THE ECOLOGY OF CROPPING SYSTEMS

G.R. Conway,

Multiple Cropping Project,

Chiang Mai University

Summary

Ecology and agriculture and closely linked topics. The important ecological concepts relevant to agriculture are productivity, stability and sustainability. In cropping systems these are affected both by the individual crops and by the interactions between the crops. Agricultural development concentrates first on increasing productivity, but we also have to consider stability and sustainability.

THE ECOLOGY OF CROPPING SYSTEMS

Gordon R. Conway*

Multiple Cropping Project

Faculty of Agriculture

University of Chiang Mai

I am by training both an agriculturalist and an ecologist. These subjects have always been closely related, both in theory and practice. The linkage can be seen most clearly in the study of traditional shifting cultivation systems (or swidden agriculture) such as is practised by the Lua' and Karen people in the lower part of the highlands of Northern Thailand. Under this system the farmers cut and burn the forest, grow rice or other crops for a year and then leave the land fallow to revert to forest for 6 or more years, before returning to cut, burn and cultivate again (Figure 1). Agriculture here fits into the natural pattern of ecological succession, and if such a system is to be understood and improved we need the insights and skills not only of agronomists and soil scientists, who focus on the rice growing phase of the cycle, but also of ecologists who can analyse how the vegetation succession in the fallow period restores the soil structure and fertility.

---

* On leave from the Centre for Environmental Technology, Imperial College of Science and Technology, London, SW7 1LU, England.

However, the close linkages between ecology and agriculture are equally present, if not so immediately obvious, in modern agriculture as exemplified by the sophisticated and complex cropping systems which are the subject of this symposium. In this paper I will try and illustrate how ecological knowledge, and in particular the concepts developed by modern ecology, can contribute to the understanding and improvement of cropping systems.

Agricultural Ecology.

Ecology is a discipline within the science of biology. We can see its position relative to other biological disciplines by visualising a simple hierarchy of life which represents successively more complex levels of organisation (Figure 2). Each individual biological discipline tends to focus on a different level in the hierarchy: genetics focuses primarily on the gene; cytology on the cell; physiology and behaviour on the whole organism or individual. The province of ecology is the three levels which lie above that of the organism, ie. the population, which is a collection of individuals in one place; the community, which is set of interacting populations, and the ecosystems, which is a community together with the physical and chemical elements on which it depends. If we now turn and look at the man made world of agriculture we can see a parallel hierarchy to which, in similar fashion, the agricultural disciplines can be related. But here, above the level of the individual plant or animal a range of disciplines substitutes for

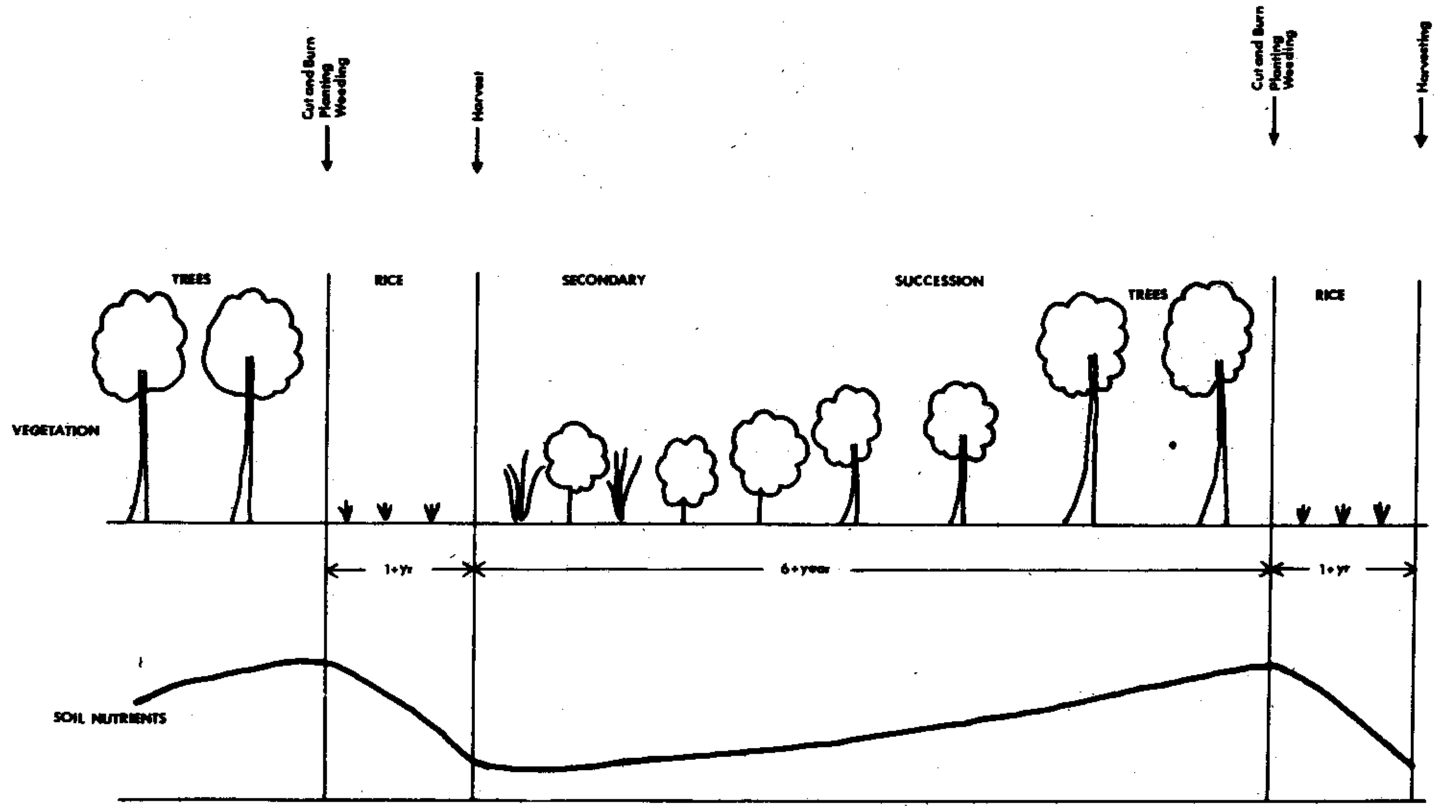


Figure 1. Swidden agriculture system of Lua' and karen in Northern Thailand

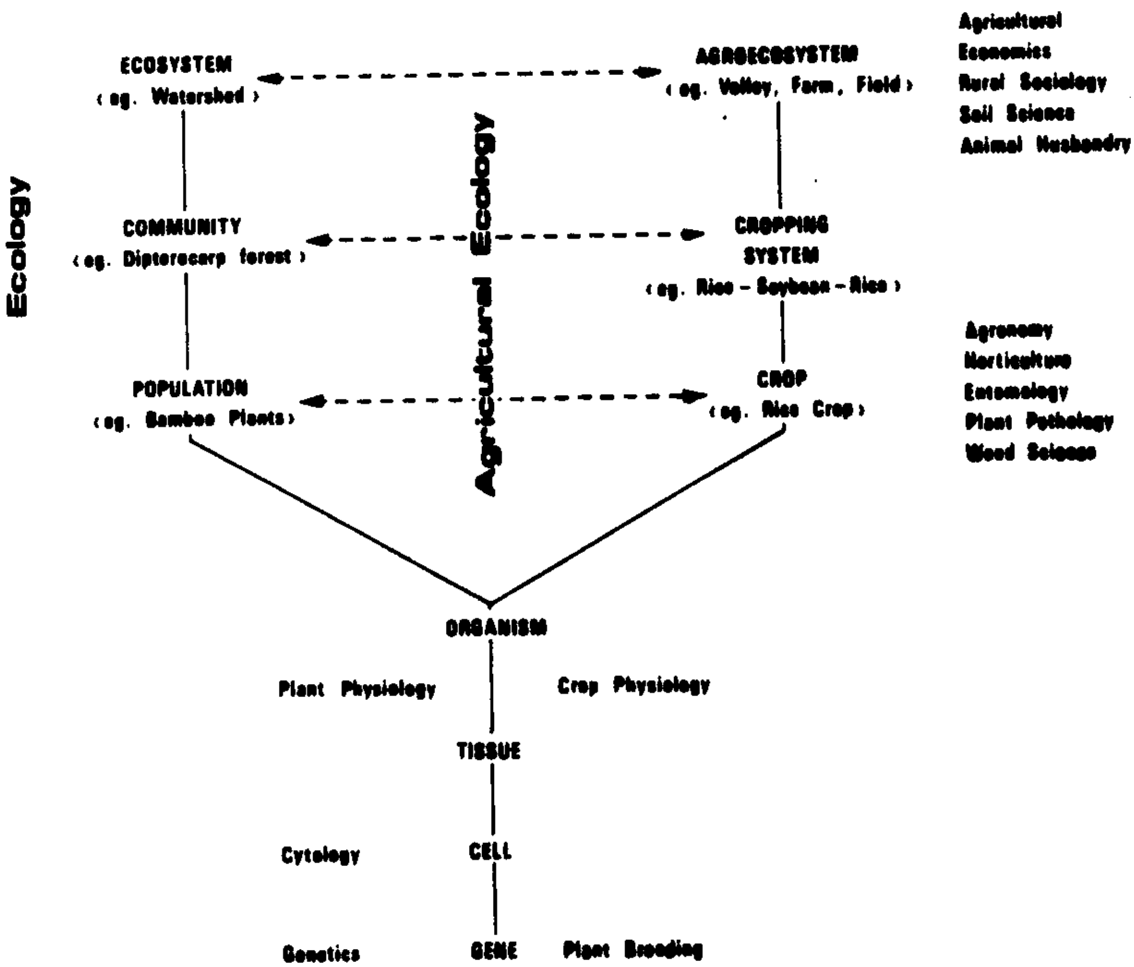


Figure 2. The hierarchies of Biology and Agriculture and their related disciplines

the single discipline of ecology. We can refer, of course, to all of these disciplines as "agricultural ecology." However I believe it will be more fruitful if instead we see agricultural ecology as a kind of bridge between the natural and agricultural hierarchies which serves to translate knowledge from one to the other.

The next question is : what is the important knowledge which should be translated in this way? Ecologists are concerned with a wide range of topics and not all of these are of relevance to agriculture. I have listed same examples of relevant ecological topics in Table 1. Unfortunately there is not time here to review all these topics. Instead I want to talk about some important ecological concepts which are basic to them all.

Productivity, Stability and Sustainability

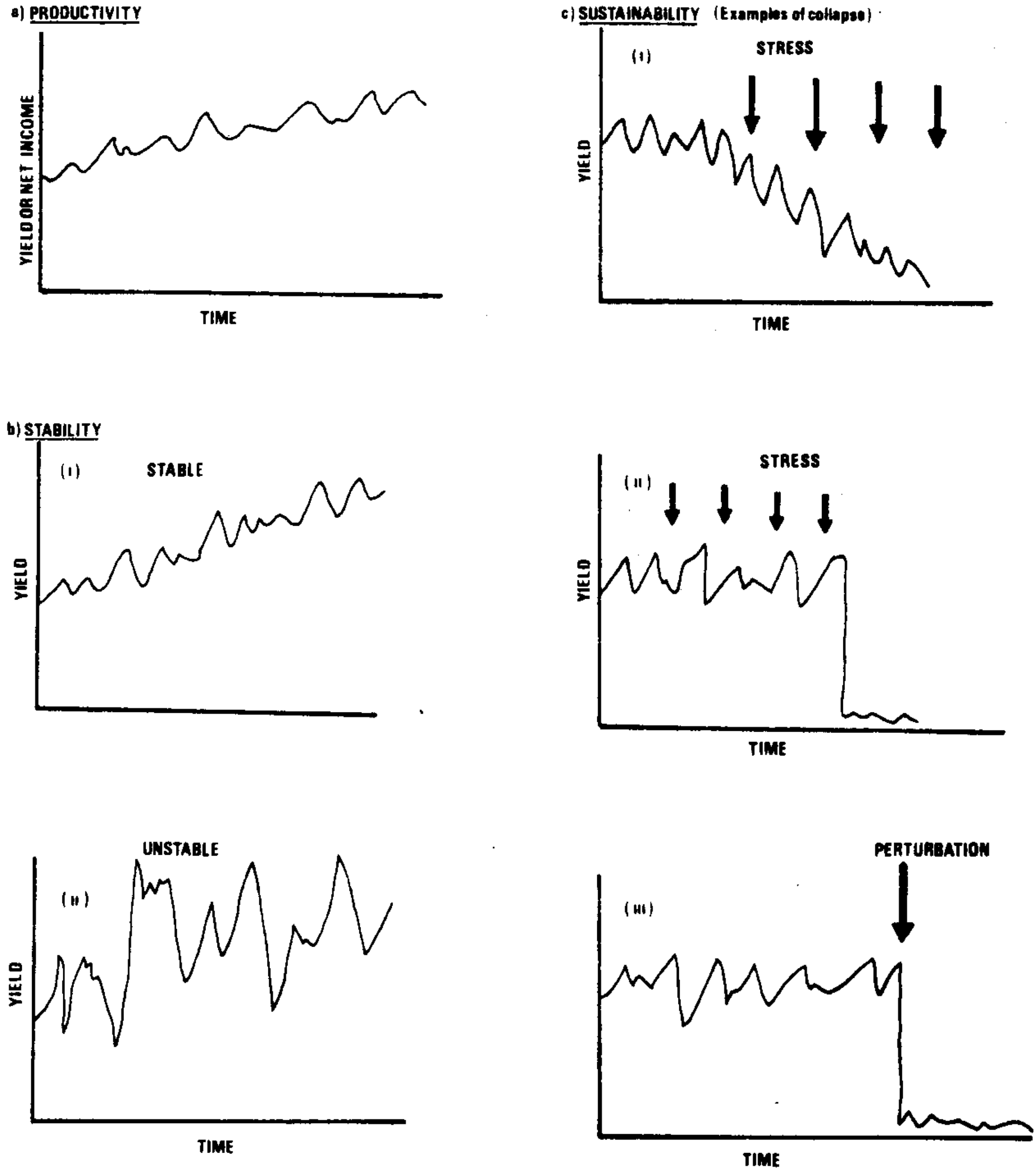
Ecologists studying the natural world are preoccupied with three important properties of ecological systems: productivity, stability and sustainability. These properties are present at all levels in the ecological hierarchy; that is, in populations, communities and ecosystems. In the natural world productivity and sustainability are selected for in evolution. Stability, however, has a more complex origin. It may or may not have selective advantage. These properties

Table 1. Agriculture disciplines and examples of ecological topics with which they are concerned.

AGRICULTURAL DISCIPLINE	Ecological Topics
AGRONOMY and HORTICULTURE	Crop competition
WEED SCIENCE	Crop-weed competition Weed ecology Biological control of weeds
AGRICULTURAL ENTOMOLOGY	Crop-pest interactions Insect ecology Biological control Integrated control
PLANT PATHOLOGY	Crop-disease interactions Disease epidemiology Biological control
PLANT BREEDING	Gene-environment interactions
SOIL SCIENCE	Soil ecology
ANNUAL HUSDANDRY	Livestock-vegetation interactions

are also present in agricultural systems, but have man selects for them and he may assign them different relative priorities at different stages in agricultural development. I will return to this point later. Let me first explain what is meant by these terms. They are all relatively easy to define but not equally easy to mersure. (Figure 3),

Figure 3 Illustation of the properties of agricultural systems



In the natural world productivity is simply the net increment in numbers or biomass. In agriculture it is the yield or net income. Stability is the degree of fluctuation in productivity produced by fluctuations in environmental factors, such as climate. It is most conveniently measured by the coefficient of variation in yield or net income. The third property, sustainability, is the ability of a system to persist in the face of repeated stress or a major perturbation. For example, can an agricultural system resist collapse if soil structure is deteriorating or if a new pest or disease suddenly appears? Unfortunately sustainability is not easy to measure. Although we can observe that a particular system has collapsed following a stress or perturbation it is difficult to determine how resistant a system is beforehand.

All of these are truly system properties. That is they arise because of unique interactions between the components of the system.

The are also inherently ecological properties, produced by ecological interactions and processes. For example, the yield of a field of rice is not the simple sum of the yields of individual rice plants grown alone, but is a complex outcome of the ecological process of competition for light, water and nutrients between the rice plants grown as a population in the field. Similarly, the stability of the yield of a rice field is a partly function of the interaction between the rice plants and their pests (the ecological process of herbivory) and this, in turn, is a function of the interaction between the rice pests and their natural enemies (the process of predation). Sustainability is also a system property but as yet we have little knowledge of the interactions and processes which produce it.

The Properties of Cropping Systems

As we can see the system properties of individual crops are complicated. The properties of cropping systems are even more complicated, yet I believe it is important that we try and understand them.

As an example let us look at a simple cropping system grown in several parts of the Chiang Mai Valley : traditional glutinous rice in the wet season, followed by soybean, followed by improved (RD) non-glutinous rice (Figure 4). Here the productivity, stability and sustainability of the system are functions of the behaviour, both of the individual crops and of the interactions between the crops, in relation to the various factors listed in the figure.

Let us take the behaviour of individual crops first (Table 2). For example, improved non-glutinous rice is potentially more productive than traditional glutinous rice when provided with high applications of fertiliser. However, the glutinous rice produces a better quality grain and also a useful crop of straw. The traditional rice, furthermore, is inherently more sustainable because of its evolved broader resistance to pests and disease. Soybean tends to be a more stable crop than non-glutinous rice because the price fluctuates less from year to year and

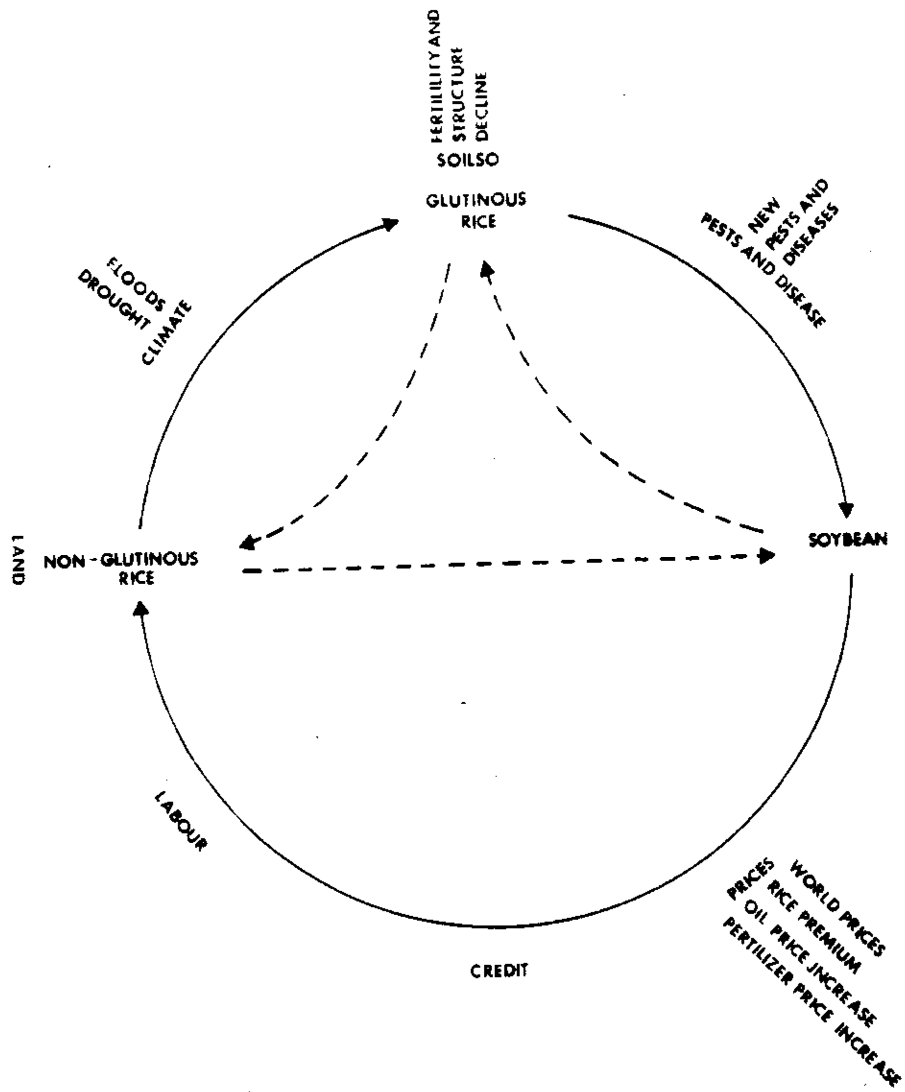


Figure 4 A cropping system showing factors which regularly affect it (inner circle) and examples of stresses and perturbations (onten circle)

Table 2. Factors contributing to the properties of component crops of a cropping system

	PRODUCTIVITY	STABILITY	SUSTAINABILITY
TRADITIONAL GLUTINOUS RICE	Poor user of high N High grain quality High straw yield	Withstands drought	Broad resistance to pest and diseases
SOYBEAN	Moderate yields	Stable yields Stable price Produces own N	Produces own N
INPROVED NON-GLUTINOUS RICE	Efficient user of high N Medium grain quality	Variable prices Dependant on good water control	Narrow resistance to pests and diseases

since it is able to produce its own nitrogen it is also less dependant on fluctuating input prices. This latter characteristic also gives soybean a high degree of sustainability.

If we now look at the interactions between crops we can see that the productivity of the cropping system as a whole may be increased by nutrient donation between the crops (Figure 5). It is also affected by the time of planting. Because soybean cannot be planted until after the end of the cold season the planting of both the subsequent rice crops is delayed. The wet season glutinous rice is thus harvested late when temperatures are lower, resulting in lower and less stable yields. Stability (Figure 9) of the system is also reduced by the influence of waterlogging on the soybean crop following the glutinous rice. However if the non-glutinous rice is adversely affected by drought the following glutinous crop may be able to compensate by utilising the unused nitrogen. Probably the most important contribution to sustainability (Figure 7) arises from the interaction of the crop sequence with soil fertility and structure. As yet we do not know the exact mechanism but there is evidence that different cropping systems have different effects on pH. In general legumes in the sequence help to restore the pH decline produced by irrigated rice (Figure 8)

As yet these diagrams are very tentative and incomplete. We need to examine a whole range of cropping systems and carefully map out the factors affecting their productivity, stability and sustainability in this way.

The Goals of Cropping System Development

Finally, I want to discuss the desirable goals of cropping system development. In general traditional agricultural systems, such as the shifting cultivation I referred to at the beginning, have low productivity and stability, but high sustainability (providing the

Figure 6 System interactions affecting porpuctiviti

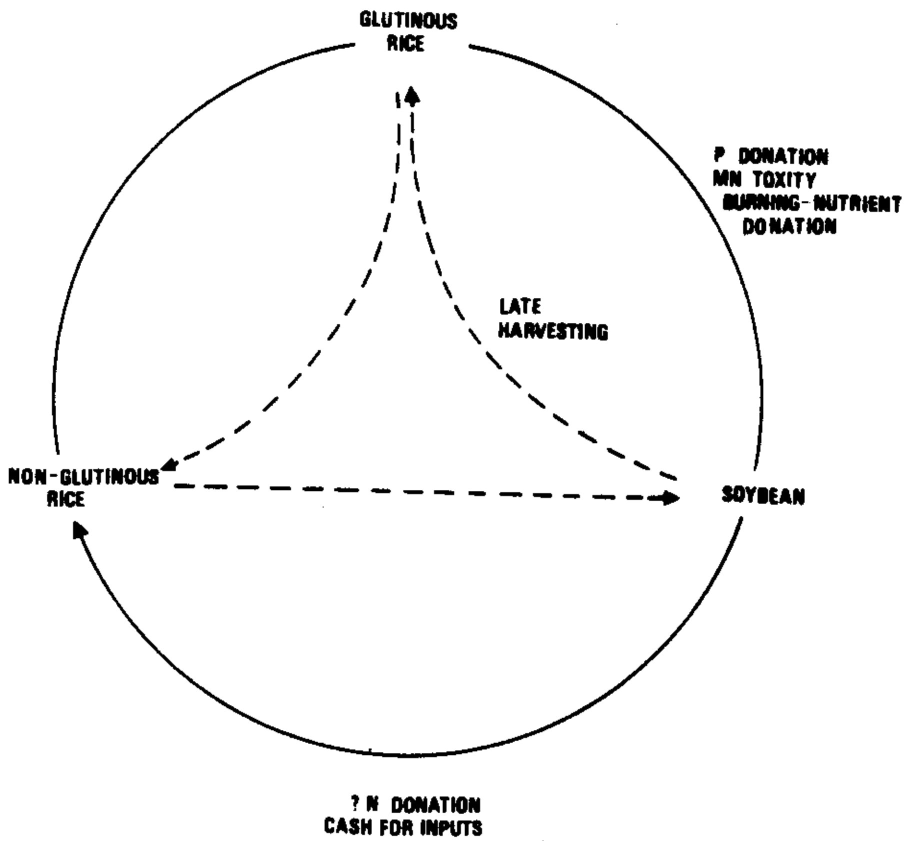


Figure 6 System interactions affecting stability

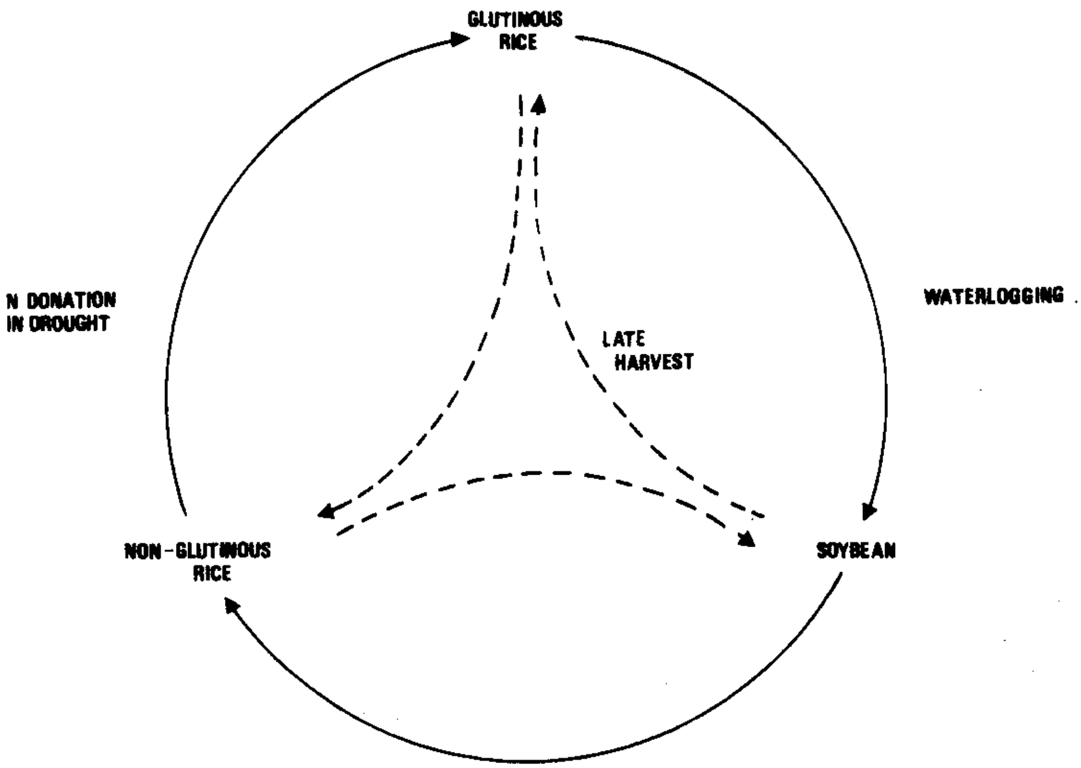
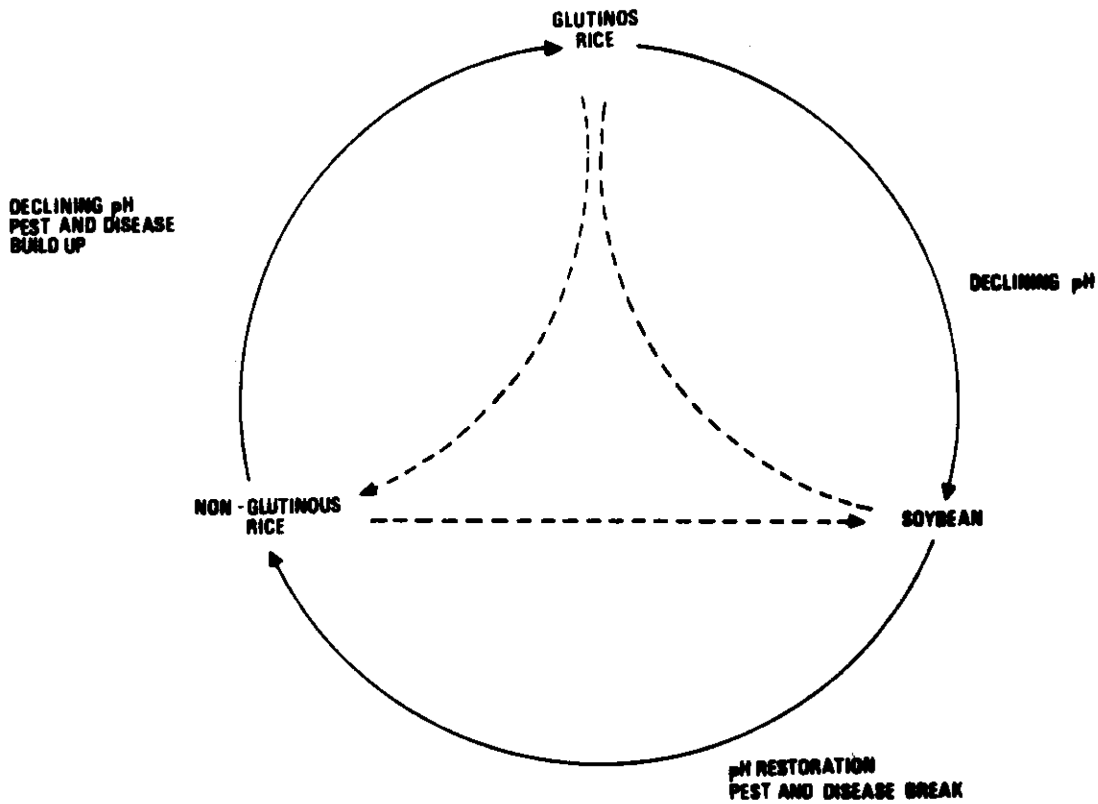


Figure 7 System interactions affecting sust ainability



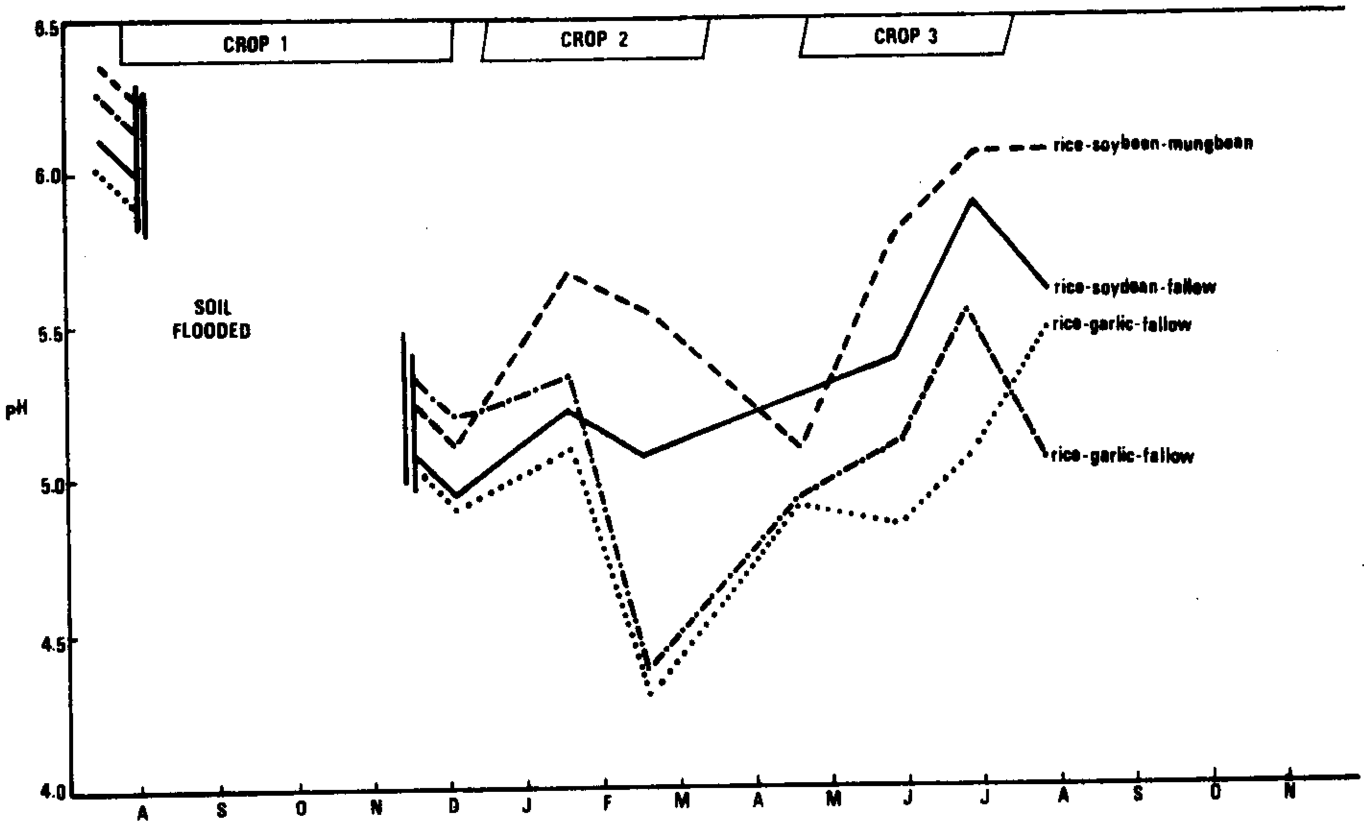


Figure 3.8 Fluctuation in soil acidity under four cropping systems
pH measured in 0.01 M $CaCl_2$ (1/5: w/v)
(Penchan and Rerkasem, Unpubl. data)

fallow period is kept long enough). Traditional cropping systems such as glutinous rice followed by soybean tend to be rather more productive and stable yet retain a high degree of sustainability (Table 2). However the introduction of new high yielding rices, while greatly increasing the productivity may also lead to lower stability and sustainability. This was particularly true of the introduction of the first IRRI rice varieties, such as IR8 and its relatives. Yields fluctuated widely but have tended to decline, in part due to growing pest and disease attack. Recent IRRI varieties such as IR36, IR42 and their relatives combine high productivity with high stability, particularly in variable rainfall conditions. But they have poor sustainability. These varieties are rapidly succumbing to tungro disease in the Philippines and Indonesia.

Ideally I believe we are looking for cropping systems which combine high productivity with high sustainability and in most circumstances these properties should have equal priority as development goals. However the desirability of high stability is more complex. High Stability may be incompatible with high sustainability. A cropping syetem which fluctuates to some extent is continually adapting to changes in different factors. Such continuous adaptation may help it to withstand long term stress or a major perturbation and hence promote high sustainability. As a development goal it thus seems wise to aim for high productivity, but moderate stability which will be coupled hopefully with high sustainability.

Table 3. Properties of cropping systems at different stages of agricultural development

	PRODUCTIVITY	STABILITY	SUSTAINABILITY
SHIFTING CULTIVATION (One year cultivation, 6+years fallow)	LOW	LOW	HIGH
TRADITIONAL CROPPING SYSTEM (Glutinous rice/soybean)	MEDIUM	MEDIUM	HIGH
IMPROVED SYSTEM (IR8 based)	HIGH	LOW	LOW
IMPROVED SYSTEM (IR36, IR42 based)	HIGH	HIGH	LOW
IDEAL SYSTEM	HIGH	MEDIUM	HIGH