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■ *Research Paper*

Evolution of Farming Systems and System Philosophy[a]

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Farming systems (FSs), and ways of thinking about them, evolved in space and time. Rapid evolution took place in the last two decades when crop and livestock yields increased, together with concerns about their socio-economic and biophysical trade-offs. The application of farming systems research (FSR) to agricultural development was a response to problems arising from a predominantly reductionist approach to research and a cornucopian view of external inputs. Modern technologies were either not welcome or caused unexpected negative trade-offs. This paper reviews definitions and forms of FSR and the need for evolution in thinking about agricultural development. Application of thermodynamic theory (TDT) to the study of farming systems influences discussion between cornucopians and conservationists, and between reductionist and holistic approaches to research. There is a need to recognize context (suitability of technology), and to pay more attention to relations within systems (system dynamics) and to defining criteria for sustainability. The paper links biophysical and socio-economic processes, gives a physical background for the anthropomorphic concepts of waste, and reviews aspects of objectivism and constructivism. It is argued that FSR can only advance if the full portent of these issues is considered in thinking about development of FSs. Copyright © 1999 John Wiley & Sons, Ltd.

Keywords context; relation; farming systems; philosophy; thermodynamics

INTRODUCTION

Farming systems and thinking about farming change continuously. These processes can be called the evolution of farming systems and system philosophy, if change is called evolution and if thinking about systems is called philosophy. Rapid change took place in the last two decades in both temperate and tropical regions in terms of yield per animal or plot, and in terms of input use. All over the world the grain yields went up at spectacular rates during the green revolution and individual levels of production in

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animals followed a similar trend (Alexandratos, 1995; Porcire and Rabbinge, 1997). Wheat yields in the UK and USA increased by 3 and 4 kg^{-1} ha^{-1} y^{-1} respectively until 1950, but after that they shot up by 50 and 70 respectively. Rice yields in Indonesia jumped from about 2000 to 4000 kg^{-1} ha^{-1} y^{-1} between 1967 and 1980 (De Wit *et al*., 1987). Animal production showed increases of similar magnitudes. Milk yields increased in the Netherlands, rising from less than 4000 in the 1960s to about 8000 kg cow^{-1} y^{-1} currently (Berentsen *et al*., 1997), a development that is matched in many other countries and animal species (Rerat and Cauchik, 1995). Thus, biophysical indicators of farm input and output patterns change, together with socio-economic and cultural–psychological characteristics of farms and societies. For example, the prices of inputs and outputs commonly change, together with reliance on external resources, farm size, farm ownership and the method of farming, often as a cause and result of increasing population pressures (Pretty, 1995; Giampietro *et al*., 1992; Alexandratos, 1995). Such changes in yield, prices and farming methods, within and between countries, constitute temporal and spatial evolution of farming systems. Also, they are triumphs (of sorts) for the mainly reductionist philosophies behind research, which focused on single commodities such as milk and grain (Bawden, 1991; Plucknett and Smith, 1982).

Satisfaction with the achievements of the reductionist focus on yields is justified, but it should not lead to complacency. In the first place, production of enough food does not imply proper distribution, and food exports do not imply a well-fed local population (Amartya Sen, 1981). Secondly, world population continues to rise, together with expectations about quality of consumption per person. In particular, the demand for food of animal origin and luxury foods is likely to increase (Alexandratos, 1995; De Haan *et al*., 1997). Thirdly, the grain breeding centres of the Coordinated Group of International Agricultural Research (CGIAR) recognized in the 1970s that their success has negative trade-offs (Plucknett and Smith, 1982). These trade-offs included negative socio-economic consequences from the largely biophysically and technocratically engineered green revolution on small farmers. Some small farmers were forced off their land because they did not apply the new technologies that led to lower prices and higher costs for inputs. Concern about social side effects was accompanied by concern about the limited acceptance of green revolution technology in remote and marginal areas. These issues were further compounded by environmental problems associated with increasing yields all over the world, such as declining water tables and soil fertility, and more reliance on agro-chemicals (WCED, 1987; Conway and Barbier, 1990).

The adoption of farming systems research (FSR) methodologies and philosophies primarily by the CGIAR institutes a few decades ago arose from an emerging awareness of the problems associated with technical successes in terms of yield increases. FSR was a typical product of an evolution in thinking, i.e. an evolution of philosophy about agricultural development, which consists of theoretical and more practical approaches (Byerlee *et al*., 1982; Simmonds, 1986). Although the theoretical roots of FSR lie in ecology and general system theory (Hart, 1982; Ison *et al*., 1997), apparently pressure from policy makers and farming communities for immediate results from FSR has fostered practical developments and procedures at the expense of the theoretical base to FSR.

The development orientation of FSR started mainly in tropical agriculture (Shaner *et al*., 1982; Norman and Gilbert, 1982; Simmonds, 1986; Norman *et al*., 1995), and in terms of key issues for this paper FSR originated as a response to the realization that:

- the green revolution technology was only useful in certain farming systems — an issue that we refer to by the term 'CONTEXT', and the phrase '*beauty is in the eye of the beholder*'; and
- the positive effects of technology were usually accompanied by negative and unexpected trade-offs — an issue that we refer to by the term 'RELATIONS' and the phrase '*ceteris imparibus*'.

FSR became important in temperate regions somewhat later than in the tropics (Gibon *et al*., 1996; Ison and Ampt, 1992) even though workers from temperate regions helped to develop the theory of (agricultural) system behaviour before development-oriented FSR caught on in the tropics (Von Bertalanffy, 1968; Checkland, 1972; Ison *et al*., 1997).

This paper discusses evolution of farming systems and system philosophy. It assumes that this evolution is the cause and/or result of issues such as increased population pressure, greater use of inputs and/or exhaustion of local resources, due to factors within and/or outside of agriculture (Hayami and Ruttan, 1985; Van Der Ploeg and Long, 1994). The paper does not elaborate on 'environmental' problems caused by modern agriculture and other sectors of society (WCED, 1987; Rerat and Kauchic, 1995; De Haan *et al*., 1997). Instead, we stress that the essence of these problems boils down to either mining of the environment in one place and/or eutrophication in other places, an issue that will be dealt with in this paper by using thermodynamic theory (TDT). We also stress that biophysical problems are likely to be associated with problems of social change and stress (Kaplan, 1994; Griffin, 1979; Van Haaften and Van De Vijver, 1997). This relation is often ignored in hard systems approaches but it is well recognized by soft systems approaches as stressed by many speakers in this conference.

The focus of this paper is the evolution of thinking about farming systems in terms of two points: first, the application of TDT to the study of farming systems in general; and second, the possibility of TDT offering an explanation for the existence of context and relations. It is proposed that an understanding of such theoretical issues can advance thinking/understanding about farming systems. The emphasis on TDT is justified because its principles may explain most general behaviour of systems. This approach implies that resources are finite, that waste is part and parcel of development, and that cornucopian world views, which were prevalent in mainstream thinking on agricultural development in past decades, need to be complemented if not replaced by more conservationist approaches. The occasional use of inverted commas challenges the paradigmatic use of terms, the parentheses around *farming* in farming systems indicates that system behaviour as described in this paper is hypothesized to be general rather than unique for agriculture.

WORKING DEFINITIONS AND ASSUMPTIONS

Change is called evolution in this paper, and it applies to changes in systems of farming and the way we think about them. Philosophy refers to reflection or thinking about the nature of things, in this case farming systems. Research is an activity that is done by formally trained 'scientists' as well as by farmers and extension workers, and FSR is a branch of science that encompasses a large range of activities as reviewed, among others, by Byerlee *et al*. (1982) and Simmonds (1986). All forms of what Simmonds calls the FSR *sensu latu* aim to better understand the functioning of farming systems. However, some forms are academic in nature (FSR *sensu strictu*), whereas others intend to design new farming systems (new farm system design), and the best-known form of FSR aims to quickly implement developmental actions in the field, hence the terms farming systems research and development (FSR&D).

A central tenet of this paper is that system approaches can be applied to systems in all sectors of society, as well as agriculture (Von Bertalanffy, 1967). Importantly, the use of a systems approach does not automatically imply the use of a holistic approach, and Checkland distinguishes between systematic and systemic approaches. The first implies the use of systematic procedures and the second implies the attention to holistic aspects of systems. Furthermore, the term system can imply different things such as a process, procedure or unit (Klir, 1991; Schiere, 1995). The current definitions of a system as a unit can be summarized for the first part of this paper as follows:

> A system is a limited part of reality with clearly defined boundaries, i.e. an arrangement of components or parts, that act as a

coherent whole with a common goal that interact according to some process to transform inputs into outputs.

This definition of a system as a unit combines a series of concepts from different workers. It deliberately exaggerates notions about boundaries and goals to help us describe the paradigms which currently underpin FSR and to stress the need for FSR to evolve to better cope with complex systems. Thus, the above definition is a stepping stone for discussion, which will be complemented by another definition that puts less emphasis on boundaries and goals.

The notion of clearly defined boundaries defines the boundaries to a system in such a way that the system is affected by its context, but not vice versa. This constraint was expressed by one of our 'reductionist' friends who stated that 'the boundaries are not well defined if the system affects its surroundings'. Whereas analysis of hard systems emphasizes the need for rigid boundaries, it is the soft systems methodology (SSM) that stresses the need for flexibility based on constructivist approaches to science (Checkland, 1972). SSM even questions whether a system exists as an objective entity. The definition of a boundary is further complicated when we realize that boundaries tend to be 'selectively' closed. For example, a boundary consisting of an aluminium sheet may be closed for atmospheric nitrogen and light but not for electricity and sound. Also, the boundary between two neighbouring farms may be relevant for the tax office but the neighbours may consider a road or a canal as a much more practical boundary.

The notion of a goal or purpose is pervasive in much system thinking. It originated in Aristotle's thinking where it was known by the Greek term 'telos', meaning 'goal' (Checkland, 1981; Klir, 1991; Bawden and Ison, 1992). The idea that subsystems work towards a common goal probably lends legitimacy to the reductionist philosophy which tends to assume that work on one part automatically benefits the whole. It may also be at the root of the often unspecified use of terminology such as progress and improvement. However, the very existence of a goal is a matter of debate if one accepts that the goal is 'in the eye of a cognitive agent' (Klir, 1991). In our view the question is not whether there is a goal or not, but that it is 'unrealistic' to assume that every subsystem strives for a common goal. Anyone who tries to raise a family, coach a football team or implement a policy will probably agree. Klir continues to say that 'a system may thus be viewed from the standpoint of different goals. It satisfies each of them to some degree'.

The last notion concerns the fact that in the above definition a system can be a physical unit such as a maize plant, a cow, a herd or a farm, as well as more abstract items such as political organizations, traditions or thought patterns (Odum, 1971). The distinction between biophysical and socio-psychological systems is reminiscent of the Cartesian distinction between body and soul, and between the naturalists and anti-naturalist (Luyten and Hoefnagel, 1995). The distinction is a matter of perception and Von Bertalanffy hoped, according to Checkland (1992), that ideas derived from the behaviour of organisms, which biologists had developed, could actually be applied to wholes of any kind. Philosophical systems can evolve therefore, just like animal species, companies or farms. We realize that mechanisms and manifestations of these evolutions differ, but we maintain that they have a fundamental common logic and behaviour that goes beyond accidental similarity (Odum, 1969, 1971; Cavalli-Sforza and Feldman, 1981).

(FARMING) SYSTEMS AND THERMODYNAMICS

Everyone in agriculture or business must sooner or later be struck by the similarity in behaviour that occurs across systems as divergent as, for example, nations, businesses, crops and cows in terms of output to input (Figure 1). Response surfaces may be linear or curvilinear, depending on the resolution and place or range of measurement, but the general pattern is that an increased input flux on the x-axis will first lead to increased output on the y-axis. Beyond a certain point, however, the increase declines and may even become a negative return to inputs. Importantly, the increased flux, i.e. resource flow per unit of time and space, is associated with a change in resources 'quality'. In animal production the flux can be maintained by low-quality resources on the lower end of the *x*-axis, e.g. straws, but an increased resource flow at the higher end is invariably associated with higher-quality resources. For example, the subsistence farmer and a rural village can operate on solar energy and biomass, but a 'modern green revolution farmer' and an industrial town need condensed fossil fuels and other high-quality resources (Nisanka and Misra, 1990a, 1990b; Giampietro *et al.*, 1992). The broken vertical line in Figure 1 indicates a point where, for example in agriculture, no fertilizer is given but where there is a rather hidden supply of nutrients from reserves within the system.

The general relationship between input and output in Figure 1 can be specified for the production of grass, milk or meat (Figure 2) and Figure 3 shows how the higher input flux for cows is associated with a shift in quality of input from straw and poorly digestible feeds towards concentrate feeds. The implication is that organisms such as cows can only yield a higher output on higher-resource flux feeds if the type of animal changes from native cows (such as Zebu cattle) to pure-bred dairy animals. Similarly, for a grass crop, the shift from low to high nutrient fluxes through applications of dung or fertilizer leads to a higher yield only if those higher fluxes are associated with more 'productive' varieties of grass.

The continued increase of output over input as in Figure 3 is a point of debate since many will argue, as we did in Figure 1, that the law of diminishing returns should operate. Figure 3 represents the heart of the argument by De Wit (1992) that continued linear responses to, for example nitrogen fertilizer, are associated with the use of 'improved' varieties, additional water or more nutrient etc. That argument implicitly acknowledges that diminishing returns exist if one sticks to one type of organism/system over a changing resource flux. Further, the argument ignores, in a typical reductionist fashion of considering only one resource, that the change in organism is only possible by an investment in

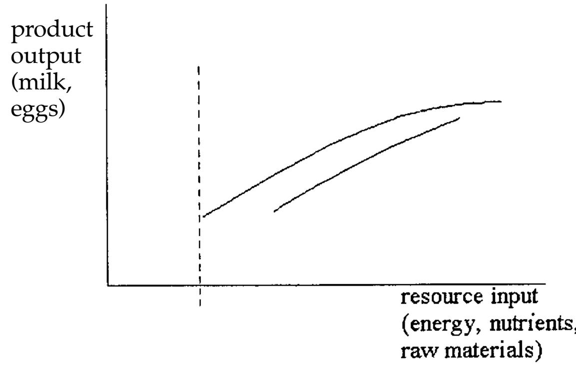

Figure 1. Generalized response of systems to increased input fluxes

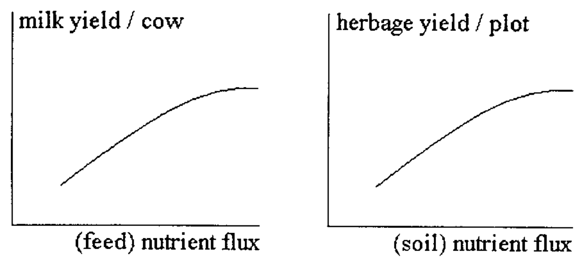

Figure 2. The effect of increasing resource fluxes from feed and soil nutrients on output from cows and grass respectively

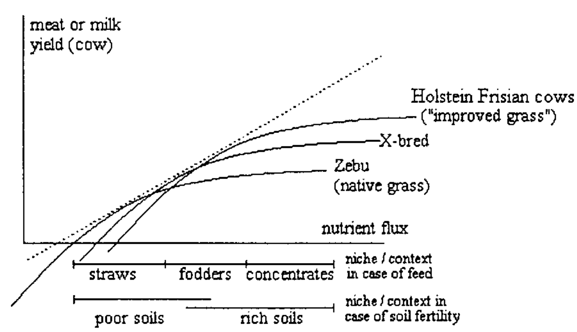

Figure 3. The aggregated response of different organisms to increased resources fluxes. Negative production (weight loss) may occur with inputs of very poor quality

other resources such as 'better' varieties or support systems, and higher use of chemicals or irrigation water. The point is that each flux (niche) has its own optimum organism, where optimum is defined as the tangents of the angle between the x axis and the dotted line in Figure 3. This makes it impossible to answer the generalized question 'which (farming) system is most efficient?'

The similarity in response to resource fluxes for systems ranging from cows, grass, societies and thought systems may not surprise everyone, but it is not widely recognized. We hypothesize that this similarity goes deep, and that it can be explained at least partly from TDT, a branch of science founded by people who helped to develop steam engines early in the nineteenth century. They noticed that 100% efficiency of energy conversion was impossible and they formulated two basic laws that hold today (Lyklema, 1991). The first law describes the conservation of energy as follows:

> Energy can neither be created nor destroyed as the sole outcome of a process; only the form of energy can change.

According to this law it is possible to change mechanical energy into heat, chemical energy into mechanical energy, and feed energy to energy in the form of dissipated heat and meat, milk, eggs, hides, draught etc. The second law, however, gives direction to the type of change that can be expected:

> Any system, if left on its own, tends towards a state of maximum entropy.

Entropy here is a measure of what, on a molecular scale, is called the degree of disorder, but macroscopically is called *the unavailable part of the energy*. Importantly, all resources are a form of energy — steel, rubber or even water in the tap or in an aquifer all represent a form of order. The implication of the second law is that all resources tend towards a higher degree of disorder, an academic description of the more popular term 'waste'. As a consequence of the first and second laws there is a need to distinguish between types of energy, and a need to acknowledge that waste is an inherent trade-off of development and resource use. Thus waste is an unavoidable, physical and quantifiable consequence of development. The amount of waste (unavailable resources!) can be reduced but not made zero. Natural systems solve waste problems by harbouring a variety of organisms, each with their own niche, that use and minimize waste. Conversely, specialization in modern farming increases specific outputs at the expense of increased waste (Giampietro, 1997). The basic logic of this tendency towards disorder is easily understood by using probabilities; i.e. it is more likely that a system tends to disorder than to order. It is also more likely for rubber, pottery, farms or steel to disintegrate rather than be formed spontaneously.

Three important issues for this paper in relation to TDT are as follows. First, why do unlikely systems exist if they tend towards high entropy when left on their own? Second, why do systems assume a specific shape and what should be done to keep them in shape? Keeping a system and its context in shape is basically the same as keeping/making a system sustainable! Third, are cornucopian development philosophies that rely on unrestricted supplies of energy for continued development of (farming) systems valid in the long term (Barnett and Morse, 1963)? We propose that such cornucopian views need to be balanced by conservationist approaches which stress the need to shape (agricultural) system development according to resource availability (Meadows *et al.*, 1972; Daly and Cobb, 1990).

The answer to the question about why systems exist at all lies in the fact that most systems are not closed; i.e. they are not left to their own devices. All farming systems and their components are basically open and they are ' fed', with energy in the form of solar radiation, labour or with nutrients such as fertilizers (Von Bertalanffy, 1967; Odum, 1971; Prigogine and Stengers, 1985). In turn these systems produce food, fibre, shelter, income and waste in the form of dissipated, unavailable energy. In simple words, but as a consequence of the second law, the throughput of energy/resources causes structure to develop in the system, while still leading to greater disorder in the surroundings (Atkins, 1984; Prigogine and Stengers, 1985). If the system is left without resources, it will collapse, and thus it is vital for the sustainability of a system to both maintain its resource base and not get choked in waste.

This relation between TDT, resource fluxes, maintenance requirements of a system and output levels was first explained to us by an ecologist (P. Elenbaas, personal communication 1994). He showed us that primitive prokaryotic blue algae require less energy for maintenance than more developed eukaryotic green algae. At higher fluxes, however, the green algae outperform the blue algae. TDT would support that a less likely system requires more energy for maintenance, but it allows that such a system outperforms its 'simpler relative' at higher fluxes. This 'algae' principle exists in many systems, e.g. in the difference between C3 and C4 grasses, between tropical and temperate cows, and for a range of organisms between protozoa and homoiotherms (Schiere, 1995). We hypothesize that this relation between resource flux and system output is generally valid and that it provides an explanation for the phenomena in Figure 1–3. The algae principle can also explain why Figure 3 consists of different curves, where the first curve is — somewhat metaphorically — the response by Zebu cattle, the second is the response by cross-bred cattle, and the third is the response by pure-bred cattle. Similarly, the Zebu and the pure-bred curves can be replaced by native and improved grass or even by curves for different sized companies.

The use of TDT has thus far led to the following important consequences for the understanding and handling of the evolution of farming systems and system thinking:

- Resources turn slowly but surely into less accessible forms; i.e. entropy increases. Neither matter nor energy is lost but it becomes less available. This fact may impact on our lifestyle sooner than the exhaustion of resources. It challenges the validity of cornucopian visions of development and it forces policy makers to adopt more conservationist approaches. It also gives a physical underpinning of the perception of waste and it might eventually allow quantification of this problem.
- Our thinking about resource shortage is put into a different light. We need to distinguish between types of energy and it is misleading to express different energy densities in one single unit. All 'fuels' cannot be used by all organisms, also since the energy is contained in different carriers: oil, straw, sugar, firewood (Mansson and Grade, 1993; Giampietro *et al.*, 1992).
- Agriculture may use only some 10% or less of the world's fossil energy (WCED, 1987) but it also uses other ordered resources such as water and soil fertility. Solar energy may eventually provide us with rather unlimited energy; however, the availability of usable (low-entropy) resources, water and space may eventually limit the continued development of agriculture. This also applies to other sectors of society, and evolution of current assessments of energy efficiencies is urgently required (Patterson, 1996).
- People and funders involved in the application of FSR should get to grips with the fact that order outside the boundaries must necessarily decrease; i.e. a system may be a limited part of reality but it necessarily affects its surroundings. This forces reductionist traditions to adopt more systemic approaches.
- Each organism performs most efficiently near its own unique flux range when efficiency is defined as the tangents of the angle of the dotted line in Figure 3; i.e. the ratio of output over input. The optimum flux range can be called both niche and context, and it is tempting but incorrect to compare 'average resource efficiency' of systems that occupy different niches.

CONTEXT AND CONSTRUCTIVISM

TDT provides a possible explanation for the fact that systems, ranging from cows and grass to farming systems, have their own niche. This concept from ecology lies at the basis of the choice of the first keyword on this paper, i.e. context, and it is defined by the respective resource flux. This context concept may apply to both the biophysical aspects of the farm systems and the socio-economic aspects of the family system. The link between biophysical and socio-economic factors underpinned the adoption of

FSR. As worded by Norman and Gilbert (1982); 'in most types of agriculture ... the unit of production and the farming household are intimately linked and cannot be separated'. They continue:

> the primary objective of FSR is to improve the well-being of individual farm families by increasing the overall productivity of the FS in the context of the entire range of private and societal goals, given the constraints and the potential imposed by the technical and human elements which determine the existing farming systems.

The concern about biophysical and socio-economic suitability of a technology led to the concern about context. It forced an evolution of development philosophy towards adoption of a system approach that defined recommendation domains (Byerlee *et al.*, 1982; Fresco and Westphal, 1988). Hitherto it was common to assume general validity of research results obtained under controlled conditions, which gave rise to development technologies consisting of a combination of inputs such as seeds, fertilization, extension, plant protection measures or irrigation, all designed to adjust the context to the technology.

Hereafter we refer to the issue of context with the words 'Beauty is in the eye of the beholder.' This is a useful metaphor because resource flux of soil type, the place in the valley or the distance to the main road determines whether a technology is useful, and also, suitability of a technology also depends on who looks at the matter and in which way. At a deeper level, it also depends on who defines the system and in which way, eventually challenging that a system as a unit exists at all or whether it is a mere construct (Chambers *et al.*, 1989; Ison *et al.*, 1997). This is illustrated in a figure that looks like a duck when seen from the right bottom corner, but like a rabbit when seen from the left bottom corner (Figure 4). The beak of the duck becomes the ears of the rabbit when shifting the point of view from right to left. The essence of the duck/rabbit drawing is also present in the question as to whether there is a difference between black and white, an answer to be defined by context. In daylight there is no doubt, but in the dark there is room for argument. Similarly, any number such as nine means little if it refers to dollars available to buy a house, but it is a lot if it refers to the number of children in a family. More serious differences in perception due to context and beholder occur when, for example, men and women are asked to make a map of their village (Figure 5). The problem can be solved partly with better definition, but physiological research has now shown that it is unlikely on biological grounds for different people to have the same perception (Maturana and Varela, 1987). Therefore, the issue at stake might evolve from how to best arrive at one objective truth towards how to cope with multiple realities. Jackson (1997) makes a significant point in this regard by stressing the need for pluralism. Significantly, the idea of pluralism implies that one should not argue about what is best — reductionism or holism — but about when reductionism is best and when holism (or the combination of the two) is best. Indeed, the context determines the validity of a philosophy, which, like technology, has its own niche in which they fit best.

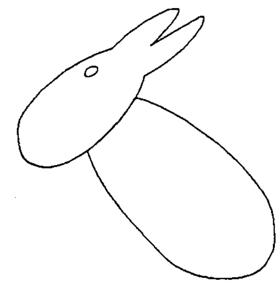

Figure 4. A drawing that represents both a rabbit or a duck depending on the point of view (based on Wittgenstein, 1934)

The implication of all this is that the suitability of a technology does not only depend on its niche and resource flux but also on who looks at it with which kind of interest. A case in point in the evolution of thinking about farming systems is the inclusion of gender issues in FSR methodology. It was found, for example, that women reject a technology if that implies more work and less income for them, or if the husband keeps the

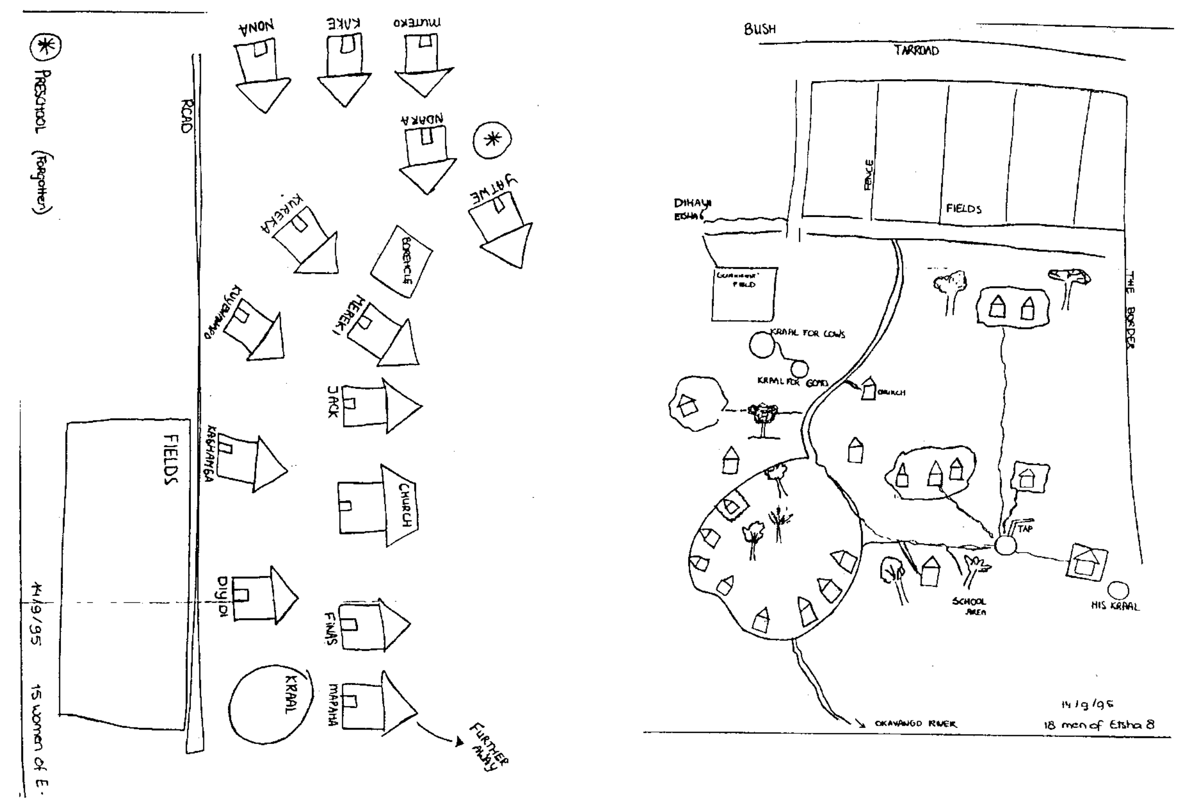

Figure 5. The map of a village in northwestern Botswana as drawn by women (left) and men (right) (Mestebeld and Snoeijen, 1996)

extra earnings for himself (Feldstein and Poats, 1989). The attention to gender issues is just one case of more generally prevalent differences in interest and perception between partners in society or agricultural development. Merchants and policy makers have different interests from farmers and so there are differences of interest between hierarchical levels in systems. This underscores the point and change of philosophy that subsystems do not necessarily work together as a 'coherent whole for a common goal'. In fact, they may have actually conflicting ideas and goals that converge and/or diverge depending on the context and the observer (Olsen, 1971; Schiere and Grasman, 1997). A similar tension is described to exist between the interest of subsistence farmers who tend to look at short-term survival on one hand, and FSR specialists on the other hand who look at long-term and overall sustainability at higher levels of system aggregation (Posner and Gilbert, 1991). In the same vein Conway (1985) proposed to use several criteria rather than one for agro-ecosystem analysis. The general validity of this insight is suggested by the work on issues of sustainability which attempts to define sustainability as a compromise between different interests (WCED, 1987; De Wit *et al.*, 1995). Furthermore, a growing set of methodologies has developed to cope with conflict of interest, using both quantitative and qualitative approaches as discussed during this conference and by, for example, Vereijken (1994) and Conway (1985).

The understanding that usefulness of a particular technology or intervention depends on its place, on the beholder and on several different criteria is a turning point in the evolution of system philosophy. It represents a shift towards constructivism, away from — or in addition to — objectivism (Roling, 1996). The issue at stake is the notion of one objective truth versus the notion of a socially constructed truth. The former is usually associated with the reductionist approach and the latter with a more systemic one. The acceptance of constructivism as commonly done in SSM requires in our view another definition of a system that might be framed as follows:

> a system is a construct with arbitrary boundaries for discourse about complex phenomena to emphasize wholeness, interrelationships and emergent properties. (Roling, 1994).

Further, both the definition of a system and the notion of a common goal were rephrased by Engel (1995) based on Checkland's work:

> a system has no goal, it is given one depending on the context and who looks at it.

Indeed, a cow has a different goal/purpose for a politician who wants to have cheap milk for export than for farmers who want to earn a living and who tend to see an inverse relationship between yield and price. Equally, a religion or philosophy has a different meaning for a believer than for an outsider.

The constructivist notion that 'everything depends on context and observer' is disconcerting for many of us from a predominantly reductionist tradition. De Boer (1985) expresses such discomfort:

> Formulation and execution of agricultural policy based on FSR is handicapped by its micro nature. At this level farming systems diversity becomes apparent and the researcher has difficulty coming up with general economic or agricultural policies that consistently produce the desired effect. Policy makers, on the other hand, desire policies that can be implemented with available instruments at the national or regional level. They don't like to hear the FSR specialist's plea that every farm is different, that government policies may have to be tailored for very specific regions or production systems and be implemented at the local level.

The possibility to see things from another angle, however, has also a comforting aspect. It allows planners and farmers to provide a purpose, rather than to fatalistically accept a given purpose. It also directs work in development provided one knows where and for whose interests one works. Modern FSR uses methods such as transects to establish which problems and opportunities are relevant in given agroecozones (Conway and Barbier, 1990; Chambers *et al.*, 1989).

Such a focus on context is a change in thinking from reductionist/objectivist, to holistic/constructivist measurement. It also challenges the validity of the basic notions of Descartes, who aimed

> to divide each of the difficulties under examination into as many parts as possible, and as might be necessary for its adequate solutions.
>
> to conduct [my] thoughts in such order that, by commencing with objects the simplest and easiest to know, I might ascend by little, and, as it were, step by step, to the knowledge of the more complex; assigning in thought a certain order even to those objects which in their own nature do not stand in a relation of antecedence and sequence. (Descartes, 1637)

Attention to context underpins the urge to establish classifications of farming systems (Ruthenberg, 1980; Nestel, 1984; Schiere, 1995). Unfortunately, however, even the usefulness of a classification depends on context and observer. Due to different points of view, classifications vary across disciplines such as economists, agronomists, maize breeders, animal production people, politicians and farmers. This is further complicated by the fact that the choice for classification criteria depends also on region and on place in the hierarchy. Moreover, any classification, like a technology or philosophy, may affect is own context and therefore its own validity. Reductionist approaches permit the temporary assumption that a system does not affect its surroundings, but TDT through the existence of relations implies that such an assumption has a fundamental flaw since any system affects its surroundings and context. All this requires an evolution towards a dynamic approach of system classification, the topic of the next section.

RELATIONS AND SYSTEM DYNAMICS

The assumption '*ceteris paribus*' is common in much agricultural research. It implies the notion also present in Descartes' statements that all other things remain equal while affecting change in only one point, or while understanding a detail separated from its context. *Ceteris paribus* epitomizes the reductionist approach that tests the usefulness and behaviour of an innovation by assuring that context remains the same. Sooner or later this type of research is likely to separate from reality when contexts tend to vary rather than remain constant. This Cartesian approach has helped and will continue to help in unravelling difficult problems, but there is an increasing awareness that 'things' do not operate or mean the same when they are isolated as when they are in a system. The concern about negative side effects is recognized in the statement that *a change in any one input (or, indeed, any part of a system) may affect any other part of the system, including its outputs and its resulting changed needs for other inputs* (Spedding, 1995). The recent focus on the need for testing newly developed technologies on variable farms is a typical example of an evolution in development thinking. It aims also to study the behaviour of an intervention in practical and varying contexts rather than only in controlled conditions (Norman *et al*., 1995).

The essence of interactions between systems and their environment can be captured with the second keyword of this paper, i.e. the term relation. Their existence follows from the two laws of TDT, and from the definition that states that a system transforms inputs into outputs. We proposed therefore to supplement the *ceteris paribus* assumption with that of *ceteris imparibus*. This assumes that the rest is changing due to an intervention, even if the other external factors such as politics and markets remain the same. The second law of TDT implies that side effects of (anthropocentric) development are likely to be towards disorder, i.e. towards increased waste disposal problems. It also implies that expectations about achievements of FSR to solve global problems will remain unrealistic if they consider negative trade-offs as accidental effects, and if they ignore the effect of systems on their own context. System behaviour is in essence dynamic and one may wonder, therefore, whether sustainability can be measured in terms that are static in space and time (De Wit *et al*., 1995). A major illusion about FSR has probably been that it was expected to provide a lasting static solution for systems that are, paradoxically, meant to grow/expand under assumed conditions of *ceteris paribus*.

There is, however, a case of relatively stable areas of system behaviour, which could make us think that nothing changes. The predator–prey relationship is a useful concept for discussing this aspect of system dynamics (Holling, 1973; Cohen and Stewart, 1994; Schiere and Grasman, 1997). The idea is that the number of prey animals (e.g. rabbits) can increase when the predator density is low. However, the number of predators (e.g. foxes) increases when the rabbits multiply to the point that the fox numbers grow so high that the number of rabbits declines, followed by a subsequent decline in fox numbers, a subsequent increase in rabbit numbers, and so on and so on. The foxes and rabbits affect and maintain their own context within certain maximum/minimum values where their numbers remain stable while fluctuating. Only when threshold values are exceeded is there a drastic change in the systems. By analogy (farming) systems with targets beyond threshold values invite collapse, and the setting of sustainability criteria might be seen in this sense as the setting of maximum values for development, a politically difficult but highly relevant issue.

The greenhouse effect and ozone layer depletion are global examples of system-induced context changes that need to be taken very seriously if society is serious about sustainability (WCED, 1987). Equally so, large-scale use of external inputs is starting to produce problems at a global level. On regional scales there are issues such as erosion/deforestation or problems such as a dairy industry that succumbs to its own success by flooding the market. In terms of crop production it is the green revolution that forced grain prices down to such an extent that small farmers were squeezed out of business (Griffin, 1979). On plot and plant scales the well-intentioned introduction of legumes for fixing of atmospheric nitrogen can lead to soil acidification. We consider systems to encompass biophysical and socio-economic aspects, and support the general notion that political chaos and psychological stress can also result from the interaction between systems and their context and the specific notion of resource depletion (Van Haaften and Van De Vijver, 1997; Kaplan, 1994).

The effect of systems on their own context causes an extra complication for those of us who are used to objectivist approaches and conditions of *ceteris paribus*. The existence of relations as explained by TDT leads to system dynamics which imply that what is useful today may not be useful at another point in space and time, an issue noticed among others by Maxwell (1986) and De Wit *et al*. (1995). Understandably, the original emphasis of FSR relied on quick results from so-called development-oriented forms of FSR, a remarkable change of development philosophy in the context of that time. One author (JBS) remembers how research managers used to oppose field research by saying that it was impossible to do 'real' agricultural research in variable conditions, a position epitomized by barbed wire and electric fences to keep out the neighbouring farmers. Furthermore, the growing awareness about the existence of system dynamics also implies that research should aim more at understanding processes rather than focus on static detail. It is tempting here to refer to the analogy between the difficulty of knowing both the position and the speed of an electron, also known as Heizenberg's uncertainty principle. (Prigogine and Stengers, 1985). The analogy may seem far-fetched, but it is not 'farther fetched' than the 'analogy' between a falling apple and the orbiting moon observed by Newton. The analogy is likely to exist due to so-called fractal behaviour of systems which shows that a phenomenon can occur at different levels of system hierarchy (Cohen and Stewart, 1994; G. De Zeeuw, personal communication, 1998). The real implication of the analogy is that FSR will lose insight in processes if it focuses on static detail, and vice versa. The practical use of space/time transects based on multiple perceptions of farmers and interdisciplinary researcher groups is an effort to get an idea about evolution and state of systems in space and time. The use of approaches and concepts such as predator–prey relation and attractors from the theory of non-linear system behaviour is likely to provide useful tools and methodologies to cope with the complexities of the study of system dynamics (Prigogine and Stengers, 1985; Gleick, 1987; Maxwell, 1986; Cohen and Stewart, 1994).

CONCLUSIONS

Form, function and philosophy of (farming) systems change, a process than can be called evolution (Grigg, 1974; Ruthenberg, 1980; Schiere, 1995). The rapid increase in yields from crop and animal production systems has been impressive, and credit is due to reductionist science that helped to bring it about. However, any system that is allowed to grow unchecked eventually affects its own context. Thus, traditional thinking about agricultural development had to necessarily face self induced change, such as socio-economic and biophysical disorder outside the systems being studied (WCED, 1987). The introduction of FSR as a set of methodologies to better understand and apply technical interventions was a leap in the evolution of system philosophy. Among others it helped to create awareness about the need for interdisciplinarity, context and relations (Conway and Barbier, 1990). The performance of FSR has been considerable, but less than expected. One reason for this disappointment lies in the unrealistic expectations which are largely based on cornucopian and reductionist paradigms. They overlooked the importance of the second law of TDT, which implies that any local increase in order necessitates a decrease in order elsewhere. This challenges the philosophy that the availability of energy resources is no restriction to continued development at the current rate and, more importantly, it inherently links the problem of waste production to development.

Concepts from TDT help to explain the notions of context and relations, which forced the international agricultural research and development agencies into accepting more holistic system approaches. These concepts provide new insights into the philosophy in development, such as the fact that waste and disorder are inherent properties of farming systems. Further, the scope increases when it is combined with new insights about the constructivist nature of science, and about the dynamic relations between systems and their contexts. For example, it recognizes that different actors in development have conflicting rather than common goals, even though there can be common goals at certain points in space and time (Olson, 1971). By stressing the importance of context it also helps to understand why different (development) paradigms and philosophies can be maintained. In other words, pluralistic and dualistic approaches imply that the question 'either/or' needs to be replaced by 'which combination of viewpoints'. The attention to context changes research questions from asking whether treatment/philosophy A is better than treatment/philosophy B into: 'When, where and for which observer is A better than B?' The combination of all this offers scope for increased collaboration and understanding between disciplines.

The move away from objectivism may be disconcerting at first but it allows us to more effectively cope with situations where conflicting interests abound. Also, once the context is defined, it is possible to give our work a new perspective and direction. The absence of a simple objective truth agrees with Kuhn's vision on the need to combine several paradigms rather than to use one single paradigm (Luyten and Hoefnagel, 1995). It implies an evolution in scientific teaching towards accepting several notions on what constitutes research, rather than teaching one form of 'true' research. Administrators, like scientists, have to accept the fact that generic rules and objectives may need to be replaced or complemented with system-specific objectives. Both industrial and agricultural practice has started to accept principles of tailor-made and floating objectives (Renting *et al*., 1994; Campbell, 1996; Roberts and Coutts, 1997). The setting of standard rules, regulations and criteria is further complicated by the fact that any system affects its own context (i.e. meaning and validity) if it exceeds boundary values, an issue that can be partially understood by non-linear system theory and constructivist approaches. The application of these new theoretical insights can help traditional, often reductionist research, to get out of a deadlock, challenged by the prospect of exciting new approaches in the evolution of farming systems and system philosophy.

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