Corn Belt, where the farmer is in bondage to the insatiable appetite and immense vulnerability of his monstrous hybrid corn (Lathrap, 1977). The technologies of the 'green revolution' in this century have resulted in a greatly increased production but often with deleterious consequences on the plants and animals involved (Hodges & Scofield, 1983), the environment and the quality of human life (Altieri, 1989). In the Third World a growing population demands food but the economic and environmental costs incurred through bolstering food production may prove too great (Bongaarts, 1994; Vereijken, 1992). In Latin America development policies favor the growing of crops for export and modern technologies are adopted, but specially in areas with few environmental constraints for agriculture. However, the enormous biological diversity (there are four megadiversity countries in the region: Brasil, Colombia, Perú and México) and cultural heterogeneity, calls for diverse strategies for development (Altieri, 1992).

Today, after the major economic crisis of the 1980s, Latin American countries are pulled into the existing international order and change policies in order to serve the unprecedented debt, embracing neo-liberal economic models (Altieri & Masera, 1993). The peruvian program of stabilisation and liberalisation initiated in 1990 is one of the most extreme in the region and is requiring exceptionally high costs (Sheahan, 1994). In spite of the 'growth with poverty' (Altieri, 1992), half of the households still lie below the poverty line, a situation that has not changed since the 1970s (Feres & León, 1990). After decades of protectionism, farmers have now to abide by the rules of the open market, with severe consequences in terms of food security and stability of rural communities.



Violence is another feature of recent peruvian history, and agricultural research and development has played a role: in the 1960s one of the ideologues of the *Sendero Luminoso* rebel group was concerned by "the insidious introduction of values and behaviour from an alien culture [exemplified by the *hacienda* system and modern technologies], thereby destroying the emotional and ecological equilibrium which had enabled *campesino* communities to withstand centuries of exploitation and aggression" (Harding, 1988). A conclusion is that conventional development strategies appear to be fundamentally limited in their ability to promote equitable and sustainable development in the region (Altieri & Masera, 1993).

### **The search for sustainability**

Development strategies are in part a result of what farmers, researchers or policy-makers think or believe. Agricultural paradigms represent collections of attitudes that determine people's overall understanding of how agriculture works, how it relates to society and the physical environment, and what types of practices, organisations and institutions they believe are best for agriculture (Beus & Dunlap, 1994). As an alternative to the ideal of infinite growth and prosperity, paradigms are evolving in a progression which involves increasing integration of economic, ecological and social systems into the definition of development and the organization of society (Colby, 1991). Agroecology has been proposed as a new scientific discipline that defines, classifies and studies agricultural systems from an ecological and socio-economic perspective (Altieri, 1983). This paradigm delineates the ecological principles necessary to develop sustainable production systems, but these cannot be implemented without modifying the socio-economic determinants that govern what is produced, how it is produced and for whom it is produced (Altieri, 1989). It has even been suggested that sustainability will never be achieved unless the primary vicious circle is broken by a market system based on social consensus between producers and consumers to control technology and save the biosphere (Vereijken, 1992).

Sustainability refers not only to one of the key properties of agroecosystems (Conway, 1985) but has received considerable attention in the last years in the concept of sustainable development. It was defined in the Brundtland report in 1987 as "development that meets the needs of the present without compromising the ability



of future generations to meet those of the future". This inevitably leads to the concept of sustainable agriculture, which can be viewed from ecological, social and economic perspectives, and as a series of interacting systems at various spatial scales (Yunlong & Smit, 1994). Most definitions of sustainable agriculture include food productivity, food safety, resource protection, quality of life and environmental quality (Stockle *et al*, 1994), and in Latin America it is generally considered to have the following objectives (Altieri, 1989):

- ▶ To be diversified in space and time;
- ▶ to be dynamically stable;
- ▶ to be productive and self-sufficient;
- ▶ to conserve and regenerate natural resources;
- ▶ to have economic potential;
- ▶ to be socially and culturally acceptable, and
- ▶ to have self-promoting and self-help potential.

This paper explores the agroecological perspective at the farm level. The starting point is the Vegetable Crops Experimental Farm (VCEF) at UNALM, in Lima, Perú, a 20-hectare conventional farm where research and commercial production takes place. The central questions are:

- ▶ why should VCEF be converted into an ecological farm?
- ▶ how can it be done?

The objectives are to present the antecedents and the conceptual frame of reference, and to propose a theoretical action plan to convert the farm, identifying the major research questions. For this, the characteristics of a prototype of the new farming system are outlined.

## II WHAT IS AN ECOLOGICAL FARM?

Some of the differences between the several variants of alternative agriculture (regenerative, natural, biological, bio-dynamic, LEISA, organic, etc.) are the result of academic work or of a philosophical background, but the principles and practices that lie behind are essentially similar (Lampkin, 1990). I shall refer to them as ecological agriculture, although in a later stage it should be clear that a major difference with organic agriculture (as enforced by certification agencies based on production standards) is that the latter has no quantified objectives in environment and nature/landscape, and as a result needs to be considerably improved to become acceptable to the majority of consumers (Vereijken, 1995).

The conceptual understanding of ecological principles is essential, not the simple rejection or approval of management practices. The systems approach and the analysis of the structure and function of agroecosystems focus on exploring options for future agricultural production systems which are in harmony with nature and the environment, while economically and socially acceptable (LUW, n.d.), thus providing a unifying concept in production ecology (Lowrance et al, 1984). This approach has been used in Latin America. Gliessman et al (1981), for example, concluded that a thorough understanding of the ecological processes functioning in the traditional agroecosystems in the tropics, coupled with the development of a productive system with which the *campesino* can identify, holds out the possibility to develop potential sustainable and intensive production despite the various well-recognised limiting factors.

The VCEF is part of the sector of periurban agriculture, where the environment suffers intense degradation and traditional systems have almost disappeared. Although the importance of the ecological principles in agriculture has been acknowledged (CONAE, 1990; RAE, -1992), for several reasons they remain far from farm practice in the intensive horticultural production and no comparable ecological farms exist in the region. It is better then to conceive an ideal farm. The key characteristics of an ideal ecological farm are (Lampkin, 1993):

- protecting the long term fertility of soils by maintaining organic matter levels, fostering soil biological activity and careful mechanical intervention;



- ▶ providing crop nutrients indirectly by using relatively insoluble nutrient sources which are made available to the plant by the action of soil microorganisms;
- ▶ nitrogen self-sufficiency through the use of legumes and biological nitrogen fixation, as well as effective recycling of organic materials including crop residues and livestock wastes;
- ▶ weed, disease and pest control relying primarily on crop rotations, natural predators, diversity, organic manuring, resistant varieties and limited (preferably minimal) thermal, biological and chemical intervention;
- ▶ the extensive management of livestock, paying full regard to their evolutionary adaptations, behavioural needs and animal welfare issues with respect to nutrition, housing, health, breeding and rearing;
- ▶ careful attention to the impact of the farming system on the wider environment and the conservation of wildlife and natural habitats.

These are the general principles that may guide the conversion of the VCEF to ecological farming. Hodges & Scofield (1983) summarized three major factors that differentiate conventional from ecological agriculture: it tends to simplify the system to a greater extent, increasing its instability; it tends to introduce more factors which are foreign to the ecosystem; and it frequently imposes stress upon the system because of its continual search for maximum productivity rather than the optimal productivity which is the preferred goal in ecological agriculture. Classical comparisons with conventional systems in the area can lead to misunderstandings, but they are a necessary step if an alternative is to be developed and presented to society, avoiding common misconceptions like overstressing the replacement of chemical inputs by organic ones.



### III UNDERSTANDING THE CONVERSION PROCESS

#### Research in ecological farming systems

Research is urgently needed into methods by which yields and farm incomes can be increased by integrated lower-input systems of farming that can base inputs on an understanding of interactions between inputs and other components of the farming system (Edwards, 1987). Integrated systems may be considered as compromise forerunners of ecosystem-oriented farming systems capable of addressing long-term demands of sustainability (Vereijken, 1992). Any outcome of research, however, depends on the goals of the researcher and the methodologies applied.

Two broad approaches have developed in recent years, basically in Europe and the US: comparison of ecological against existing conventional farming systems, and the research and development of ecological farming systems in its own right (Lampkin, 1993). Comparisons are more common and always problematic specially since the nature of research will be more system-oriented in ecological agriculture while conventional agriculture research is more specialised and commodity-oriented. Besides, the performance measures may vary, the time period may limit the validity of the results and several non-system determined factors may obscure conclusions (Lampkin, 1993). In spite of this, a sensible approach might be not to choose between development or comparison but to consider both as necessary. The experimental systems have to be developed fully before they can be judged in comparison with conventional agriculture (Vereijken, 1990). For the research and development of ecological farming systems the main approaches are experimental units, pilot farms, surveys, case studies and modelling (Lampkin, 1993; Vereijken, 1990).

In Perú, and to a certain extent in Latin America in general, research on ecological agriculture has concentrated on the analysis of traditional agricultural systems (Altieri, 1990) and in several ecological techniques. The development of ecological farming systems has focused on small farms, generally in areas where environmental constraints are prevalent. Several non-governmental organisations are involved in researching and developing these systems, often in collaboration with university staff (Torres *et al*, 1992). Comparative research is scarce in the country and the lack of methodologies to evaluate ecological farming systems has been identified as a



major constraint for development (IDMA-CONAE,1992).

Universities in Perú have generally played a rather active role in promoting the techniques of the 'green revolution' but there is now an increasing number of researchers involved in discussion groups and projects with NGOs in the field of ecological farming systems. I view the engagement of universities in the design and testing of experimental integrated/ ecological farms as a necessary step in the scientific understanding of these systems and in the quantification of the objectives in order to make them more accessible to society. This should not be viewed as another top-down approach, which have proved limited in Latin America (Altieri & Maser,1993), but as a first step in an interactive process with farmers.

#### **The conversion process in practice**

The period of several years needed to change a farm from conventional to ecological management is known as conversion or transition (Lampkin & Padel,1994). For organic certification agencies it is "the time which passes between the start of organic management and certification of crops"(IFOAM,1994). Because of the time period involved, which may vary from farm to farm, the changes needed to set up a fully operational farm based on ecological principles may extend beyond the moment in which certification is granted and a symbol allowed to be used.

The reasons why a farmer may choose to convert its farm are variable and several studies from Europe and North America reviewed by Lampkin (1993) generally indicate that the reasons are largely non-financial. These may be:

- ▶ husbandry problems and desire to produce better crops;
- ▶ environmental concerns and search for harmony with nature;
- ▶ concerns about food quality;
- ▶ ethical or religious concerns and ideals;
- ▶ political or philosophical views of the food system;
- ▶ expectations of better financial performance, and
- ▶ personal motivations like concern for family health, desire to be valued by consumers and creative instinct.



A change of attitude in the farmer [as well as in the researcher or policy-maker] is often the first step. He must be confident that the conversion is feasible and flexible enough to consider a large number of innovations in the farm management (Lampkin, 1993). Strengthening intuitive skills rooted in imagination is also necessary to switch from the conventional management system, which is characterised by the aim to control and manipulate variables and a bottom line profitability, such as analysing crop by crop for returns (Kirschenmann, 1988).

A conversion plan should include at least four components: assessing the farm's resources, anticipating weaknesses, developing a model crop rotation and creating a field plan (Kirschenmann, 1988). MacRae et al (1990) employ an evolutionary approach to the conversion process that starts with increased efficiency (altering conventional systems to reduce inputs and improve management), followed by substitution (environmentally benign practices and products are established) and finally by redesign (problems are solved internally by site- and time-specific design and management). They consider redesign to represent the final aim (an ecological farm) although it is difficult to conceive the first two steps in this approach without a previous and careful redesign to start with. In the European network on ecological arable farming (Vereijken, 1994; 1995) redesign is used to represent not only the final stage but the creative process -in the sense of restructuring- that starts with the definition and quantification of objectives for the design of farming prototypes.

The design of a farming system that is adapted to its environment should be the first and most basic objective of the designer, although ecological theory is currently unable to define accurately the constraints which should be placed on farm design and operation. As a consequence, modern ecological farming systems will still involve a considerable degree of uncertainty and risk (MacKinnon, 1975). The principles of ecological engineering (Jorgensen, 1989), the tools of agroecosystem analysis (Conway, 1985) or the knowledge of soil nutrient cycling processes (Hendrix et al, 1992) have provided ideas for the design of agricultural systems for Latin America, focused mainly in the study of the highly diverse traditional small-holder agriculture (i.e. Altieri, 1983; Ewel, 1986; Gliessman et al, 1981). The maintenance of biological diversity and nutrient cycling mechanisms are considered as global principles that are common to all agroecosystems and therefore essential in the design of



sustainable agricultural systems; a first step should be to draw on the existing body of knowledge and practices (Edwards *et al*, 1993). In Perú, farm design that considers ecological principles as well as Andean culture has long been regarded as a basic step towards sustainability (CONAE, 1990). Permaculture practitioners also place great importance on farm design, including the household, according to ecological principles (Mollison, 1988).

Several studies, mostly in the Northern Hemisphere, have studied the changes that occur in a farm during conversion and afterwards. Although they include comparative as well as case or experimental studies in different regions, they provide insight into the process. Many include livestock in the farm operation and most concentrate on annual arable crops; the conversion of intensive vegetable operations has not been found in literature, although vegetables are often part of the rotation or a side activity in the farm:

#### **Time of conversion**

Although certification agencies generally limit the duration of this period, it is done for marketing purposes and has no defined scientific basis. IFOAM (1994) states that the conversion should be at least one year of full application of the standards and not more than one complete rotation, and french organisations allow from 2 to 6 years (Reynaud, 1990). Normally the transition may take 3 to 6 years (MacRae *et al*, 1990) or 5 to 10 years (Kirschenmann, 1988). In Chile it was found that a 5- year transition period was necessary to reach similar sugar beet production levels under organic and conventional managements (Venegas & Aguilar, 1992). It appears that the time will depend on the characteristics of the farm, in particular its past history, and on the plans (gradual or complete conversion of the farm) (Kolmans, 1995). Changes in the structure and function of agroecosystems are complex and after a period of adjustment may extend into longer term, perennial effects (Hendrix, 1987). Besson *et al* (1990), for example, mention that the conversion phase for soils lasts longer than intuitively admitted and may extend to about 20 years. Hypothetical transition curves illustrate the time frame and proportions of the major changes in agroecosystems (Fig.1):

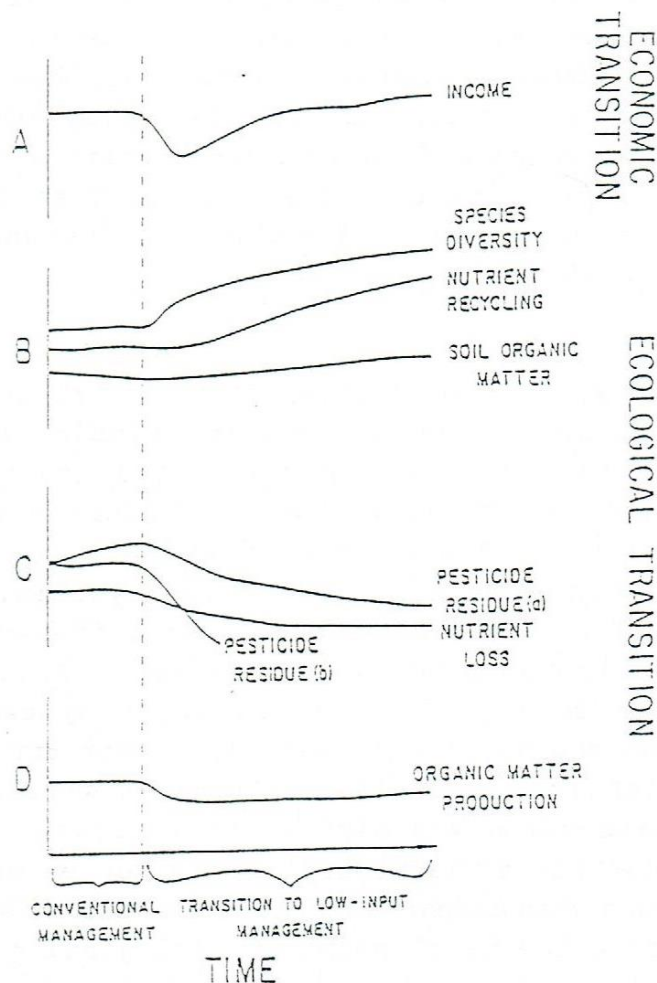


Figure 1: Hypothetical transition curves for various economic and ecological properties (Source: Hendrix,1987)

### Energetics

Energetic efficiency is expressed as the ratio *energy output/input*, and sustainable agroecosystems maximise this ratio by using minor amounts of auxiliary energy, specially in the form of inputs that require large amounts of fossil energy to be produced (Caporali *et al*,1989;Pimentel,1993). An objective definition of energetic efficiency is difficult since it can be assessed at different hierarchical levels (individual, societal, ecological), and its measurement should assess embodied energy values like, for example, the energy input spent to build and to maintain a tractor (Giampietro & Pimentel,1991). Low-input systems tend to maximise energetic efficiency. In a study of different corn and sorghum management systems in Ne-braska, for example, energetic efficiency decreased



with the addition of nitrogen fertiliser in most systems and increased when a legume, not a cereal, was the previous crop. In the same study, however, energetic efficiency was not different between traditional and no-tillage, and was greater when herbicides were used (Franzluebbers & Francis, 1995). Great differences can be found among crops. Pimentel (1993) found that the energetic efficiency of organic corn was 184% higher than conventional, while in organic potato it was only 2% better.

### **Yields**

Stanhill (1990) analysed data for 26 crops and two animal products at 15 sites in Europe and North America, finding that organic/conventional ratios had a mean value of 0.9 and were normally distributed. These results showed yield differences to increase with the general level of the yield and that interannual variations were of similar magnitude for all farming systems. Differences might be expected in different farms with different crops. The Rodale experiment in Pennsylvania, for example, found that during a 5-year rotation corn yield in a low-input system was 75% of conventional, but the difference was much lower for soybeans and small grains (Liebhardt et al, 1989). During a 4-year rotation in California, tomato yield was significantly lower in an organic system, while bean yield was significantly better or not statistically significant when compared to the conventional system (Temple et al, 1994). During the development of ecological prototypes for small farmers in northern Perú, yields of polycultures were consistently higher than the predominant biculture in a 4-year rotation. Furthermore, ecological polycultures proved to be nutritionally superior than the conventional system (CONAE, 1990).

Lampkin & Padel (1994) analysed several european studies and found that absolute yield levels are increasing over time but at a slower rate than for comparable conventional systems. A conversion-specific crop yield decline (additional to that which might be expected under an established organic system) is often mentioned but not found universally (Lampkin, 1993). Yields of field vegetable crops in organic systems have been estimated to be one-third lower than conventional in the UK (Marland, 1989) and a survey showed them to be 23% lower in France (ABC, 1991). It has even been suggested (Pimentel, 1993) that yields of organic vegetables and fruits are substantially reduced and that integrated systems that include the judicious use of agrochemicals may be necessary to maintain similar yields as in conventional systems.



### **Economics**

Economic comparisons can be misleading for various reasons (Lockeretz, 1989) but are of great importance. Results of studies have depended on variations in the production system studied, crops produced, year-to-year variations in weather, soil type and assumptions of price and cost structures (Fox et al, 1991). Prices, for example, do not reflect the externalities of conventional agriculture (pollution, environmental degradation), and the value of inputs is perhaps too low because future demand is much discounted (Martínez-Alier, 1995). Besides, trade-offs among environmental and human health objectives, and between these objectives and the economic viability of farms, are not well understood (Fox et al, 1991). Farm income decrease during conversion has been attributed to reduced output, new investments to adjust to a higher enterprise diversity, fixed cost increases or lack of access to premium prices. In general higher prices are required, in addition to lower costs, in order to compensate for reduced yields in ecological systems (Klonsky & Livingston, 1994; Lampkin & Padel, 1994; Vereijken, 1992). In one case it was shown that in integrated, low-input wheat production considerable savings on pesticides could almost compensate for the resulting yield depressions (Vereijken, 1989). Furthermore, many farmers consider that their organic systems should be able to function profitably without premium prices (Lampkin & Padel, 1994). In Perú, where an established market for ecological products does not exist, premium prices can be paid by a reduced elite and so the profitability of alternative systems probably needs to be based on lower costs, greater efficiency and macroeconomic policies.

### **Management**

Management problems are common during the conversion period, sometimes as the major concern. This is often due to the complexities of a more diversified enterprise and the need to implement structural changes in the farm like including new crops, alterations in buildings, adoption of different machinery, establishment of hedgerows, errors in the planification of rotations and improved handling of manure (ABC, 1991; MacNaeidhe, 1992). Labour use is generally higher on organic farms than on comparable conventional farms, because of the greater diversity of enterprises, marketing and processing activities, the addition of labour-intensive crops in the rotation (Padel & Lampkin, 1994) or the need for skilled labour and timely field operations (Andrews et al, 1990). Organic small farms in Latin America require much more labour force than conventional ones, and weeding is the most demanding activity (Castañeda, 1995).



## **Soils**

Soils under organic management experience many changes, with new dynamics not yet well understood, that result in part from significantly higher inputs of carbon associated with organic matter and the reduction or termination of chemical fertiliser and pesticide use (Scow *et al*, 1994). An inappropriate design, specially crop rotations, lack of manure, or the introduction of reduced tillage are frequent causes of limited crop growth in the first years. High-demanding crops like grain corn (Liebhardt *et al*, 1989) and tomato (Temple *et al*, 1994) may well be avoided as the first crops in the new rotations to avoid excessive income reductions due to nitrogen deficiency. In the Rodale experiment it was found that in general organic practices increase rates of CO<sub>2</sub> evolution and soil nematode and earthworm counts, and alter microarthropod populations; the data suggested that organic amendments tend to enhance soil biological activity, while tillage disturbances tend to disrupt the biotic community (Werner & Dindal, 1990). Long term comparisons in New Zealand and the US showed that ecological farms have soils of higher biological and physical quality and lower erosion rates (Reganold, 1988; Reganold *et al*, 1993). In spite of this evidence no generalizations are possible and variations from farm to farm may be high as is being shown through the development of ecological nutrient management with pilot farmers in The Netherlands (Kloen & Vereijken, 1994).

## **Pests, diseases and weeds**

A general view is that organically grown crops, at least in the long term, are less susceptible to pest and disease attack. Although this field tolerance has not been demonstrated conclusively, specially with exogenous pests that move into the crop each season (Peacock & Norton, 1990), the experience of growers in California indicates that fewer disease and insect problems exist overall in organic systems (Klonsky *et al*, 1994). The variability of responses is great and some of the reasons that may explain this behaviour are allelochemical modifications in crops, differential plant nutrient concentrations, differential plant development induced by organic fertilisers (Culliney & Pimentel, 1986; Workneh, 1993) and greater agroecosystem diversity (Risch *et al*, 1983; Vereijken, 1995). In open field vegetable production, leafminers, some species of aphids and whiteflies, and spider mites, are all considered to be usually under good biological control in the absence of pesticides (Zalom & Fry, 1992) and in a survey in France 1 out of 3 farmers in conversion did not consider necessary to apply curative measures against pests



and diseases, but the cost of weeding was 2.7 to 4.5 times higher than in conventional systems (ABC,1991).

Conversion experiments show that changes in pests and diseases are often not so marked as in weed populations, and weeding is generally mentioned as one of the major difficulties in this period (Lanini *et al*,1994). In a survey in the UK organic farmers considered weeds, slugs and birds, and specific insects and diseases, as the most serious problems (Peacock,1990). In The Netherlands, monitoring strongly suggested a trend of increasing abundance of annual weeds in integrated systems, probably due to a lower success of mechanical control and changes in weed dynamics (Lotz *et al*,1993). Weed dynamics are complex, however, and research on low-input no-tillage systems indicated the potential importance of insect seed predators in reducing weed numbers and biomass, combined with the allelopathic effects of surface mulches (House & Brust,1989). To summarise, integrated crop protection implies a maximum of prevention (starting with a sound crop rotation) and a minimum use of chemicals, while organic systems rely totally on biological and physical methods (Wijnands,1990).

#### **Produce quality**

Improved food quality, in special vegetable crops, is very often mentioned as a major difference between ecological and conventional farming. One problem remains in the assessment of quality, as it is a variable concept, but in general vegetables appear to be more palatable and nutritive when grown ecologically (Woodward *et al*, 1989). With some crops, however, there may be causes for concern. In a study of conversion in wheat production, for example, yields and quality were generally good, but none of the varieties reached a grain protein content considered as minimum for bread making (Storey *et al*,1993).

#### **Landscape and wildlife**

The preservation and enhancement of natural areas is not a peripheral luxury for society but a capital investment from which we expect to draw interest (Odum,1969). In the european network on ecological farm prototypes this has been acknowledged and nature/landscape equals food supply in the hierarchy of objectives, with ecological infrastructure management as one of the key methods in the design (Vereijken,1994). Diversification in farms through management of ditches, hedgerows or ponds improve the landscape value of the region and supports wildlife, with effects on pest regulation and



nutrient cycling. Trees, for example, break up the monotony of crop land, soften the microclimate, attract wildlife and reduce noise and dust levels (Schaefer, 1989). Practices that ecological farmers follow, like reduced tillage, soil cover, polycultures or management of edges benefit wildlife and support increased bird abundance (Best, 1990). In Pennsylvania, for example, daily survival rates of two species of birds, as well as total species diversity, were higher in organic than in conventional orchards (Fleutsch & Sparling, 1994).

The literature available deals predominantly with temperate regions but provides insight for experiences in tropical and subtropical regions as well. It reveals that during the conversion process management skills, and probably capital, are needed to adjust to a more diversified operation, and that yield reductions might be expected. Gradually, crops, nutrients and pests start establishing new balances, while human beings find their role in them, and after several years the ecological farm will probably produce yields slightly lower or equal than in the conventional system. Cost reductions, greater efficiency, conducive macroeconomic policies and, hopefully, higher prices may assure profits. In the end, the viability of ecological farming may be guaranteed through an integration into the ecological and socio-economic processes interacting at the landscape or watershed level. It is a great challenge that starts with an understanding of how an agroecosystem functions.

#### IV CONCEPTUAL FRAMEWORK

##### The analysis of agroecosystems

Ecosystems were originally described in 1935 as "the whole system, including not only the organism complex, but also the whole complex of physical factors forming what we call the environment", and later as "a system composed of physical-chemical-biological processes active within a space-time unit of any magnitude" (Jackson, 1991). Agroecosystems are ecological systems modified by human beings to produce food, fiber or other agricultural products, with social value as the recognisable system goal (Conway, 1987). Their boundaries acquire a socio-economic dimension, and they can be arranged in a hierarchic scheme (e.g. field-farm-village-watershed-region) (Conway, 1985). In a hierarchy, systems and sub-systems are relative terms and each level organises the next level below and adds emergent qualities; if one knows only the properties of the lower level the emergent qualities are unpredictable (Jackson, 1991). In Fig. 2 it can be visualised how agroecosystems are also sub-systems in the major system in which human societies and the natural environment are organised.

The effort to understand agroecosystem structure and function helps in overcoming the reductionistic view that prevails in agricultural research and development. Each level in the agroecosystem hierarchy has to be analysed and developed both in its own right and in relation to the other levels above and below, and this totality used as the basis for development (Conway, 1987). Elements of a certain level are used to answer questions on a higher integration level and studies of higher integration levels reveal missing elements at lower levels (LUW, n.d.). The relevance for sustainability is notorious. Fresco & Kroonenberg (1992) argue that ecological sustainability should be viewed with respect to distinct time and spatial scales and Hendrix (1987) has suggested that the sustainability of reduced input systems may actually be a landscape or regional-scale problem. Lowrance *et al* (1986) consider that sustainability can best be addressed by recognising the dominance of agronomic constraints at the field scale, microeconomic constraints at the farm scale, ecological constraints at the watershed or landscape level, and macroeconomic constraints at the national and transnational level.



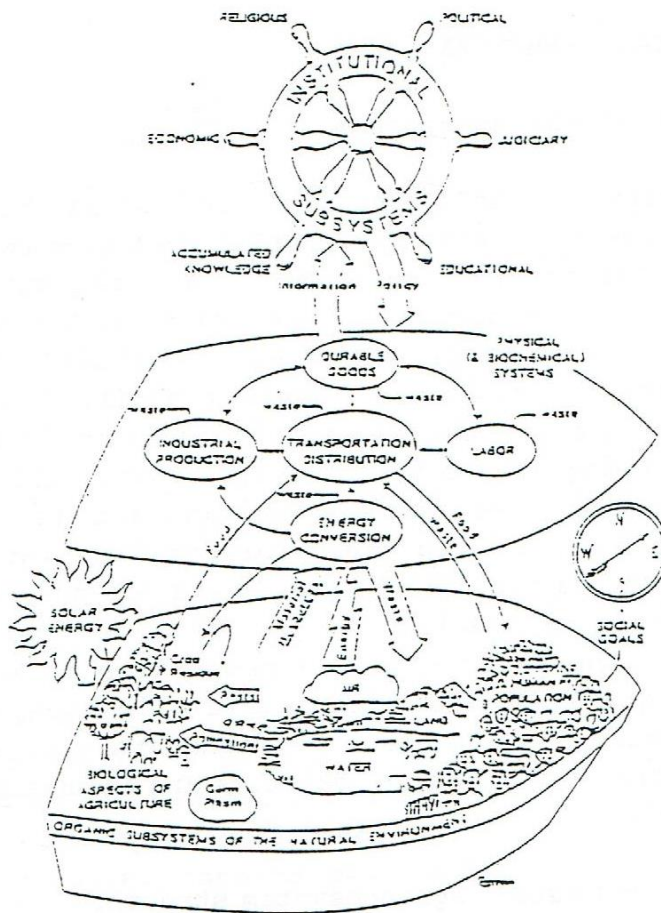


Figure 2: Conceptual elements of the relationship of human societies and the natural environment (Source: Edens & Haynes, 1982, modified from Haynes et al, 1981)

It is not easy to assess the sustainability of agricultural production systems, not only because the evaluation will be influenced by the conceptual definition of sustainability, but also because several constraints affect the quantification of attributes and parameters (Stockle et al, 1994). Conway (1985) considers that an assessment of agroecosystem's performance has to be made not in terms of the theoretical goal (increased social value) but in relation to those key system properties that contribute most directly to realising the goal (productivity, stability, sustainability and equitability). Marten (1988) adds a fifth key

property -autonomy- although Conway (1987) considers that it, as well as others like diversity, market penetration or cultural acceptability, contribute to social value through the four key properties. These key functional properties are hierarchical because the agroecosystems themselves are hierarchical, and one of the major reasons to evaluate them is to compare the performance of alternative forms of agriculture (Conway,1985;Marten,1988).

**Productivity** is the output of valued product per unit of resource input. Common measures are yield or income per hectare, or total production of goods and services, but it can also be converted to caloric or monetary values and even to employment or aesthetic value, in ways that are difficult to measure (Conway,1987). It is only meaningful when expressed as efficiency of production (Marten,1988).

**Stability** is the constancy of productivity in the face of small disturbing forces arising from the normal fluctuations and cycles in the surrounding environment and can be measured by the coefficient of variation in productivity determined from a time series of measurements (Conway,1987). Diversity of possible responses is a key to adaptability, and therefore stability (Fresco & Kroonenberg, 1992;Marten,1988).

**Sustainability** is the ability of an agroecosystem to maintain productivity when subject to a major disturbing force, which can be due to internal processes that cumulatively undermine productivity. It concerns whether a given level of productivity can be maintained over time, and involves the ability of farm management to maintain agroecosystem function (Conway, 1987;Marten,1988).

**Equitability** is the evenness of distribution of the production among the human beneficiaries (Conway,1987), and can be assessed with respect to the distribution of agricultural products or with respect to access to inputs, two views that are often closely linked but not always (Marten,1988).

**Autonomy** is concerned with an agroecosystem's degree of integration, as reflected by the movement of materials, energy and information between its component parts and in and out of the agroecosystem, and by the control of these movements (Marten,1988). Berr (1973,cited by Venegas & Siau,1994) mentions that the viability of a system is assured if, besides being sufficiently autonomous, it possesses



self-organisation and self-control capacities.

An early step in the multidisciplinary analysis of a given agroecosystem is to identify the important factors and processes that affect the primary system properties, a procedure particularly useful at the beginning of a project when data are scarce. For objective analysis, objective criteria should be used for selecting one measure instead of another, although the ultimate purpose of evaluating agroecosystem performance is to attain better agroecosystems, a process in the domain of value judgements (Conway, 1985; 1987).

Progress can be made in developing tools for evaluating sustainability if we first focus on identifying systems that are clearly unsustainable, basically by a loss of 'systemic integrity', and then build up our ability to identify those that appear more sustainable (Lowrance *et al*, 1984; Stockle *et al*, 1994). Jodha (1994) presents a list of indicators of the unsustainability of agriculture in dry tropical areas as negative changes related to the resource base, the production flows and management practices, with the next essential step being the classification of the indicators. Some problems remain, like the separation of a short-term decline from an unsustainability indicator and the identification of threshold values.

Stockle *et al* (1994) propose a scheme for evaluating the relative sustainability of agroecosystems. It includes a list of major attributes and constraints for each attribute; these should then be scored assigning weights to each of them to produce a figure of merit. Their scheme follows Altieri's (1989) objectives for agroecosystems, and a key element is the quantification of the specific constraints within each attribute, a difficult task that requires direct measurements, expert opinion and simulation modelling. Dalsgaard *et al* (1995) draw from the approach of agroecological engineering pioneered in China and propose four main system attributes (diversity, cycling, stability and capacity) for the quantification and ranking of farming systems along a scale of increasing ecological sustainability.



## **A methodic way to more sustainable farming systems**

Several visions of ecological agriculture have limited use because they are hardly defined in measurable terms and elaborated and tested into concrete farms. In view of this, a methodic pathway to more sustainable farming systems has been proposed (Vereijken, 1992) and is currently being researched by a European network on the design and testing of integrated and ecological farming systems (Vereijken, 1994a,b;1995). In The Netherlands the development and comparison of alternative agricultural systems started in 1979 in the Nagele experimental farm (Vereijken, 1990).

In this methodology, the first step is to organise the objectives of the farming system in a hierarchical way. The major values and interests involved are divided into food supply; employment; basic income and profit; abiotic environment; nature and landscape; and health and well being. Each of these values is defined in measurable parameters, and then the objectives of the farming vision (i.e. world-market-oriented, ecosystem-oriented or integrated) are quantitatively expressed in these parameters. In Appendix 1 a general matrix for this procedure is shown (Vereijken, 1992) in general terms, as a framework for the definition and quantification of parameters relevant for local conditions. Quantitative definition is indispensable for a consistent elaboration, but it depends on the overall strategy. Integrated farming systems are considered as a compromise for the short term, the final goal being ecosystem-oriented farming systems for sustainability. This last vision is considered to require consumers to be willing to pay higher prices for farm products sold under a label of certified organic quality (Vereijken, 1992).

With the overall strategy formulated, appropriate methods and techniques should be developed, requiring the action of various disciplines (in disciplinary institutes or university departments, for example). Once operational they are used to compose and develop region-wise prototypes, preferably on experimental farms. When the prototype becomes viable it can be tested and improved with pilot farmers in the region, to explore the potential impact of the prototype system in practice and to develop safe and generally applicable variants. The last stage is to mobilise extension and education and provide for the information they and the farmer need to consider the adoption of the system (Vereijken, 1992).



## V METHODOLOGY

In accordance with the conceptual framework and taking into consideration the antecedents of foreign studies dealing with the conversion process and with the comparison between conventional and ecological farming systems, the following steps are followed here to answer the central questions in this paper:

1. For the initial diagnosis of the current farming system the main constraints are identified taking as a basis the tomato crop, which is the most intensively grown vegetable in the region. In this way, tomato exemplifies how the system has been intensified in the last decades, and the consequences of this process. For this, an analysis at the field level, the key sources are the last study on vegetable production costs at VCEF (Delgado de la Flor *et al*, 1994) and the growing handbook produced by the management team of the VCEF (Ugás *et al*, 1995). This publication is intended to disseminate the 'state of the art' in conventional vegetable growing in the central coast of Perú and was finalised coinciding with the planning phase of this report. The identification of constraints then goes up into the farm, landscape and national levels. In Appendix 2 a brief description of the farm is presented to complement this analysis.
2. The major constraints identified are then plotted against the key properties of agroecosystems (Conway, 1985; Marten, 1987) in order to assist in the hierarchical arrangement of the objectives behind the conversion process.
3. The design of an alternative farming system starts with making a hierarchy of general and specific objectives. Unless otherwise stated, the methodology employed is the same being applied in the european network on integrated and arable farming systems (Vereijken 1992; 1994a, b; 1995).
4. The major objectives are then transformed into multi-objective parameters and conceptually defined.
5. With the european experience as reference, a preliminary set of multi-objective methods is proposed and conceptually defined.
6. Parameters and methods are linked in a theoretical prototype as a framework for the design of the methods.

7. The 'state of the art' in ecological vegetable growing at UNALM is outlined in relation to the parameters and methods.

8. A plan for action is proposed.



## VI DESIGNING THE NEW FARMING SYSTEM

### The performance of the current farming system

#### The field level

Tomato originated in Perú and was domesticated in México in pre-columbian times, and is intensively grown in the central coast of Perú for the fresh market and for processing. It is used here to exemplify how the VCEF is organised and behaves at the field level, the management of individual crops, a first step in the identification of the major constraints that affect the functioning of the agroecosystem.

#### 1. Life cycle

Most vegetable crops are annuals or biennials and perennials grown as annuals. The exceptions are green asparagus and artichoke, perennials grown for 10 and 3 years, respectively.

#### 2. Growth habit

Where modern, determinate tomato cultivars are available, they are preferred over traditional, indeterminate cultivars. Staking has proved to increase yields with indeterminate cultivars of crops like sugar pea and pickling cucumber but labour costs are difficult to meet.

#### 3. Climate

Tomato is grown the year-round. Pests are predominant in summer (especially maggots and fruitworms) while diseases are severe in winter (especially late blight). Although these two distinct cropping seasons are recognised, management is rather uniform for both of them.

#### 4. Cultivars

18 tomato cultivars predominate, mostly hybrid, although open-pollinated cultivars form the bulk of the total seed use. All tomato seed is of foreign origin. Local tomato cultivars have disappeared, mainly because of their long growing period, short shelf-life and disease susceptibility. The peruvian vegetable sector is becoming increasingly dependant on hybrid and generally imported seed.

Locally-produced open-pollinated seed is still a large share in local crops/cultivars and those propagated vegetatively. Seed production, with a few exceptions, is in private, non-specialized hands; seed certification schemes in the vegetable sector collapsed some years ago and have not been reestablished.

#### 5. Crop establishment

Direct seeding and transplanting are always manual (by hand or using small sowing machines) and so labour intensive. Nurseries are not always well established, seedlings tend to be older than the optimum and disease transmission (viruses and nematodes in tomato) occurs. Fields are thoroughly tilled before sowing, generally disced twice, and a flat and smooth seedbed provided for direct-seeded crops.

#### 6. Plant density

Although optimum populations are generally known they tend to be lower in farmer's fields. Mechanisation, soil fertility and weed infestation are the criteria most often used to determine actual stands. Poor germination, soil-borne diseases, lepidopterous pests, bird attack and insufficient soil moisture very often affect stands.

#### 7. Soils

Soil fatigue caused by improper rotations and chemical fertilisation appears to have increased in the last years. PK soil reserves are generally sufficient but high-demanding crops respond to chemical fertilisation of these nutrients. Most crops present nitrogen deficiency when not fertilised and micronutrient deficiencies have increased. pH is only slightly above the optimum range for vegetables and salinity is not a major concern, although this varies among fields. Erosion and leaching of nutrients has seldom been identified as problems in this vegetable sector.

#### 8. Fertilisation

The two only sources of organic matter are crop residues and manure. Crop residues are often incorporated into the soil but when too lignified they are gathered in the sides of the fields and burned; composting areas were set aside but never used. Manure (from cows or small animals from the university's stables) is insufficient and the standard recommended application rate of 20 ton/ha of cow manure is seldom followed. Green manuring/cover cropping is not practiced in the region and the oldest organic fertiliser in the country, guano, is generally sold as a mix with chemical fertilisers.



Chemical fertilisers are generally used although financial limitations restrict their use to the most demanding crops and to nitrogen fertilisers. Application techniques are rather well known but NPK dosage is based on standard recommendations. In tomato, foliar fertilisers and growth stimulants are often mixed with pesticides as a standard practice. Soil analysis are used in the experimental areas; farmers seldom use them.

#### 9. Irrigation

Production depends on the scarce water available for irrigation. Furrow irrigation is the common practice and the open canals are not well maintained in the region. Localised irrigation systems are seldom used. Water quality can be a reason for concern due to the transmission of human diseases through leaf and root crops, and also because of heavy metals contamination. When water is abundant irrigation is sometimes too frequent, and when scarce irrigation is often too heavy and at wider time intervals. Water conservation techniques like mulching or reduced tillage are also often misunderstood.

#### 10. Weeds

Weeds grow year-round and exert a great pressure on farm management. The main control methods are hand weeding, mechanical cultivation and herbicide use, in this order. Cultural methods of control like crop rotation, localised irrigation, mulching, manipulation of plant density or intercropping are known but considered complicated. Innovative methods like flame weeding, brush hoes or geese weeding are unknown. Farm workers, more often than farm managers and researchers, identify several positive values of weeds but find it difficult to integrate them into management methods.

#### 11. Pests and diseases

Tomato exemplifies better than any other crop the 'technological treadmill'. Through the years higher-yielding cultivars have been introduced to serve the processing industry, displacing fresh-market tomatoes, which are now a rarity. Improved cultivars require a more intensive use of fertilisers and pesticides (intensive often equals more, although this has changed with the economic crisis). Monocropping is intensified, along with nematode populations and soil-borne diseases. To save seed transplanting is favored, disseminating nematodes and viruses. Increased use of pesticides disrupts biological control, along with the disregard of natural vegetation areas. Resistance to pesticides and resurgence of pests are wide-



spread. As a consequence, pest and disease control is generally one of the major causes of concern for farmers and a common reason for failure of tomato crops. Control thresholds does not exist in practice.

#### 12. Harvest and postharvest handling

Vegetable crops are always harvested by hand, which is labour intensive. Acceptable postharvest losses are increased by the inefficient marketing structure and lack of sufficient storage facilities.

#### 13. Yields

Vegetable crops for the fresh market and for the processing industry are the main outputs in this horticultural sector but often crop residues of asparagus, brassicas or legumes are sold as fodder. Average yields for the region provide an equivocal image as tomato, for example, can yield from 20 to 80 ton/ha/crop; 40 ton/ha is considered a minimum acceptable yield, and in other regions of Perú as much as 100 ton/ha can be produced. In less intensively produced vegetables yield ranges are narrower. Yield per se is widely considered a measure of agronomic efficiency, and when they are high and profits low the blame is generally put on the market. With conventional technologies and enough water, vegetable yields are generally high by international standards, although few farmers can achieve them.

#### 14. Food quality

Consumers in the region are becoming increasingly concerned about vegetable quality because of recent epidemics as cholera and mass media attention to pesticide residues on food. Vegetables are often targeted as health threats in this particular sector of periurban agriculture. This has opened a small market niche for organic products.

#### **The farm level**

The previous description of how crops are grown facilitates the identification of the main factors and processes that are affecting the 'systemic integrity' of VCEF. Some of these constraints, however, can only be dealt with at higher or lower levels in the agroecosystem hierarchy. When looking at VCEF it makes sense to consider, following Stockle et al (1986), that agronomic constraints dominate at the field level, while at the farm level the dominance switches to



microeconomic constraints. Several cycles operate and can only be understood at the farm level (cycling of nutrients, transfer of insects between fields and borders or natural vegetation), as well as processes that cumulatively affect sustainability (parasitic nematode proliferation, wind reduction by wind curtains, accumulation of pesticides in the soil, or the role of birds in rodent population dynamics).

Since short-term profitability is the main goal the farmer or researcher often overlooks or disregards these cycles and processes in the race to increase yields. Whatever the dominant constraints at any level, their effects can also be traced at any other level. In integrated and ecological farming system the analysis is focused on farms, rather than in individual fields. The main groups of constraints at the field and farm levels that need to be addressed at the farm level are mentioned here, along with comments relevant to the conversion period:

#### 1. Crop diversity

The selection of crops is done mainly on an economic basis and depend on the farmer's expertise and preferences. Vegetable growers are specialised, and few non-vegetable crops are included in these operations: potato, sweet potato, dry bean, strawberry and fodder maize. In VCEF the bias is strong as university regulations require only vegetable crops to be grown. Although several commercial vegetable crops are available, the design of an appropriate crop rotation for integrated or ecological systems would require the inclusion of crops not typical in the sector, as green manures/cover crops. It is revealing that in VCEF, as well as in many comparable farms in periurban horticulture, crop rotations plans have been gradually ignored because of economic problems and market distortions. In relation to crop genetic resources a new design of VCEF should also consider the development of underexploited local crops and cultivars for farmer's use, moving ahead from the traditional strategy of germplasm collection and documentation. Research on crops like vegetable amaranth, for example, has already provided promising results.

#### 2. Seed supplies

Sustainable vegetable production should reduce the dependence on foreign seed. Local seed production of open-pollinated cultivars should be encouraged, although this highly specialised activity



will probably needs to be dealt with at the landscape (watershed) and national levels.

### 3. Nutrient cycling

Nutrient cycles are known in a theoretical way but have never been quantified in VCEF. Nitrogen contents are low and in the new design nitrogen needs should be met including non-vegetable legumes and improved manure handling. Guano and fowl manure must be considered along with cow manure, but manure from intensive livestock holdings may bring along undesirable amounts of salts or chemicals. Manure availability is a major limiting factor in periurban agriculture.

### 4. Pests and diseases

Intensive phytosanitary measures are a characteristic of the current system. Vegetables, more than other crops in the region, suffer from serious yield reductions caused by pest and disease attack. Since many of them attack several vegetable crops in common (nematodes, leafminers, maggots, cutworms, spider mites, damping-off, viruses, etc.) they should be managed at the farm and landscape levels, including natural habitats and wildlife reservoirs.

### 5. Weeds

Intense weed infestation is also characteristic of vegetable crops, and in VCEF it has been exacerbated by poorly-planned rotations and bad management. In the new design this problem should be addressed in first place by crop rotations.

### 6. Mechanisation

The dominance of disc ploughs, which are used to prepare fields before every crop (it may be every 3 to 5 months), places a stress on soil organisms and physical and chemical properties. Alternatives are not readily available, and techniques of conservation tillage are largely unknown.

### 7. Farm infrastructure

Private ownership of the land is the norm but accelerated urbanisation tends to decrease farm size and numbers. The layout of the fields would probably need to be adjusted to allow a proper crop rotation, and irrigation ditches managed to reduce water losses while contributing to the concept of ecological infrastructure. Bad road maintenance within and between farms generally produces considerable amounts of dust that on the foliage of low and early crops in this arid zone may limit photosynthetic efficiency,



specially in winter months. In VCEF a water reservoir for an experimental drip irrigation area can be better integrated into the farm design.

#### 8. Management

Lack of knowledge of specific techniques in integrated/ecological agriculture will likely be a major constraint that should be addressed through interdisciplinary research in the design and prototype of the new farming system. Field labour availability, in the particular case of the VCEF, is not a problem, but current financial considerations make impossible to meet the farm's demands.

#### 9. Profitability

Vegetable farms in the region find it increasingly difficult to keep profits high. Yields are the main target in this respect and can be profitable if sufficient inputs are insured. This clearly sets limits to long-term viability of the farms. Profitability is multidimensional and its mechanisms are more clear in the higher levels in the hierarchy. It should be based on the local market, although export has appeared in the last year as an often rewarding, but still limited, possibility to improve profits.

#### 10. Contamination

At the field and farm level contamination is more concerned with labourer's security during manipulation of chemical products (poisoning is a recurrent situation), and with the cumulative effects of chemicals in soils.

### **The regional/landscape/watershed level**

The main constraints to sustainability at this levels are:

1. Water is one of the main limiting factors, in part because of environmental degradation at the watershed level, major climatic shifts, and competition with the city of Lima.

2. Environmental degradation in several aspects is characteristic of periurban agriculture in the region. Urbanisation, industrial developments and agriculture coexist and pose serious threats to the quality of life. At this level, the growing perception by consumers that vegetable producers are responsible for food and environmental contamination will impose limits on farmer's actions.



3. Lack of integration among farmers: economic crisis and migration from several parts of the country tend to detach farmers from their social and natural environment. In spite of centuries of integration, today in this area individualism predominates and this is a cause of concern because farmers are the managers not only of their farms but of the landscape where they and their farms exist. This lack of integration extends when talking about farmers in the edge of the city and the urban population. In fact, urban dwellers often consider farms as an unacceptable limit to urban expansion, in spite of official efforts in the opposite direction.

4. Vegetable supply is rather unstable and for a growing and undernourished population in suburban Lima vegetable consumption is a key for good nutrition. Marketing structures and unaffordable prices, along other aspects like dietary preferences and the social prestige that the consumption of products derived from beef and wheat (often imported!) grant, limit the further inclusion of vegetables in the diet. One major factor affecting vegetable supplies and prices is the inefficiency of the established channels providing market information.

5. The decreasing number of livestock operations in the area (urbanisation pushes them away faster than vegetables) is a limiting factor in the supply, and accesibility, of manure.

6. Unemployment is high in the region and any proposed contribution of agriculture to sustainable development should consider farm employment as a key component.

7. In a country under structural adjustment, macroeconomic policies have restricted the access to credit by small and medium-size farmers. Processing companies and pesticide distributors often fill in this gap promoting their interests, which are seldom focused on sustainability.

For the design of a new farming system several multidimensional constraints should be taken into consideration but in the beginning it is better to pay attention at the farm and at the levels below and above. Once identified, it is important to recognise which factors at the landscape and regional levels, and even higher in the hierarchy, affect farming in a negative way. The previous analysis shows that the VCEF and the average vegetable operation



in the area are not efficient, neither from the conventional nor from the ecological point of view. It is a paradox that farmers, with their enormous farming knowledge, find increasingly difficult to farm efficiently. Most answers should certainly be sought at other levels, but this should not hide the fact that a great share of this knowledge is being lost in the wake of urbanisation and policies that promote 'internationalisation'. Overall, the results of this analysis are similar to those obtained in vegetable periurban production in Southeast Asia (Midmore, 1994). It is clear that several non-system factors are interacting and should be considered during the testing, improvement and dissemination of the prototypes.

In the beginning of a project it is useful to identify the major factors and processes that affect the key properties of agroecosystems, as suggested by Conway (1985;1987) and Marten (1988). I have selected what I consider the main characteristics of the current farming system that may affect the design of a new one, and plotted them against 5 key system properties (Fig.3). No attempt was made to arrange them in order of importance because of the subjectivity of this procedure and only the major effects are showed. The methodic way proposed by Vereijken (1992) is more operational in the sense that it provides a method based on the quantification of the objectives of the farming system. The designer arranges the objectives in order of importance according to the way he perceives the current situation. The analysis proposed by Conway, however, is a powerful tool to assist in this perception.

The picture now is that of a system that has lost much of its 'systemic integrity'. That is, the main processes linking different components of the agroecosystem, from which emergent qualities appear, have been affected as to impose considerable stress on the key system properties. It is no surprise that all the constraints affect sustainability, as this property integrates several others, in large part by processes that are affecting the farm in a cumulative way. Soil organic matter, for example, has been decreasing through the years because economic reasons forced an extensification of the system, inducing the set-aside of fields or improper fallows, and because manure is less available as a result of increased urbanisation. Since this extensification is expressed as a lower cropping intensity and not by a lower use of inputs on a field, autonomy is affected. Equitability, in this analysis, deals more with the access of farmers to scarce resources (water, information, manure) than with the distribution of outputs. Productivity and



Figure 3: Main constraints identified in the current farming system at VCEF and major effects on key agroecosystem properties

	Prod.	Stab.	Sust.	Equit.	Aut.
Low crop diversity	+	+	+		+
Soil organic matter	+	+	+		+
Low nitrogen	+	+	+		+
Abuse of chemicals	+	+	+		+
Pest & disease problems	+	+	+		+
Scarce water	+	+	+	+	+
No animal husbandry	+		+	+	+
Sub-optimal mechanisation	+	+	+		
Insufficient knowledge	+	+	+	+	+
Bad market infrastructure			+	+	+
No premium prices			+	+	+
Low landscape integration	+	+	+	+	+
No consensus farmer-consumer		+	+	+	+
Low profitability	+	+	+	+	+
Contamination	+	+	+	+	+
Unemployment			+	+	+
Limited access to credit	+	+	+	+	+

stability are affected in more or less the same way, although for VCEF and comparable farms yields are a concern not so much because they are low but of increased variability in time. In this sense, resilience appears to be low. However, it is also clear that possibilities of improvements from an ecological perspective exist, and that the potential for agriculture in the region is still high.



Now it is possible to proceed into the methodic way, with a better capacity to identify the goals of the farming system to be proposed. Firstly, two questions should be answered:

► **Why to convert VCEF into an ecological farm?**

The previous analysis shows an experimental farm that, for several reasons that are not all discussed here, is not fulfilling the objectives that motivated its establishment more than 40 years ago: to investigate vegetable crops farming systems to efficiently increase production for the local and foreign markets. The financial and managerial crisis it is facing, along with the environmental problems it has created, does not allow for a thorough fulfillment of other missions like conservation of crop genetic resources, adequate outreach activities, education within UNALM, and guidance in the vegetable sector in Perú. I assume that a new vision of its role is needed to start getting out of the current crisis. I believe that a well-planned conversion to a more sustainable system through the interdisciplinary design of a new farm will provide, not an immediate solution to financial problems, but a new and more consistent frame of reference against which VCEF can judge its performance in the short and long terms. Frame of reference, in this sense, is a "set of accepted values by means of which an individual or group can evaluate its behaviour" (Williams, 1979).

► **What is the agricultural vision behind this process?**

I believe that an ecosystem-oriented farming vision should guide our actions in agriculture. However, the intensive horticultural farming system in periurban Lima and, to certain extent, in the central coast of Perú, will probably need a gradual transformation. This is specially true considering the process that the country is facing, with its economic, political and social facets. The current situation of a country emerging from widespread violence and poverty requires a compromise between immediate needs and long term goals. In this way, the development of an integrated system can only be considered as a short term compromise. As the conversion process progresses and our scientific knowledge of the behaviour of the farm improves, it would be possible to envision and design an ecological farm. It can only be done, however, in close contact with farmers; this could ideally be done through testing and prototyping in actual farms at a later stage. The overall strategy for the integrated farming system that I propose for VCEF has been formulated by Vereijken (1992):



1. Changing from greater production to cost reduction and the improvement of quality of both products and production methods through substituting expensive and/or potentially noxious inputs by both agricultural and ecological knowledge, labour and non-chemical husbandry techniques.

2. Encouragement and conservation of flora and fauna on and around farms to stabilise the agroecosystem.

### **The methodical steps**

#### **STEP 1 : Hierarchy of objectives**

The establishment of an integrated horticultural experimental farm in UNALM will have the following objectives:

General and specific social values and interests involved in the farming system, in order of importance:

1. Basic income/profit: at the farm, region and national levels.
2. Food supply : in sustainability, quantity, stability, quality and accesibility.
3. Employment: at the farm, region and national levels.
4. Abiotic environment: in relation to soil, water and air.
5. Health/well-being: of urban and rural people.
6. Nature/landscape: in relation to landscape, flora and fauna.

These values and interests have been arranged hierarchically and are shown in Fig.4. From now on we shall refer to the new farm design to be outlined in this paper as La Molina prototype.

In La Molina basic income/profit is the main objective because in first place, and under the current situation in Perú, farming should prove to be a viable activity. Several factors affect profitability, many out of the control of the farmers, but no alternative to the conventional system will be accepted if not profitable. The situation here resembles that of the polish prototype in the european project: since the income of farmers has been strongly reduced because of economic reforms, ecological innovation such as an integrated system is only feasible if profitable.



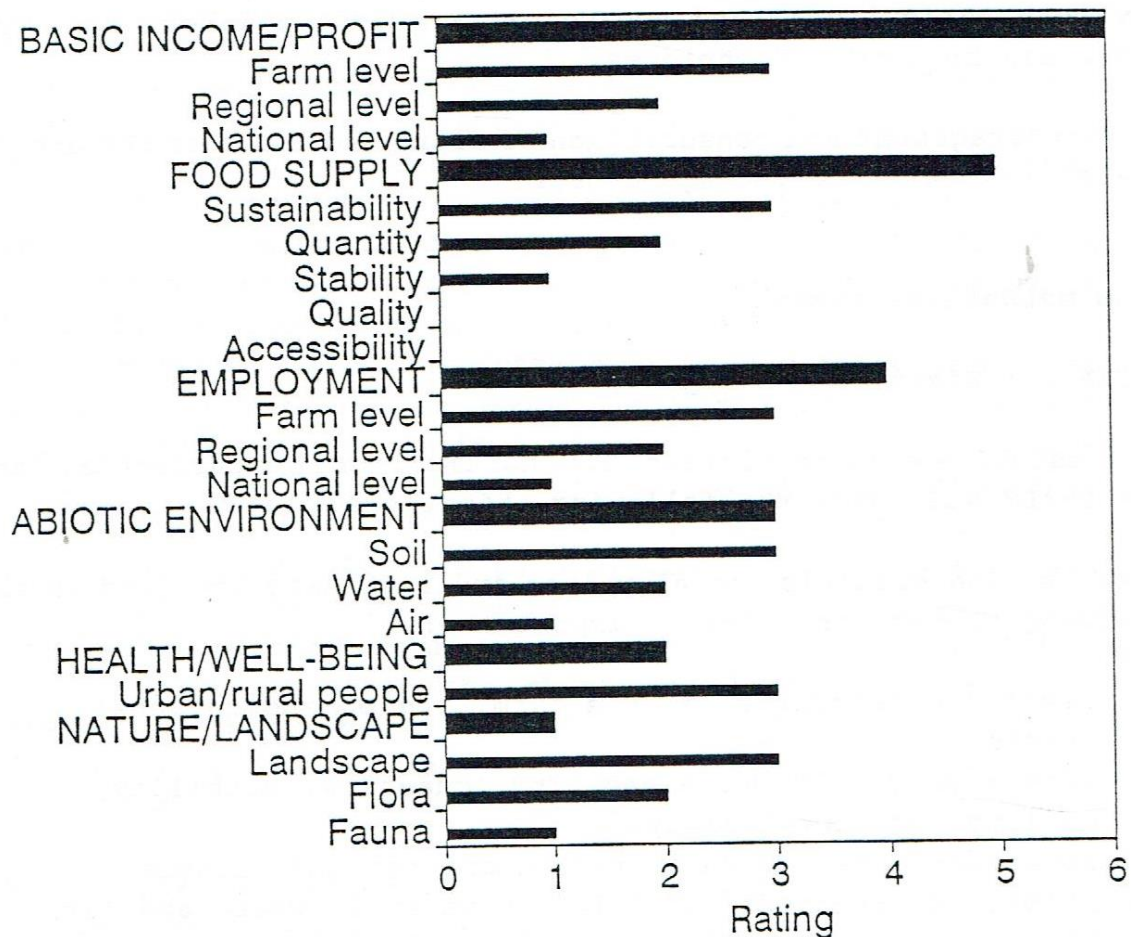


Figure 4 : Hierarchy of objectives in the integrated horticultural farming system in La Molina

Food supply is the second major objective in a region where undernourishment is widespread and vegetables should play a key role as sources of vitamins and minerals. In order to remain viable, periurban vegetable growers should produce food in a sustainable way and in enough quantity to feed a growing population. Annual variations should be decreased, improving stability. Accesibility would be improved in the future as, hopefully, production costs decrease. Quality will improve as less and better inputs are used,

but it is not yet regarded by society as the major concern in food supply. Extensification of the system would result in better quality, but the lower production and absence of premium prices will render the system not viable.

Employment is the third objective as the economic crisis is driving farmers and their families out of the land, and unemployment is widespread in the region. Activities that can increase the demand of labour would then be considered as superior.

The quality of the abiotic environment is the fourth objective, specially because bad rotations, inadequate mechanisation, lack of enough manure and excessive use of chemicals are affecting the capacity of the soil to sustain healthy crops. Agricultural activities can deteriorate the quality of water more than it is already. Air quality is affected by pesticide drift, dust during tillage and burning of straw, and this is already creating problems with the neighbouring residents.

Health and well being is in the fifth place because this methodology requires the ranking of objectives according to the problems perceived at the present time. Most of the concerns about the health and well being of people are addressed in the other objectives, and I do not differentiate between urban and rural population because in periurban agriculture the distinction is not so clear cut. Farm animals are not included in this considerations since most farms are stockless.

Nature/landscape comes in the last place because of the overwhelming predominance of the other values. However, it is a fact that the region is subject to intense environmental degradation due to agriculture, industry and urbanisation. It is hoped that as designing, prototyping and testing advance, it will be possible to place nature/landscape higher in the hierarchy, as La Molina moves from an integrated vision to an ecosystem-oriented vision. This can take time but, in the short term, the quality of nature/landscape is being partially addressed in the other objectives.



The objectivity of this procedure may be challenged if viewed in isolation of the whole methodology. The experience of the European network shows it to be operational in the sense that the major perceived objectives are defined in terms of quantifiable parameters, and that these are multiobjective, covering also many of those low in the hierarchy. Nevertheless, the procedure seems easy but it often needs to be revised, to link up with the second (parameters) and third (methods) steps (Vereijken, 1994). It is worth trying in La Molina where endless discussions often turn into philosophical or political issues, an effort towards holistic thinking that may lose touch with the farm if not defined in practical terms. The hierarchy of objectives, however, is not static, as it may change along with society, and specially when moving away from experimental into actual farms. Furthermore, it represents now the idea of one person and, as a first step, should be endorsed or revised by the design team.

#### **STEP 2a : Quantification of the objectives in parameters**

Objectives need to be expressed in parameters to be quantified, which will be used as the desired results at the evaluation of the prototypes. Here it is useful to identify a limited set of parameters to ensure that the objectives are integrated sufficiently. It should be clear that this is an educational process too, and that the criteria for selecting one parameter instead of another may change while designing and prototyping. A large set of parameters does not assure better integration and thoroughness; rather, it may entangle researchers in a web of data. At UNALM, fortunately, different faculties and departments could assist the design team in a fruitful interdisciplinary endeavour.

Since the search for integration in agriculture is based on ecological principles, it is relevant to draw from the experience of the European network in the selection of parameters. However, the quantification will obviously vary, and there will be a need to add particular parameters or to modify the general ones. Accordingly, 13 parameters are proposed here to cover the top ten objectives of the integrated vegetable farming system in La Molina (Table 1).

**Table 1. Shortlist of parameters according to the top ten objectives of the integrated horticultural system in La Molina**

- 1. Basic income/profit - farm level**
  - 1.1 Net surplus (NS)
  - 1.2 Energy efficiency (EE)
  - 1.3 Water use efficiency (WUE)
  - 1.4 Pesticide index (PI)
  - 1.5 NPK annual balances (NPKAB)
- 2. Food supply - sustainability**
  - 2.1 Organic matter annual balance (OMAB)
  - 2.2 Ecological infrastructure (EI)
  - 2.3 Soil biodiversity (SB)
  - 2.4 Soil structure and compaction (SSC)
  - 2.5 Farm employment (FE)
  - 2.6 Crop diversity (CD)

see 1.2, 1.3, 1.4, 1.5
- 3. Basic income/profit - regional level**

see 1.1, 1.2
- 4. Employment - farm level**

see 2.5
- 5. Food supply - quantity**
  - 5.1 Target yield (TY)

see 2.6
- 6. Abiotic environment - soil**
  - 6.1 Nitrogen available reserves (NAR)

see 1.4, 1.5, 2.1, 2.3, 2.4
- 7. Employment - regional level**

see 2.5
- 8. Basic income/profit - national level**

see 1.1, 1.2
- 9. Abiotic environment - water**

see 1.3, 1.4
- 10. Health/well-being - rural/urban people**

see 1.3, 1.4, 2.2, 2.5

A conceptual definition of these parameters is given below. The actual quantification should be done by the design team based on the state of the art of vegetable growing knowledge, national and/or international regulations, and local characteristics. In the beginning many of them will have to be quantified as 'better than the conventional system' or 'not less, or not more, than the present situation', and we do not know if some of the quantifications will really assure sustainability. Since the design and prototyping of farming systems is in its infancy, the risk has to be taken, and only experience (repeated tests of prototypes on actual farms) will tell if the quantification was too conservative or too radical.



The relationships between farm components are hard to understand and these may become weaker or stronger in the course of the conversion process. Flexibility and common sense are then necessary at every step. Figure 5 provides an idea of the complexities of the interactions between farm components. In this sense, several of the parameters may quantify processes that serve in the accomplishment of the desired objective.

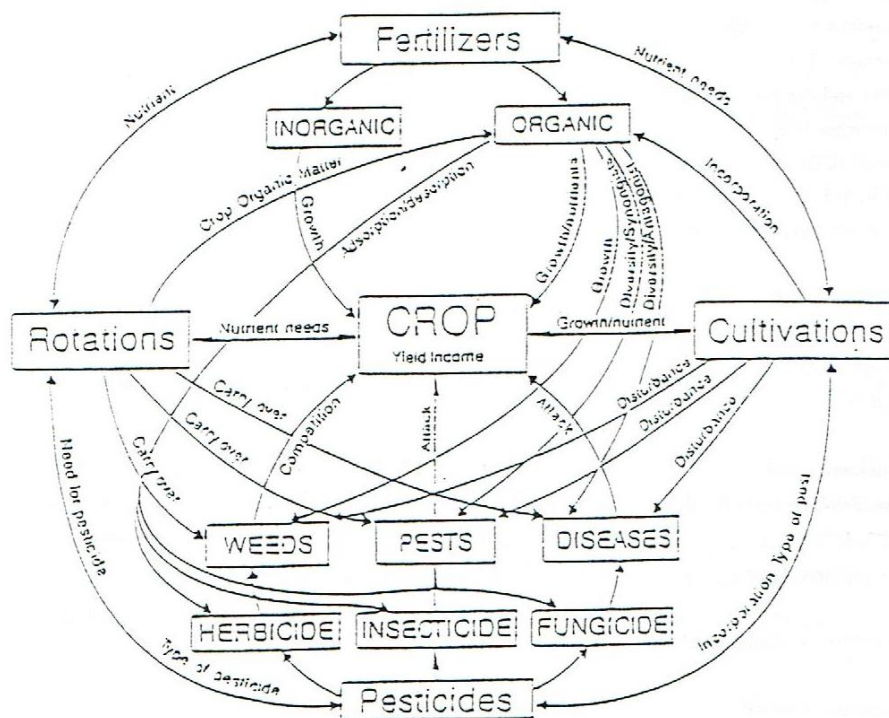


Figure 5. Main interactions between components of integrated farming systems (Source:Edwards,1987).

**NET SURPLUS (NS)**

*yield minus all costs, including an equal payment for all labour hours (NS > 0)*

NS should be quantified first in terms of the NS that has been obtained in VCEF in the past years, and then increased to make it acceptable. However, it cannot be isolated from the whole set of parameters, as is currently done in conventional systems. Equal payment for labour is a sensitive issue, and increases ahead the official minimum wage should be gradually sought after.

#### **ENERGY EFFICIENCY (EE)**

*energy output (produce) / energy input (machinery, fertiliser, pesticide, labour) (EE > x)*

Energy efficiency is a basic parameter to measure the ability of a farming system to reduce its dependence on non-renewable sources of energy, thus improving its sustainability. Giampietro & Pimentel (1991) indicate that this integrating parameter seems able to provide a common indicator which can be used to describe changes at different hierarchical levels. A calculation of the EE in a hypothetical rotation in VCEF showed a value of 0.6 (Ugás, 1993), expressing a considerable higher level of inputs in relation to the energetic value of the produce. This calculation should be refined to adjust to the actual situation and used as a starting point.

#### **WATER USE EFFICIENCY (WUE)**

is the amount of irrigation water needed to produce a unit of produce, and can also be expressed in economic terms. This is an important parameter quantifying objectives in basic income/profit (because of the expenses incurred in securing enough water), food supply-sustainability (being a scarce resource, higher efficiency increases the sustainability of the system), abiotic environment-water (higher efficiency may reduce contamination of water by agrochemicals and, eventually, quality of groundwater) and health/well-being (increased efficiency will reduce competition with the city and allow an expansion of green recreational areas).

#### **PESTICIDE INDEX (PI)**

*pesticides applied.year<sup>-1</sup>.farm<sup>-1</sup>/same in conventional reference system (PI < x)*

A reduced input of pesticides is one of the major aims of the new farming system, and can be easily compared with the actual system. An improved parameter would be Environment Exposure to Pesticides (EEP) for air, soil and water, based on the persistence, volatility and mobility of the pesticides used. In this case, no reference with the conventional system is needed to assess its compliance with the objectives, except for the initial quantification. This parameters provide quantification for several objectives, mainly basic income/profit (because of their high cost), sustainability and quality of soil and water (because of the direct and cumulative effect of pesticides on the environment) and health/well-being (because of the reduction in poisoning of farm workers, and the production of vegetables with less residues).



#### **NPK ANNUAL BALANCES (NPKAB)**

For the quantification of the annual ratios between inputs and outputs of the major plant nutrients, a range has to be established according to what is agronomically desired and environmentally acceptable. In the end, this compound parameter will quantify objectives in basic income/profitability (because of a gradual reduction in chemical fertilisers), food supply-sustainability (because of a gradual increase of organic fertilisers and a limit on available reserves) and quality of soil and water (because of reduced contamination).

#### **ORGANIC MATTER ANNUAL BALANCE (OMAB)**

*OM inputs / OM outputs (OMAB > x)*

Inputs are crop residues, including green manure, and organic waste as manure, all of which are affected by a humification coefficient. Output is the estimated loss of OM by respiration and, less important in La Molina, erosion. SOM in La Molina ranges between 1.5 and 2%, which is considered low for the region and should be improved. SOM is a central point in ecological agriculture and provides a quantified objective for sustainability and the quality of soil, but may influence negatively basic income/profit if the reliance of the new design on manure (a very scarce resource) is overemphasized.

#### **ECOLOGICAL INFRASTRUCTURE (EI)**

*EI > x% of total farm area*

Ecological infrastructure is the part of the farm laid out and managed as network of linear and non-linear habitats and corridors for wild flora and fauna, including buffer strips. In La Molina it provides quantification basically for sustainability and health/well-being (because it may enhance biological pest control, protect against environmental vagaries, improve a degraded landscape, create a better environment for farm workers and provide for recreational areas), but it also has repercussions in objectives like basic income/profit and nature/landscape. Currently in VCEF EI=3.2% of total farm area, while the european network has established a target of 5%. A related parameter is plant or bird species diversity, and target species should be selected. Measurements in VCEF for this study included a separation of the existing EI into 9 different sectors according to the predominant vegetation and an identification of 66 herbs and shrubs, of which 85% were flowering in the spring of 1994. 18 species of trees are present too. Regarding birds, observations during the last 8 years (Renán



Valega, pers. comm.) indicate the presence of 17 beneficial species (from the pest control point of view) and 19 species that can behave as crop pests.

#### **SOIL BIODIVERSITY (SB)**

This compound parameter, as is the case with NPKAB, needs to be refined by the design team for La Molina before any quantification is attempted. Under this heading I have included european parameters that consider detritivore biomass and species, earthworm biomass and species, beneficial indicator species and soil respiration, all of which quantify objectives in terms of sustainability (soil life enhancement is, as OM content, a key point in this respect) and quality of soil. This parameter has also repercussions on other objectives like basic income/profit in the long term.

In relation to earthworm counts, relatively easy to measure and of very practical use with farmers, measurements done for this study in VCEF showed a range from 1.3 earthworms/m<sup>2</sup> (in a field where pesticides and fertilisers were added through a drip irrigation system) to 30 earthworms/m<sup>2</sup> (in a 0.5 ha field where no pesticides have been used for 7 years). In a typical field (conventional management and furrow irrigation) the count was 7.3 earthworms/m<sup>2</sup> (all measurements up to a depth of 0.45 m ). This gives an idea of the actual situation and of the potentiality of the soil to sustain increased biodiversity once integrated measures are taken.

#### **SOIL STRUCTURE AND COMPACTION (SSC)**

Standards measurements of soil structure and compaction provide quantification related to sustainability (because of the long term effects of mechanisation) and soil quality, but it indirectly relates to other objectives such as basic income (associated with reduced costs) and health (associated with unacceptable emissions of dust close to human settlements). Mechanisation, at the same time, has effects on water use efficiency and is closely related to weed control in a system with reduced herbicide inputs. At VCEF some fields already show the formation of a hard pan, with negative effects on deep-rooting crops such as asparagus, and soil structure is severely disturbed during the intensive tillage prior to planting. All of this justifies the inclusion of this parameter, better quantified as an improvement from the actual situation, in terms of several conventional ways to assess soil physical fertility.



#### **FARM EMPLOYMENT (FE)**

*labour hours hectare<sup>-1</sup> (FE > x)*

This is the main parameter to quantify the objectives of employment at the farm and regional levels, but has repercussions on the overall sustainability of the system and on the quality of human life because of high unemployment rates. Currently, for example, one tomato crop (5 months) requires 117 man-days hectare<sup>-1</sup> (60% of which for harvesting). This is now viewed as uneconomical but in an integrated system it may well be viewed as a beneficial side-effect of periurban agriculture.

#### **CROP DIVERSITY (CD)**

This local parameter is of difficult quantification, and should be judged as the increased inclusion of certain crops and cultivars into the rotation and in the management of the ecological infrastructure. This for two reasons. First, an integrated system cannot rely solely on vegetable crops, as is the current mandate of VCEF; in order to provide with all the plant nutrient needs, it is likely that green manures should be included, as well as for an efficient control of parasitic nematodes. Second, it is a mandate that VCEF should take care of the conservation and promotion of vegetable crops genetic resources, of great importance since the central Andes is a center of origin of crops (i.e. tomato, chili peppers, squash, lima bean, etc.). This mandate is currently only insufficiently accomplished. CD is similar to the european parameter Utilisation of Local varieties.

#### **TARGET YIELD (TY)**

Target yields are defined in terms of the conventional system (*TI > x%*) and, as in some of the european prototypes, sets a limit to extensification. That is, the new design would be viable and acceptable only if certain minimum yields are achieved, with direct implications for quantity of food supply. In this case, national yield averages are of no use since they are very low; the reference should be a compromise between the maximum yields achieved in the area, the current yields in VCEF and the yield reductions anticipated in a conversion process like the one that is proposed here. This would need to be quantified on a subjective basis for La Molina, but improvements can be expected in the course of testing.

#### **NITROGEN AVAILABLE RESERVES (NAR)**

NAR is a parameter considered when assessing the NPKAB, but is highlighted in this scheme because of the general low nitrogen content of soils in La Molina (in contrast with PK contents, which are medium or high) and the sensitivity of farmers and researchers to this issue. At the same time, it may focus attention in the phenomenon of groundwater pollution which is hardly an issue in La Molina since the depth of the water table (more than 80 m) and the clay content of soils (10-20%) are considered to prevent it. In some fields in the region, however, this may not be the case. In this respect, this parameter may also consider, when included in an appropriate management method, the handling and application of manure.

#### **STEP 2b : Establishment of methods and techniques**

To develop prototypes of integrated farming systems, potentially conflicting objectives should be sufficiently integrated in a set of suitable methods and techniques that bridge the gaps between conflicting objectives and are not harmful to the others. If some objectives are not sufficiently integrated, additional methods may be needed (Vereijken, 1994b). In view of this, 6 multi-objective farming methods are proposed to achieve the major 10 objectives quantified in 13 parameters. The publications from the European network provide the guidelines for the design of these 6 methods.

For each method the following is provided:

- a. Brief definition.
- b. Main characteristics in La Molina theoretical prototype (that is, a model of how the new system may look like and state of the art of integrated/ecological knowledge in UNALM).
- c. Research needs in order to achieve a coherent design.



## MULTIFUNCTIONAL CROP ROTATION (MCR)

### a. Definition

MCR plays a central role by linking soil parameters and CD to TY, a multi-objective crop parameter, and to NS, FE, EE and WUE, multi-objective farm parameters that link together several environmental and socio-economic parameters. MCR identifies and characterises potential crops for the region according to profitability and their potential role in biological, chemical and physical terms, and can only achieve the desired results if it is laid out in an agro-ecological way (field adjacency, field size, ecological infrastructure, etc.). MCR is a major method with regards to weed control and is supported by ICP.

### b. Main characteristics in La Molina

Several vegetable crops are available for the rotation, but these are insufficient to achieve the desired results in term of soil fertility and pest (basically nematode) control. For this reason, crops other than vegetables must be considered, a fact that requires an institutional change in UNALM. However, the experience of VCEF in the management of a large number of crops is an asset that will facilitate a good design of the MCR. Sufficient knowledge is available regarding the characteristics of individual crops, but research on actual crop rotations is limited to experimental plots. The Department of Phytopathology (Nematology section) has traditionally contributed to VCEF with respect to nematode control using resistant cultivars and trap plants, as well as more efficient methods of nematicide use (although these products are likely to be banned in the near future). Intercropping has been researched to some extent in vegetable production, and is rather frequent in smaller fields in the region, but management problems have prevented it to become a commercial practice.

### c. Research needs

- the role of green manures as nitrogen sources and trap crops for nematodes in a field basis
- market information, which is largely unreliable for vegetable crops
- nitrogen transfer (expected N contribution to subsequent crops) of several crops, which has rarely been calculated
- intercropping of vegetable and other crops to increase resource use and lower pest, disease and weed intensity



## INTEGRATED NUTRIENT MANAGEMENT (INM)

### a. Definition

In INM most nutrients derive from organic waste and biological nitrogen fixation (through green manures and legume crops), and are supplemented, decreasingly in time, by chemical fertilisers. It supports MCR in achieving the TY and other multi-objective farm parameters by maintaining agronomically desired and ecologically acceptable nutrient reserves in the soil, and OSM by maintaining an appropriate OMAB. The general design involves the tuning of outputs and inputs of the major plant nutrients, based on the MCR, which will often need to be revised to attain a good balance with INM.

### b. Main characteristics in La Molina

Nitrogen will be the main limiting factor, since P and K contents are generally medium and can be maintained through a MCR and the addition of manure or composted crop residues. Nitrogen should increasingly come from biological fixation provided by green manures since vegetable legumes are generally poor fixers and manure is scarce. It can be foreseen that, in the first years of the conversion, the farm would still rely on chemical nitrogen. There is considerable expertise in the Department of Soils and Fertilisers to assist the design team in this respect (efficient use of fertilisers, biological nitrogen fixation, composting, vermicomposting, etc.), as well as laboratories and experimental facilities.

### c. Research needs

- the use of green manures in vegetable production, which has never been attempted on a commercial basis
- enhancement of vesicular-arbuscular micorrhiza as well as free-living nitrogen-fixing bacteria; research exchange with Cuba, a country with old expertise in these areas, would be highly desirable
- characterisation of all the crops candidates for MCR according to their major characteristics for preserving physico-chemical soil fertility
- techniques for the enhancement of earthworms



## ECOLOGICAL INFRASTRUCTURE MANAGEMENT (EIM)

### a. Definition

EIM should be designed to support MCR in achieving multi-objective farm parameters by providing a habitat for beneficials, a key point in this degraded environment. In addition, it should contribute to objectives in CD (through the enhancement of wild relatives of crops and the inclusion of several multi-purpose species in hedgerows and windbreaks) and health/well-being and nature/landscape objectives.

### b. Main characteristics in La Molina

The EI already existing is a good start, but it should be managed accordingly to the objectives of the farm system, and not simply left alone to grow and serve as border with other fields. An important limitation for EIM is the fact that several crop pests and pathogens are often found in the EI. It would be desirable that several of the plant species enhanced in the EI should have additional values like providing forage for small animals, habitat for bees, minor building materials or food like fruits and tender leaves. The role of plant diversity is widely recognised as reducing pest problems in smallholder agriculture, but this has seldom been acknowledged or researched in commercial farms like VCEF. EIM would perhaps be considered the most innovative method in the prototype of the new farming system.

### c. Research needs

- the effects of the annual alteration of EI caused by the removal of spontaneous vegetation in water canals, and the management techniques necessary to prevent negative effects
- selection of potential species based on their ability to provide refuge for beneficials and not for pests and pathogens
- selection of multi-purpose species
- determination of the role of birds in pest (including rodent) control and techniques to enhance their presence
- selection of plant species to improve the landscape value of the system (according to flowering, support of butterflies and others)

## MINIMUM SOIL CULTIVATION (MSC)

### a. Definition

MSC should be designed to assist MCR in achieving multi-objective crop and farm parameters by incorporating crop residues, controlling weeds and restoring physical soil fertility from compaction by machines, while at the same time contributing to OMAB and SSC, as well as other soil parameters.

### b. Main characteristics in La Molina

Most of the crop husbandry methods that can be mechanised are managed in such a way. This, however, is far from optimal and before every crop the soil is ploughed to a depth of 30 cm, affecting soil structure and favoring a reduction in SOM, as well as disturbing soil life. The discs that completely turn the soil would probably need to be replaced by other less disturbing implements, as well as big tractors by smaller ones to improve weed control. This method would require intense assistance from the Faculty of Agricultural Engineering, since techniques of conservation tillage have seldom been researched in vegetable production.

### c. Research needs

- techniques of conservation tillage to improve incorporation of crop residues, reduce soil disturbance, conserve water and control weeds successfully.
- integration of mechanisation and management techniques like mulching, intercropping or trellising
- improved tools and implements

## INTEGRATED CROP PROTECTION (ICP)

### a. Definition

ICP is a method to achieve the objectives quantified as PI, and additional to MCR and INM to sustain multi-objective farm parameters (NS, FE, EE, MY), that aims to selectively control harmful species with minimum exposure of the environment to pesticides. It should be viewed as a complement to EIM, MCR, INM and MSC in the management of pests, pathogens and weeds.



#### b. Main characteristics in La Molina

The extremely intense pest, disease and weed problems in La Molina would not allow for a drastic reduction in pesticide use in the beginning, but should progressively be replaced by a selection of pesticides based on EEP. The European network specifies the EEP for soil, water and air, and Kovach *et al* (1992) have provided a method to measure the environmental impact of common pesticides used in vegetable production.

Biological control is evident in some pests and would surely be encouraged by EIM and a selection of pesticides, along with the difficult task of establishing action thresholds. EIM should be careful in not encouraging species that may harbor virus and its vectors. Soil-borne diseases and nematodes should be addressed basically by MCR and INM. Weeds would be controlled mainly by MCR and MSC, but vegetables are sensitive crops in the first stages of growth and herbicides should be increasingly replaced by hand weeding, mulching, localised irrigation or innovative methods like flame weeding.

The Departments of Entomology and Phytopathology have a long tradition in IPM. Unfortunately, vegetable crops are not a priority but there is considerable expertise to assist the design team and some research is on its way. Good scouting, the availability of threshold levels for important pests and good selection of pesticides would already be a considerable improvement from the current situation if only the people needed could be brought together. Weed-free periods for several crops have been determined at VCEF, but in spite of this several innovative control measures are unknown.

#### c. Research needs

- improved application techniques to aid in the progressive reduction of pesticide use
- action thresholds
- botanical pesticides
- effective control of pests and diseases transmitted with vegetative seed
- several techniques of cultural control for specific pests and diseases.

## **FARM STRUCTURE OPTIMISATION (FSO)**

### **a. Definition**

FSO is considered as a finalising method to render an agronomically and economically optimised prototype economical optimum too, by determining the minimum amounts of land, labour and capital to achieve the multi-objective farm parameters (NS, FE, EE, WUE). In this way FSO supports the other 5 methods, and the design involves modelling by linear programming.

### **b. Main characteristics in La Molina**

FSO may contribute by providing tools to determine the need to scale up the investment in terms of labour, new machinery, new irrigation systems or improvements in the water reservoir, for example. In La Molina, contrary to the european network, a scaling up of the farm area would be undesirable because although it might be possible to negotiate land from other departments of UNALM, this would seriously limit the dissemination of the prototype at a later stage. Comparable farms in the region do not have the possibility to do so.

The Departments of Mathematics, of Economics and of Statistics would ideally provide experts to assist in this method

### **c. Research needs**

To be determined during the establishmnt of models and a reliable database and runs of the FSO model with different variants.

## **STEP 3 : The theoretical prototype**

A prototype is not ready until the methods are designed. However, they cannot be designed independently from each other and in arbitrary order, and should contribute to the major objectives within a consistent farming system and by mutual support (Vereijken,1995). Therefore, the way in which the methods are linked one to the other is presented here as a theoretical prototype, including the order in which they should better be designed (Figure 6). The major relationships between the different methods and parameters was considered in the definition of the methods.



A prototype is as flexible as the farm itself, and according to the european experience it will probably be necessary to adjust it as one proceeds into further steps of designing and testing. Here it is used only as a very first step to aid in the visualization of how the new farming system would be organised at the farm level.

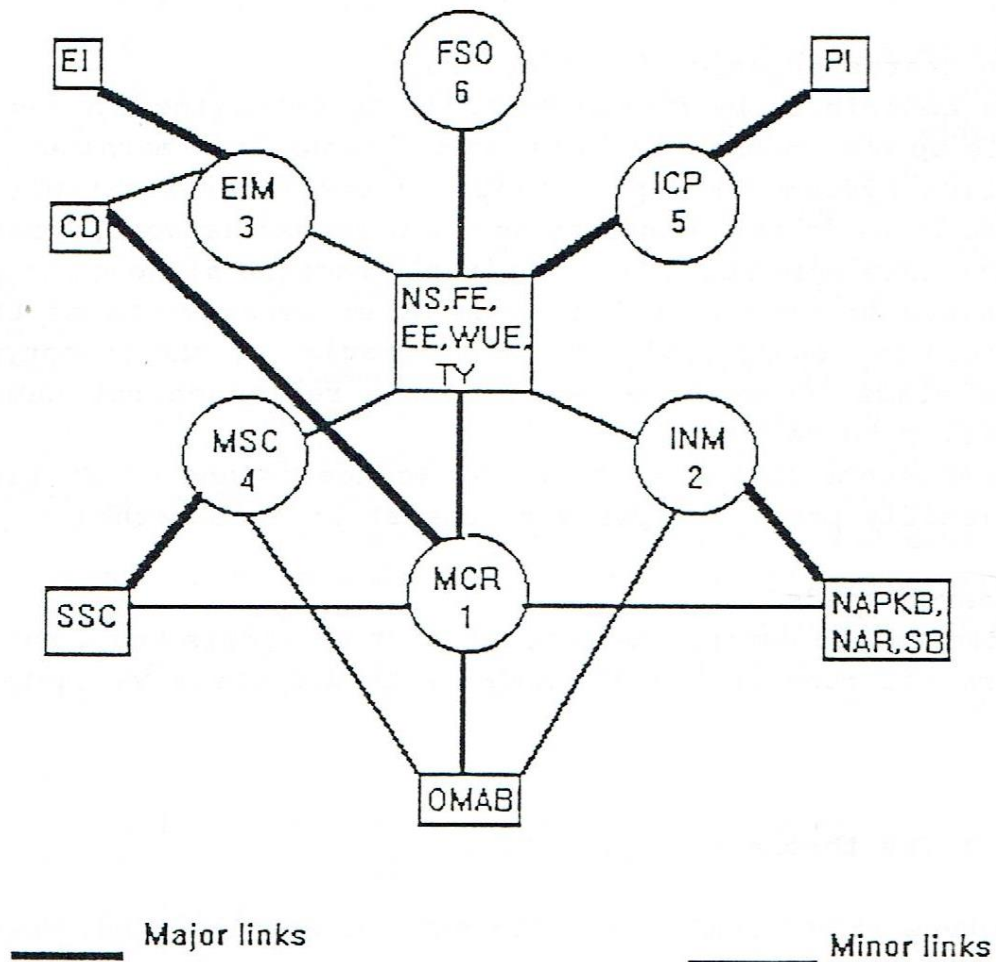


Figure 6. Basic theoretical prototype linking parameters (squares) and methods (circles) in La Molina, including the order of designing of the farming methods.

A prototype like this illustrates the relationships between farming methods in the new integrated design, stressing the need for interdisciplinarity. Conventional management acknowledges the relationships between farming techniques but fails to integrate, and evaluate, them accordingly.

The order in which the methods are to be designed is a result of this vision, although in reality progress is made simultaneously in various fronts. Crop rotation is the first and basic method to achieve major farm objectives, and the profitability of the system depends on the team of crops selected. For an essentially vegetable operation this is even more important because of the difficulties in the establishment of a proper rotation, in part because of the limited market for certain crops and the similarities of pests and diseases among them. Nutrient management differs considerably from the conventional approach in which the nutrient needs are determined for each crop and rarely for a whole rotation. For La Molina, in this respect, an important change will probably be the inclusion of non-vegetable crops in the rotation to adjust a proper nutrient management regime. Ecological infrastructure will be optimised probably in the long term but it should be managed from the start to provide refuge for beneficials and improve the landscape quality of the farm. Soil cultivation is important for weed control and to improve soil quality but, along with integrated crop protection, it complements the first three methods in several respects. Crop protection, in this integrated system, is not the basic method for pest, disease and weed control, but a complement in cases where the general design cannot account for specific problems, and will surely be adjusted in the course of designing and testing. Finally, farm structure optimisation is a general finalising method that will provide tools to determine the need to scale up the operation to render it ecologically and economically viable.



## VII ACTION PLAN TO START THE CONVERSION PROCESS

The recommendation drawn from this paper is to convert VCEF to an integrated system, with an ecosystem-oriented vision guiding long-term actions. The integrated vision allows for a progressive transition into more sustainable farming systems, something of particular relevance in La Molina because of the long tradition of conventional management, the lack of experience in comparable ecological farms, and the short term profitability requirements.

Barret (1985) has provided a problem-solving algorithm that takes an holistic and integrative approach to decision-making in real world resource management. Because of its clarity I shall use it (Figure 7) to discuss the first steps that would be necessary to start the conversion process through designing and prototyping.

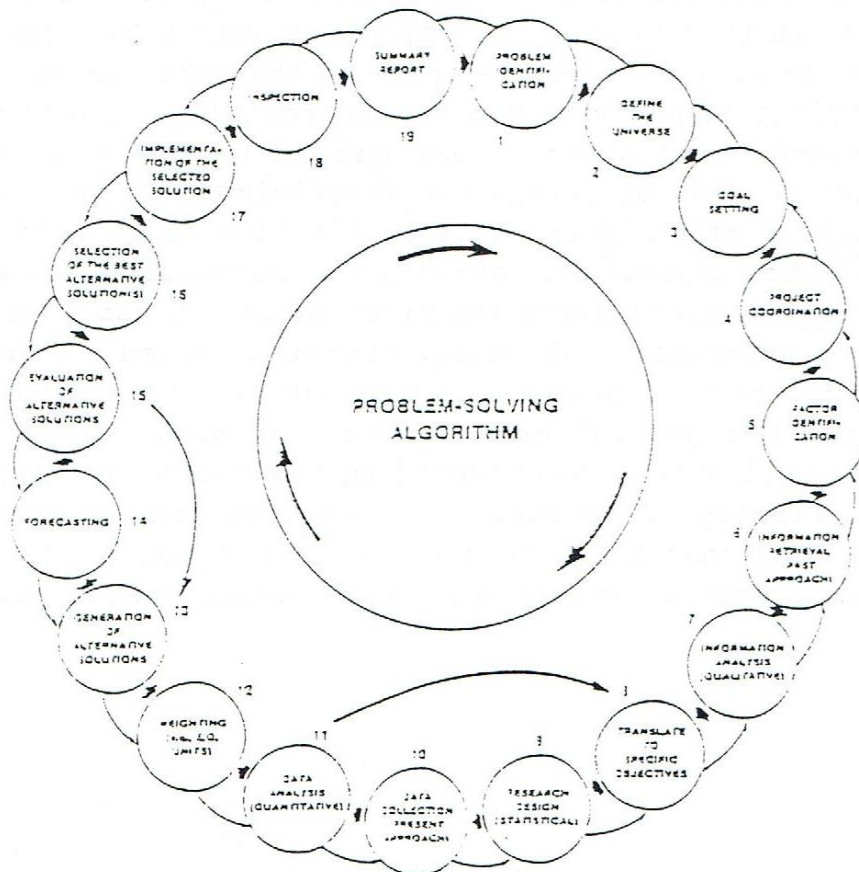


Figure 7. The 19-step problem-solving algorithm  
(Source: Barret, 1985)

#### Step 1. Problem identification

This step is one of the more difficult. The basic limitation in the identification of 'the problem' in VCEF is that the conventional agronomic wisdom views bad management and inefficient input use as the main factors affecting farm performance. To adequately identify the problem in VCEF the leaders of the university should allow creativity and innovation in the analysis and solution of problems from an integrative perspective, considering the possibility of opening a new door for research in integrated farming systems as a contribution to sustainability. Sustainability, of course, should be recognised by the leaders as a major long term goal, not just the profitability of a farm in the context of a highly distorted economy.

#### Step 2. Definition of the universe

In this case the immediate universe is VCEF, but for a consistent involvement of the research community, prototyping should be considered as a first step in a long process that starts with design and, in the final steps, considers testing and redesigning on actual farms. The universe should then be the region, the periurban vegetable sector in Lima.

#### Step 3. Goal setting

The short term goal is the development of an integrated farming system, as has been discussed in the previous section, as a short term compromise with long term ecological agriculture.

#### Step 4. Project coordination

A steering committee to coordinate the whole process should be assembled (the design team). This should ideally include, besides the present management of VCEF, members from other departments of UNALM. A starting point can be the 'Circle of Agroecology', an already existing discussion group that brings together specialists from different areas of agronomy and sciences like ecology, sociology, animal husbandry and forestry.

#### Step 5. Factor identification

The major factors affecting the present farming system, and those that may affect the conversion process, have been outlined in this report. In this step it is important to determine which factors, independently of the farming system, may also affect the results. A lack of financial reserves or of sufficient flexibility in the administrative procedures inside UNALM, for example, cannot be



accounted for in analysing system-specific characteristics.

Step 6. Information retrieval (past approach)

The purpose is to collect and catalogue existing research and practical information. Due to the innovative nature of the process proposed, this step is of great importance to assure the involvement of enough researchers, most of whom at the present time consider integration in farming systems as an ideal situation but lack sufficient information of experiences elsewhere in the world to consider them as practical alternatives. In this and the following steps a useful methodology would be the one proposed by Oomen and van Veluw (1994) for the analysis of mixed farming systems.

Step 7. Information analysis

In this step all important existing information that has been collected is reviewed by the steering committee.

Step 8. Translation to specific objectives

This step corresponds with the quantification of the major objectives in measurable terms in the methodic way.

Step 9. Designing additional research for statistical validity

In this step research is designed to collect relevant information when data are not available for a particular factor.

Step 10. Data collection (present approach)

New data needs to be collected if valid past data are lacking.

This can be considered as a necessary start, in spite of its redundant appearance. It follows in a way the methodology used to conceive a new farm prototype, and includes forecasting and the evaluation of alternative solutions if the main design proves incomplete or not adequate for the reality of the farm. The algorithm proposed by Barret (1985) can be useful in this process in UNALM, basically because it requires coherent analysis of existing information, one that requires interdisciplinary collaboration. So, after an initial thorough analysis of the present system, the research group can enter the methodic way as is suggested in this paper. In any case, it would probably necessary to repeat certain steps or go back in the process as new information becomes available and a new understanding emerges. Ideally, this paper could generate discussion in UNALM that may lead to a decision: the present farming system should be changed in an integrated and innovative way.



## VIII DISCUSSION

The search for sustainability is a worldwide process and several farmers and organisations in Latin America are struggling to find ways to integrate this vision into actual farming systems. Major universities, however, remain basically outside of this mainstream, except for individuals participating in several isolated projects. It can be said that in UNALM a minimum staff with knowledge of, and commitment for, integrated/ ecological farming systems already exists, with some of the pioneers still active in research and education. What is desperately needed is interdisciplinary work in the field.

The characteristics of an ecological farm remain far from full compliance in practice. In the particular case of periurban vegetable production in Perú, real integrated/ecological farms are non-existent. A review of the literature regarding the conversion process from conventional to low-input/ecological agriculture, although scarce, reveals common characteristics. There is often, for example, a yield decrease in the first years and some times a buildup of particular pests and diseases whose control relied heavily on chemicals. The review of literature of this report is clear enough in establishing the major tendencies of change during and after the conversion.

In the case of VCEF several reasons may justify a progressive transition. This can be implemented in two ways: part of the farm can be first turned into ecological farming, while the rest remains conventional; or the whole farm can be progressively turned into an integrated farming system, as a short term compromise, with the long term view of an ecological system. I consider the second option more realistic. Some of the reasons that justify this approach are:

- an intensive production system like this needs time to adapt, even when crops of a short-growing period and year-round cultivation will allow faster results than probably in temperate zones with one crop per year.
- the severe economic crisis that affects the performance of VCEF will not likely change dramatically in the beginning, unless sufficient funding is assured. This limitation will constrain the flexibility needed for a more drastic conversion.



- the management team still needs to be convinced of the feasibility of establishing an integrated system first, an ecological system afterwards.
- the organic market needs to be developed in order to allow consumers to pay premium prices for ecological products.
- soil organic matter reserves are low while manure is scarce and will be even more scarce in the future. For this reason a longer period will be required to achieve a desired balance in the soil.
- much information is needed about ecological processes at the farm level

In a way, the plan proposed follows the evolutionary approach of McRae *et al* (1990): it starts with increased efficiency but ends with an internal solution of problems by site- and time-specific management. As Gliessman (1987) has stated: "It is important that agronomists combine their extensive knowledge about the ecology and management of single species populations of crops with the ecologists' extensive knowledge of species interactions and community processes". Furthermore, intervention by science and technology in an integrated farm requires consideration of the whole system and the socio-economic and biophysical flows within and through the system (Edwards *et al*, 1993). All of these with the broader goal of developing the ability to quantify the ultimate emergent quality of the agroecosystem- its sustainability (Gliessman, 1987).

Integrated/ecological systems are based on the understanding of the interactions of the different components of an agroecosystem, such as a farm. For this purpose, agroecosystem analysis provides a valuable set of tools to analyse the performance of a particular system. Such analysis has been sketched in this paper and should be considerably refined once the decision to convert the farm is taken. Once done, the methodic way being tested in the european network for integrated/ecological farming system provides a rare methodology to get into the conversion with clear goals (quantified!) in mind and which serve as the standard against which the newly developed farming system should be tested.

In this paper the first three steps of the methodic way have been more or less outlined. It should be clear however that a complex process like this cannot be based on the ideas of one person. A basic pre-requisite is a clear understanding of the goals and particular objectives involved in the conversion; if this is not



clear for the design team as a whole from the beginning then it would be difficult to proceed and, most importantly, to adapt to the several constraints that will appear in time.

The methodic way can probably be challenged from several angles but it is flawless in the sense that the assessments are done against the objectives defined and quantified by the design team and not against some vague criteria or international standards of little relevance for local conditions. Of course the quantification remains a major issue but it should not impede the process from going on because in the course of the conversion new information may arise that will allow a refined quantification of some of the objectives that were inaccurately defined.

This is already an important improvement of the common situation in Latin America in which ecological projects often start the setting-up of farms or the conversion of farmers' fields taking into consideration ecological principles but without adequate quantification of the desired results. Progress is then, many times, made in the same conventional terms of profitability, or subjectivity dominates the procedure. Science cannot advance in this way.

This methodology should not be viewed as another technology imported from industrialised countries, or as a top-down approach that farmers will then be required to follow. Ecological principles are of universal application, and what is imported in this case is a methodology to interpret these principles in terms of the local characteristics of the environment where the farm is located, and taking into consideration that the objectives behind the process cannot be universally defined, neither in time nor in space.

Finally, enough expertise exists already in UNALM to attempt to implement a conversion process in VCEF. It will be a hard process, perhaps a long one, but if the university wants to offer long term solutions to the country it is obvious that the stress presently put on technological solutions cannot be maintained. Not only because technology alone has proved not to solve the problems of a large portion of farmers, perhaps the majority, but also because integrated systems are based on local resources and characteristics and makes use of external inputs if necessary. This will obviously increase the autonomy of farming from external influences and would be a step forward to a more real democracy.



For VCEF, which has been so active in promoting modern technologies and export crops, this is a good opportunity to show that it takes care for the interests of agriculture in general, and not mainly for the interests of those that can pay for research to be done. Education will also greatly benefit from an experience like the one proposed here, specially since students are increasingly coming from urban families, and these are the future agronomists that, if not used to integrating different aspects of reality in real farms, are more likely to pretend to solve problems applying purely technological measures. It should be said that students in UNALM are already a major force demanding changes.

Several of the considerations in this paper should be refined, and some added, by an interdisciplinary design team. Sustainability, moreover, cannot be confined to agronomic or ecological understanding. However, this paper can be considered as a first step that, if succesful, may induce progressive but sustainable changes in the way UNALM analyses agriculture at the farm level. Appropriate solutions can be found only if appropriate questions are asked.

## IX CONCLUSION

At this point it is possible to conclude that a conversion of VCEF into an integrated system is possible, based on information gathered in Perú and around the world and based on ecological principles. A methodic way has been followed and adaptations to the particular conditions of VCEF introduced. In this way, an ecological farm could be envisioned as a long term goal.

The final recommendation is to use this paper as a discussion document and to start the conversion process. Even if the process fails to be succesful, an unlikely event, the interdisciplinary endeavour will prove highly beneficial for UNALM.



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**APPENDIX 1 : GENERAL MATRIX FOR DEFINITION, ELABORATION AND  
EVALUATION OF FARMING VISIONS AND SYSTEMS**  
(Source: Vereijken, 1992)

Social values or interests involved	Parameters	Objectives of the 3 basic visions		
		world-market oriented	integrated	ecosystem- oriented
1 <i>Food supply</i>				
1.1 quantity	food/person in energy equivalents	-	WHO	WHO
1.2 quality				
- nutritional value	composition of single products in relation to a daily diet	-	WHO	WHO
- harmful compounds and micro-organisms	content of single products in relation to a daily diet	L	≥L	>L
- taste	appreciation by taste panells	S	S	S
- appearance and suitability for preservation and processing	various commercial and industrial standards of single products	S	S	S
1.3 stability	variation in yields (kg ha <sup>-1</sup> ) in relation to (inter)national food stocks	L	L	L and FAO
1.4 sustainability				
- soil fertility	content of air, water, nutrients, org. matter input/output of dry and organic matter	S	S	S
- climate	input/output of CO <sub>2</sub>	-	≠	≠
- non-renewable resources	input (non-solar)/output of energy	-	max.	max. and >
1.5 accessibility	input/output of phosphorus	-	min.	min. and <
	prices of single products in relation to a daily diet	L	L	S <sup>2</sup>
2 <i>Employment</i>				
2.1 at farm level	full-time workers/farm	min.	≠	≥
2.2 at regional and national level	full-timers in agriculture and related industries and services	-	S	S
3 <i>Basic income and profit</i>				
at farm, regional and national level	income/hired worker	L	≠L	≥L
	income/entrepreneur	max.	max.	≥L hired worker
4 <i>Abiotic environment</i>				
4.1 soil	emissions/ha of: persistent and accumulating compounds such as heavy metals and pesticides	L	≠L	>L
4.2 air	volatile compounds such as NH <sub>3</sub> and certain pesticides	L	≠L	>L
4.3 shallow and ground waters	mobile and persistent compounds such as nutrients and pesticides	L	≠L	>L
5 <i>Nature and landscape</i>				
5.1 flora and fauna	various indices of diversity	L <sup>3</sup>	max. <sup>4</sup>	max. <sup>4</sup>
5.2 landscape	nature and culture historical uniqueness functionalism (agriculture, nature recreation etc.)	-	S	S
6 <i>Health and well-being</i>				
6.1 health and well-being of animals	veteninary and ethological parameters	L	≠L	>L
6.2 health and well-being of humans	medical and sociopsychological parameters	L	≠L	>L

<sup>1</sup> Objectives: WHO and FAO is norms of the United Nations, stated by World Health Organization and Food and Agriculture Organization. (>) L and S is (better than) (inter)national Legal or System-specific norms towards certain values. Max. and min. is effort for maximal or minimal quantity or effect.

<sup>2</sup> Prices of products from ecosystem-oriented farming have to be higher than those of market-oriented farming, but a wholesome diet based on ecoproducts does not necessarily have to cost more than a conventional diet.

<sup>3</sup> Nature and landscape conservation are separated from agriculture.

<sup>4</sup> Nature and landscape conservation are integrated with agriculture.



## APPENDIX 2 : BRIEF DESCRIPTION OF THE VEGETABLE CROPS EXPERIMENTAL FARM

The peruvian coast is a narrow (40 - 150 km) strip of desert in western South America with an elevation of 0 to 500 masl; above 500 m the first ranges of the Andes start. In peruvian geographical terms the coast receives the name of *chala*, which in quechua and other local languages denote an environment characterised by the presence of stones, gravel and sand and the stational occurrence of fogs, which allow the growth of a typical vegetation type called *lomas* during the winter months. The central coast is also the most densely populated region in the country, and where the most intensive agriculture is practiced. As is common in Latin America, in the same region coexist a broad range of farmers, from small subsistence growers with a certain relation to urban markets to big export-oriented commercial enterprises. The most important crops are cotton, corn, potato, sweet potato, beans and a large variety of fruits and vegetables. The rather mild weather, however, allows the year-round cultivation of several tropical and temperate crops.

### Climate

The climate is arid and two main growing seasons are differentiated: winter (April-September) and summer (October-March). Average monthly temperatures range between 15°C and 25°C, with a minimum of 13°C and a maximum of 30°C. Relative humidity is lower in the summer months (70-80%) and higher in winter (80-90%). Monthly rainfall ranges from 0.0 mm to 1.5 mm. Solar radiation is high in summer but can be low in winter due to fog and a thick cloud cover. No catastrophic events (hurricanes, frost, floods) occur.

### Soils

The soils are of alluvial origin, with low content of organic matter and nitrogen, medium content of phosphorus and potassium, and low biological activity. pH is slightly alkaline and adequate for vegetable production. The soil has a good structure but aggregates crumble easily during tillage. Although some differences might be expected among different fields in the farm, a typical soil analysis is as follows:

Sand	: 58 %	OM	: 2.14 %
Clay	: 20 %	P	: 48.5 ppm
Silt	: 22 %	K <sub>2</sub> O	: 705 kg/ha
pH	: 7.2	CaCO <sub>3</sub>	: 4.47 %
CEC	: 13.2 meq/100g		
EC	: 1.7 dS/cm		

### Water

VCEF could not exist without irrigation. Water is becoming the main limiting factor as cycles of low rainfall in the Andes, as well as environmental degradation in the watershed, affect the amount of water brought down by the Rimac river. Most importantly, farms have to compete with the city of Lima because the same water is purified and used for home consumption. Water pollution is a cause of concern because of mining activities in the highlands and uncontrolled urbanisation. Groundwater in VCEF is deeper than 80 m and cannot be used for irrigation because it is expensive to extract it and, when available, it is used as potable water. Irrigation is accomplished by gravity (through open furrows) except for a small field where drip irrigation is practiced.

### Crops

Due to university's regulations VCEF is devoted to the experimentation and commercial production of vegetable crops. In the last years, however, some non-vegetables have been included: fodder corn, potato, sweet potato, dry beans and strawberry. The main vegetable crops are the following, bold type is used for the most abundant in the last years' rotations:

#### Winter crops

- ▶ Solanaceae : tomato, pepino (*Solanum muricatum*)
- ▶ Liliaceae : **asparagus** (seedlings)
- ▶ Cucurbitaceae : squash (*Cucurbita maxima*), **caigua** (*Cyclanthera pedata*)
- ▶ Brassicaceae : **cabbage** (red, chinese and green), **broccoli**, cauliflower, radish, turnip
- ▶ Fabaceae : snap bean, green pea, **green bean**
- ▶ Alliaceae : onion, garlic
- ▶ Asteraceae : **lettuce**
- ▶ Poaceae : **sweet corn**, baby corn



Summer crops

- ▶ Solanaceae : tomato, pepino, sweet and chili pepper
- ▶ Liliaceae : asparagus (seedlings)
- ▶ Cucurbitaceae : squash, caigua, cucumber, zuchinni,  
cantaloupe, watermelon
- ▶ Brassicaceae : cabbage, broccoli
- ▶ Fabaceae : lima bean (*Phaseolus lunatus*), snap bean
- ▶ Poaceae : sweet corn