MIXED CROP-LIVESTOCK SYSTEMS IN SEMI-ARID REGIONS

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ABSTRACT

Many forms of mixed farming exist, each with mixed blessings that differ between place and perceptions of stakeholders. Mixed blessings are a focal point of ancient and modern argument in tension between pastoralists and sedentary crop farmers, as well as between specialized and modern conservation farming. This chapter provides a framework to understand this variation. The first section explains terminology and it illustrates the variation between different mixed systems in relation with drivers like climate, input availability, culture and mindsets. After that a set of system classifications is shown, one of which is based on relative access to land, labor and capital as a guide for policy setting, research and teaching (Section 2). Concepts of modern system thinking are described to better understand the driving factors behind the emergence of mixed farming, also using arguments from ecology, psychology and thermodynamics (Section 3). The last two sections elaborate on what we call linear and non-linear issues in mixed crop-livestock farming. The linear ones relate to 'straightforward' aspects like food production from crops and animals on short term, issues of nutrient balances and use of crop residues for feed or mulch (Section 4). Non-linear issues relate to trade-offs and mode changes, crop choice that interacts with animal production and soil organic matter levels. They also relate to aspects of policy setting for regional development which reflect the notions that are important in understanding on-farm and between farm mixed systems (Section 5). The concluding comments set choices for farmers and policy makers on whether and how to encourage mixed farming (Section 6). The paper uses a variety of cases to stretch the imagination, based on notions from different forms of system thinking. It also uses both inductive and deductive approaches to hypothesize on how the variety of mixed systems behave according to changing drivers. In this way the paper provides a framework to better discuss the development of mixed farming and of sustainable development in agriculture and society.

Section 1: Introduction.

1.1. General

Various forms of mixed crop-livestock farming help people around the world to make a living, both in favorable and difficult environments. Crops tend to yield more energy and protein per unit land area than animals but nutritive value and income from animal produce tends to be higher than from crops (Crotty, 1980; Spedding, 1979). Livestock can also support cropping, e.g., by permitting wider crop rotations, managing risk, adding value to crop residues and grains, or supplying dung and/or draught power. Livestock is even essential for human survival in arid zones and cold mountain ranges where crops can hardly thrive. Inclusion of crops in livestock systems can help provide feed for animals in low input systems and recycle excess nutrients in high input systems. Mixed farming is thus relevant around the world for poor *and* wealthy countries. In this chapter we aim to explain the variation in mixed farming systems around the world. To do so, we use a large number of cases, rather than to focus on one or only a few. We also use a mix of inductive and deductive reasoning, including simple scenario studies. This chapter is not a guide on how to farm in specific areas since enough was written about that in the last decade or so (Dregne & Willis, 1983; Loomis & Connor, 1992; Pearson, 1992; Rowland, 1993; Devendra & Sevilla, 1995; Schiere & Kater, 2001).

Figure 1 generalizes changing functions and forms of the wide variation in mixed crop-livestock systems around the world. The diagram chooses 500 mm rain as a rather arbitrary point from which crops can start to grow. Crops can be grown at lower rainfalls, however, depending on rainfall distribution and evaporation and indeed, generalization is difficult. For example, Israel has situations of 250 mm average rainfall with -fertilized- wheat yields of 3500 kg/ha (13% moisture), and at some 500 mm in the Sahel one can expect some 3000 kg/ha of grain. The 1984-1999 mean wheat yield in the semi-arid southern Great Plains at Bushland (Texas) was approximately 1850 kg/ha using 190 mm mean seasonal precipitation that was augmented with 185 mm soil water stored during fallow (Baumhardt et al., 2000). And long-term (1968-1988) mean wheat yields in semiarid eastern Oregon were greater than 4100 kg/ha using approx. 510 mm water (Payne et al., 2001). Still, inclusion of areas with less than 500 mm annual rainfall implies reference to rangeland and pastoral systems with livestock only, at least in some regions.

In spite of difficulties in generalization Figure 1 illustrates the essence of this chapter to discern general logic in an initially confusing variation. That variation is conceived to originate from changing relations between mankind, crops, cultural settings and animals, according to what we call socio-cultural and bio-physical drivers such as cultural preferences, climate, soil types and prices. This introductory section sketches relevance, variation and “definitions” of mixed crop livestock systems. It also summarizes a generalized list of advantages and disadvantages in mixed systems.

1.2 Relevance and definitions of mixed systems.

Mixed farming is the largest category of agricultural systems in the world. It occurs where livestock serves to add value to crop products, to diversify crop rotations and/or help recycle nutrients, whether animals graze on communal and private lands, or in plantations such as coconut estates. Indeed, many farmers with little access to resources rely on mixed systems around the world (Powell et al., 1995; Murgueito, 2002; Schiere & Kater, 2001). And mixed farming also re-emerges in high input systems that have to recycle their resources, on farm *and* on regional level (NRC, 1989; Ho & Chan, 1998; Van Keulen & Schiere, 2004).

Mixed systems can combine crops and livestock to different degrees. On the livestock side, ruminants (cows, sheep or goats) provide added value by converting fibrous feeds like straws. Monogastrics (pigs and poultry) also provide cash income by converting by-products like from grain into high value foods, and/or by serving as saving account for subsistence farmers. Ruminants in feed lots as in the North American plains also provide income, but in that case the scale of mixing is large and inter-regional (Sections 2 and 3). Livestock keeping thus occurs in various forms and uses various strategies to survive in often difficult conditions, e.g. by adjusting herd size and/or animal type, as well by accepting temporary weight loss (Behnke et al., 1995). Also, crops cope with harsh conditions, e.g., by being drought-tolerant, deep-rooting, quick maturing or otherwise adapted. The combination of livestock and crops can thus result in an even wider range of systems, but this chapter shows that variation repeats itself, i.e., there is a limited number of basic forms. This allows farmers, researchers and or business men to learn from each other in seemingly different situations.

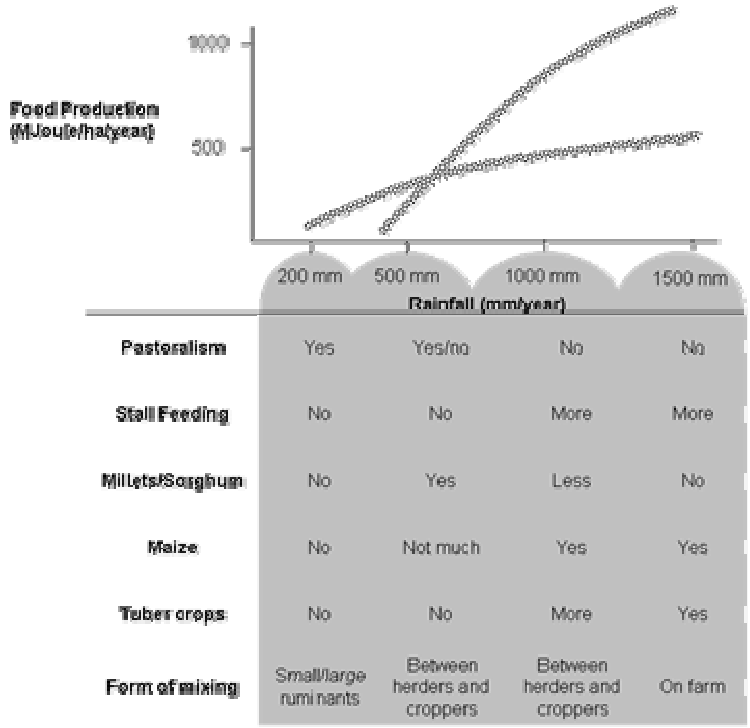


Figure 1. Approximate number of people that can be fed from livestock (shallow curve) and crops (steeper curve) in conditions ranging from very arid to more humid (based on Jahnke, 1982 and Spedding, 1979).

In terms of 'area-wise' relevance, mixed systems cover about 2.5 billion ha of land, of which 1.1 billion ha are arable rain-fed cropland, 0.2 billion ha are irrigated cropland and 1.2 billion ha are grassland. In terms of total contribution of mixed systems to world food supply one can first look at food supply from crops and animals separately. In that sense, the role of grains and tubers from mixed systems in the world food supply is shown in Table 1. And mixed systems contribute to world livestock products with just over 50% of the meat and 90% of the milk currently consumed (CAST, 1999). About half the meat and milk produced in these systems comes from countries of the Organization of Economic Co-operation and Development (OECD), Central Europe and the former Soviet Union. The remainder comes from the developing world. Second, one can look at mixed systems in terms of socio-economic importance. In that sense, about two-thirds of the rural poor rely on mixed systems for their livelihoods (ILRI, 2000). Such data indicate the relevance of parts of the mixed system. However, we stress that it is impossible to quantify the importance of parts if the whole is more than the sum of the parts. Interactions between the livestock- and crop- 'component' in aspects such as soil fertility, feed supply, socio-cultural dynamics of rural societies and livelihood require a 'mixed-systems-paradigm' rather than focus on parts (Sections 4 and 5).

Year = 2002	Production kg / per capita	MJ/kg*	MJ per capita	Percent of energy
Cereals	327	143.8	4910	532.7%
Roots	112	4	446	5%
Sugar crops	254	4	1020	10.9%
Pulses	9	18	163	1.8%
Nuts	1	30	43	0.5%
Oilseeds	87	25	2160	23.2%
Vegetables	112	2	223	2.4%
Stone fruits	49	4	197	2.1%
Berries	1	3	3	0.0%
Tropical fruits	44	3	131	1.4%
Spice	1	15	14	0.1%

Table 1. The contribution of crops from mixed farming systems to world food supply (FAOSTAT database 2002: http://apps1.fao.org ,dated 2004-2-1). MJ / kg is a measure of the energy in the edible part per kg of foodstuff.

1.3. Definitions.

Variation of crop livestock systems makes definition of mixed systems difficult, needed and counterproductive at the same time. Definitions can be given, but varying rainfall patterns, evaporation and soil types makes them often less than useful for local use. This was already apparent in the discussion on generalization in figure 1. In addition, there is a problem of "semantics", i.e., confusion on terminology between countries and scientific traditions when discussing mixed systems around the world. The term "mixed systems" is used by many people for mixed crop-livestock farming. Others, however, take it to imply a "hodgepodge", thus not doing justice to the intricacies of the systems. Also the terms "dry", "semi-arid" or "rain-fed" are confusing to say the least. People from dry regions can consider rain-fed agriculture to belong in high rainfall areas of Ireland or north eastern India. The distribution of rainfall within and between years adds to the complexities of definition (Fig 2), aggravated by differences in socio-cultural or economic access to irrigation or stored water.

We therefore characterize rather than define 'mixing' and 'semi-arid regions'. This is to stress that variation is rule rather than exception. Characterization versus definition is also the, perhaps, unconventional essence of this chapter that states that variation is better understood by expanding rather than by narrowing the focus (Section 3). Indeed, many definitions can be given for mixed farming, including fifteen listed by Sumberg (1998) alone, and more can be added (Ruthenberg, 1980; Sere & Steinfeld; 1996). We characterize mixed systems for this chapter as:

> *Aggregates of more or less interconnected subsystems; mainly livestock and crops, managed by a farmer (man or woman), a family and/or community, operating at farm, local or (inter)-regional scales, and deriving economic, social and/or agro-ecological advantages from the interactions between subsystems.*

Farming in dry and semi-arid regions is characterized as:

> *The type of agriculture requiring cropping practices that include adaptations to soil water deficiency during the growing season. These areas are in the semiarid and sub-humid climatic zones shown on the UNESCO map of the arid regions of the world* (UNESCO, 1979; quoted by Dregne & Willis (1983).

1.4 General contexts of mixed farming in dry regions

We stress that all systems are interrelated and mixed systems are therefore related with the 'outside' world. In this sense, we emphasize that much mixed crop livestock farming occurs in a context where perhaps most of the teaching, research and policy setting tends to specialization, at least until recently. Such single focus on either crops or livestock in specialized systems is associated with mainstream reductionist mindsets that tend to look at parts rather than wholes (Section 3). Unfortunately, the latter also tends to carry a notion of being modern and efficient. Specialization had advantages, but overspecialization also has its negative trade-offs (NRC, 1989; Durning & Brough, 1991; De Haan et al., 1997).

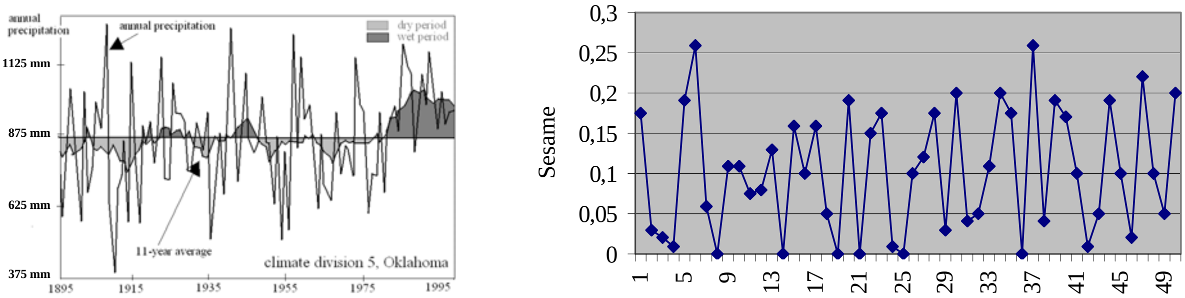


Figure 2. Variation of annual precipitation (left) in the 20th century for the Central Oklahoma Climate Division in region 6 (Source Garbrecht & Schneider, 2000); and crop-yields in Syria (based on .....).

The choice for or against mixed farming depends largely on what we here call "drivers". These drivers are exogenous and endogenous biophysical factors like climate, population pressure, market prices and soil types. They also are socio-cultural factors as mindsets and perceptions (paradigms) of farmers, think-tanks, consumers and teachers or researchers. The stress on socio-cultural aspects in this chapter implies explicit attention to the notion of mindset (= paradigm). Indeed, even quite similar information can lead to contrasting policies, depending on such perceptions and mindsets. For example:

- The context of global warming induces some to say that there is no need to change farm practice because agriculture will collapse anyway, or because they fail to see long term trends. Others use the same information to stress the need for new approaches, cropping patterns or even mindsets.
- The context of growing population pressure leads, according to some schools to improved farming methods (Boserup, 1965). Others, however, interpret the same information as reflecting pending 'collapse' of predator-prey relations and adaptive cycles (Section 3).

In terms of attitude, this chapter particularly distinguishes between cornucopian mindsets on the one hand, suggesting that higher population density can be compensated with more and/or better use of inputs. Conservationists on the other hand stress the need for stewardship.

This chapter emphasizes that biophysical and socio-cultural drivers together form the context. Price, soil type, rains, temperature, motivation, attitude and culture "drive" the system into certain "modes" (Section 2). At the same time, the farming systems themselves affect the context, e.g., the construction of a road provides a context that makes it easier to buy inputs, which in turn can lead to choices for crops and animals that can exhaust water aquifers or unduly increase soil nutrient status, which again drives the system to other modes. This interaction of context and farming system is called co-evolution, a notion from system ecology and complex system thinking explained in sections 2 and 3.

This chapter further considers policy setting concerned with the shaping of context, i.e. policy can both promote and discourage mixed farming. Therefore, examples of the interaction between system drivers and mode of farming are now shown, to provide initial clues for policy makers and farmers on how, when and where to aim for which kind of mixed farming (Section 5). The following paragraphs also intend to give a first glance at the variation *and* similarity in mixed systems around the world.

1.4.1 Crop-livestock farming and climatic factors in the US plains.

Mixed crop-livestock systems represent a range of farm production alternatives that have climate as a driver throughout the southern Great Plains of the USA, e.g. parts of southern Kansas, eastern Colorado and New Mexico, and the Oklahoma and Texas panhandles (Thelin and Pike, 1991). Precipitation, the primary 'driver' in the southern Great Plains decreases from east with approximately 900 mm near central Oklahoma to west with <400 mm in eastern New Mexico, but it varies little from north to south (Fig. 3). Much of that precipitation occurs during the summer, to the benefit of grainfill by winter cereals near Kansas; however, a pronounced bi-modal (spring and fall) precipitation pattern in Texas may enable establishment of summer and fall crops for forage (Baumhardt & Lascano, 1999).

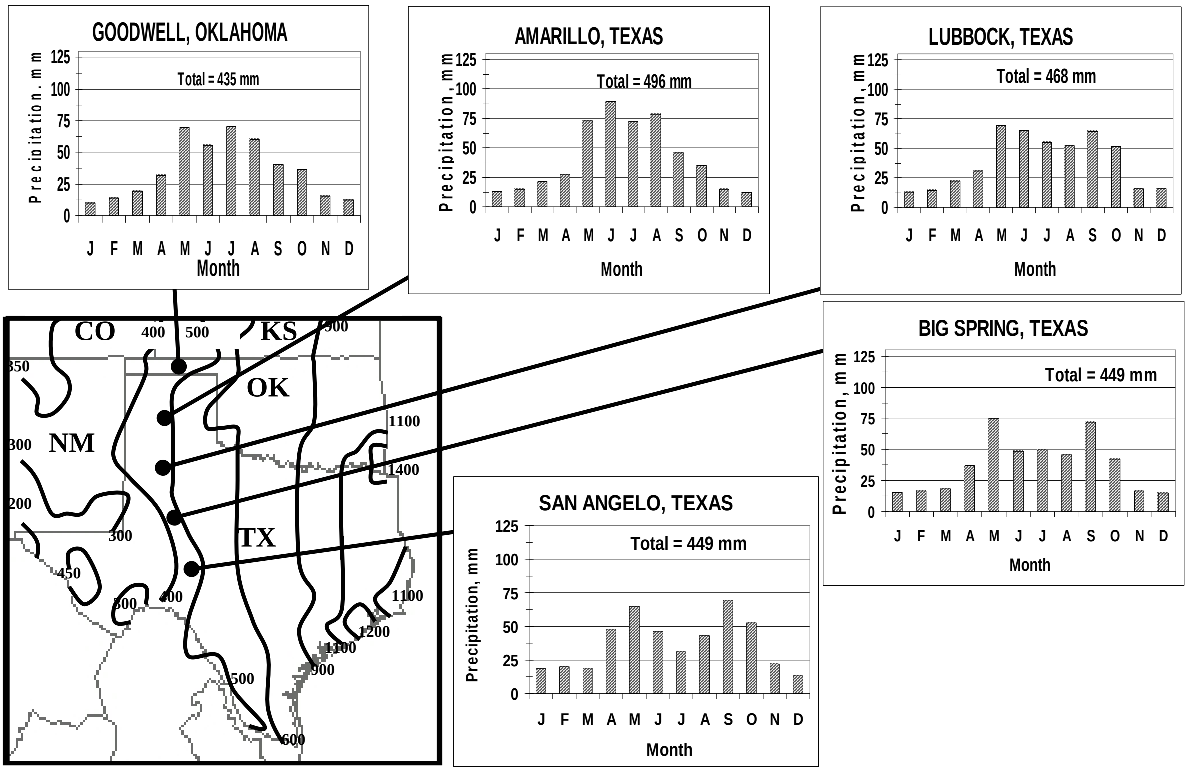


Figure 3. Southern Great Plains precipitation increases from west to east, varies little north to south, and occurs primarily during the summer growing season in the north compared with a bimodal, May and September, pattern in the south where climate is more dramatically influenced by the Gulf of Mexico (after Baumhardt and Salinas-Garcia, in press).

The effect of limited rainfall is compounded by an increasing potential evapo-transpiration where precipitation decreases. This results in water deficits (evaporation minus precipitation) that increases from 750 to more than 1500 mm along the east to west transect (Baumhardt & Salinas-Garcia, in press). Consequently, cropping sequences adapted to water deficit conditions usually optimize crop use of precipitation with residue-retaining tillage practices (Jones & Popham, 1997). Also, forage grazing is restricted in these mixed cropping systems to conserve crop residues needed to increase retention of stored soil water by restricting losses of water as runoff or evaporation. The point of showing the effect of both precipitation and evapo-transpiration in figures 3 and 4 illustrates a central point in the discussion of mixed systems with notions of complexity (section 3). The essence is that mixed farming forces farmers, researchers and policy makers to consider the interplay of different factors rather than to adopt a single focus approach that is the mainstream paradigm in specialized mono-cropping. Farmers in mixed farming need to look at the joint yield of crop and animal, often in uncertain conditions, not at maximum yields of single parts as in generally more predictable contexts (section 5). What drives the shape of mixed farming is not only one climatic factor (rainfall) but also evaporation and their often unpredictable combination.

Drought-tolerant crops such as cotton become more prevalent with the increased water deficit from east to west (Baumhardt and Anderson, in press). Livestock are often integrated into these cropping systems after severe water deficit conditions preclude normal mechanical harvest of grain, usually in the west. This is a striking similarity with farming practices in other places of the world, e.g. in the Middle East and Australia (section 2.4.2). Also for example in Latin America (e.g. Argentina) there are cases where very dry periods do not make it economically convenient to harvest the grain! The most adaptable cropping systems on the southern Great Plains of the USA often include livestock and drought tolerant crops, because they represent sustainable management solutions to dryland cropping in terms of spreading risk, resource use and added value.

The move and associated change of mindset to more sustainable management strategies was occasioned by the dust storms of some eighty years ago (section 5.3.2). Good initial biophysical conditions in the early years combined with a mindset of exploitation led to dramatic change of both biophysical context and mindset. A newly looming challenge to Great Plains farmers that rely on irrigation is the potential depletion of the Ogallala aquifer that underlies some 450,000 km^2 from South Dakota to Texas (Stewart, 2003). As a result of the declining Ogallala aquifer water supply on the Texas High Plains, irrigated land has decreased from 2.4 to about 1.8 million ha since 1980.

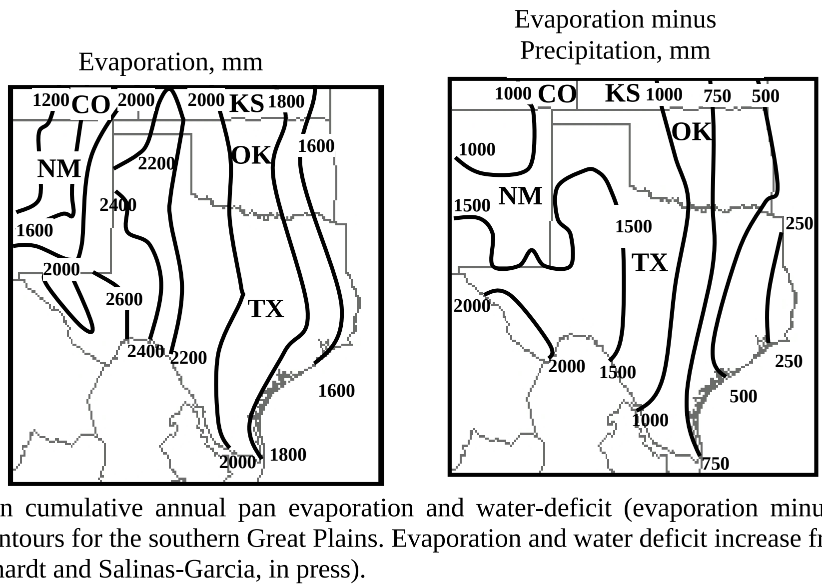


Figure 4. Mean cumulative annual pan evaporation and water-deficit (evaporation minus precipitation) plotted as contours for the southern Great Plains. Evaporation and water deficit increase from east to west (after Baumhardt and Salinas-Garcia, in press).

1.4.2 Intensive mixed farming systems Western Africa (based on Harris, 1996)

The Kano zone in the Sudano-Sahelian region of Nigeria is site of intensive mixed farming for the last 30 years. Small ruminants eat crop residues, e.g. of groundnuts and cowpeas, which are good quality fodder. The nitrogen in the residues of leguminous crops is conserved in the manure, which is transported with compound waste back to farmers' fields for use as fertilizer. Legume grains are sold, earning cash, which farmers may use to purchase inorganic fertilizer if they wish, and more nutrients are added to the system when Harmattan dust (wind from the north carrying sand from the Sahara and North-Sahel) is deposited on fields during the dry season. Till today, this allows farmers to manage a nutrient recycling system centered on small ruminants and based on high labor inputs. They keep animals tethered within the compound during the rainy season, collect crop residues and weeds for fodder and transport their manure back to the fields. Several drivers were important in the development of this farming system. First, the high population density of the past decades provided labor. It was also a source of agricultural innovation combined with a high density of small ruminants and donkeys. Second, the land tenure system was modified so that farmers have usufruct rights over the land they farm. Third, settlements are dispersed and farmers moved to live relatively close to their fields, to minimize time to reach the fields and to transport crop residues and manure between fields and the compound. Fourth, farmers started to use organic fertilizer on their fields, and fifth, investment in oxen, ploughs and cultivators by a few farmers have become economically viable because they can hire out the ploughing and cultivation service to other farmers. In addition the farmers started to engage in crop livestock and tree growing to diversify their income. Many also practice non-farming economic activities, especially during the dry season. This allows them to cope with risks, whether environmental (e.g. drought) or economic (e.g. price fluctuations). The dependence on external inputs is still low, allowing farmers thus far to remain relatively independent of fluctuations in the economy. Farmers still use little inorganic fertilizer, and they continue to cultivate seed lines of favored indigenous cultivars, rather than to use seed of commercially supplied high yielding varieties. Hence, despite being one of the most densely populated areas in semiarid West Africa, the system is both a productive and sustainable example of farming in what could be called New Conservation Agriculture, i.e. in the NCA mode of (table 3). Increasing population densities and labor availability are for the time being essential for agricultural intensification (Boserup, 1965); involving increasing use of crop residues to feed livestock and use of farmyard manure on the fields.

1.4.3 New mixed systems for smallholders in semiarid regions of Indonesia

Continuous annual cropping, overgrazing, unjustified lopping of the shrub and fodder trees, limited water supply, and intense heat stress during the dry season are the drivers that resulted in increased land degradation and reduced land productivity in many parts of the world. In the mixed farming systems of semiarid areas in Indonesia, for example, livestock feed availability is a major limiting factor, and research was started on forage crops, involving a so-called three-layered forage system. Forage crops (grasses and herbaceous legumes, leguminous shrubs and fodder trees are the respectively first, second and third layer (Nitis, 1995). They are combined with the food crop (maize, soybean, and cassava) in three topographical (flat, sloping and undulated) land conditions. Cattle, goats and chickens are included after the first year and the system has been shown to increase food crop production, quantity and quality of forages, as well as carrying capacity of the land. The system also reduces soil erosion, it increases soil fertility and firewood supply. Similar approaches are tested and applied, for example in the so-called alley cropping systems of Africa and Asia where crops, trees and animals are mixed at a very narrow time and space scale (Ohlsson, 1999; Kang et al., 1990)

1.4.4 Mixed pig production systems in Spain: the Dehesa (based on Larovere, 1998)

The ‘Iberian’ pig and the interaction of commercial production with local ‘Dehesa’ farming form a mixed system typical of regions in Southwestern Spain and neighboring Portugal. The semi-arid (Mediterranean) climate, low soil fertility, prevalence of oak and cork trees are system drivers, combined with low population densities, traditional pastoralism and poor infrastructure. The Iberian pig retained some ‘wild’ traits, as its specific adaptability to difficult environments, the distinctive taste of its meat (the famed ‘acorn ham’) and its active behavior. The animal can roam freely and feed on natural resources, like grass and acorns of cork trees. It drinks from ponds and streams, receives minimal care and no feed supplements, while the manure is neither collected nor processed and left in the field. The institutions that support this typical crop-livestock system are the regional governments The system helped the said region, labeled a ‘less-favored’ area within the European Union, to develop in an ‘endogenous’ way, and efforts are made to implement conservation policies towards sustainable exploitation of its natural ecosystem functions. A modern variant of the system is to breed the Iberian pigs semi-intensively and to introduce the pigs into the cork oak grazing for the last 3 months before slaughter in October-January. The system benefited from the ‘environmentally friendly’ origin of its products. Producers learned to improve their label for quality meat, to partially justify their high price. Limited market opportunity, scarce promotion outside the national borders, and relatively high prices so far prevented intensified production. The success of this system did not so much result from planning that aimed at realization of specific goals, but it was attained almost ‘accidentally’. Local producers and governments have not too easily abandoned a traditional activity in favor of modern specialization and for realizing the important role of this system in sustainable natural resources management. This may represent a success because it was left alone, or at least not pressured into change for ‘*the sake of development*’.

1.5 Mixed farming and mixed blessings

Both positive and negative synergy occurs among people, animals, crops and soils in mixed systems, and table 2 lists what we call mixed blessings from mixed systems from both commercial and subsistence farming around the world. It illustrates the possible confusion and it is a next step after figure 1 to show that one can understand variation by expanding rather than by narrowing the focus. The biblical story of tension between the crop farmer Cain and the herder Abel is one of the many examples which show that a) crops and livestock often have common as well as conflicting interests, and that b) their relative importance differs between contexts and perceptions. The story is often replayed where regionally mixed systems with crops and livestock are under pressure (Hussein et al., 1999). In many regions pastoralists even invaded cropping areas, among others a reason to construct the Great Wall of China (Crotty, 1980). We call such conflicting phenomena mixed blessings, a concept inherent to complex-system thinking (section 3). Farmers, teachers, research and policy makers have to decide on what to select out of the “mixed” blessings, a typical topic for work with soft system thinking (section 3). What is good in one place may not be good somewhere else and similar issues occur in left and right hand columns of Table 2. That is the heart of our argument against a cookbook approach in this chapter. It is also the argument to embark on an effort at classification of the many different mixed farming systems around the world.

Section 2: Mixed farming, different classifications.

2.1 General

The variation of forms and functions in mixed farming systems is confusing at first, but classifications helps show how mixed systems co-evolve with mindsets. By focusing on the effect of drivers, they can help guide policy decisions to either favor or disfavor mixed farming.

Advantages	Disadvantages
- *buffer* against *trade and price fluctuations*	- requires *'double' expertise*
- *room for choice and different farming styles*	*-hard to upscale, less economies of scale*
- *buffer* against *climate fluctuations*	- *risk* of *disease* and *crop damage*
- *erosion control* through forage production (such as grasses)	- *livestock can cause erosion* due to soil compaction and overgrazing
- higher *nutrient recycling* due to more direct soil-crop-animal-manure relations	- *nutrient losses* can increase through intensive recycling
- *diversified income* sources	- continuous *labor requirements*
- *draught power* allows larger cultivated area and more flexible residue management	- *increased area of land required for a given production*
- *more rapid* planting by use of animal draught	- *extra (women) labor required for weeding*
- controls weeds	- *carries weeds; risk of crop damage*
- *investment and savings* option	- requires *capital*
- alternative *use for low-quality roughage*	- competes with other *use of crop residues*
- *social* function	- cause of *conflict*

Table 2: A generalized list of advantages and disadvantages of livestock in mixed systems. Note that Many issues occur both in both left and right hand columns, see text on perceptions, complexity and classification.

2.2 Variation in, and similarity between mixed systems

A central notion in this chapter is to understand variation by expanding it, rather than to focus on one or a few cases. In that sense, we start by saying that any system is mixed in one way or another, being a 'whole' that consists of parts which together perform different activities. In that sense even specialized grain systems are mixed – at least in time - since they too practice some form of rotation and/or fallow. Even many specialized livestock farms are mixed, for example when they have different age groups in one herd. And a mono-cropped field is a mixed system considering that it includes soil-plant-human interactions (fig 5c). In addition, crop and animal keepers all over the world practice 'mixed' farming at either herd or farm level by mixing different feeds, crops and animals (Breman & De Wit, 1983; Slingerland, 2001; Pearson, 1992). Finally, specialized crop farmers can form mixed systems with 'specialized' grazers at regional levels (fig. 5d). Livestock producers in the range-land areas of north and south America provide young stock (feeder cattle) for crop areas where animals are fattened, and the same occurs around the world, e.g. in figure 6.

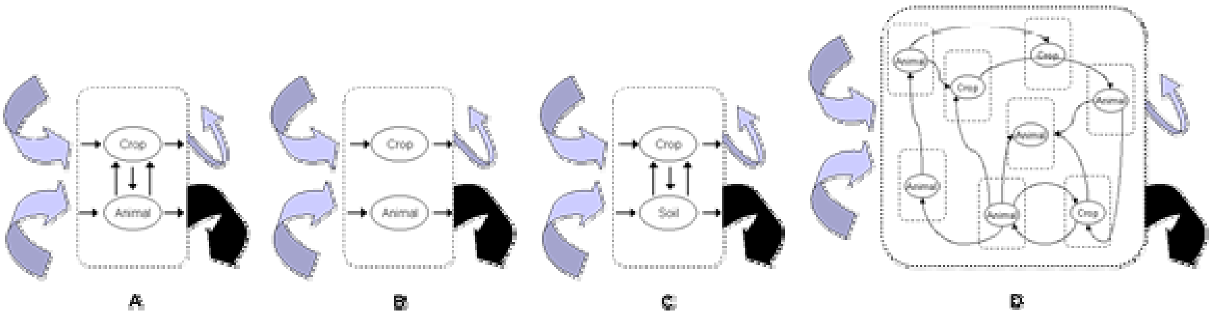


Figure 5: Different structures of mixed systems at different levels of system hierarchy. A: a mixed crop livestock system integrated at farm level; B: a mixed crop livestock system (diversified) where components are not closely interlinked at farm level; C: A mono-crop of grain with interactions between interrelated soil – plant subsystems; D: a mixed crop-livestock system at region level where individual farms are specialized in crops or livestock. Solid lines are sub-system boundaries; broken lines are farm boundaries; dotted lines are higher level boundaries (at our usual level of observation). The diagram focuses on biophysical components and flows; similar diagrams can include socio-cultural aspects (see fig. 12).

Stretching the mind by listing such a large array mixed systems at many different levels may seem farfetched. It aims, however, to unlock knowledge for better understanding of the nature of mixed systems in general. At high levels of generalization one can apply concepts from disciplines like ecology and complex system theory to the study and management of mixed systems (Lefroy et al., 1999; Gunderson & Holling, 2002). In addition, one can use insights and concepts from mixed farming for problems in public administration (section 5). There too, form and function in mixed system repeat themselves, beyond crop-livestock system into other parts of society and nature in general. (Jorgensen, 2002). A deeper look at the nature of systems in general shows that specialized (=un-mixed) systems cannot even exist on their own. The laws of thermodynamics implies that no system can function without input and output, i.e. a resource gradient is always required and present. Moreover, one system is needed to process the "waste" of another system, the essence of the law of requisite variety by Ashby (1958), and more practically by Coppock et al. (1986). This does imply emergence of (mixed) systems with resource flows between them, a reason to introduce the notions of complex system theory in this chapter (section 3). Mixing and variation is thus a fundamental attribute of systems in general. And the issue of policy choices on "specialization" vs. "mixing" lies, therefore, in the degree and level of mixing, and not in whether mixing is needed or not.

Mixed systems occur in many forms of which some patterns repeat themselves. One such typical repeating pattern in many crop-livestock systems is the basic structure of biophysical resource flows such as nitrogen and energy (fig. 7). Relative importance of these resource flows can differ between modes of mixed systems (section 5.4.2), and according to perceptions of different stakeholders (section 3) but the basic structure of the resources flows does not differ much. The diagrams in fig 5 and 6 tend to focus on biophysical aspects, but socio-cultural aspects are included and highlighted, e.g. in fig. 12.

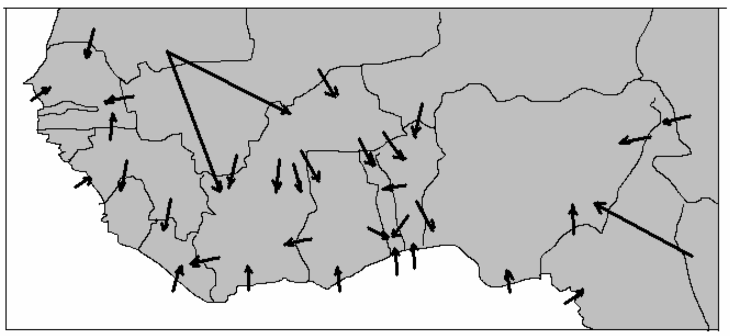


Figure. 6. Interregional trade in live animals and meat, some examples from Western Africa, consisting of flows for meat, traction and young stock for subsequent fattening near the cities (Faye and Fall, 1999). The flow is caused by different drivers, e.g. climate (animals tend to be raised in the drier Sahel region), disease pressure (trypanosomosis in the more humid coastal region), economic development (imports of meat from Europe).

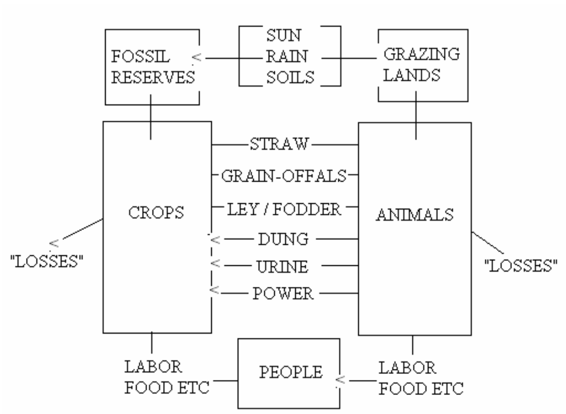


Figure 7. Basic structure of biophysical resource flows (e.g. nitrogen and energy) in mixed systems (Schiere et al., 2002). This diagram is based on a rich picture as in fig. 12 and it underlies the diagram in figure 19.

An additional case of variation in mixed farming due to mindsets is the difference due to respectively cornucopian and stewardship attitudes (section 1.4). Another case, particularly relevant to mixed farming in uncertain climates is that farmers in semi-arid regions are more used to live with uncertainty (and variation!). Uncertainty is a fact if life for them that rules their decisions on whether or not to mature or graze a grain crop (fig 8), or to sell or keep livestock. Farmers from more favorable regions tend to plan the harvest or stock sales in a quite different manner. Preparation and feeding of silage is a well-known way to “cancel” scarcity in climates with regular feed “shortages” (‘tMannetje, 2000). But farmers in uncertain drought conditions tend to cope with variable feed supply by selling animals, using other crops, grazing vs. harvesting, non-cropping or even risking mortality in the herd. Still another difference in mindset occurs between strategies used by ‘wealthy’ farmers with high investments and market orientation on the one hand, and subsistence farmers with low investments and cash reserves on the other hand. For example, large farmers in the Darling Downs of Australia may skip a year when they expect a drought (even saving water for the following growing season). Their cash expenses for inputs and plowing are too high to risk a crop failure, and food can be bought at the supermarket (K.G.Rickert; pers.comm., 1997). Subsistence farmers in other countries tend towards so-called response farming, i.e. intermittent planting, according to the rain they expect to get (Wafula, 1993). Their cost of planting is not too much, and without harvest they cannot easily shop for food in the local market.

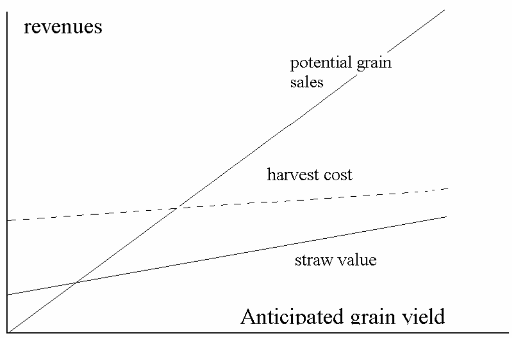


Figure 8. Costs and revenues for grazing or harvesting a mature crop (based on Nordblom, 1983) The graph was developed in Syria, but farmers around the semi-arid world identify with the issue.

2.3 Classifications of mixed systems

The search for repeating patterns is central in attempts at classification. This section therefore, proposes four different classification of mixed systems, as a start and to better discuss mixed blessings of mixed systems based on socio-economic and bio-physical ‘drivers’:

- *On-farm versus between-farm mixing.* The on-farm mixing takes place within one level of system hierarchy (fig. 5a/b). The between-farm mixing occurs in systems that are regionally mixed as in fig 5d (Slingerland, 2001). This second form also occur increasingly in high external input agriculture (HEIA) of table 3, where mixing helps mitigate waste disposal problems of specialized farming while maintaining perceived advantages of scale (Ho & Chan, 1998; Lantinga et al., 2004; Van Keulen & Schiere, 2004).
- *Diversification vs. Integration.* The first tends to occur in contexts with abundant resource supply of expansion and high external input agriculture (EXPAGR and HEIA in table 3). Its crop- and animal components co-exist “independently” as two specialized systems (fig 5b). Integration tends to occur especially in contexts of reduced access to resources, e.g. in low external input and new conservation

agriculture (LEIA and NCA in table 3). It's farm components are inter-dependent, and animals provide dung for crops in return for crop residues (fig 5a). Integration can increase efficiency by allowing more recycling, but it can be 'riskier' than diversified farming by being more interdependent. Use of concepts from other disciplines as suggested in section 2.2 helps to better understand mixed blessings. For example, in the language of system ecologists, a higher "redundancy" in less efficient "diverse" systems represents a buffer in case of shock (Giampietro, 1997). Also the so-called K-strategy (slow, stable and integrated) tends to be more efficient but riskier than the faster and more diversified r-strategy (Gunderson & Holling, 2002; section 3.4f)

- *Mixing in reliable vs. unreliable rainfall areas.* Animals in reliable rainfall areas can help ensure nutrient cycling and soil conservation, but in unreliable rainfall areas they tend to serve primarily for risk mitigation (Heitschidt et al., 2004), at least partly because of their mobility (Swallow, 1994). Animals can also be a hedge against drought because they can use immature failed crops. For example, a system designed for southern Israel (average annual winter rainfall 250 mm) in the 1970s had half the farm sown to wheat, while the other half was in herbaceous natural vegetation. In favorable years the natural vegetation provides enough feed for a good crop of lambs, and the wheat produces a respectable grain yield. In un-favorable years, when grain yield would be low anyway, the wheat is grazed. This avoids overgrazing natural vegetation and/or the need for emergency sales of (part of) sheep. Also, straw stocked in good years serves as feed during the dry season (Alberda et al., 1992). A typical choice for mixed farmers in semi-arid regions is indeed on whether to graze or crop (fig. 8).
- Mixing in contexts of *wet winters / dry summers* vs. *high moisture and temperature year-round.* The first are called Mediterranean systems (López-Bellido, 1992) that can apply soil improvement methods like improved fallows, so-called leys (section 4.3.1) because decomposition rates of soil organic matter are low in winter (cool) *and* in summer (dry). The latter systems always have high rates of decomposition and need to constantly re-circulate mobile nutrients to avoid leaching.

2.4 Mixed blessings, classifications, issues of time, space, perceptions and hierarchy.

The number of mixed blessings is large, and generalized inventories as in table 2 show that advantages even can be disadvantages and vice versa, depending on context and mindset. One way to cope with such confusion is to establish classifications as started above. One refinement is to arrange different systems along gradients that represent changes in "drivers". Many such gradients can be identified, and the classification of table 3 uses access to land, population pressure and attitude to farming. The resulting classification reflects co-evolution between system and context in time and space of which some examples are discussed first.

2.4.1 Co-evolution of farming systems in time, a generalized framework.

Mixed crop-livestock systems co-evolve with their context. Our stress on co-evolution is due to the notion that (mixed) farming systems are not static entities, but constantly changing in time and space (table 3). When land is relatively abundant, crops and animals exist parallel in so-called EXPansion AGRiculture (EXPAGR). Animals and crops are complementary but they do not considerably exchange resources among them (fig. 5b). As land becomes scarce, in part due to the success of this type of farming, an expanding farmer population is forced to keep animals together with crops. Higher exchange of resources like dung, crop residues and animal draught is then required (fig 5a), a mode of farming that we call integrated Low External Input Agriculture (LEIA). When access to land further decreases, and/or when policy or economic conditions allow, one has an option to start using external inputs like feed and fertilizers, the High External Input Agriculture (HEIA). National input supply policy and teaching has a role to play here (section 2.4.5). Keeping of animals and crops starts to “disintegrate” as specialization sets in, i.e. as in fig 5b. This mode permits advantages of scale and labor efficiency, i.e. who wants to carry around dung and crop-residues if tractor fuel, fertilizer and animal feed are cheap?! This same mode, however, tends to eventually choke or starve itself due to excessive environmental impact of its “waste”, and/or due to exhaustion of resource bases like aquifers (NRC, 1989; Van Keulen and Schiere, 2004; Stewart, 2003). When agro-chemicals from both crop and animal production start to behave as pollutants, a shift towards “re-integration” can start, also depending on mindset of farmers and public. It is a farming mode that we call New Conservation Agriculture (NCA) often using elements of ecological agriculture (Cox et al., 2004). This mode of farming occurs widely, e.g. after the US dustbowl that led to ‘conservationist’ farming when EXPAGR modes had helped to run things down (section 5.3.2). The tendency to organic farming is a similar and significant mode change of the recent decade (NRC, 1989). It is at least partly occasioned by a mindset (=paradigm) of consumers and producers which declines to use external inputs, even if those input are well available (Altieri, 2002)

Table 3: Stylized characterization of modes in mixed crop-livestock farming, arranged according to drivers of relative access to land, labor and capital (based on Schiere et al. 2002).

Mode of farming	EXPAGR	LEIA	HEIA	NCA
		Relative access to production factors[1]		
- land	+	-	-	-
- labor	-	+	-	+/-
- capital	-	-	+	+/-
		Characteristics of farming		
- source of animal feed	Outfield[2]	Infield[2], roadsides	Infield, import	Infield
- nutrient flows	Linear[3]	Web-like[3]	Linear	Web-like
- role animals as saving	High	Medium	Low	Low
- importance of excreta				
*dung	Positive	Positive	Negative	Positive
*urine	Neglected	Positive	Negative	Positive
- source of energy for labor	Humans/animals	Humans/animals	Fossil fuel	Fossil fuel/animals
- form of mixing[4]	Diversity	Integration	Specialization	Integration
- place of mixing	Between *ánd* on-farm	On-farm	Between farms	Mainly on-farm
- role of leys[5]				
*for weed control	NA[2]	Low/NA	NA	High
*for nutrient dynamics	NA[6]	Low/NA	NA	High
*for erosion control	NA	Low/NA	Low/NA	High
- ratio outfield/infield				
*local level	High	Low	Low	Low
*international level	Low/NA	Low/NA	High	Low/NA
- yield per animal	Low	Low	High	Medium
- feed supply	Medium	Medium	High	Medium
- attention for resource base	Low	Medium	Low	High

[1] access to land, labor and capital is to be read within a column, contrary to what has to be done for the comparison of system characteristics between modes (over rows). For example, a ’-‘ for labor in the HEIA column means that labor is relatively scarce compared to capital inputs in that mode; not necessarily as compared with LEIA where it is indicated with a ’+’. [2] Outfield refers to distant grazing lands away from the farm; infield refers to mainly local croplands around the farm/village. [3] Linear and web-like implies emphasis on throughput and recycling, respectively. [4] see text under 'classification' [5] improved fallow. [6] NA: not applicable

2.4.2. Co-evolution of mixed systems in space.

The change of systems according to their “drivers- in space and time illustrate a combination of “chaos and order”, i.e., of variation and repetition of form. One example of system change in space along the temperature gradient occurs from South to North on the US Great Plains (section 1.4.1). Cotton monocultures are replaced by (grazed) wheat pastures, ending in mixed farms with sorghum for grazing or grain, depending on expected rainfall. From east to west, along a rainfall gradient, mixing shifts from maize/grass/dairy systems to extensive grazing and cow/calf operations. The biophysical "drivers" from South to North and from East to West along these transects are temperature and rainfall. Similar patterns occur from central to south east and south west Australia where temperature and rainfall gradients drive change from cattle herds to mixed grain/legume/sheep farms (fig. 9), much like what was discussed under section 1.4.1. Similar changes occur in Argentina, China , South Africa and on the Indian sub-continent on the Karachi - Bombay transect. The diagram in fig. 10 is just another illustration pattern, here from North to South in Sub-Saharan Africa, again with rainfall as a driver, and strongly associated with changes in socio-cultural values (=mindsets). An effect of population pressure *in time* is shown from left to right in the central column. No clearer illustrations can be given of variation that repeats itself.

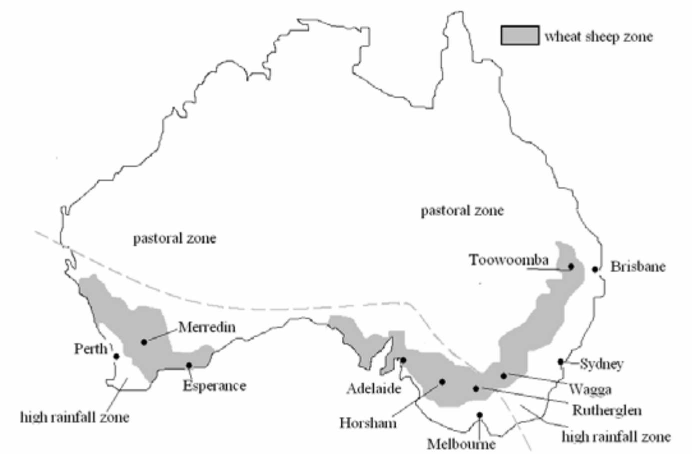


Figure 9. A map of Australia with the change of patterns in mixed farming in space across in Southern Australia and in relation to the annual rainfall. The zone of winter dominant rainfall is to the South of the dotted line. This map shows a snapshot on how crop-livestock systems change in space, i.e., over years the situation is likely to change also (section 2.4.4, Puckridge & French, 1983; quoted by Loomis & Connor, 1992).

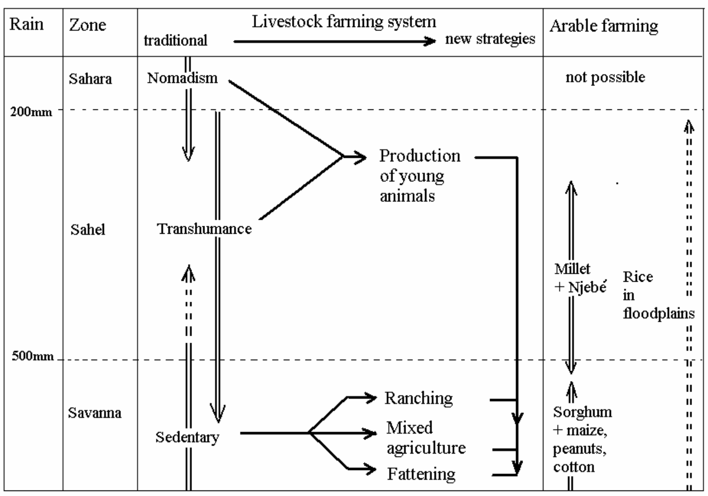


Figure 10: Spatial and temporal changes in mixed farming based on drivers like annual rainfall (top to bottom) and increased population pressure (left to right in central and right hand column. (Breman and De Wit, 1983).

2.4.3. Change of mixed farming in China (based on Dong, 2003)
Rangeland constitutes 41% of China's total territory but it contributes less than 1/3 of beef and lamb production and around 30% of milk yields (EBRRC, 1997). Currently, crop-based livestock production systems are characteristic of cattle and sheep farming in most agricultural areas of China. Introduced pure beef cattle and their cross-breeds with local Chinese yellow cattle are kept at household levels for meat production. Local and improved breeds of sheep are raised at small scale farms for wool production. Animals are mostly fed straw and stover as roughage and maize or agricultural by-products like wheat bran and rape cake as concentrate supplements. Roughly 0.76 billion Mt straw is produced in China annually and half is used as roughage by ruminants (Feng and Zhang, 2001). The semi-arid areas in the south-east edge of Inner Mongolia Plateau and the northern Loess Plateau are the so-called transition zone (= mode change in space) between the pastoral and cropping areas. It is a potential livestock production base where animals, purchased at low price from pastoral areas, can be fed on low value straws and crop by-products imported from cropping areas. Crop by-products are also used as feed to supplement grazing animals like Mongolian cattle and yaks during harsh winter seasons, even in pure pastoral areas like the Inner Mongolia and Qinghai-Tibetan Plateaus. Conversely, the livestock in those areas can benefit crop farming by providing draught power for ploughing and manure

2.4.4. Mixed farming in Australia, changes in time and space.
Mixed farming in Australia, also referred to as grain/grazing systems, mostly occurs in zones with between 350 and 700 mm rainfall annually, and it occupies a land area of up to 50 million hectares (McLennan, 1996; Perry, 1992). A range of cereal and pulse crops, sheep (meat and wool) and mainly beef cattle enterprises dominate these areas (fig. 9). Attempts to develop rainfed grains and fibre farming system in the semi-arid tropics of Northern Australia have failed with a few exceptions like the Atherton tableland and the central highlands in Queensland (Chapman *et al.*, 1996; McCown, 1996). This has been due to a variety of market access problems and high climatic variability. Extensive grazing of mainly cattle on native grasses is the most common form of land-use in the semi-arid tropics of Australia.

In southern Australia, the use of pastures containing legume species such as Subterranean clover (*Trifolium subterranean*), annual medics (*Medicago spp*) and Lucerne (alfalfa – *Medic ago saliva*) have long been used as a profitable and sustainable method of maintaining soil structure and fertility (chemical and structural). The role of pastures in cropping systems has been reviewed by Puckridge and French (1983), Robson (1990) and Bellotti (2001). The past two decades showed a trend with mode changes in time towards shorter pastures phases within the crop-pasture rotation, more continuous cropping and the usage of N fertilizers. This reflects higher returns from cropping, relative to livestock enterprises (McCown *et al.*, 1987), pasture decline (Carter *et al.*, 1982) and soil acidification (Hochman *et al.*, 1990).

Degradation processes such as salinization of soils and waterways, soil acidification, animal and bird habitat loss forced land managers and policy makers to consider new management practices on these mixed farming systems. They often represent principles from "mixing", e.g. the use of perennial pastures (Ridley et al., 1998) and trees in mosaic arrangements (Brennan et al. 2003), stricter tree clearing guidelines and more attention to matching land use practices with land capability. In the northern grain belt (northern New South Wales, southern and central Queensland), recently available perennial pasture legumes (*Lablab purpureus* cv. Endurance, *Macroptilium bracteatum* cv. Juanita, *Clitoria ternatea* cv. Milgarra and *Hedysarum* spp) have recently been commercially released (Whitbread et al., 2004). The availability of these legumes, combined with favorable beef prices and declines in soil fertility have prompted farmers to increase pasture sowings on previously cropped soils.

2.4.5. Mixed farming and access to fossil fuels (F. Funes-Monzote, pers. comm. 2004)
A peculiar change from specialized to mixed farming took place in Cuba after the change of the socialist bloc in 1989. The originally specialized livestock and crop systems were based on HEIA principles, driven by cheap oil and fertilizers from the former USSR. After those supplies ceased in the late 1980s the HEIA system moved from a rather linear structure (fig. 5b and 19) to more web-like structures of NCA (fig 5a and 19). Specialized HEIA systems that were perceived to be stable collapsed after the supply of oil-based inputs ceased. Less access to inputs implied less options to correct nutritional status of the animals, less pumping of water for irrigation, and less economies of scale. Interestingly, the existing organic farming movement could provide a way out with experiences from mixed systems, nutrient recycling, and use of farmer's knowledge and importance of soil organic matter (Funes et al., 2001; Sinclair & Thompson, 2001; Wright, 2005). Previously specialized farms went back (or forward) to mixing. Individual animal yields dropped and had to be re-adjusted to what was available from the farm, illustrating the notion of communal ideotype (sections 3.4c and 5.4.1). This is strikingly similar to mode changes in HEIA of rich countries where specialized farmers had to find other ways to handle their waste "production" (Nell, 1998; Van Keulen & Schiere, 2004). In both cases, farming is forced towards recycling, web-likeness and adjustment of production, whether by lack of inputs or excess waste (fig. 13 and 14). When fossil fuel is cheap, however, systems tend to re-integrate at regional level to maintain economies of scale (fig. 2.1a). When fossil fuels are scarce the farmers move (back) to small scale inherent to LEIA, when dung and crop residues have to be eventually carried around by the farmer. The large landholdings in Cuba did not (yet) shape into smaller farms, but the process is ongoing, by use of trees, dung application and other measures for recycling.

2.4.6. Mixed farming in West Asia, North Africa, Central Asia and the Caucasus.
Erratic rainfall patterns and increasing competition for land and natural resources severely affected traditional crop-livestock systems in the countries of West Asia (Iraq, Jordan, Lebanon, Syria) and North Africa (Algeria, Libya, Morocco and Tunisia). The number of small ruminants increased steadily, parallel with the rise in human population as a driver, and the effect is a set of mode-changes in the production system (Delgado et al., 1999; Haddad, 1997). In North Africa and Jordan, demographic pressure led to out-migration and off-farm employment, while traditional crop-livestock systems persist without much change in productivity. In these systems human population and demographic pressure thus acted as drivers of change. Elsewhere in West Asia, e.g. in Syria, the situation is different. Des-integration (= specialization) of crops and livestock production occurs at farm level, leading to intensification of either commercial livestock raising or barley cultivation as separate activities (Métral, 2000; Nygaard & Amir, 1988; Treacher, 2000; Tutwiler et al, 1997). This trend has been spurred by a feed-to-meat price ratio in Syria that encourages farmers to use large quantities of supplementary feeds. Especially favorable meat prices encouraged farmers to specialize into intensive lamb fattening production to generate a better income than from traditional crop-livestock systems (Bahhady et al., 1997; Tutwiler et al, 1997). Intensive fattening provides a fast income-generation due to high turn-over of lambs in three months cycles. Farmers interviewed in a nation-wide survey of fattening systems in Syria (Hartwell and Iníguez, 2004) stated that lamb fattening was less risky than traditional livestock rearing because: a) feed and forage only has to be bought for one fattening batch and not for the whole year, b) intensively reared lambs do not have to be moved for grazing (less mobility problems) and c) fattening could be done when cash was available (no long-term investment).

These farmers also get income from manure production to be used for between-farm mixing or industrial purposes. Intensive lamb fattening systems also provide urbanized farmers a good income-generating option (ICARDA, 2005).

Central Asia and the Caucasus (CAC) consist of large landmasses from deserts to mountains and steppe land. Over 72 million people live mostly from small scale mixed crop-livestock systems on some 416 million ha in Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgistan, Tajikistan, Turkmenistan and Uzbekistan. Traditional “commercial” agriculture is slowly recovering from the environmentally damaging specialized crop monoculture systems of the Soviet era, which left farmers with problems such as soil salinity, depleted ground water levels and crop pests and diseases (ICARDA, 2002). International research and development programs now assist small-scale mixed farmers with new crop varieties, water management and conservation, soil and salinity, rangeland rehabilitation, feed and livestock management, genetic diversity and human resource development (ICARDA, 2003). ICARDA aided farmers to rehabilitate and develop their agriculture through integrated research on small ruminants, range and crop systems. The key entry point for income-generation of farmers in the CAC, was to diversify their production systems e.g. from pure wool and pelt sheep production systems to systems with higher emphasis on produce like meat and milk. One success story in terms of indigenous development is told of two Turkmen farmers that were introduced to milking strategies and milk processing techniques in workshops around West Asia (Suleimanov, 2000). They applied the knowledge that they obtained from other sheep farmers in West Asia to their own flock upon their return. After some time the cheese that they produced proved to have a high market value and it now provides them with a significant income while the traditional pelt and wool have almost no value (ICARDA, 2003). Apart from more socio-cultural work on the output side, there also has been attention for the use of saline drainage water for irrigation of annual and perennial halophytes such as *Atriplex* spp, *Suaeda altissima*, and *Climacoptera lanata* as feed (Annamuhamedov et al, 2002). Improved utilization patterns and biodiversity of Central Asian rangelands are other successful activities spread through farmers contacts (Street et al, 2002; Zhambakyn et al, 2002).

Section 3: System Approaches for Mixed Farming

3.1 General

Various forms of system thinking can help to further understand the logic, variation and mixed blessings of mixed farming. Three approaches from modern system thinking are used therefore, namely hard-, soft- and complex system methodologies. We cut many corners, but we stress that sustainability of (mixed) farming systems need be evaluated at different levels and with various criteria. This is called the triple bottom line in this chapter. It refers to the need to use several criteria rather than one alone in management and/or policy decisions, e.g., cash returns, soil organic matter and community wellbeing (Conway, 1987; Rickert, 2004). Typically, the reductionist “specialization mindset” tends to focus on only few aspects to assess system performance, e.g., dry matter yield or monetary returns. Mixed farming by its nature requires a more “holistic mindset” that focuses on wholes rather than parts; hence, we use three distinct system methodologies, reflecting the use of the triple bottom line. More reading on system thinking is available in for example Klir (1991); Ison &Russel (1999) and Schiere et al. (2004a).

3.2. Basic concepts in system thinking and the effect of “paradigm”.

Much system thinking revolves around the following notions of what a system can be:

- *a static notion,* considering a system as a *unit* in space, with boundaries, goals and parts arranged into a particular structure that converts inputs into outputs, and serving a

common goal (fig. 11). This approach tends to describe a mixed system in terms of its parts rather than as a 'whole' with internal trade-offs and tensions.
- *a dynamic notion,* considering a system as an established *way* of doing things in time, with "parts" organized into a particular structure in time, while converting inputs into outputs. This approach tends to processes and ways of farming, much related to aspects of attitude and mindsets,
- *a space - time notion,* considering a system as a "mode", i.e., as a dynamic arrangement (structure) of parts and processes in space *and* time, where everything is related with everything, ultimately addressing issues of co-evolution and mode changes.

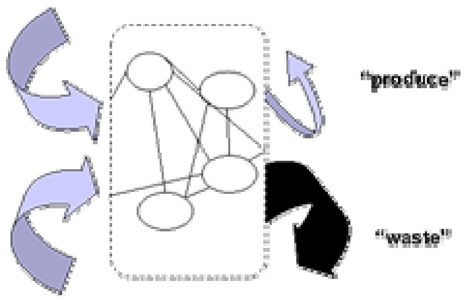


Figure 11. A system as a unit, as referred to throughout these notes. Its parts together convert inputs into desired and 'undesired' outputs. The "produce" arrow is deliberately drawn thinner than the 'waste'-arrow since resource use efficiencies hardly exceed 50% (except when expressed as money). Inverted commas stress that different perceptions are possible on notions of produce and waste. For example, most crop-livestock systems see straw as waste of grain-production, and resource (e.g. mulch for soil protection or feed for animals).

Much system thinking also uses notions like boundaries, hierarchies, inputs and structures. But mindsets of the different forms of system thinking differ, and therefore the interpretation of the concepts, thus determining the analysis and outcome of the study. For example:
- *regarding boundary choice*: a millet field on a mixed farm can be studied as a specialized unit / activity in a restricted time span that does not affect neighboring "space". It can also be seen as integral part of a rotation where the plants interact with aspects like soil organic matter balance, animals, farmers livelihood and weed infestation over time. Typically, work on perennial grains as by Turner & Rabalais (2003) reflects concern about grain yields as well as landscape and water quality in the Mississippi river. This represents quite different mindset than the reductionist specialization focus on grain yield alone.
- *regarding choice of level in the system hierarchy*: systems can be considered "mixed" at farm level with animals and crops on-farm, or at regional level with animals and crops separated into farm units that exchange resources between farms (Fig. 5). Hierarchies also exist in time, e.g. days, weeks or years, and choice of time scale affects interpretation. Large mode changes that took place, for example, when fertilizer was introduced appear to be rather gradual when measured in hours, days or weeks, but drastic when measured in terms of years or decades. Conversely, a failed harvest in one year can be disastrous for a farmer surviving on a minimum, but it can go unnoticed in macro-economic studies that use years or decades as unit of time (fig 2a).
- *regarding inputs and outputs*, these can be chosen as easy to quantify kilos of seed, hours of labor, amounts of cash, liters of petrol, kilos of grain or milk or as organic matter yields. They can also be chosen to consist of more qualitative aspects like skills, knowledge, emotion, satisfaction, intention and sense of 'belonging'. Either of these 'inputs' can be transformed into quantifiable grain yields, soil organic matter levels, milk yields but also into qualitative notions of satisfaction, social stability and/or sense of belonging, the approach of land conservation groups (Campbell, 1996). In addition, an output considered waste for one system can even be a resource for another (see inverted

comma's in fig. 11), representing a change of mindset that currently takes place in many wealthy countries as they shift from column 3 to 4 in table 3.

- *regarding "structures"*, i.e. the way in which the farming system is organized within and between its components, one can see them as agro-ecological structures with resource flows as in figure 5 and 7; as rich pictures that combine biophysical and socio-cultural resources and components as in figure 12, or as political or socio-cultural structures in for example livelihood analysis (Chambers & Conway, 1992).

3.3. Principal system approaches.
Choice of method follows choice of mindset and paradigm, two concepts that we consider to cover the same meaning for the purpose of this paper. Choice of paradigm affects the management and policy setting, farm practice, research priority and teaching approach. We use three complementary forms of system thinking to balance otherwise inevitable bias for one or the other, e.g. for biophysical *or* socio-cultural. Particularly for better understanding of mixed systems we thus stress the need to use a triple bottom line approach rather than a single focus on one aspect or another. At the risk of oversimplification, the three system approaches are outlined in the following section.

a) Hard system methodologies (HSM) are predominant among technically oriented people. They focus on quantification ('to measure is to know'), the use of so-called "hard facts" and aspects of "matter", e.g., kilos of nitrogen, wheat or milk while assuming clear boundaries and strict definition. More qualitative 'issues of mind' tend to be left to sociologists, politicians or anthropologists, some of which, however, also prefer to stick to use of "hard facts". In addition, HSM tends to more statically describe how things are, rather than on how they develop and co-evolve. It does study change in systems, e.g. in scenario studies, but it cannot well explain mode changes due to interaction between system "drivers" like climate, market prices or culture. Its focus on parts makes it difficult to understand interactions between different criteria and environmental factors. HSM also tends to be empiricist versus rationalist, i.e., it focuses on observation and causal relationships rather than on reasoning. Nevertheless, dynamic models and multiple goal programming are typical HSM tools and interesting work is done for mixed systems at various levels in semi-arid regions by workers like Morrison et al. (1986), Hamadeh et al. (1996) and Sissoko (1998).

b) Soft system methodologies (SSM) focus on issues of motivation, learning, relations, mindset and empowerment. For example, a livestock owner may 'rationally' know that selling in the face of drought is advisable, but cultural considerations or other sound reasons can prevent the sale. And crop farmers may know that sorghum is a more efficient water user than maize, but they continue to plant maize for reasons of tradition or a particular crop insurance program. Most, if not all problems can be perceived differently by different stakeholders and awareness about choice implies learning as well as negotiation (=co-evolution) internally and externally (Kersten & Ison, 1994; Rasmussen, 1999; Walker & Janssen, 2002). This explains at least partly why many mixed blessings occur on both sides of the table 2. A typical case of different problem perception is from women in the arid state of Rajastan (India) who told researchers that wanted to introduce new feeding systems for the dry season:

> *"we have no problems with drought … we sell animals when the dry season starts" (D.V. Rangnekar and C. Conroy, pers. comm. 1998)*

Agronomists identify other problems than soil scientists, and politicians have other interests than individual farmers (Ackoff, 1999). Even men and women can have different opinions on advantages of mixed farming (Feldstein and Poats, 1987), while conservationists take other decisions than cornucopians based on differences in mindsets (section 1.4). In the agro-pastoral systems of Western Africa it is hard to define the owner of the farm (man, woman, mother-in-law, bank or chief). '*Ownership*' may even be a non issue in some societies, to be replaced with users-rights in situations with communal land use (Bromley, 1992), and in the US or Australia it may also be hard to define the 'ownership of a farm, a crop or a herd, between in-laws, brothers or the seed company, in spite of formal agreements.

SSM tends to use boundaries, processes, goals and sub-systems as fluent notions rather than as real 'things' as tends to be done by HSM. The SSM looks at qualitative and quantitative resource flows in their system diagrams, e.g. issues of biophysical and socio-cultural nature, resulting in so-called rich pictures (fig 12). They differ from system diagrams as in figure 5 and 11, because they stress the use of several, even hard to quantify resource flows like emotions, while also reducing an emphasis on strict definition of system boundaries. SSM sees a system as: *"a construct with arbitrary boundaries for discourse about complex phenomena to emphasize wholeness, interrelationships and emergent properties"* (Röling, 1994).

The notion of a goal or function also takes a different meaning in SSM than in HSM: *a system **has** no goal but **is given** one by the context* (Checkland & Scholes, 1990). A major issue in this mixed farming chapter reflects a flexible and 'learning' SSM mindset, asking *"whether mixed systems **can be** important **and for who**"*. It takes distance from the more static HSM question on "*whether mixed systems **are** important **and how much***" (Checkland, 1999). In practice, this implies a choice of farmers and/or policy makers who can for example explicitly aim to pass an "inheritable farm" to their children (Habtemariam Kassa, 2003). They can also 'decide' to focus on short-term profit of anonymous share-holders. In general, mixed farming is likely to get more attention in the conservationist mindset than in the cornucopian one. The choice of organic farmers for mixed farming systems is a case in point.

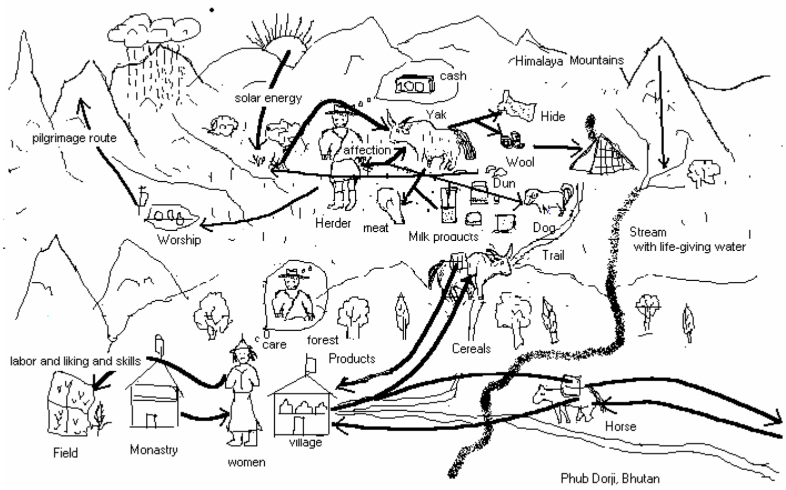


Figure 12. A rich-picture of between-farm mixing in the EXPAGR mode of Bhutan mountains. It shows how mixed farming consists of many components and relations, including biophysical ones like nitrogen.

c) Complex system methodologies (CSM) combine notions from HSM and SSM, that stress the interconnectedness among systems, also between issues of matter and mind. CSM also stresses that systems are variable and mixed at several levels, i.e. that the future cannot be predicted, but that patterns repeat themselves. This notion limits and expands the options for policy setting in a strange contradictory way. Further, and in terms of perception and scales, CSM stresses that the severity of a drought depends on for example the stakeholder point of view. A disastrous drought for a cash-strapped farmer in one year may appear a 'blip' on long term trends studied by macro-economics (fig. 2). In terms of interconnectedness, CSM stresses that a small event can cascade into larger mode changes, reflecting the notion of the butterfly effect from chaos theory (Gleick, 1987). For example, in integrated mixed systems a failed harvest in one year can lead to stress and subsequent illness in the family or animal herd, a related lack of cash or motivation, resulting in eventual collapse of the system. It is obvious that CSM thinks less rigidly about boundaries and relations than HSM.

Basic CSM notions now start to trickle down into main-stream thinking on agricultural development, e.g. in the notions of complex adaptive systems (see point "f" below) and inherent uncertainty, as well as use of notions from thermodynamics. Particularly farmers and researchers in mixed systems of uncertain semi-arid regions, however, have known aspects of complexity as a fact for many years (Behnke et al, 1995). The CSM interpretation of farming systems reflects principles that are described by other sciences in other ways, e.g. psychology, meteorology, epidemiology or pure physics (Odum, 1975; Prigogine & Stengers, 1985; Gunderson & Holling, 2002; Schiere et al., 2004a). Perhaps the most relevant principles of CSM are that:

- dynamics and variation are part and parcel of system behavior;
- specific patterns tend to repeat themselves.

The strange contradiction in these two principles means that nature - and the future - are inherently uncertain, but that one can recognize and sometimes even predict repetitive system behaviors.

3.4. Mode changes, variation, learning and similarity in mixed crop-livestock systems.
Mixed farming in semi-arid regions provides many cases to illustrate this variation and repetition of form and processes, as already apparent in the section on classifications. This section first discusses some general system behaviors and then takes cases of mode change in mixed systems from different parts of the world to show how HSM and SSM aspects combine into CSM phenomena such as mode changes associated with paradigm shifts. Some of these repeating patterns are:

a) *Emergence, self-organization and co-evolution,* i.e., the way that farming emerges in relation with its biophysical and socio-cultural contexts. Driving factors include rainfall (table 1), input and output prices (table 3), social pressure for high yields, and teaching on 'parts' rather than on 'wholes'.

b) *Lock-in* or *path-dependence* implies that systems can start to develop in a fixed direction that prevents change (Arthur, 1999). For example, use of specialized machines results in crop-choices determined by equipment-economies, rather than by water-use efficiency that initially may not have been an issue. Research traditions and peer reviews can lead to similar lock-in. Likewise, loss of local seeds or landraces can result in "lock-out", i.e. making it impossible to "return" to previous systems. Importantly, lock-in occurs in both HSM and SSM aspects of mixed farming, habits can result in from machine-choice as well as from acquired mindsets!

c) C*ommunal ideotype (as opposed to an individual ideotype)* refers to the tension between high individual yields and plot or herd yields, i.e. the choice for yield of parts rather than of wholes (Jones and Sandland, 1974; Donald, 1981; Schiere et al., 1999). To utilize the potential of a mixed system at a farm level one may indeed have to adjust the yield of the sub-systems (Table 9; figure 16). By extension, the single attention to grain-yield may go at the expense of soil organic matter, and attention for animals may go at the expense of the crops, illustrating both the need and difficulty to use the triple bottom line. The notion of the communal ideotype also provides additional explanation for the fact that some mixed blessings of mixed systems occur at both sides of table 2 where the general inventory does not specify level of system hierarchy at which the mixed blessing occurs.

d) *The algae principle* is apparent in many graphs in this chapter, e.g. in fig.1, 9 and 10. It describes how 'simple' systems need less maintenance, but are also less capable of processing resources. In other words, at low resource fluxes like <500mm rainfall, only sparse rangeland vegetation can survive for use in livestock production. At higher resource fluxes it is possible to have more output, but the organisms that process the resources also need more maintenance due to their higher 'complexity'. In the simplified case of figure 1 the crops do not grow well at <500mm rainfall, but at > 500 mm the crops process more resources than the grasses. The principle was found by Elenbaas (1994) for green and blue algae. Much if not all of it can be generalized since it has explanation in thermo-dynamic theory (Schiere et al., 2004a).

e) *Predator-prey cycles* refer to conditions where consumers, politicians, individual farmers, plant populations or animals act as predators on the resource base. Notions like *stability* and *resilience* are related to these behaviors in which stability refers to the pressure a system can take before breakdown, and in which resilience can be seen as the capacity to return to its previous state after collapse (Holling, 1973). The predator prey cycle occurs where foxes prey on rabbits, but also where farmers reduce their grazing and/or cropping pressure to make the resource base survive (Noy-Meir and Seligman, 1979; Heitschmidt et al., 2004; Bromley, 1994). One way to "survive" in a stressed mode is to adjust behavior, mindset and production process, a form of learning that applies to both biophysical and socio-cultural aspects of farming communities (sections 3.5.2; 5.3.2 and 5.4.3)

f) *The adaptive cycle* is a behavior in which systems tend to first develop fast, independently and inefficiently in the so-called r-strategy, i.e. the diversified type of mixing of EXPAGR and HEIA in figure 5. After that, systems tend towards integration with more recycling of each other's resources in the so-called k-strategy, essentially found in weblike modes of LEIA and NCA of table 3 (Gunderson & Holling, 2002). An added feature is the r-strategy of EXPAGR and HEIA that are less interrelated, less efficient but with higher redundancy and therefore higher buffer. It tends to be better capable to withstand shock because each part can stand on its own. The k-strategy of LEIA and NCA is more efficient, but it has less redundancy (reserves) and it is more sensitive to disturbance due to the higher inter-connectedness and less buffer than the r-strategy.

g) *Fractal behavior* refers to repetition of form and processes at many system levels in space and time (Mandelbrot, 2000). The fractal nature of mixed farming systems shows where a system is mixed (in space) at animal, plant, herd, plot, farm, village, regional and (inter)national level (section 2). In time it shows when (ir)regularities of, for example nutrient uptakes, occur in hourly, daily, weekly intervals etc. Mixing at higher levels of space can have advantages, but it tends to be more energy intensive, because of the costs for communication and the need to recycle resources between parts at larger distance (trucks replace oxcarts and dungbaskets). Thus, it should be no surprise that cheap energy shifts mixing into higher levels of system hierarchy, e.g. from on-farm mixing in LEIA (with little energy) to interregional mixing when specialized HEIA farms dispose nutrients to cropping systems at larger distance (table 3 and figure 5). A good case of mixing in time is a plot that has wheat in one year and that is fallowed in the following year.

Many other 'patterns' exist and recur, often in fractal fashion, e.g. *hibernation* (the capacity of a system to survive temporarily at lower maintenance); *depopulation* (where existing 'species' such as businesses, cropping patterns, management practices, cultural traditions or tribes disappear by migration and/or starvation); and the *tragedy of the commons* (exploitation vs. conservation of the common goods) (Hardin, 1968; Bromley,1994). Some more of these are discussed as non-linearities in section 5.2. The point here is that systems and their contexts continuously change (each other) at various levels, and as part of overall system dynamics. At the same time, and with some practice, it is possible to discern similarity and repetition of patterns, thus enabling one to learn and to predict. This notion of dynamics and learning, if true, implies *acceptance of variation* and the non-equilibrium paradigm that does not think in definitions and static solutions, but in characterization, variation and repetition of patterns (Behnke et al., 1995; Parker & Stacey, 1994; Marcussen, 1999; Schiere et al., 2004a). The rest of this chapter mostly uses the term non-linearity for aspects related with non-equilibrium system-behavior.

3.5. Mode changes in mixed farming

Many practical examples of repeating biophysical and socio-cultural mode changes have already been shown, e.g., in figure 1 from pastoral with mixed herds to mixed crop livestock systems and between the columns of table 3 and in figure 14. A decisive mode change for US farming was the dustbowl some 80 years ago (section 5.3.2), which led to a massive paradigm shift in farming. From rather specialized cornucopian monoculture of cotton, farming changed into more conservationist forms of mixing and even to other ‘mixed thinking’ with crop-rotations for sustained long term yields. More mode changes are likely in the US plains due to declining water aquifers, as in many tropical mixed systems (towards specialization) due to greater access to inputs, and in temperate specialized systems towards mixing due to problems of waste disposal. All this provides direction to policy setting, e.g., rising energy prices are likely to re-establish the relevance of mixed farming, and especially the integrated forms of LEIA and NCA. Today, the highly innovative efforts at finding perennial grain crops for better farming in the dry regions of the North American plains represent another typical paradigm shift and mode change (Cox et al., 2004; Jackson & Jackson, 1999). In such a mode change one can see the fluidity of the distinction between hard and soft issues, and close interaction between issues of matter and mind. Such mode changes at the regional level that both concern the management of mixed systems, but in different guises, are now given.

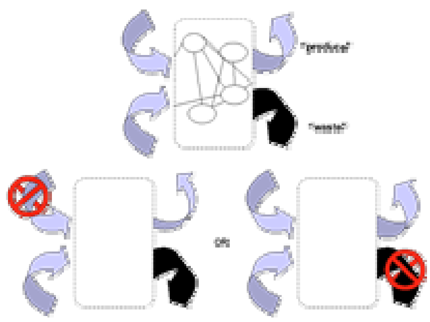


Fig. 13. Different causes resulting in similar mode changes. The top figure represents a system as in figure 11. In the lower left hand figure the input supply (e.g. fertilizer, water, feed) is disturbed. The lower right hand figure shows a problem with ‘waste’ disposal (e.g. dung, straws, etc.). This case is discussed in 2.4.5 for changes due to either less access to fossil fuel in poor, and problems with “waste” in richer contexts..

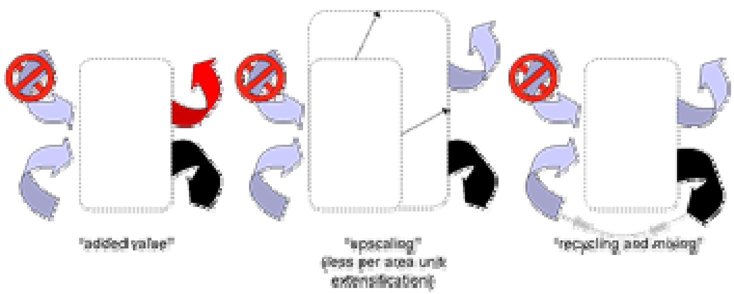


Fig. 14. Three strategies to overcome reduced resource flows of Fig. 13. The left hand figure illustrates use of added value (see darker shading produce arrow), the central one emphasizes larger scale, the right hand one chooses recycling and mixing to maintain resource flow *in* the system.

3.5.1. Non-equilibrium approaches, a new paradigm?

The more traditional ecological notions of steady successions from 'lower' to more stable and 'higher' states is increasingly challenged over the past decades by what we call CSM notions of non-equilibrium, both for socio-cultural and biophysical systems (Parker and Stacey, 1994; Hodgson, 1996; Gunderson and Holling, 2002). The new line of thought tends to hypothesize that an ecology in arid regions with high rainfall variability is determined by a combination of climatic and biotic factors of which animal grazing is only a part. The argument implies that 'rangeland degradation' or 'desertification' is not caused by overgrazing alone. They may be part of a natural process of vegetation decline and growth in response to rainfall, which ruminant numbers merely follow. An analysis with data from the People's Republic of China on rangeland policy shows no strong evidence for the proposition that in a non-equilibrium system, animal herd growth and decline are primarily determined by the level of precipitation. It appears, however, increasingly likely that other factors may be at play, including soil properties and the socioeconomic and institutional environment. Similar concerns have been expressed strongly for African rangeland, i.e., that governments should re-assess their notion that a drought is to be coped with by traditional approaches, e.g., drought feeding strategies. (based on Ho, 2001; Behnke et al., 1995; Leach et al., 1999; Garcia, 1981)

3.5.2. A mode change in mixed farming from Machakos (Kenya)

A typical case of population pressure as a driver of mode changes in time is that of Machakos district (Kenya). The key of this system lies in a variety of livestock feeding methods. In the past, possibilities to integrate crops and livestock were neglected and the contribution of livestock to household -cash- income was limited. Farming systems were of the diversified kind. One way to change was to establish individual titles to land, visualized in demarcation and enclosure of grazing areas, a mode change in socio-cultural aspect. After this, some farmers recovered and developed the grazing areas to provide grazing, timber and fuel. They use multipurpose animals, they do not aim at fast maturity, they even accept seasonal weight loses of their livestock, but they aim at high production on an area basis (section 5.4.1). Higher stocking rates can now be maintained using crop residues, i.e. increasing population led to reduced grazing land areas, a change in the role of cattle, and replacement of livestock by crops as the main source of cash. Adjustment was a key to sustainability and "drivers" like shortages of land in parts of the district, combined with a national economic recession, local leadership, high costs of education and other expenses for raising children, led to voluntary family planning. Also, the process was supported by a program in which people that had migrated to the city sent money back to the villages the process.

The evolution of the Machakos system in time, however, differed in space between drier and wetter areas of the district, and it depended on farm size:

- in the semi-arid region, animal draught power was important in various water conservation techniques, reducing risks of crop failure. Farmers on smaller farms combine wet-season grazing with dry season use of crop residues, while larger farms rely more on grazing
- in the sub-humid region, where high population density leads to very small farms, draught power is no longer necessary and cattle are valued more for manure and milk.

In general, where land is scarce, fodder production is combined with soil conservation and stall feeding or tethering. Mixed farming changes mode from diversified into integrated. And other ways of range improvement such as hedging, fencing, bush and indigenous tree management and scratch plowing become attractive because they need labor but almost no cash (based on Slingerland, 2000 and Tiffen et al., 1993 and1994).

Section 4: Linear aspects of "technologies" in mixed farming.

4.1. General

The notion of 'linear aspects of technology' reflects thinking in terms of straight-forward solutions. Clear distinction between linear and non-linear is impossible, just as it is impossible between hard and soft aspects of system thinking. The differences are maintained, however, to ensure that their essence is taken into account, and to reflect a deliberate choice for the use of the triple bottom approach for the study of (mixed) systems. In this section and the next, we present a brief overview of existing (non)linear technologies, but before that we make two additional comments on the term technology and its relation with the context of mixed farming. First, the term "technology tends to –unfortunately- imply a focus on "hard system" approaches, e.g., the use of machines, fertilizer, water, seed or marketing. We include soft aspects in technology, e.g. issues of management and mindset. Motivation and skills are clumsily considered as inputs, and satisfaction or social relations as outputs, a disputable but useful notion based on figure 11. Second, the context determines what is 'good or bad', in interaction with the system and its stakeholders. Therefore, technologies here are 'directions' to be chosen and adapted by the stakeholders, farmers and/or policy makers. Particularly mixed systems in semi-arid regions are highly variable and they occur in unfavorable and non-standardized conditions that make standard recommendations less than useful.

We start with some aspects of short term food supply. After that we discuss linear aspects that represent a rather random choice of technologies from the input side (crops, use of feed and fodder, breeds and tradition), from the output side (grain yield, milk, meat, dung, satisfaction) and from the management (allocation and combination of resources in the system).

4.2. Food and income from mixed systems: the short term

The carrying capacity, i.e., the capacity to 'feed' people from day to day can be considered as a linear and short term goal (=output) of any mixed system. The term "feeding" is here to be taken in a broad sense, i.e., to also imply provision of clothing, food, and cash. In that sense, cropping alone can feed more people per hectare than animals and on the short term, except in harsh conditions (figure 1). With linear reasoning, the number of people fed by combinations of crops and animals is represented by a straight line C'L' in figure 15. In practice, however, there is non-linearity (Morrison et al., 1986; Schiere et al., 2002), i.e., the line C'L' becomes concave for badly managed systems, and convex when mixed farming is done well. The carrying capacity, expressed in Joules/area unit, declines with a factor 5 to 10 when proceeding from pure cropping on the left to pure livestock keeping on the right. But prices per Joule for animal products tend to be higher, also by a factor 5 to 10, so in money terms it often makes little difference to produce crops or livestock. In terms of linear 'food' production there is thus good reason to combine animals and crops, if done well.

4.3. Soil organic matter and food production: the long term.

Soil organic matter is essential for different reasons in different conditions, but its main role is to maintain the production potential of the long term food supply. Organic matter can function to supply plant nutrients to the growing vegetation for which is has to be decomposed. When *not* decomposed it plays a role in maintaining soil structure, moisture balance and soil fertility. Different cropping systems contribute to the soil organic matter balance in different ways and farmers in (agro-ecologically) well-endowed regions have intricate management practices to maintain soil organic matter levels across farms and plots, e.g. through leys or other special rotations. Farmers in poor contexts may decide to concentrate the compost or fresh organic matter on a limited area or just around the plants. On a larger scale, they take nutrients from the so-called outfields away from home to the in-fields near the farm house

(Giller et al., in press). Or women may decide to use the straw or leaves as fuel or animal feed, if not for sale. Some crops deposit their organic matter in the top soil layers, others have deep tap roots and still others form dense mats. Organic matter of legumes decomposes more rapidly than that of graminea like cereals or grasses; the stable organic matter remaining after decomposition or composting is approximately 5 – 20% of the original substrate (table 4).

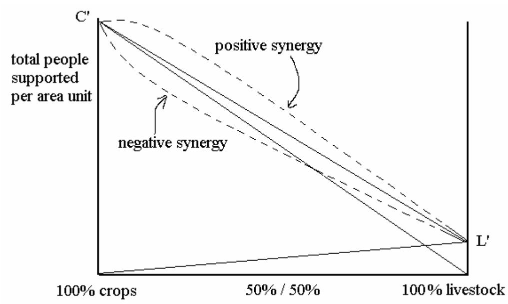


Figure 15. The number of people fed from crops alone (left) and by animals alone (right). Broken lines indicate what happens at various degrees of mixing crops and animals, with positive synergy shown in the "hump" of the broken line C'L', and negative synergy in badly managed systems as concave broken line C'L'. (See text).

Table 4. Lignin content and humification coefficient (h for five types of organic material, determined in a 10-year pot experiment (based on De Haan, 1977)

Organic material	Lignin (% of DM)	h (%)	
		Sandy soil	Clayey soil
Grass	8.0	37	24
Wheat straw	11.2	25	27
Cattle feces	21.7	47	40
Farm Yard Manure	29.0	60	57

Note: the humification coefficient is the fraction of the organic matter that remains after one year.

Animals affect soil organic matter levels by grazing, trampling, compaction and/or by depositing soil nutrients in manure, or else by allowing crop rotations that include a fodder crop. A typical rotation with livestock in the system is use of grazed grain crops, or of leys (an improved fallow), where fodder crops regenerate the soil more rapidly and differently than a natural fallow (Lopez-Bellido, 1992; Perry, 1992; Bosma et al., 1994; section 4.31). More intensive crop rotations include "ley"-crops at a rather short time scale of one season, instead of one or more years. For example, farms in the semi-arid and irrigated Gangetic plains and Nile delta depend on a mix of legumes and mustards (oil-seeds) mainly grown in winter. They help to maintain soil nitrogen levels and possibly even to mobilize phosphorus (Hoffland et al., 1989), while providing soil organic matter through root systems, stubble and manure. In the end, sustained cropping with annuals alone is likely to deplete soil organic matter levels. Remarkable in this sense are mode-changing attempts to design systems with perennial grains. (Pimm, 1997; Jackson & Jackson, 1999; Cox et al., 2004).

4.3.1 Ley systems.

In dryland semi-arid agriculture, a ley system is a way of farming where grass and/or legumes are grown in short rotation with crops (Lopez-Bellido, 1992; Perry, 1992). Ley systems can be a useful alternative to continuous cropping with annuals, e.g. because of:

- positive synergy due to physical association of crops and animals, where animals graze crop residues and higher quality pastures while returning nutrients to the soil in manure
- Nitrogen and soil organic matter (SOM) build up during the pasture rotation provides

nutrients for subsequent crop production.
- Amelioration or reduction of soil physical degradation and/or erosion due to over-cropping.
- Break the life cycle of soil and stubble borne pathogens

A ley system can be better than either sole cropping or livestock, if well done. In semi-arid systems, the most commonly quoted advantage is that legume based pastures provide better animal feed and leading to build up in soil-N for the subsequent cropping phases (‘tMannetje, 1997). Ley systems are particularly useful for so-called mediterranean systems with dry hot summers and wet cool winters (section 2.3). McCown *et al.* (1987) showed in southern Australia that an ideal context for ley pastures occurred when economic conditions favor a high proportion of pasture to crops. As profitability of cropping increased relative to livestock production, farmers were growing crops at the expense of pasture leys, replacing biologically fixed nitrogen with inorganic fertilizer. A case from mixed farming in central Queensland shows that a combination of high cattle prices in the late 1990’s, declines in grain protein content and lower returns from cereal production, prompted farmers to grow pasture systems on land usually used for cereal production. Plantings of *Clitoria ternatea* (butterfly pea) have increased from 500 ha in 1996-97 to 30,000 ha in 1999-2000 (Doughton *et al.* 2001).

A different case of ley systems occurs in dryland cropping systems for most of the North American Great Plains that utilize fallow periods within cropping sequences to store precipitation as soil water that, consequently, increases yield. The resulting inefficiency of precipitation use, however, encouraged efforts to intensify crop sequences by introducing legume production during a “green fallow” (Schlegel and Havlin, 1997). These crops consumed soil water and reduced yields of the subsequent grain crops in Kansas. But in regions where water is not the most limiting factor for crop growth dryland legumes may succeed in limited forage production. Depending on cultivar, Walsh et al. (2001) concluded that forage production was adequate for grazing and potential expansion of mixed cropping systems in southeastern Wyoming. The ley cropping system using Austrian winter peas (*Pisum sativus* subsp. *arvense*) as a grazing forage grown within the wheat (*Triticum aestivum* L.) fallow rotation practically doubled the net economic return compared with the conventional wheat–fallow cropping sequence (Krall et al., 2002). Economics aside, dryland cropping systems also benefit from soil erosion control provided by the crop cover during the intervening 14-month fallow. This system is principally experimental and rarely applied by farmers in the Great Plains, except for the eastern fringe. This exception shows once again the variations between (mixed) farming systems and their contexts, the niche suitability of technologies, and the need to classify systems before coming to specific statements.

Ley farming is also found in more humid (high altitude) dairy systems of otherwise diverse ecologies in for example Western Europe and Eastern Africa (Stobbs, 1962). Ruthenberg (1980) describes how the drier lower altitude areas of Africa have conditions (drivers) that do not favor ley farming, e.g. lack of fertility improvement with grass leys; unfavorable capital / output ratios associated with intensification demanding greater labor and capital inputs, dependence on improved animal husbandry practices and the requirement of increased marketing and pricing incentives. McCown (1996) even argues that appropriateness of leys as a development option should be questioned in all but special circumstances. Even if technical and infrastructure problems of ley farming are solved, Ruthenberg (1980) say that population pressure tends to rise to levels that need intensification beyond that of leys to continuous cropping. Since that time, however, many technical and infrastructure problems have been overcome. Legumes can replace or augment grasses in the pasture phases of leys (‘t Mannetje, 1997). Livestock markets developed in many areas, creating cash flow and incentives to change animal husbandry. New land for crop production is limited and overuse of existing land for crop production has resulted in soil fertility decline and low crop yields. Wortman and Kirungu (2000) formulated for African conditions some 16 boundary conditions driving successful adoption of forage legumes, e.g. the perception and knowledge base of farmers; land size and tenure; attitude to risk; labor availability; legume type and value to name a few. Pure ley farming with long-term scales is rare, but use of dual purpose forage/grain legumes in inter- or relay-cropped maize is a common practice in many places.

4.3.2 Collection and use of animal excreta.

Mixed crop livestock farming in conditions of abundance of land is often based on grazing of extended outfield areas to concentrate nutrients through manure on infields near homesteads (EXPAGR in table 3). This is still common in the agro-pastoral systems of Western Africa (Fussel, 1992; Schlecht et al., 2001 and 2004; LaRovere et al., 2005. The outfield/infield ratio for sustained cropping in such systems ranges from more than 15÷1 to 0.5÷1, depending on conditions and management (table 5). Large efficiency gains are possible by more intensive manure and crop residue management, and many alternatives exist although supplementary fertilizer use is difficult to avoid on the long term (Powell et al., 1995; Enyong et al., 1999; Schlecht & Buerkert, 2004). Intensified management involves the transition from burning crop residues to residue grazing including collection and stall feeding. Nitrogen loss from urine through livestock may account for 2/3rd of the ingested amounts, and poor cropping or manure application can nullify conservation efforts aimed at dung alone. Overall, the dung and urine flows represent an essential relation between crops and livestock (table 6).

Table 5. Some outfield/infield ratios for sustained cropping in Western Africa (based on Breman, 1990).

Ecosystem /	Farming system/ Production target	Required ratio
Northern Savannah	Feeding draught oxen	0.5 – 4
	Breeding + feeding draught oxen	10
	Breeding + feeding draught oxen + maintaining soil fertility	15
Southern Savannah	Feeding draught oxen	1- 2
	Breeding + feeding draught oxen	8
	Breeding + feeding draught oxen + maintaining soil fertility	15

Table 6. Effect of dung and urine applications on pearl millet yields (all based on Powell et al., 1998)

Animal type	Manure applied first year†	Cropping season following manure application†					
		First		Second		Third	
		Urine application‡					
		Yes	No	Yes	No	Yes	No
		Mg ha^{-1}					
Cattle	3.1	5.5	3.6	2.4	2.0	2.6	2.5
	7.1	6.0	4.2	4.6	2.7	4.9	2.8
	10.1	5.9	3.8	4.0	2.9	4.5	2.9
		(0.40)§	(0.28)	(0.58)	(0.29)	(0.74)	(0.35)
Sheep	1.5	5.0	3.0	2.6	1.7	2.2	2.2
	3.2	5.8	3.7	2.6	1.7	3.4	1.9
	5.0	5.7	4.0	2.7	1.8	3.6	2.4
		(0.24)	(0.36)	(0.23)	(0.22)	(0.29)	(0.26)
Control (n=4 plots)	0	3.0 (1.41)		0.9 (0.23)		1.1 (0.34)	

Note1: (†) Manure applied in 1990 (first year) only. Yields during second and third cropping season reflect millet response to residual manure from the first year.‡Manure applied either by corralling animals on plots for 1, 2 or 3 nights (urine "yes") or manure hauled from the barn (urine "no"). § SEM in parentheses

Simple calculations show the magnitudes of the losses as in the following cases, with rounded off figures and based on De Ridder & Van Keulen (1990):

- a field with a 20 cm tillage layer contains .2 * 100 * 100 m^3 topsoil per ha. With a specific bulk density of 1.4Mg/m^3 that represents 2 800 000 kg topsoil. If such a soil has an organic carbon content of 3 g/kg (or an organic matter content of roughly double that value), and a relative rate of decomposition of soil organic matter 0.06 yr^{-1}, then 500 kg of carbon is required to maintain that organic carbon level. Different organic materials have different humification coefficients, i.e. 0.5 for straw, 0.3 for animal manure and 0.2 for compost. To maintain the organic carbon content at 3 g/kg one needs roughly 2250 kg of straw (C-content 0.45 kg/kg), 4800 kg of animal manure (C-content 0.35 kg/kg) or 8500 kg of compost (0.3 kg/kg), all expressed in dry matter per ha.
- corralling can save considerable amounts of nitrogen and organic matter for application on the infield, thus reducing the required wasteland grazing for nitrogen supply of the crops! A cow of 300 kg body weight, ingesting 2% of its bodyweight daily in terms of dry matter ingests about 2200 kg of organic matter annually. With a digestibility of 55%, that implies production of 990 kg of dung for manuring. Consequently, the soil in the above example requires about 5 animals to meet the organic matter requirements per ha.
- burning of some 3000 kg dry matter (straw) per ha (the “waste” from approx. 2000kg grain) with 4% crude protein or 0.65% nitrogen makes roughly 20 kg of nitrogen go up in smoke, i.e. the equivalent of approx. 50 kg of urea, in addition to potential soil organic matter and/or valuable mulch
- using straw as bedding is a way to keep the straw nitrogen in the system, together with part of the urine-N of the animals (6-12 kg N/ 1000 kg straw dry matter). Urine contains roughly 60% of the ingested nitrogen, and an animal of 400 kg, ingesting 8 kg of dry matter daily with 12% crude protein, excretes approximately 35 kg of nitrogen annually. Again some 75 kg of urea is saved because urea-N from urine will almost completely volatilize as ammonia.

Bio-physical, economic and socio-cultural aspects of mixed farming interact, the basic notion in this chapter on mixed farming. In that sense, farmers have more to worry about than only nitrogen balances or soil organic matter. They have to manage conflicting labor needs, neighbors’ attitudes, cultural practices and cost-price ratios. Farm realities are mixed realities, but calculations like the ones given above do show some basic ‘linear’ rules of the game for improved management of mixed systems.

4.3.3 Crop residues for feed, fuel or fertilizer.

In our opinion, crop residues can be considered to consist of tree-leaves, weeds, grasses, legumes from leys as well as grain straws. This approach of stretching the variation fits the ‘tradition’ of this chapter that aims to discern repetition of patterns by increasing rather than by narrowing the scope. For that reason, we also consider crop-residues to include by-products of food processing (milling of grain; oil extraction from oil seed crops, ginning of cotton). Each of these products can play a role in mixed farming in semi-arid areas, and it is typically a “mindset” issue to see crop residues as ‘resource’ rather than ‘waste’ or ‘by-product’.

The different residues can be used as feed, mulch, bedding for animals, fuel, compost, building materials, soil amendment for erosion control, or as cash-income if sold for paper manufacture or used for mushroom cultivation (Staniforth, 1982). But this use of crop residues requires a classification as done in section 2 for mixed systems. Two classifications are given here, one from soil science and chemistry (table 7) and one from animal nutrition (table 8). Importantly, they illustrate a) conflicting *and* complementary use of crop ‘residues’, and b) different perception between academic disciplines that can be solved by addressing issues of semantics. For example, the notion of "*good and poor quality*" is almost reverse for animal nutrition and soil improvement, providing a potential win-win situation in mixed farming. Nutritionally good quality feed is highly digestible that rapidly decomposes after incorporation in the soil. This leaves relatively little stable soil organic matter, and it makes the rather abundant nitrogen susceptible to leaching or volatilization. Nutritionally poor quality residues that are not well digestible leave much organic matter that decomposes only slowly (Palm et al., 2001a; Giller, 2000). In other words, what is good for feed is not so good for the soil and vice versa.

Table 7. Proposed categories of organic materials based on N, lignin, and polyphenol contents and their hypothesized effects on nitrogen supply and soil organic matter (Palm et al., 2001a)

Resource quality category	Resource Quality Parameters *N, lignin, soluble polyphenols* (g kg^{-1})	Nitrogen supplying capacity	Soil organic matter formation
High quality	N >25, lignin < 150 and polyphenol < 40	High and immediate	Little or negative effect on total SOM; increased active fraction (microbial biomass)
Intermediate-High quality	N > 25, lignin > 150 or polyphenol > 40	Delayed, short or long term	Increased particulate (light) and passive fractions
Intermediate-Low quality (Short term)	N < 25, lignin < 150 and polyphenol < 40	Low – Short term immobilization	Little effect on total SOM
Low quality (Long term)	N < 25, lignin > 150 or polyphenol.> 40	Very low and possibly immobilization	Increased particulate (light) and passive fractions

Table 8. A classification of crop residues according to crude protein content (CP), content of digestible energy (TDN), C/N ratio and CP/TDN ratio (based on Schiere & De Wit, 1995).

Crop residue type	CP%	TDN%	C/N ratio	CP/TDN
Category I: good quality			Approx.	
Oilseed cake	28	70	10 – 25	0.40
Concentrate feed	15	65		0.23
Legume tree leaves	24	60		0.40
Category II: medium quality			Approx	
Medium quality grass	12	60	20 – 40	0.20
Rice bran	11	55		0.20
Mature tropical grasses	10	55		0.18
Category III: poor quality			Approx.	
Maize stover	6	50	40 – 90	0.12
Rice straw	4	45		0.09

Note: values are approximations .

The low feeding value of straws and stovers is a problem if they are to be used as animal feed. However, this 'problem' exists *partly* in the minds of academics only and the importance of 'perception' and 'mindset' as stressed by SSM surfaces again. Farmers in arid regions have learned to live with low nutritive value, they adjust their crop choice and feeding strategy, or they do not even consider straw to be a feed. They can burn it, sell it, use it as mulch, bedding, etc. Still, fibrous crop residues can be important as animal feed and the low feeding value can be overcome in many technical -linear- ways that are, however, not always economically feasible. These methods include chemical processing, alternative crop selection and supplementation strategies (Sundstol & Owen, 1984; Owen & Jayasuriya, 1989; Schiere & Nell, 1993; Kiran Singh and Schiere, 1995).

Section 5: Non-linearities in mixed systems.

5.1. General

Complexities and trade-offs were only mentioned in passing till now. They are the main topic in this chapter however, elaborated as ‘non-linearities’, a term that aggregates processes that do not behave in a straightforward manner. They include curvilinear responses and mode changes such as between the columns of table 3, and in figure 1 where pastoralism is replaced by mixed farming when rainfall exceeds 500 mm. Economists call this ‘break-even’ points, but non-linearities also occur beyond economics. They can be both nasty and pleasant, depending on the stakeholder and his/her mindset, becoming visible when considering the effect of more than one driver at the same time. This is away from a specialist focus, and towards the integrative approach that looks at the combination of fertilizer and planting density, rain, markets and population growth. Non-linearities are inherent in work and mindsets for mixed systems, and in the use of the triple bottom line that pays attention to several criteria at the same time. In fact, linear behaviors do not exist, just like ‘non-mixed’ systems do not exist (section 2). It can be useful to assume linearity over a narrow range, e.g. to establish how much water is required per gram of photo-synthesis, or labor required to milk a cow. But non-linearities are rule, no exception. They deserve more attention in research, teaching and policy making than thus far. This section first reviews a set of simple and common sense non-linearities with relevance for mixed systems. It then discusses specific cases of non-linearity in mixed systems at plot-, herd-, farm-, regional and national level to illustrate the general validity, excitement and challenge in these notions for future work.

5.2. Non-linearities and surprises, some text-book examples

The following rather random series of comments and examples on non-linearities ranges from common sense to far-fetched and it is sequel to the part on repeating behaviors in section 3.4. It is followed by practical cases that can be better understood with the principles given here:

a) non-linearity in a very basic form occurs as convex dose response curves (fig 16) where an initial response to an input like for example nitrogen tends to be high at first, eventually tapering off assuming other factors remain unchanged. This illustrates, as important sideline a major difference between on the one hand linear (equilibrium) approaches that think in terms of ‘*ceteris paribus*’ (all other things remaining the same), and non-linear / non-equilibrium approaches on the other that think in terms of ‘*ceteris non paribus*’ (all other things changing).

b) *non-linearity as mode change* occurs when one response curve intersects with a second one (fig. 16). This requires a ‘choice’ by the farmer (or policy-maker) to decide the level of input as well as on the type of crop or animal to be used. A typical case was figure 1 where ‘farmers’ have no reasonable choice to mix animals or crops below approx. 500 mm rainfall, but beyond which ‘he’ can chose between crops and/or livestock. Note that the range below 500mm allows choice to mix animals. This represents fractal behavior, i.e., repetition of behaviors at various system levels where the choice of animals or crops becomes a choice for animal A, B or C (section 3.4.d). In case of such non-linearity a policy maker at the regional level can avoid or accelerate mode change, deciding for higher / lower resource flows in the region, e.g., by subsidizing or taxing the respective input or output. Choice by farmers at the plot level occurs where higher plot yield in fig. 16 is first achieved by denser planting, after which it is only achieved at the expense of individual plant yields according to the principle of the communal ideotype (section 5.4.1).

c) *non-linearities as small –chance- events that have large -irreversible- effects*: A particular system (farm, region, animal or crop) may be rather stable over a given range of drivers in space and time. A freak weather pattern or wrong reading of long term resource patterns, however, combined with for example persistent overgrazing, excessive cropping or political change can trigger irreversible processes (section 5.3.1).

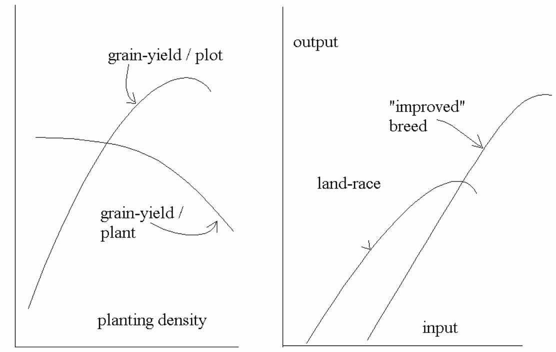


Figure 16: Non-linearity in plot *and* individual plant-yield (left) showing how progressive increases in planting densities affect individual plant performance (based for crops on Cocks, 1985; with striking similarity for livestock by Jones and Sandland, 1974). The right hand graph illustrates non linearities in a more basic form of the algae principle (3.4).

d) differences often increase rather than to diminish. For example, a farmer in LEIA systems where dung is scarce (table 3) is likely to apply the dung and/or irrigation water around the plant only, or on soils that yield most. Thus, poor soils get less while they would need more for sustained farming (P. Motavalli and M. Anders, pers. comm., 1992; Giller et al., in press). In the same way, animal keepers tend to give the best feed to the highest yielders, and in mixed systems the farmers tend to allocate more resources to crops than livestock, or vice versa depending on which part of the whole yields more (section 5.4.3). In socio-cultural and political terms, the poor get poorer while the rich get better, especially in contexts with restricted access to resources.

e) averages vs variation. Use of averages is a handy way to cope with variation, but it gives other results than use of desegregated values. For example, feeding calendars based on average values and availability of crop-residues miscalculate carrying capacity (fig.17), and nutrient balances differ, depending on the scale used in the study (Schlecht & Hiernaux 2004). LEIA systems with little access to external resources cannot well correct local deficiencies of for example nutrients, water, information, motivation and / or skills regarding the uncertain future. As a result, they handle variation in different ways than HEIA, and even those systems now start to see advantages of recognizing patchiness within farms. “Precision farming” in crops involves, for example, sensing meter-scale variations in soil fertility, correcting these at the time of fertilizer or seed application. LEIA systems are keen to “exploit” local variation because of lack of inputs, cornucopian HEIA systems are interested in local variation to reduce waste disposal problems, and an associated possibility to reduce expenses. Conservationist NCA systems are keen to work with variation in order to be better stewards of their land. The similarity of LEIA, HEIA and NCA in this respect was shown already in section 2.4.5 and fig 13 and 14.

f) issues of scale are part and parcel of the previous point on use of averages and they also occur in the difference of between and on-farm mixing (fig. 5 a/d). Between-farm mixing tends to lead to larger plots and herds per farm, even when the total area of one crop or type of livestock remains the same in the region. And one might here hypothesize that larger scale tends to increase energy costs and disease incidence. And of course there are other non-linearities here too. Financial costs and biodiversity indexes are likely to be less per unit product, if large scale equipment is used on larger farms. Less farmers of larger individual scale also cause significant mode change (non-linearity) in the collapse of support services (machine shops, post offices, schools). In other words, unintended degradation of countryside and agricultural production may result from cheap energy, a typical non-linearity where too little is not good, nor too much (Odum, 1975). An additional but different issue of scale as stressed in CSM is the perception on irregularity of for example climate and prices on season and farm level. Individual farmers have to cope with short term fluctuations that tend to go unnoticed by macro-economists and general trend-watchers. Examples of that were given in the multi year average of figure 2. and in the arguments on the role of different crop- and animal species in maintaining farm cash-flow and stability (section 5.3.3).

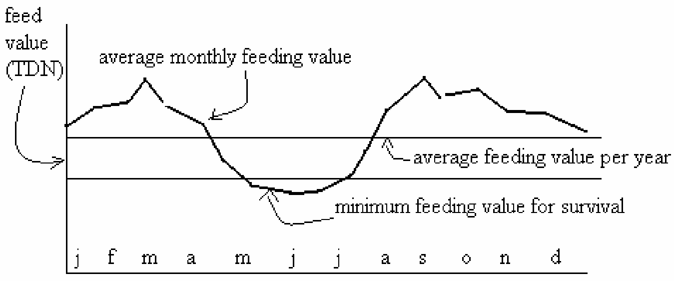


Figure 17. Use of averages versus variation in feeding calendars based on a study of mixed farming in the semi-arid eastern parts of Java (based on Zemmelink; 1986). The average feeding value (as system driver) seems to be good enough to support reasonable production levels through the year. Monthly values show, however, that feeding value in May - June are below what is needed, even for survival.

g) system dynamics due to different time and space scales. The diagrams with different time scales at mixed farms in fig 18 shows non-linearities in the sense that change of climate or cropping patterns can affect breeding schedules. For example, a late rain can upset the lactation of a cow, or labor calendars for local cropping and off-farm work. More hidden and mixed socio-cultural and bio-physical cases of differences in time scales is where seasonal, operational and community perceived "calendars" differ (Kersten & Ison, 1994). Typical biophysical examples of non-linearity occur where crops and animals differ in terms of 'inherent' time scales, e.g. where a C_4 crop can process more CO_2 per time unit than a C_3 crop (Hatch & Slack, 1970; Monteith, 1978). Such non-linearities also occur in case of animals, where as their (mature) body size increases, the maintenance per unit body weight increases with approx. the power 0.75 (AFRC, 1993). Feed intake is proportional to maintenance, i.e. the turnover per body-mass and unit of time is higher in small than in large animals. In other words, small animals have a higher turn-over and they can eat more per unit time and per kilo body weight. Small animals also tend to reach their mature weight earlier and reproduce more rapidly (cf. Guinea pigs vs. cows). In other words, time scales of mixing change with body size of animals. Sudden flushes of resource density can better be used by small than large animals. This is one reason 'pure' pastoralists have mixed herds of different animal species (goats, cows, camels) with varying time scales and foraging behavior (P. Leegwater, pers. comm., 1999). The effect also emerges in the choice for poultry as the most appropriate animal to value grain surpluses from 'bumper' crops of favorable years and in climatically variable regions. Variability in time scales is also a major consideration in decisions on the use of animal manure (or any other organic nutrient source). Decomposition of the organic materials and the associated mineralization of the nutrients is difficult to synchronize with the demand for nutrients of growing crops (Vanlauwe & Sanginga, 2004), representing an interesting management challenge for efficient farming. To some extent this can be controlled by selecting a material with specific chemicals, but the environmental conditions that co-determine the rates of decomposition are impossible to control, particularly in conditions of mixed farming in semi-arid regions. Finally, the time scale of soil degradation is shorter than of soil-regeneration (Fresco & Kroonenberg, 1992; Roose & Barthès, 2001).

h) non-linearity as irreversibility implies that a given situation cannot be restored. Situations can be *re*-created, but not by going in reverse (Scheffer et al., 2001). Environmental degradation, a fight between people based on an accident, malnutrition, one sided education and / or competition for resources can lead to permanent distrust, again showing the inter-relations between 'hard' and 'soft' aspects of system behavior (Van Haaften, 2002). The good news of such crises is that they can aid the mode change by adding sense of urgency, depending on local leaders and luck.

i) Input - output balances and resource use. Integrated mixed systems re-use nutrients and tend to prevent them from leaving the system. Also, animals digest organic matter quicker than what would happen in composting processes. This implies quicker nutrient turn-over, allowing a system to more often re-use them as much as to incur higher losses. In some cases the trees pump nutrients from the subsoil, and some crops mobilize phosphorous or fix nitrogen (Kang et al., 1990; Hoffland et al, 1989; Sanchez,1976; Ohlsson, 1999). This higher internal turn-over may help to incorrectly *and* initially suggest that systems can be closed, a notion that cannot be true (Von Berthalanffy, 1968). Nutrients can be re-cycled but some inevitably leave the system in produce or as a loss, and recycling itself needs energy input, e.g. from the sun.

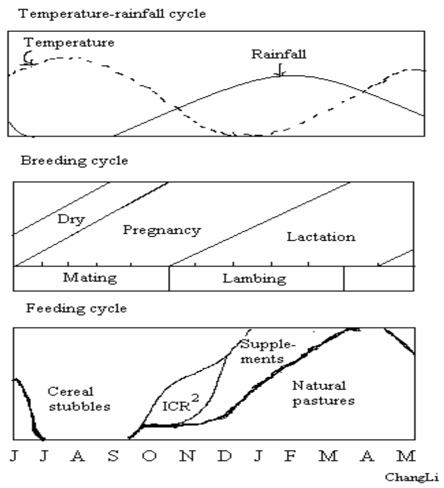


Figure 18: Different time scales in breeding, feeding and cropping (Thomson, 1987). A superscript '2' indicates that it is a crop residue based on irrigated cultivation; the caption to the y-axes is shown top left of each box.

5.3. Non linearities, practical cases

Many more examples of non-linearity can be given, but the available space leaves room for only a few more practical cases. They illustrate the close interplay between mindset and biophysical drivers at plot and regional level, as well as the importance for policy to use the triple bottom line approach.

5.3.1. Irreversibility in psychology, soil degradation, gene-pools and social skills

One typical example of irreversibility in biophysical terms refers to vegetation dynamics in drier parts of semi-arid areas where the woody component is often limited to bushes. The combination of deforestation, cropping, mind-sets, politicians and climate can disturb such apparent "bush" equilibrium, leading to rapid disappearance of the vegetation that leaves bare soil only. During intense rain showers, drops are not intercepted by vegetation but hit the bare soil and breakdown the soil surface structure into crusts that lead to run-off. The bare soil, although containing seed banks of annual herbaceous species, will have difficulty to produce a vegetation cover because this crust prevents infiltration of water. Neither the return of high rainfall years nor removal of livestock will easily lead to regeneration of vegetation, unless “mode-changing- management-concepts” are applied (Savory and Butterfield, 1999). In their approach, grazing can help break the crust, allowing the soil and vegetation to regenerate if done properly. One point to notice here is that non-linearities (new methods) are sometimes needed to solve problems caused by previous ones. Another is that animals in such systems are to be valued for their ‘holistic’ function, producing meat as well as maintaining the vegetation. Compelling analogies in other sectors of society occur where the loss of a particular social skill, gene-pool or cultural institution leads to irreversible change, also called lock-out as opposed to lock-in. In terms of mixed farming it may be more difficult to go from specialized into mixed, than from mixed into specialized, due to loss of skills, investments in equipment and even ‘holistic’ thinking. Keeping freedom of choice is one of the advantages of mixed farming (table 2). Principles and thinking from mixed farming have shown to offer useful alternatives in the case of Machakos in Kenya and even in the specialized HEIA systems in Western Europe.

5.3.2. The dustbowl in the central US plains, non-linearities in farming and thinking
Wind erosion during a sustained drought from 1931 to 1939 devastated almost 40 million hectares of range and farmlands in a five state area including Texas, Kansas, Nebraska, Oklahoma, and Colorado that was eventually named the “Dust Bowl” (Hurt, 1981). The most severely affected farmland was centered within a 160 km radius at Liberal, Kansas (37° 2’ N, 100° 55’ W). This once native range for the North American bison had been labeled the “Great American Desert” by explorer Stephen Long about 1820 (Price & Rathjen, 1986) suggesting a harsh and droughty environment. But subsequent Euro-American settlement expanded during periods of favorable rains from 1882-1887 and 1895-1906 (Johnson and Davis, 1972). Native rangeland was cultivated using tillage methods adapted from the more humid US regions that buried most of the plant residues. The booming wheat market in response to growing European demand during World War I, beneficial rains that averaged about 100 mm above the 515 mm norm from 1918 to 1929, and increasing agricultural mechanization accelerated cultivation that exposed millions of hectares of potentially erodible soil (Baumhardt, 2003). The subsequent drought from 1930 to 1940 triggered wind erosion of excessively tilled land and produced the Dust Bowl.

The drought area committee headed by Morris Cooke considered the nature and causes of the Dust Bowl and recommended “mode-changing-solutions” in a 1936 report to President Roosevelt (Cooke et al., 1936). They noted that “Dust Bowl” farming practices did not conform to natural conditions of the Great Plains. It had developed dependency on an adverse type of mixed farming of the EXPAGR type (table 3), based on overgrazing and excessive plowing, which exposed loose soil to the wind. The committee concluded that farming practices to reduce run-off and increase water storage in the soil were critical to agricultural success in a region of limited annual precipitation. However, the 1862 federal homesteading policy exacerbated land degradation by offering unrealistically small farm allotments for the semi-arid Great Plains and actually encouraged over utilization of pasture and cultivated land (Cooke et al., 1936) until corrected with larger land allotments in 1916 (Gray et al., 1938). In 1933, Hugh H. Bennett, director of new Soil Erosion Service, called for an awakening to improved farming practices that encouraged diversified crop production, combined with the use of improved cultural practices and tillage implements (Baumhardt, 2003).

Wind is common and drought recurrent on the Great Plains. Therefore, new management practices were developed and land policies revised to reward farmers for using contour plowing, listing, and strip cropping conservation practices (USDA-AAA, 1937). The Dust Bowl wheat mono-culture required timely fall and winter precipitation for crop establishment. It evolved into wheat-fallow and wheat-sorghum-fallow cropping sequences that used precipitation stored as soil water during fallow to improve crop establishment. Tillage practices that degraded structure or natural cohesiveness of soil were replaced by the new non-inverting Graham-Hoeme plow, which was capable of penetrating the hard dry soils, controlling weeds and retaining crop residue on the soil (Allen and Fenster, 1986). The practice of retaining crop residues on the soil surface during fallow increased precipitation storage about 20% (Greb et al., 1979), improved yield and permits limited grazing. Ultimately this resulted not only in different relations between people, crops, livestock and the soil, but also in different ways of thinking about agriculture. This non-linearity at level of farm, state and beyond combines 'soft' socio-cultural and biophysical aspects, as well as thinking and practice at farm and regional level.

5.3.3 Crops, livestock, assets and cash flows, more dynamics and surprises

Any standing crop or an animal herd implies flows and stocks of capital at different time scales. In annual crops the stock is the genetic value of the seed (in storage) while the flow is the crop produced in the field to be harvested and sold or consumed. In perennial cropping such as in orchards, the stock can be the tree and the flows the fruits, branches for animal feed, etc. Animals are added to the herd by purchase or reproduction, they are lost due to slaughter, sales, mortality and theft. Some of the flows are rather regular such as from daily sale of fruits or milk. Others are regular at larger time scales such as annual harvests or the sale of young animals. Increase in animal stock, for example, also occurs due to increases in animal body weight that can be "harvested" only once at sale or slaughter. Other embodied capital in crops and animals are the growth of the tree (volume of wood), the pruning status of the tree (ability to produce fruits), training status in draught animals and proven fertility or genetic merit in female animals or in collected seeds, to be harvested only when the product is sold or rented. The implication for mixed systems can be that net gains from crops may be higher than from certain animals (or vice versa). However, dairy animals and certain crops, for example, can be kept to maintain a steady income through milk, when for some time no cash flow from other farm activities takes place. Moreover, livestock has benefits over other forms of saving. Argentinean farmers are not "poor", but they also at some point took animals as a saving account when inflation rates were soaring. Livestock is resistant against inflation, and this was exactly what happened during the 80's and the beginning of 90's in Argentina. Livestock thus fulfills many interrelated socio-cultural and biophysical functions that affect the dynamics of the system (Based on Crotty, 1980; Slingerland, 2000; Moll, 2005).

Another typical non-linearity relating biophysical and social aspects of mixed farming such as in western Africa relates to effects of 'wrong' crop-livestock mixing in situations where land is still abundant (EXPAGR in table 3). For example, the introduction of draught animals often leads not to intensification (better ploughing, mechanized weeding, more manure) but to extensification (increase of cultivated area, bottlenecks in weeding / harvesting, less manure per hectare). Introduction of livestock can help to exploit more land, thus leaving an illusion that resources are abundant. In societies where children inherit land of their parents, the available area per child decreases to the point where animal draught is no longer feasible due to limited access to animal feed and manual labor increases (Powell et al., 2004; Sumberg, 1998). Or else, availability of draught helps men to plough more land, often leaving women with a severe labor shortage as their work-load for planting and weeding increase. La Rovere et al.(2005) shows that intensification of these mixed systems does not necessarily go at the expense of soil fertility as suggested by Van Der Pol (1992), but poorer section generally have to find work outside agriculture. Estimates for urbanization are that close to 50% of the African population already lives in urban condition, and social unrest is a growing factor. Mixed farming is one form of agriculture that has to come up with “mode-changing-alternatives” that the general fossil fuel intensive trend to specialization cannot offer.

5.4 Non-linearities, lessons for the future

Non-linearity is the work area where we think that most advances can be made. Three additional cases are given from daily mixed farming practice at farm, village and higher levels. They refer to a scenario study on the communal ideotype, a remarkable case of differences and similarities in the structure of nutrient flows, and a choice at country level regarding use of research funds for improvement of either coarse or fine grains. We deliberately include a thought experiment in section 5.4.1 to stress the use of reasoning to complement empirical approaches that are hard and unproductive for short term decisions in complex systems.

5.4.1 Optimum vs maximum yields in a mixed system of India at farm level

The term “communal ideotype” was often used in this chapter of the monograph for the phenomenon that total system yield at plot- or herd level does not always go well with increased sub-system yield (section 3.4). The principle is illustrated for a case with animals and crops at the farm level, where milk production “density” can be considered as a system driver (Table 9). It was found, unintentionally, by a thought experiment for a hypothetical but realistic mixed farming system in the semi arid regions of India, northwest of Bombay. The calculations showed that individual animal yields beyond a certain point resulted in lower total milk yield of the farm, higher cotton area cropped at the expense of a lower area of food-grain and associated farm income. The main reason is that straws from grains can be used by less productive animals. The ‘straw’ cannot be used any longer if animal performance increases, and thus the joint value of straw and grain eventually becomes lower than the single value of the cash crop, in this case cotton. It is the case of fig. 16 replayed, and similar effects are reported for mixed farming systems with sheep - wheat - barley systems in Syria where lower individual animal yield was needed to achieve higher crop and total farm yields. The importance of this point cannot be stressed enough because it reflects the use of a triple bottom line, i.e. a paradigm change essential to better understand mixed farming in resource poor conditions. It implies a need to seek a new balance of attention, towards the performance of whole farms and regions, away from attention to parts and individual yields.

Table 9. Optimum crop combinations, herd size and production at different individual cow productions, with a basal ration of straws, and access to a small fixed area of good quality fodder (Patil et al., 1993)

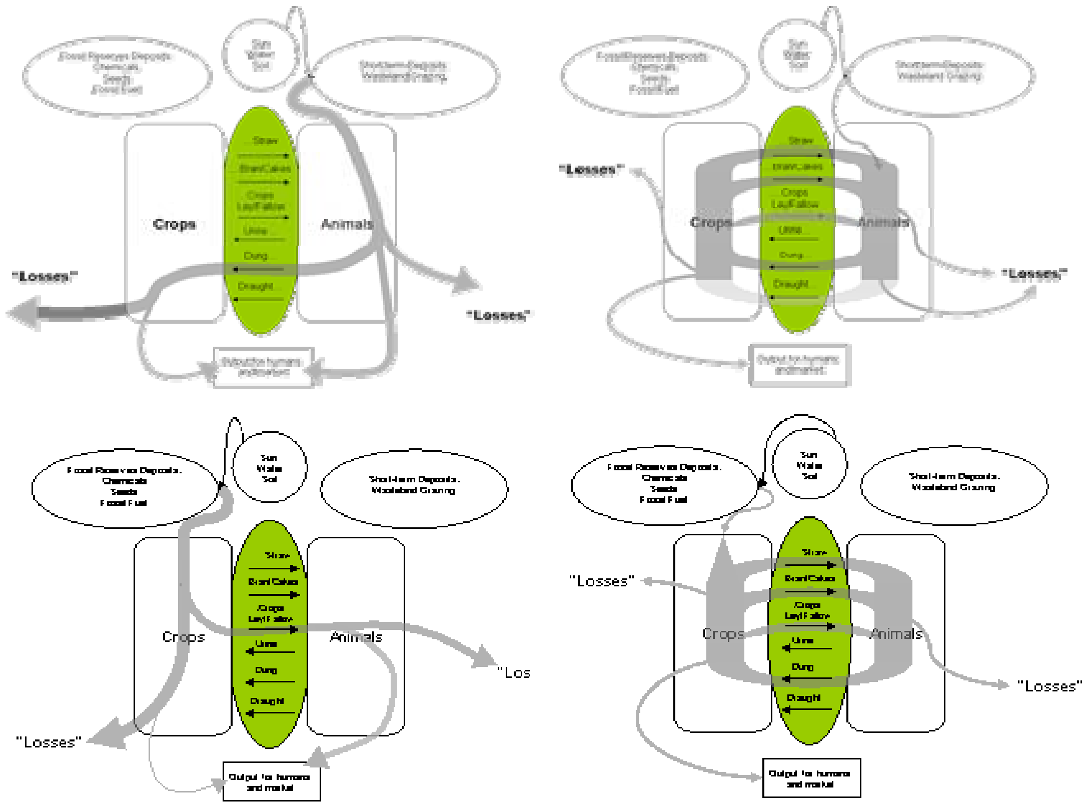
Individual Production (L/day/cow)	System production (l/day)	Herd size (cows/farm)	Cotton (ha) See note 1	Total income from milk and crop sales (Rs./day/farm)
0.3	1.0	3.5	0	10.5
2.0	5.1	2.5	0	22.2
4.0	7.8	1.9	0	30.4
6.0	9.5	1.6	0	35.4
8.0	10.6	1.3	0	38.9
10.0	10.6	1.1	0.4	39.1
12.0	10.4	0.9	0.8	38.9
16.0	6.6	0.4	1.0	27.6

Note 1: total area is 1 ha, *i.e.*, 0 ha cotton implies 1 ha of sorghum, 0.4 ha cotton implies 0.6 ha sorghum, etc.; Note 2: cows are “tropical” cows and a milk yield of 10 lts. for a small tropical animal of 350 kg is comparable with 20-25 liters for a larger “temperate” cow; Note 3. Rs is Indian Rupees, at that time 1 US$ ~ 25 Indian Rupees)

5.4.2 Mode changes in mind-sets and nutrient flows at farm and higher levels

The most spectacular case of variation and similarity in mode changes occurs, perhaps, in the nutrient flows of mixed systems (fig. 19). In this case, the nitrogen flows have a rather linear shape in both EXPAG and HEIA (left hand top and bottom). Linear here means that flows may be crooked or branched, but they can be stretched into some linear “fishbone” structure. Such linear structures are typical of throughput-oriented systems, and rather different from the web-like ones in the right hand diagrams for LEIA and NCA. The most remarkable variation and repetition of form is that the flows represent mirror images of each other. The EXPAGR mode has an Z-swing that starts in the middle top (sun, water, soil), traveling via the waste land grazing areas and the animals to the crops on the left and onwards to the humans on the center below. The HEIA flow has a similar, but reverse S-swing. The same mirroring occurs for the weblike flows in resp. LEIA and NCA on the top and lower part of the right hand side of the graph. A major, if not *the* most salient point of this variation and similarity is that a system needs be also understood in terms of relations, not only in terms of its parts (crops, animals, people).

Figure 19. Stylized mode changes in relative importance of nutrient flows (in this case nitrogen), depending on the access to resources and attitude to farming (based on Schiere et al., 2002). From top left clockwise the diagram represents nutrient flows in EXPAGR, LEIA, NCA and HEIA (see also table 3).



5.4.3 Policy choices for allocation of research funds

National policies tend to be based on choices for country level interests and use of averages. This represents an interesting issue of scale and hierarchy, i.e., in this case a country is seen as one large mixed system, and the choice to fund research for a particular crop at national level is likely to affect system efficiencies at lower levels. One case is that crop-insurance for maize and not for sorghum in the US may be a reasonable policy from a national point of view and in terms of money. But it encourages farmers to grow maize (for its insurance) rather than sorghum, which is more suitable ecologically and economically in drought prone areas (J. Dahlberg, pers.

comm. 2003). Another case is that funds are often allotted on relative importance of crops in the national economy, generally measured as grain output.

What counts again in this case is the use of the triple bottom line versus a choice for single measurement approach (section 3.1). For example, national importance based on grain-value alone favors high yielding but ecologically demanding grain like rice or wheat. A choice to measure a combination of grain, straw and other values like erosion control, resource use efficiency or rural development might favor sorghum or millet. Particularly if the national interest includes social / ecological sustainability of poorer areas one might prefer to spend more funds on the minor crops. More specifically, the contribution of straw to total plant value in grains like wheat and rice may be around 10 - 20%, but in grains like sorghum and millets this can be more than 50% of total crop value (Schiere et al., 2004b). The choice to estimate national relevance of a crop on grain rather than whole plant value basis creates a bias towards the "better" grains that have an advantage already because they are grown in the better areas. The triple bottom line approach inherent in mixed farming mindsets would further acknowledge that "better" grains require tractors and fossil fuels. Coarser grains like millets in LEIA systems are grown almost on solar energy alone, e.g. through the use of animal traction. They use relatively little fossil fuel, thus implying different energy use efficiencies (Schiere et al., 2004a/b). The choice of investing in a better yielding crop resembles the farmers choice to use his limited resources on either the fertile or the infertile plot (section 5.2d).

5.4.4 Land reform for sustainability, non linearities at regional scale in China

A typical mode change in mixed farming on district level in China is that economic reforms of the past decades exacerbated problems of over-grazing and desertification in the pastoral areas. To deal with rangeland degradation the government resorted to nationalization and semi-privatization. It operated by thinking in terms of 'parts' and 'control'. It overlooks the interrelations due to the mixed nature of the situation as for example elaborated for sub-Saharan conditions by Marcussen (1999). Rangeland policy, based on notions of central control proved difficult and experiments with alternative rangeland tenure systems were started. Ningxia in northwest China, attempted to establish communal range management systems with the village as the basic unit of use and control. The reason was that some management regimes are under severe stress, due to large-scale digging for medicinal herbs in the grazing lands, a farfetched but real case of mixed systems at regional level. This digging resulted in conflicts between Han and Hui Muslim Chinese, during which several farmers were killed. Major drivers for degradation of grassland resources come therefore from within and from outside. The exploitation of liquorice root by farmers from outside the township helps to cause large-scale desertification, which makes matters worse. Poverty literally 'drives' farmers with such mindsets to look for extra sources of revenue: digging of liquorice root can provide most farmers with an illegal, and thus non-taxed, extra income. The case illustrates collapse of existing common property arrangements. The quality of rangeland in Ningxia continues to deteriorate due to a combination of failing village-based management with different valuation of the natural resource by other users. Degradation of rangeland will continue if the diggers of liquorice root continue to defy any law or other arrangements in their search for short-term gains, and as long as authorities continue to put all their hopes on control while ignoring the complex adaptive nature of the situation (Ho, 2000).

5.4.5 Landcare and rural development in Australia.

The Australian countryside of the past decades had slowly shifted into a mode where over-grazing, deforestation and increased scale of farming led to severe problems, like in the previous case of China, the case of Machakos and the dustbowl. Effects of inappropriate

European farming practices in the context of Australian soils combined with severe drought in the 1980s raised public awareness on pending problems. These problems led many rural communities to get together and to analyze intricacies of their “livelihoods”, from biophysical, economic and socio-cultural angles. Thus the choice for the triple bottom line as a management principle for regional development reflects - in a fractal fashion - the management principles needed for a mixed farm. Parts need to be seen in their larger whole, at regional level typically an issue to be addressed by soft system methodologies (Jim Woodhill, pers. comm. 2004). Based on individual action and supported by government funding this led a countrywide program LANDCARE that took a triple-bottom line approach to farming, society and sometimes industrial activity. Awareness about the complex adaptive nature and of the drivers behind these processes is raised through community meetings. It addressed issues of rural health and eco-literacy into school curricula, as well as issues of empowerment. As such it is, perhaps, one of the biggest experiments in applying the theory of SSM to the practice of rural development (Campbell, 1996; Roberts & Coutts, 1997). The main message is that efficient and modern farming methods can lead to disaster if not adjusted to local conditions. Initial –linear- successful ways of farming show non-linear behavior, they collapse in a non-linear way after some time of too much emphasis on too few technical parameters. It is a typical case of mode changes like in Machakos, and the dustbowl, with lessons for modern thinking about modern management and policy setting, based on understanding how systems are interrelated, rather than using a focus on parts.

Section 6. Concluding comments.

Mixed farming is important around the world, and throughout history. If well done it helps poor and wealthy farmers to spread risks, to cope with input shortage (in ‘poor’ low external input systems) and to dispose of excess nutrients (in ‘rich’ high external input systems). A mix of crops and livestock helps feed many people in the world, and it helps farmers obtain an income in different agro-ecologies. In spite of the importance of mixed farming, however, there is a trend in teaching, research and policy towards work on specialized farming. That trend associates with mindsets that focus on commodities and parts rather than on mixed farming as interconnected wholes, also called complex adaptive systems in modern system jargon (section 3). Mixed farming requires mindsets (=paradigms) that look at interactions and combinations of functions rather than at only grain, only milk, only soil, only biophysics, social aspects or maximum yields of parts. This chapter reviewed and generalized basic principles of mixed farming to supplement a large body of practical literature and farmers experience.

The variation of forms, processes and functions in mixed farming systems of semi-arid regions is explored by stretching the imagination, rather than by zooming in on a few well defined cases (section 1 and 2). This perhaps unconventional approach can help farmer-leaders, policy-makers and researchers to make better use of hidden options in mixed farming, also for more sustainable rural development. We use farfetched notions from system ecology, thermodynamics and psychology to help better understand the mixed blessings of mixed farming. We show how notions from basic sciences apply to mixed systems, and how lessons from mixed systems at farm level apply to issues of rural development and public administration at higher levels. The use of three different system methodologies reflects a choice for the triple bottom line approach, both as a matter of convenience *and* principle. In terms of convenience it helps stretch the range of insights, to maintain flexibility and to avoid hairsplitting on definitions or semantics about local differences. In terms of principle, it stresses the dynamic adaptive complex- rather than static nature of mixed crop-livestock systems, society and nature.

Variation and repetition of patterns are thus central in our discussions, as well as the notion that not all can be measured nor usefully defined. Choices are unavoidable, thus making farmers, teachers and policy makers into active players rather than neutral observers. It also implies that there is no single 'truth', nor one best policy, solution or model for mixed farming. That was the main reason to avoid a cookbook approach, besides the fact that many practical issues are well described elsewhere. Indeed, what is 'good' in mixed farming for a large farmer may not be 'good' for a small farmer. And women or poor farmers tend to have other perceptions and mindsets on what is good than men, business-people or wealthy farmers. To complicate this further, 'good' at one level of system hierarchy may not be 'good' at other levels (section 3). Some direction on the apparent confusion '*mixed blessings in mixed systems*' can be given, however, especially when one learns to see repetition in the variation, among others by designing useful categorizations (section 2).

This chapter stresses that mixing exists in many forms, and it uses variation rather than to avoid it. It also stresses that such variation and repetition is determined, by a combination of biophysical and socio-cultural system drivers, internal and external ones. Mindsets interact with soil and climate, and consumer choices interact with degree of market access. The use of the various system approaches, -behaviors, driver-notions and mindsets as well as the choice for triple bottom line provides clues for policy setting on mixed farming such as that:

- mixed farming is a fact of life for poor *and* rich contexts. The argument can be on degree and level of mixing, not on the principle,
- mixed farming needs teaching, research and policy that recognizes dynamics and differences between contexts while avoiding general statements on mixed blessings.
- much information is now available from theory and practice regarding linearities, more needs to be known on non-linearities
- the study of mixed farming provides arguments in favor of non-equilibrium thinking for teaching, research, policy, consumer behavior and farm practice. It also stresses the need to re-integrate issues of matter and mind, as well as to focus on the importance of agriculture beyond production of commodities only
- the effect of drivers, i.e., access to resources provides a framework that can help policy to better *en*courage mixed farming, among others via the mindset through innovative research and teaching, and/or by affecting the price of oil and/or labor.

The future is inherently uncertain, but much is now known on a large range of forms and scales of mixed farming and challenges abound. Water aquifers run out in places with a thus far strong base of mixed farming (e.g. the central plains of the US), and AIDS affects rural systems in Africa and Asia where mixed farming is rule rather than exception. Global policy debates have started to address issues like access to energy, climate change, the need to reduce hunger and to achieve balanced rural development. Trends like these are bound to result in major mode changes and good examples of these are shown in this chapter at plant, farm and higher levels. They support rather than to cancel our notion that mixed farming is and will become more relevant for both rich and poor contexts. If well done the work on mixed farming also carries lessons for sustainable development of society in general.

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