Crop-livestock systems: old wine in new bottles?

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Abstract

Many farmers in tropical and temperate countries manage a mix of crops and animals. In these systems crop residues can be used to feed the animals and the excreta from the animals as nutrients for the crops. Other forms of mixing take place where grazing under fruit-trees keeps the grass short, where manure from pigs is used to 'feed' fish in a pond or where young animals bred in remote areas are fattened near urban centres with high demands for meat. In addition, inclusion of livestock alters the rate of nutrient turnover, it provides a labour opportunity in slack times for crops and adds value to crop (by-)products. Livestock thus affects the socio-economic and biophysical dynamics of the entire farming system. Indeed, a wide variety of forms and processes in mixed farming are known world-wide. To different degrees they are all essential for the livelihood of farmers and for the production of food and other commodities for cities and export markets. More recently, even highly specialised crop and livestock systems in developed and developing countries have rediscovered the advantages of mixed farming. Specialised industrial pig and poultry farmers have been banned from densely populated countries such as Singapore, and in Western Europe they are obliged by law to exchange their dung surpluses with crop farmers. Moreover, the essence of many modern organic farming systems lies in the mixing of crops and animals. This paper discusses the advantages and disadvantages of crop-animal systems; it presents concepts from modern system thinking that are useful for understanding the variability in crop-animal systems. The paper also provides classifications of these systems to show that opportunities for crop-animal systems exist in low and high input systems.

Media summary

Crop-livestock systems play a major role in the dynamics of many agricultural systems. They occur in many forms and they allow more efficient use of resources than specialized systems and spreading of risks. The renewed interest in such systems to mitigate the negative (mainly environmental) impact of highly specialised agricultural systems is highlighted.

Key words

mixed crop-livestock systems; system dynamics; agricultural development; multiple goals; system theory; environmental impact

Introduction

General

In crop-livestock systems, often referred to as mixed farming systems (Sere and Steinfeld 1996), livestock and crops are produced within a co-ordinated framework. Traditionally, and still in many instances, this framework comprises a farm unit, although mixing may also take place at regional scale. 'Mixing' is used here first as a generic term, but later in this paper we show that various forms and processes of mixing can be distinguished (Schiere and Kater 2001). In many mixed systems, the waste products of one component serve as a resource for the other: manure from livestock is used to enhance crop production, whilst crop residues and by-products feed the animals. Mixed farming is the largest category of livestock systems in the world in terms of animal numbers, productivity and the number of people it services (Thornton et al. 2002). It occurs, for example, where livestock are grazed on communal land, in systems where some inputs external to the system are regularly purchased for livestock feed, or even in systems that approach the industrial type (Pearson 1992). Mixed farming systems utilize about half of all the land used for livestock production systems, or roughly 2.5 billion hectares, of which 1.1 billion hectares are arable rainfed cropland, 0.2 billion hectares is irrigated cropland and 1.2 billion hectares grassland. Mixed farming systems make the largest contribution to world livestock products with just over 50% of the meat and 90% of the milk currently consumed being produced in such systems (Figure 1; CAST 1999).

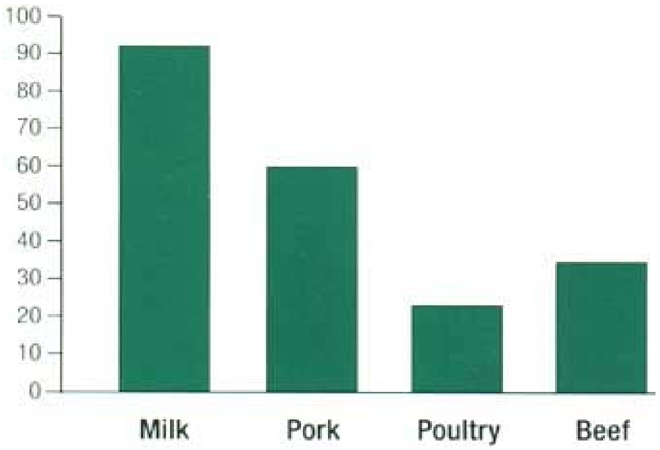


Figure 1. Percentage contribution of mixed farming systems to global production

About half of the meat and milk produced in these systems is produced in the OECD, Eastern Europe and the CIS, and the remainder comes from the developing world. Over the last decade, meat production from these systems has grown at a rate of about 2 percent per year. About two-thirds of the rural poor rely on mixed crop-livestock systems for their livelihoods (ILRI 2000). Last but not least, it is virtually impossible to quantify their indirect effects on crop production, soil fertility and the socio-economic dynamics of rural societies. Moreover, given the demand increases for livestock products forecast for the coming decades, mixed systems are going to have to provide a disproportionate part of this increase, especially in developing countries – so they will become even more important than they already are.

Livestock itself produces less energy and protein per unit land area than crops if conditions are favourable (Table 1), but it helps cropping in various ways, e.g. through the supply of dung and draught power and/or by permitting widening of crop rotations or generation of added value. In harsher conditions, such as arid, cold and mountainous regions, livestock can even be the mainstay of human food security and livelihoods. For that purpose, ruminants are particularly useful, because of their capability to convert fibrous feeds.

Table 1. Approximate number of people that can be fed per hectare of land in areas where cropping is possible (Spedding, 1979)

Commodity	Protein	Energy
Crops		
Potatoes	9.5	16.5
Rice	7	14
Maize	5.2	10.4
Wheat	6.3	8.4
Livestock		
Milk	3	2.5
Pork	1.4	2
Chicken-meat	2.5	1
Lamb-meat	1	1
Beef	1	1

This paper reviews the development and relevance of mixed crop-livestock systems, their varied forms and functions, their system-theoretical basis and their opportunities for the future in high- and low-input conditions. Part of the material presented here is extracted from a more extensive review by Schiere et al. (2004b).

Evolution of mixed farming systems

Mixed farming systems evolve over time, among others in response to changes in relative access that farmers have to land, labour and capital as illustrated in Table 2. The prevailing farming systems in the transition from gatherers and hunters to agriculturalists are obscure, but the Bible (Gen. 4) suggests that ‘originally’, arable farmers (Cain) and livestock keepers (Abel) operated 'specialised' farming systems. These systems have co-existed for a long time, till the present, especially where land is abundant, a condition here called Expansion Agriculture (EXPAGR). The arable farming systems in such conditions use long fallow periods to maintain soil fertility, and pastoral systems can supply some manure for the farmers' fields in exchange for water, cereals, etc. Typical examples of such systems are the agro-pastoral systems of sub-Saharan Africa, mixed systems in large tracts of India and small ruminant systems in Inner Mongolia (Schiere et al. 2004b).

Table 2. Schematic characterization of different modes of mixed crop-livestock farming (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	May be 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				
- 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 grazing lands away from the farm; infield refers to mainly 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

As rural population pressure increases, however, both crop and livestock farmers need to intensify production. In the absence of external inputs, the arable farmers have to increase cereal production by expanding their cultivated area to maintain food self-sufficiency for their families. These conditions are referred to as low external input agriculture (LEIA). Introduction of animal traction helped to produce more grain by allowing cultivation of more land and maintaining labour productivity. Thus, many arable farmers became livestock owners themselves, their livestock grazed the crop residues and the contracting communal village pastures (Jodha 1992). Livestock owned by crop farmers changed the system dynamics by increasing the rate of processes, e.g. the turnover of nutrients and soil carbon. Pastoralists were left with less and less land for grazing, often of marginal quality, i.e. they were doomed to extinction and again the effect of animals on socio-economic dynamics becomes evident. Pastoralists either migrated to the cities or settled and took up arable farming. With continued increase in population pressure, soil fertility management also changed to practices characterised by intensified internal recycling of nutrients. In these systems, crop residues are increasingly collected and transported to the homestead to feed animals that are kept in kraals and stables. This also creates the opportunity to collect the manure that, mixed with animal feed refusals and household waste, is applied to arable fields close to the homesteads.

Farmers owning less or no livestock use the technique of composting crop residues and household waste, returning the upgraded organic material to the fields. Ultimately, farming evolves towards zero grazing, where roughage is collected from wastelands and roadsides to be used as mulch on the fields, for composting or as feed for the animals (Stobbs 1969; 1962). This intensification of internal recycling of nutrients tends to be associated with again socio-economic and bio-physical system dynamics, changing labour productivity (Kuyvenhoven and Ruben 2002). With further increase in labour availability due to population increase and also continuing changes in social dynamics, labour migration and off-farm income become increasingly important. Livestock in such mixed farming systems can help farmers to diversify risk from crop production only, to use labour more efficiently, to earn cash for farm inputs or emergency expenses and to add value to crops or crop by-products (Table 3). Eventually, further increases in labour input do not result in further yield increases: the demise of LEIA. When a critical lower threshold in labour productivity is reached, farmers have to switch to soil fertility management based on external inputs, i.e. inorganic fertilizers, the situation of high external input agriculture (HEIA). Alternatively, farmers may seek off-farm employment, but their earnings are not necessarily re-invested in soil fertility improvement (c.f. De Jager et al. 1998).

Table 3. Advantages and disadvantages of crop-animal systems

advantages	disadvantages
- *buffer* against *trade and price fluctuations*	- required *'double' expertise* - *less economies of scale*
- *buffer* against *climate fluctuations*	- *risk* of *disease* and *crop damage*
- *erosion control* through forage production (such as grasses)	- *causes erosion* due to soil compaction and overgrazing
- higher *nutrient recycling* due to more direct soil-crop-animal-manure relations	- *nutrient losses* through intensive recycling
- *diversified income* sources	- continuous *labour requirement*
- *draught power* allowing larger cultivated area and more flexible residue management	- *increased rate of land use* - *extra (women) labour required for weeding*
- allows *more rapid* planting	
- controls weeds	
- *investment* option	- requires *capital*
- alternative *use for low-quality roughages*	- competes with other *use of crop residues*
- *source of security and savings*	- requires *investment*
- *social* function	- cause of *conflict*

Note: Many issues occur both in the left and right hand columns due to differences between stakeholders' perceptions and local contexts. This is elaborated in the text and comments on complexity and classification of mixed systems

Labour productivity increases again if farmers continue farming with increased use of external inputs, but this only happens, if markets for inputs and produce of food and cash crops allow (De Ridder et al. 2004). Under these conditions, the differentiating forces in farming systems tend to favour specialisation (Schmitt 1985). Eventually, these systems also reach their limits, among others due to the emphasis on only economic profitability, and disregard for other functions of agriculture (De Wit et al. 1987). Farming again is forced to evolve towards recycling of resources and so-called wastes have to be re-appreciated as resource in the new conservation agriculture mode (NCA).

The major bio-physical disadvantages of specialisation (= disintegration), due to high input use in HEIA, are increased waste production. Re-introduction of mixed farming systems can then be a way out (Niejenhuis and Renkema 1996; Lantinga and Rabbinge 1996). Societal effects of HEIA can include short-term benefits in terms of cheap food, and large-scale long-term change in social networks. One major advantage of mixing (= re-integration) in HEIA is the more intensive recycling of nutrients, implying a reduction in waste. It requires, however, a change in mindset, towards 'wholes' and away from 'focus on parts'. The rough list of advantages and disadvantages in Table 3 shows that some issues occur in both the left and right hand column. This is because different stakeholders have different perceptions, because an advantage at one level of system hierarchy may be a disadvantage at another level, and the evolution of systems as described above implies changing priorities.

System thinking for mixed farming

General

The large variation and apparent inconsistencies in forms, functions and processes in mixed farming systems can be better understood by using old and new concepts from system thinking. They help to provide a framework for identifying changes in relative importance of various aspects of mixed crop-livestock systems, whether they occur in dry, hot, humid or cold climates with limited and with different access to land, labor and/or capital. This section, therefore, briefly reviews three forms of system thinking that each address different aspects of what generically was referred to as mixed crop-livestock systems (Schiere et al. 2004a; Conway 1987).

Hard system thinking

This form of system thinking is predominant among more technically oriented disciplines. It focuses on so-called ‘hard facts’, ‘issues of matter’, and it stresses the need to quantify (‘to measure is to know’). More qualitative social aspects and ‘issues of mind’ are left to sociologists, anthropologists or politicians. Hard system thinking tends to focus on description of how things are, rather than on how they evolve. The term system in this sense implies:

> *a unit, with well-defined boundaries and goals, consisting of different parts that convert inputs into outputs and that work together towards a common goal*

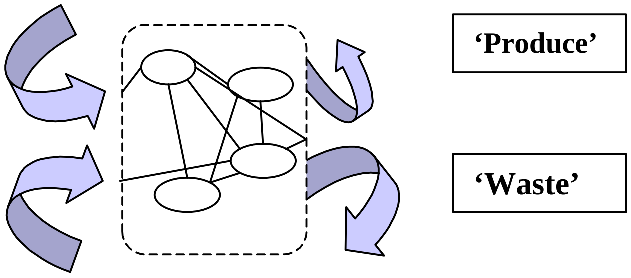


Figure 2. A system as a unit, consisting of parts that together convert inputs into desired and ‘undesired’ outputs, called 'waste'. Note, on purpose we use a bigger arrow for the ’waste’ output, to stress that many resource use efficiencies tend to be < 50% (except for money!).

This hard notion of a ‘system’ as a unit uses concepts such as:

- ‘boundaries’: e.g., where are the boundaries of the mixed systems (in time and space); a maize field is specialized unless it is considered as part of a larger crop-livestock system (Aarts 2000);
- ‘hierarchies’: e.g., does mixing occur at farm level (animals and crops on one farm), or at regional level (animals and crops in separate farm units that exchange resources);
- ‘inputs’ and ‘outputs’: how much water is required for the production of one unit of yield, how much labor is required for the production of one unit of saleable or tradable product;
- ‘structures’: i.e. how are the components of the farming system organized.

Hard system thinking does acknowledge systems dynamics, but it has difficulty coping with what happens during drastic change, as illustrated in Figure 3b. Hard system thinking tends to focus on observation and little on reasoning for scenario studies; it tends to focus on parts rather than to look at wholes, i.e. on the interaction between system and its surroundings. Crop growth modeling and multiple goal programming are typical hard systems tools, as illustrated for mixed systems by Struif Bontkes (1999) and Sissoko (1998).

Soft system thinking

One problem for hard system thinking and its emphasis on exact quantification is that different stakeholders have different (sometimes conflicting) perceptions of what a system is, on how it needs to be defined and on how its costs and benefits are to be weighed. Another problem is that qualitative (such as emotional) values may outweigh more rational and quantitative aspects. For example, a livestock owner may know that selling in the face of drought would be advisable, but pride or other ‘cultural’ considerations may prevent the sale. Also, neighbors and government services may try to ‘convince’ farmers to adopt new farming methods, even if it is against their personal preferences. Soft system thinking focuses on mindsets; it takes over where hard system thinking cannot cope. Typically, soft system thinking addresses the issue of whether farmers 'believe' excreta to be a waste or not, or whether for example policy makers 'believe' mixed farming to be modern or not. Similarly to hard system thinking, soft system thinking uses notions like boundaries, processes, goals and sub-systems, but it stresses that these are fluid concepts. Whereas hard system thinking considers the model of the system to be a (albeit simplified) representation of the real system, the soft system thinkers define a system as: *a construct with arbitrary boundaries for discourse about complex phenomena to emphasize wholeness, interrelationships and emergent properties* (Röling 1994) Soft system thinking also gives a different meaning to the notion of a ‘goal’ in systems (Checkland and Scholes 1993): a system does not have a goal but it is given one according to the context. The questions in soft system thinking therefore are not about 'what is the goal of mixed systems’, but ‘which goals society could ascribe to mixed systems’.

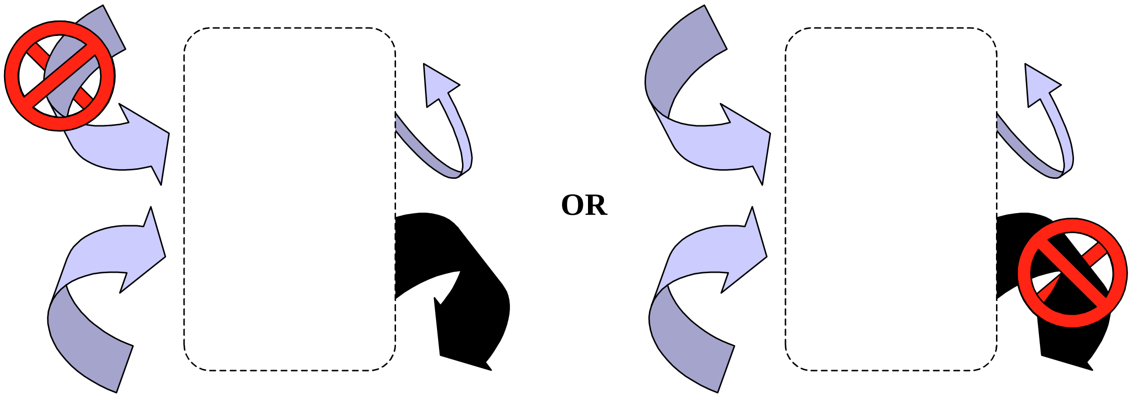
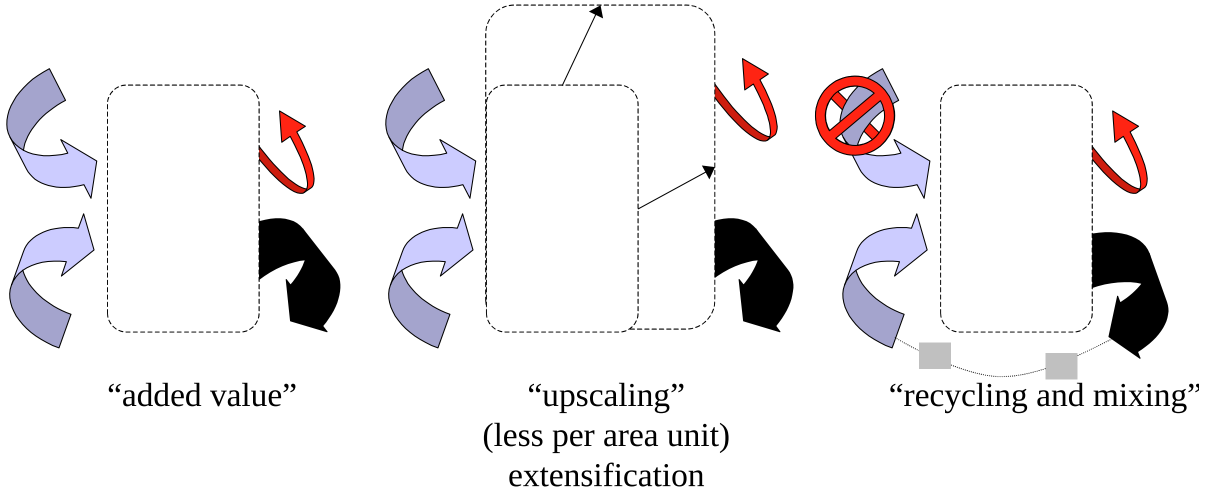


Figure 3a. Different causes resulting in similar mode changes: disturbed input supply (e.g. fertilizer, water, feed) on the left and a problem with ‘waste’ disposal (e.g. dung, straws, etc.) on the right hand side



“added value”

“upscaling”
(less per area unit)
extensification

“recycling and mixing”

Figure 3b. Different coping strategies to overcome the reduced resource flows illustrated in Fig. 3a: extra added value (left), larger scale (middle), recycling and mixing (right)

Complex system thinking

Both hard and soft system thinking find it difficult to deal with long-term developments in ‘real life’, where notions of ‘reality’ vary among stakeholders, where everything is related to everything and where prediction is impossible. Complex system thinking can help in such cases, as a new branch in system thinking that focuses on interactions, uncertainty and system dynamics (Schiere et al. 2004a; Klir 1991). Its implications now start to trickle down to daily practice in agricultural research and planning, while many farmers have known them as a fact of life for many years (Behnke et al. 1995). The study of mixed farming is a good case to illustrate the main principles of complex system thinking:

- variation of systems in time and space is unavoidable and inherently unpredictable; but:
- specific patterns tend to repeat themselves, i.e. order emerges from disorder.

The strange contradiction between the first and the second principle occurs across disciplines and sectors of society (Schiere et al. 2003). This even bridges traditional differences between hard and soft system thinking. It also gives tools/concepts to cope with mode changes, where changes in input and/or output flows result in re-wiring of the system (Fig. 3). It focuses on understanding of dynamics and processes, such as evolution and self-organisation (a 'search' for form in the system as response to internal and external conditions), predator-prey cycles (e.g. where a system over-uses its resources), resilience (where a system maintains the capacity to bounce back), stability (e.g. where a system can to some extent resist change), conflicting perceptions (where farmers have different interests than governments) and lock-in (where systems are rigid and unable to learn/change their mindset). Overall, strict distinction between hard, soft and complex system methodologies is artificial, but it is maintained, as a tool to better understand constraints and opportunities in mixed farming.

Classifications of mixed systems, variation and similarity

General

Various types of mixed farming exist that differ, but they also resemble each other in many ways; that is the essence of complex system thinking. The similarity is illustrated in Figure 4, which represents a framework for mixed systems in general. Together with categorisation, such a general framework helps to see the forest from the trees, illustrates how mixed systems can have different as well as similar structures and processes in terms of resource flows. The differences originate –or: self-organise- from different access to the production factors land, labour and capital, as well as from differences in ‘soft’ issues, such as tradition, culture, etc.. Categorisation also shows that different mixed systems have different mixed blessings, i.e. that one can gain in one aspect but loose somewhere else. What is good in one system may be negative in another, what is beneficial for one group may be detrimental for another. Uncertainty abounds, but better guesses can be made, if one manages to identify the driving forces governing system change. Driving forces are such issues as access to land, cultural values, etc. For example, a random survey of mixed systems around the world serves to ’get lost’ in variation (the first principle of ’complex system thinking’). Continuing the survey, one becomes aware that certain patterns repeat themselves (the second principle of complex system thinking). In that sense, description of the evolution of mixed systems at the start of this paper and in Table 2 illustrates how certain forms of mixing emerge in response to changing access to land, labour and capital. This section lists a few different categorisations of mixed systems, some of which are arranged according to the change of their drivers, such as access to production factors and markets in time and space.

Some classifications

Various classifications, that all are arbitrary by definition, can be used, e.g.:

- *On-farm versus between-farm mixing*, an issue of hierarchy. *On-farm* mixing implies mixing within one level, and between-farm mixing involves a higher level of integration. *Between-farm* mixing occurs increasingly in so-called High External Input Agricultural (HEIA) systems to mitigate the waste disposal problems of specialised farming (Ho and Chan 1998; Lantinga and Van Laar 1997). Between-farm mixing also occurs where animals raised in one area are fattened in another area where grain supply is abundant, or where pastoralists exchange cattle with crop products from crop farmers.
- *Diversified versus integrated systems*. *Diversification* occurs where components such as crops and animals co-exist rather independently on the farm. Their combination serves to reduce risks, but their interactions are minimal. Nutrient flows are rather linear, i.e. this form of mixing does not involve recycling of resources to a significant degree. *Integration* occurs where the components of the farm are interdependent, i.e. where animals providing dung while consuming crop residues (Savadogo 2000).
- *Mixing in the developing world and mixing in the developed world,* often incorrectly, but conveniently equated with LEIA and HEIA systems, respectively. In the LEIA of the *developing world* most mixed systems operate in situations of declining crop/grazing land ratios, and shortening fallow periods, and without adequate replenishment of soil fertility from other sources. They are thus characterized by *negative nutrient balances,* triggering downward spirals of declining soil fertility, overgrazing, increased erosion and losses in soil micro-flora and -fauna that ultimately cause significant reductions in agricultural productivity (Breman 1990). Mixed systems in the *developed world* are characterized by import protection of most animal products, especially beef and milk, and producer subsidies, especially on feed imports. This has stimulated extensive use of feed concentrates, which in combination with over-use of inorganic fertilisers, has led to large *nutrient surpluses*.

Many more classifications exist, e.g. based on the difference between low- and highland systems, between cropless and stockless systems; between temperate and tropical systems, between Mediterranean systems with winter rainfall and dry summers and deep tropical systems with humid/hot conditions year-round (Sere and Steinfeld 1996; Schiere et al. 2004b). Instead of creating comprehensive and yet infinite lists of such categorisations, we focus on the logic of variation in mixed systems due to changes in ’drivers’. We see policy as an attempt to influence the conditions/context of farming by affecting the socio-economic and/or biophysical ’drivers’. Hence, understanding the relation between specific ‘states’ of the ‘drivers’ and the prevailing systems creates options for useful policy recommendations.

Classifications of mixed systems in time and space

The issue of how a change in drivers affects the form, level and degree of mixed farming, and the implications for policy setting is addressed by searching for logical sequences in the change (evolution) of these systems. This search for repeating processes is a typical approach from complex system thinking and it involves use of disorder to see order, i.e. to look for more variation rather than to focus on one particular system. The implicit classification of mixed farming systems described as ’evolution’ in the first part of this paper and in Table 2 reflects such an attempt, based on the choice of driving factors like relative access to the production factors of land, labour and capital[1]. Starting with a look at mixed system in NCA and proceeding to a pastoral system in EXPAGR it would be difficult to discern a ‘logic’. However, a clearer pattern emerges by adding more forms of mixed farming in varying policy conditions, i.e., by adding variation, and by seeking patterns (order) in the time sequence (Table 2).

Table 2 shows that the intensity of mixing changes from ’on-farm’ diversification in EXPAGR, via on-farm-integration in LEIA to on-farm specialisation and (inter)national mixing in HEIA towards local-, between- or even on-farm integration in NCA. In other words, as implicit and explicit policy and price conditions change towards cheaper energy in HEIA there is a tendency towards specialisation.

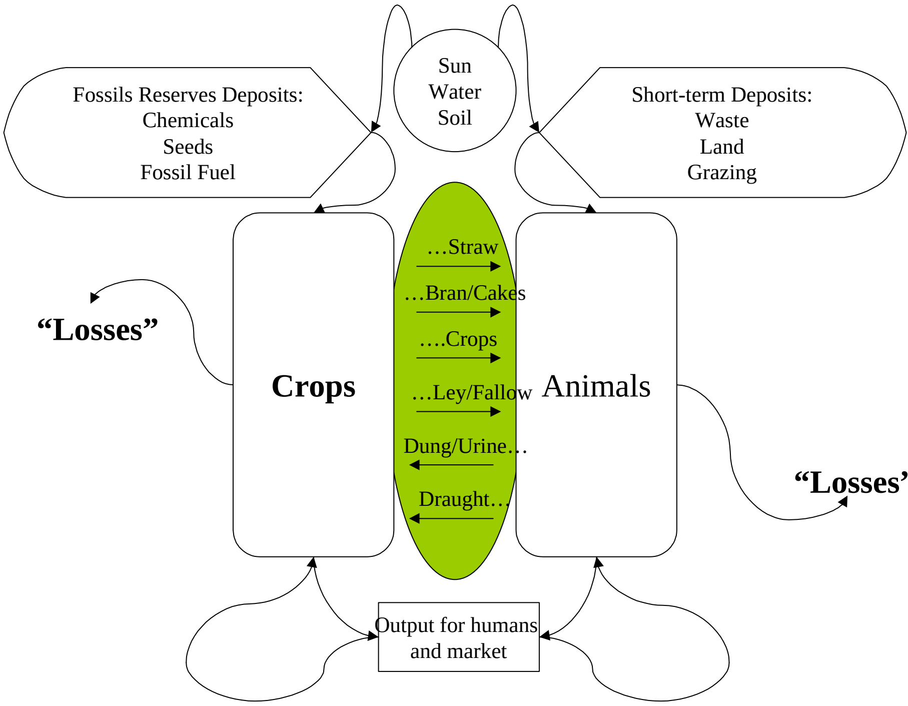


Figure 4. The basic outline of different (bio-physical) resource flows in mixed crop-livestock systems (Schiere et al. 2002)

This development is based on a combination of ’hard’ system factors as the use of fertilisers, and ’soft’ system factors, such as a tendency towards reductionism and focus on parts rather than wholes. It continues until excess ’waste’ and concern about environment affect the mindset and force systems back into mixing and attention to wholes. A similar development occurs in poor countries. If policies do not

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[1] Capital here represents access to fossil fuel-based resources such as fertilisers, mechanisation, modern communications etc. This assumes that fossil fuels are a form of saving and that savings in the form of irrigation infrastructures, soil improvements, buildings etc., are part of the value of the land.

favour use of inputs in poor conditions, mixing will shift from diversification and linear forms in EXPAGR towards integration and web-likeness in LEIA. This continues until soil mining and exhaustion cause such systems to collapse. The collapse of farming systems in both HEIA and LEIA reflects a form of a predator prey cycle, in which ’lock-in’ into a particular farming mode results in exhaustion of resource bases like ’clean’ environment and soil nutrients, respectively.

Three cases of system evolution in time and/or space

The first case of evolution of mixed systems, in time, was elaborated earlier in this paper and in Table 2. A second case, in space, is available in the pattern laid out by Von Thünen some 150 years ago for German conditions. He developed the so-called *location theory* based on changes in marginal prices/opportunity costs of production factors (Nou 1967). Von Thünen showed that near the city one finds a mix of predominantly land-intensive systems like dairy and vegetable production. At some distance from the city, slightly less intensive crop-livestock mixes are found, probably mainly ’*on farm’*, that resemble the LEIA or NCA modes from Table 2. At still greater distance he found (in the Germany of a century and a half ago!), extensive crop-livestock systems and pure grazing, such as reflected in EXPAGR of Table 2. The theory uses idealised cases, but it reflects the evolution based on access to production factors as drivers, and the basic pattern can be recognised in many farming systems of today. A third case of system evolution is found by journeying in ’space’. The essence is recognised when travelling from South to North along the temperature gradient on the US Great Plains, where cotton monocultures are progressively replaced by (grazed) wheat pastures, to 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 more extensive grazing and cow/calf operations (Schiere et al. 2004b). The drivers from South to North and from East to West in the USA are temperature and rainfall, respectively. The pattern is paralleled in Australia with evolution of mixed farming from North to South, where temperature and rainfall are the driving forces in the change from mixed herds to mixed grain/legume/sheep enterprises. The diagram in Figure 4 shows a similar change in ’space’ from North to South based on rainfall as a driver, and representing population pressure as a driver from left to right in the central column.

Summarising comments

A variety of mixed farms exists in history and around the world and even modern farming systems start to *re*-cognise the advantages of mixing. However, conflicts as well as positive interactions (synergies) exist between livestock and crops (and soil) on mixed farms. Much capital-intensive farming prefers specialisation because of the economies of scale. And the biblical story of Cain and Abel is replayed in many places till today where traditional relations between nomads and sedentary farmers are under pressure (Powell and Waters-Bayer 1995; Crotty 1980). Mixing can increase efficiency, while becoming ‘riskier’ due to high levels of integration and interdependency A good understanding of mixed farming can be achieved by using several forms of system thinking that focus on biophysical, socio-economic and dynamic aspects of system behaviour respectively and apparent contradictions between advantages and disadvantages. By providing classifications for various patterns of mixed farming one can make sense of different functions and ways of mixing crops and livestock. Indeed, advantages and disadvantages of mixing arable and livestock farming differ per region and among stakeholders, or even among different levels in the system hierarchy. A search

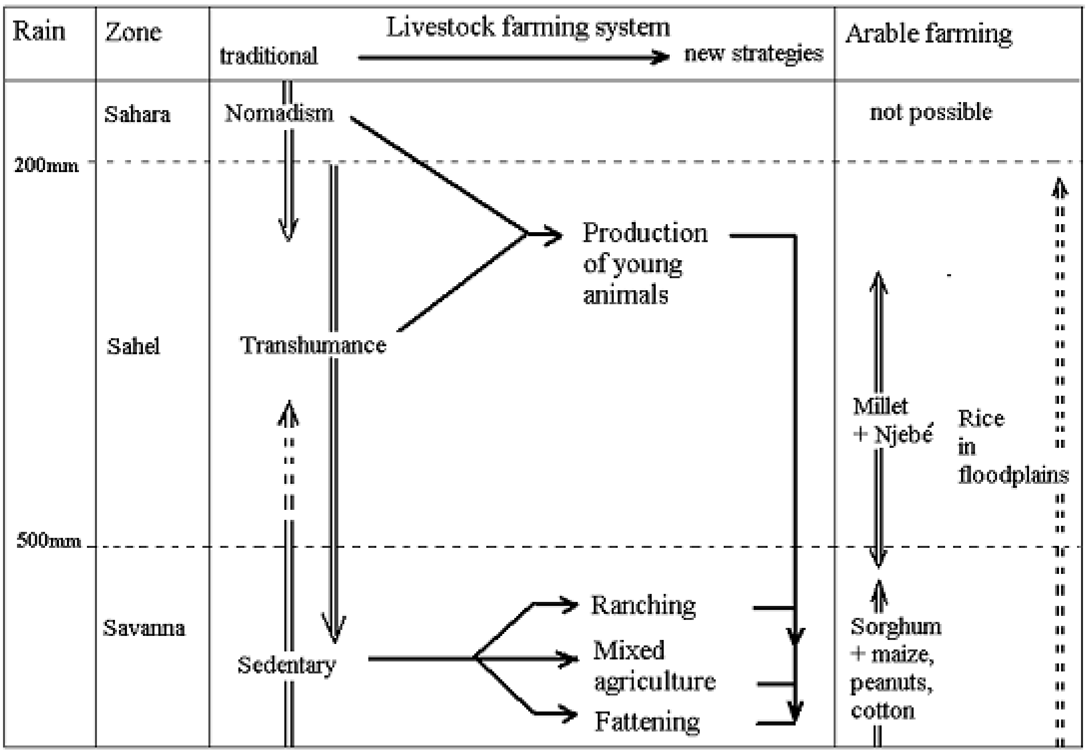

Figure 5. Spatial and suggested temporal changes in mixed farming in relation to average annual rainfall (top to bottom) and increased population pressure (left to right in central and right hand column. (based on Breman and de Wit 1983). Note the striking similarity between the processes described for rainfall as 'driver' of system behaviour from North to South in Sub-Saharan conditions with those in for example the US Great Plains (from East to West), in the Indian sub-continent across the Karachi - Bombay latitude, and from North to South in the Western part of Australia

for logical changes in mixing, here called the evolution, helps in identifying the driving forces. It is shown that socio-economic and biophysical factors, such as like population pressure, access to fossil fuel -based inputs and land resources combine to shape different types of mixed farming. Lack of access to resources, such as fertilisers causes collapse of mixed systems in poor farming conditions, and excess of external inputs causes collapse of specialised systems. Propagation of mixed farming in systems with cheap inputs requires a mindset that is concerned about the environment, or a deliberate price-policy to reduce the use of these inputs, e.g. by levying waste. Research, teaching and farmers' attitude has to shift from attention on high individual yields to high total yields. Indeed, systematic analysis provides clues for policy makers, researchers and teachers on how to create conditions that are conducive for mixed farming. Throughout the paper we have taken a deductive approach. In other words, we take and generalize experiences from many situations in order to hypothesize how the variety of mixed systems can be understood. By shaping the discussion in this way, the paper can also serve as a framework for discussing mixed systems in general, or for that matter any other farming system. Moreover, it shows that much of the excitement created around new terminology, such as 'ecosystem health' or 'new conservation agriculture' derives from the presentation of old wine in new bottles.

References

Aarts HFM (2000). Resource management in a 'De Marke' dairy farming system. Ph.D. Thesis Wageningen Agricultural University, Wageningen.

Behnke RH, Scoones I and Kerven C (Eds.) (1995). Range ecology at disequilibrium, new models of natural variability and pastoral adaptation in African savannahs. (Overseas Development Institute, International Institute for Environment and Development, Commonwealth Secretariat, London).

Bos JFFP (2002) Comparing specialised and mixed farming systems in the clay areas of the Netherlands under future policy scenarios: an optimisation approach. Ph. D. Thesis Wageningen University, Wageningen.

Breman H (1990). Integrating crops and livestock in southern Mali: rural development or environmental degradation? In 'Theoretical Production Ecology: reflections and prospects'. (Eds. R. Rabbinge, J. Goudriaan, H. van Keulen, F.W.T. Penning de Vries and H.H. van Laar). pp. 277-294. (Simulation Monographs no. 34, Pudoc, Wageningen).

Breman H and de Wit CT (1983). Rangeland productivity and exploitation in the Sahel. Science 221, 1341-1347.

CAST (Council for Agricultural Science and Technology) (1999). Animal agriculture and global food supply. Task Force Report no. 135. (CAST Ames).

Checkland P and Scholes J (1993). Soft systems methodology in action. (John Willey, Chichester).

Conway GR (1987). The properties of agro-ecosystems. Agricultural Systems 24, 95-117.

Crotty R (1980). Cattle, economics and development. (Commonwealth Agricultural Bureaux, Farnham).

De Jager A, Kariuku I, Matiri FM, Odendo M and Wanyama JM (1998). Monitoring nutrient flows and economic performance in African farming systems (NUTMON); IV Linking nutrient balances and economic performance in three districts in Kenya. Agriculture, Ecosystems and Environment 71, 81-92.

De Ridder N, Breman H, van Keulen H and Stomph TJ (2004). Revisiting a ‘cure against land hunger’: soil fertility management and farming systems dynamics in the West African Sahel. Agricultural Systems (in press).

De Wit CT, Huisman H and Rabbinge R (1987). Agriculture and its environment: Are there other ways? Agricultural Systems 23, 211-236.

Giampietro M (1997). Socioeconomic constraints to farming with biodiversity. Agriculture, Ecosystems and Environment 62, 145-167.

Ho YW and Chan YK (Eds.) (1998). Area-wide integration of crop-livestock activities. Proceedings of a regional workshop. (FAO regional office for Asia and the Pacific, Bangkok).

ILRI (2000). ILRI strategy to 2010. Making the livestock revolution work for the poor. (ILRI, Nairobi).

Jodha NS (1992). Common property resources. A missing dimension in development strategies. World Bank Discussion Paper 169. Washington D.C.

Kuyvenhoven A and Ruben R (2002). Economic conditions for sustainable agricultural intensification. In 'Agroecological innovations. Increasing food production and participatory development'. (Ed. N. Uphoff) pp. 58-70. (Earthscan, London).

Klir GJ (1991). Facets of systems science. (Plenum Press, New York).

Lantinga EA and Van Laar HH (Eds.) (1997). De renaissance van het gemengde bedrijf: een weg naar duurzaamheid. Bedrijfs- en onderzoeksplan van twee gemengde bedrijven op de Ir.A.P.Minderhoudhoeve. APMinderhoudhoeve-reeks nr. 1.

Lantinga EA and Rabbinge R (1996). The renaissance of mixed farming systems: a way towards sustainable agriculture. In 'Book of Abstracts Fourth Congress European Society for Agronomy'. (Eds. M.K. van Ittersum, G.E.G.T. Venner, S.C. van de Geijn and T.H. Jetten) Vol II, pp. 428-429.

Niejenhuis JH and Renkema JA (1996). Erneute Chancen für die Integration von Ackerbau und Tierproduktion in der betriebsstrukturellen Entwicklung aufgrund umweltökonomischen Faktoren? Schriften der Gesellschaft für Wirtschafts- und Sozialwissenschaften des Landbaues 32, 559-566.

Nou J (1967). Studies in the Development of Agricultural Economics in Europe. (Almquist & Wiksells Boktryckeri AB, Uppsala).

Pearson CJ (1992). Ecosystems of the world. Field Crop Ecosystems. (Elsevier, Amsterdam, London, New York, Tokyo).

Powell JM and Waters-Bayer A (1995). Interactions between livestock husbandry and cropping in a West African Savanna. In 'Ecology and Management of the World's Savannas'. (Eds. J.C.Tothill and J.J. Mott) pp. 252-255. (The Australian Academy of Sciences, Canberra).

Röling N (1994). Interaction between extension services and farmer decision making: new issues and sustainable farming. In 'Rural and farming systems analysis: European perspectives'. (Eds. J.B. Dent and M.J. McGregor) pp. 280-291. (CAB International, Wallingford).

Savadogo M (2000). Crop residue management in relation to sustainable land use. A case study in Burkina Faso. Ph.D. Thesis Wageningen Agricultural University, Wageningen.

Schiere JB and Kater L (2001). Mixed crop-livestock farming A review of traditional technologies based on literature and field experience. FAO Animal Production and Health Papers No. 152. (FAO, Rome)

Schiere JB, Groenland R, Vlug A and van Keulen H (2004a). System thinking in agriculture: an overview. In ‘Emerging challenges for farming systems - lessons from Australian and Dutch agriculture’. (Ed. K. Rickert) (Rural Industries Research and Development Corporation, Kingston).

Schiere JB, van Keulen H, Slingerland M, Whitbread A, LaRovere, R and Hartwell, B (2004b): Mixed crop livestock systems for dry regions. Chapter 4 in the Monograph on Dry Region Farming. (Monograph of the American Society of Agronomy; Texas A&M, Amarillo).

Schmitt G. (1985). Das Coase-Theorem und die Theorie des landwirtschaftlichen Betriebes: ein Nachtrag zum Thünen-Gedenkjahr 1983. Berichte über Landwirtschaft 63, 442-459.

Sere C and Steinfeld H (1996). World Livestock Production Systems. Current status, issues and trends. FAO Animal Production and Health Paper No. 127. (FAO, Rome).

Sissoko K (1998). Et demain l'Agriculture? Options techniques et mesures politiques pour un développement agricole durable en Afrique subsaharienne. Cas du Cercle de Koutiala en zone sud du Mali. Ph.D. Thesis Wageningen Agricultural University, Wageningen.

Spedding CRW (1979). An introduction to agricultural systems. 2nd edition, (Elsevier Applied Science, Amsterdam).

Stobbs TH (1969). The effect of grazing resting land upon subsequent arable crop yields. East African Agriculture and Forestry Journal 35, 2832.

Stobbs TH (1962). The design, working and profitability of small stall feeding units for cattle in Uganda. East African Agriculture and Forestry Journal 27, 260-263.

Struif Bontkes TE (1999). Modelling the dynamics of agricultural development: a process approach. Ph.D. Thesis Wageningen Agricultural University, Wageningen.

Thornton PK, Kruska RL, Henninger N, Krisjanson PM, Reid RS, Atieno F, Odero AN and Ndegwa T (2002). Mapping Poverty and Livestock in the Developing World. ILRI (International Livestock Research Institute), Nairobi, Kenya.

Van der Pol F (1992). Soil mining: an unseen contribution to farm income in Southern Mali. Bulletin 325. (Royal Tropical Institute, Amsterdam).