Alternative Approaches to Substitute Chemical Fertilisers in the Food Crop Sector: Integrated Farming System Approach and Beyond

Wasanthi Wickramasinghe

Hector Kobbekaduwa Agrarian Research and Training Institute
114, Wijerama Mawatha
Colombo 07

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FOREWORD

Limitations and constraints of continuous use of chemical fertilisers to increase yields in the food crop sector are known factors. In exploring the alternative means of substituting chemical fertilisers to maintain soil fertility in the food crop sector, this short study supplements some lessons learned from the crop-livestock integrated farming systems worldwide and in Sri Lanka. Some information is useful in redesigning the current fertiliser subsidy program towards a more integrated plant nutrition programme.

I hope the information provided in this working paper would be useful to the policy makers and to the practitioners to address crop-livestock integrated farming in their programs.

Lalith Kantha Jayasekara
Director
Hector Kobbekaduwa Agrarian Research and Training Institute

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Dr. Wasanthi Wickramasinghe
Agricultural Resource Management Division

EXECUTIVE SUMMARY

Use of chemical fertilisers is an expensive means of maintaining soil fertility in agriculture. Hence, exploiting alternative means of substitute chemical fertilisers to maintain soil fertility has become an enormous challenge today. This working paper reviews the lessons learned from crop-livestock farming systems worldwide and from Sri Lanka. Crop-livestock integrated farming in the world has proven its sustainability as a farming system that requires minimum chemical fertilisers to replenish soil fertility. New Conservation Agriculture (NCA) is a winning combination that enhances nutrient recycling and intensifies land use for higher farmer profits. Of the main crop-livestock farming systems identified in Sri Lanka, village based small holder rice-vegetable-dairy farming system in the hill country is a well integrated farming system. However, livestock in the Sri Lankan farming systems constitute a smaller proportion. Integrated plant nutrient system provides a more holistic approach to maintain and sustain soil fertility from both organic and inorganic sources.

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ALTERNATIVE APPROACHES TO SUBSTITUTE CHEMICAL FERTILISERS IN THE FOOD CROP SECTOR: INTEGRATED FARMING SYSTEM APPROACH AND BEYOND

1. INTRODUCTION

Use of chemical fertilisers is an expensive means of maintaining soil fertility for food crop production owing to the escalating chemical fertiliser prices. On the other hand, continuous use of chemical fertilisers destroy the soil structure, turn the soil acidic and bring about nutrient imbalances resulting in nutrient interactions. Organic matter in the soil does not improve with application of chemical fertilisers. On the other hand, it leads to erosion and loss of top soil. The yield increases obtained during the early years of chemical fertiliser use gradually decrease and addition of extra fertilisers had brought only marginal benefits.

Having learned the limitations and constraints of continuous use of chemical fertilisers for increasing yields, exploiting alternative means of substitute chemical fertilisers to maintain soil fertility has become an enormous challenge today. Using organic matters in agriculture is not a new phenomenon and has been a long tradition in Sri Lanka. Before chemical fertilisers were introduced, organic forms – green manures, crop residues and farm yard manure- were used in large quantities for improving soil fertility. Also a season of farming was followed by a fallow period for replenishment of soil fertility. Integrated farming systems approach is another alternative that could substitute chemical fertilisers to a greater extent by integrating crop production and livestock production. It is known to be a viable and sustainable answer. Also in the recent past, several techniques have been developed, such as 'organic farming', 'eco-organic agriculture' and these methods require only organic fertilisers.

Traditionally, a wide variety of mixed farming systems has been used worldwide. The best known form of mixed farming is use of crop residues to feed animals and use of excreta of animals as nutrients for the crops. Even many highly specialized crop and livestock systems in developed and developing countries are rediscovering the advantages of mixed farming. The integration of crop and animal production is well developed in the farming systems of Asia, particularly in small-scale agriculture. There is marked complementarity in resource use in these systems, with inputs from one sector being supplied to others. Integration of crops and livestock is often considered as a step towards sustainable agricultural production because of the association of intensified organic matter and nutrient cycling. Residues of different crops represent the main on-farm source of organic matter and nutrients. This combines well with the presence of livestock since animals play a vital role as capital assets for security and as a means of saving, for cash income and nutrient flows. Management of crop residues in such regions is closely related to their utilization in animal feeding.

This short study attempts to document some experiences from the integrated farming systems worldwide and from the existing crop livestock systems in Sri Lanka to explore the scope of complete substitution of chemical fertilisers in food crop production by means of integrated farming approach as a viable option. Empirical evidence from a sustainable crop-livestock integrated farm in the food crop sector of Sri Lanka where the total fertiliser requirement is substituted by organic materials by means of crop and animal residues is presented at the end.

2. INTEGRATED CROP-LIVESTOCK FARMING SYSTEMS WORLDWIDE AND LESSONS LEARNED

The distinction between diversified and integrated crop –livestock farming systems is that diversified systems consist of components such as crops and livestock that co-exist independent of each other. In particular, farmers can operate dairy, pigs and crops as quite independent units. In this case the mixing of crops and livestock primarily serves to minimize risk and not to recycle resources. Integration is done to recycle resources efficiently. Integration is practised most often in farming systems in many tropical countries where products or by-products of one component serve as a resource for the other - dung goes to the crops and straw to the animals. In this case the integration serves to make maximum use of resources. In an integrated system, crops and livestock interact to create a synergy, with recycling allowing the maximum use of available resources. Crop residues can be used for animal feed, while livestock and livestock by-products can enhance agricultural productivity by intensifying nutrients that improve soil fertility, reducing the application of chemical fertilizers. A high integration of crops and livestock is often considered as a step forward, but small farmers need to have sufficient access to knowledge, assets and inputs to manage this system in an economically and environmentally sustainable condition over a long period. Unfortunately, these systems tend to become more vulnerable to disturbance because mixing of resource flows makes the system internally more complex and interdependent (FAO, 2001).

In Asia, the integration of livestock, fish and crops has proved to be a sustainable system throughout centuries. The best known integrated mixed farming is probably the case of mixed crop-livestock systems. Cropping in this case provides animals with fodder from grass and nitrogen-binding legumes, leys (improved fallow with sown legumes, grasses or trees), weeds and crop residues. Animals graze under trees or on stubble, and provide draught power and manure for crops. This system integrates crops and ruminants such as cattle, buffaloes, sheep and goats. Few different mixed crop-livestock systems could be found as follows.

2.1 Mixed Crop-livestock Systems – different modes

Even in integrated systems, the exchange of resources such as dung, draught power and crop residues take place in degrees that differ among the so-called modes of farming (Schiere and De Wit, 1995), based on the availability of land, labour and capital respectively.

- Expansion agriculture (EXPAGR)
- Low external input agriculture (LEIA)
- High external input agriculture (HEIA)
- New conservation agriculture (NCA)

2.2 Different modes of mixed farming

The EXPAGR mode is implemented where land is abundant i.e. where shortage of land or local fertility can be overcome by migration or by expansion into other regions. Typical examples of mixed farming in this mode are found in West Africa and in old Asian and European grazing systems. Animals were sent out to graze and would (occasionally) come home to "pull the plough or fertilize the crop fields". The crop fields themselves could move elsewhere if local soil fertility declined. However, this mode is becoming rarer as land resources are getting exhausted throughout the world.

Mixed farming in LEIA is implemented where the shortage of land can no longer be overcome by migration or use of substantial areas elsewhere for grazing. Lack of access to external inputs such as fuel, chemical fertilizers or pesticides implies that only increased use of labour and skills offers a way out. This also implies the introduction of modified practices, and the need to adjust demand according to resource availability. Dung is carried around on the farm by using more labour because lack of soil fertility cannot be compensated by shifting to more land or by employing more livestock to "produce" more dung. In LEIA systems the latter is considered a resource but it is a waste product in HEIA systems. If not managed properly and if demand for food and other crops is not adjusted to the carrying capacity of the soil, this can result in mining of soils and/or collapse of the systems.

Van der Pol (1992) calculated that the cotton-cereal systems in southern Mali earned 40 percent of their income by mining the soil. However, this cannot go on indefinitely and sooner or later the system will collapse if there are no changes. Some researchers think that animals, when managed correctly, can serve to fill part of the gap between the output and the input of nutrients in the system, together with proper use of chemical fertilizer.

Table 1: Characterization of Different Modes of Mixed Crop-livestock Farming

Mode of farming	EXPAGR	LEIA	HEIA	NCA
Relative access to production factors				
Land	+	-	-	-
Labour	-	+	-	+/-
Capital	-	-	+	+/-
Characteristics of farming:				
Source of animal feed	Outfield	Infield2 roadsides	Infield Import	Infield
Role of animals as savings account	High	Medium	Low	Low
Importance of excreta				
- Dung	Positive	Positive	Negative	Positive
- Urine	Neglected	Positive	Negative	Positive
Source of energy for labour	Humans/animals	Humans/animals	Fossil fuel	Fossil fuel/animals
Form of mixing	Diversity	Integration	Specialization	Integration
	Can be between and on-farm	On-farm	May be between farms	Mainly on-farm
Crop residue feeding	Irrelevant	Very relevant	Irrelevant	Relevant
Role of leys				
- For weed control	NA3	Low/NA	NA	Important
- For nutrient dynamics	NA	Low/NA	NA	Important
- For erosion control	NA	Low/NA	Low/NA	Important
Output of milk or meat per animal	Low	Low	High	Medium
Attention to conservation of the resource base	Low	Medium	Low	High

Source: FAO 2001

Mixed farming in the HEIA mode is not frequently found because it implies plentiful access to resources such as external feed and fertilizer that make exchange and recycling of resources at farm level not relevant. Exchange of resources between farms only exists, as seen in the section *On-farm versus between-farm mixing.* After the excessive use of fertilizer, farmers are forced to recycle the waste. In the HEIA mode the demand for output determines the use of inputs. The use of external resources can reach such high levels that the environment is affected by emissions from the crop and/or animal production systems, ultimately leading to waste disposal problems, thus forcing HEIA into NCA.

NCA is a mode of farming where production goals are matched as closely as possible to the resource base. This approach represents a mix between HEIA and LEIA, i.e. it aims to replace the removed nutrients but it also aims to achieve keen farming and adjusted cropping and consumption patterns to suit local conditions. The use of leys (improved fallows for grazing) is important to regenerate soils, to add nitrogen, to mobilize phosphate and to suppress weeds (i.e. to avoid herbicides).

An integrated farming system consists of a range of resource-saving practices that aim to achieve acceptable profits and high and sustained production levels, while minimizing the negative effects of intensive farming and preserving the environment. Based on the principle of enhancing natural biological processes above and below the ground, the integrated system represents a winning combination that

(a) reduces erosion;
(b) increases crop yields, soil biological activity and nutrient recycling;
(c) intensifies land use, improving profits; and
(d) help reduce poverty and malnutrition and strengthen environmental sustainability (FAO 2001).

2.3 Advantages and Main Constraints of Integrated Crop-livestock systems:

2.3.1 Advantages

In an integrated system, livestock and crops are produced within a coordinated framework. The waste products of one component serve as a resource for the other. For example, manure is used to enhance crop production; crop residues and by-products feed the animals, supplementing often inadequate feed supplies, thus contributing to improved animal nutrition and productivity.

The result of this cyclical combination is the mixed farming system, which exists in many forms and represents the largest category of livestock systems in the world in terms of animal numbers, productivity and the number of people it services. Animals play key and multiple roles in the functioning of the farm because they provide livestock products or can be converted into prompt cash in times of need. Animals transform plant energy into useful purposes: animal power is used for ploughing, transport and in activities such as milling, logging, road construction, marketing, and water lifting for irrigation.

Animals also provide manure and other types of animal waste. Excreta have two crucial roles in the overall sustainability of the system:

(a) **Improving nutrient cycling:** Excreta contain several nutrients (including nitrogen, phosphorus and potassium) and organic matter, which are important for maintaining soil structure and fertility. Through its use, production is increased while the risk of soil degradation is reduced.

(b) **Providing energy:** Excreta are the basis for the production of biogas and energy for household use (e.g. cooking, lighting) or for rural industries (e.g. powering mills and water pumps). Fuel in the form of biogas or dung cakes can replace charcoal and wood.

Table 2: Nutrient Content in 100 Kg of Cow dung

Nutrient	
N	1.74 %
P2O5	1.68 %
K2O	0.92 %
Fertiliser	
Urea	3.8 Kg
TSP	3.6 Kg
MOP	1.5 Kg

Source: Department of Agriculture, 2008

Crop residues represent the other pillar on which the equilibrium of this system rests. They are fibrous by-products that result from the cultivation of cereals, pulses, oil plants, roots and tubers. They are a valuable, low-cost feed resource for animal production, and are consequently the major source of nutrients for livestock in developing countries.

The overall benefits of crop-livestock integration can be summarized as follows:

- Agronomic - through the retrieval and maintenance of the soil productive capacity;
  It helps improve and conserve the productive capacities of soils, with physical, chemical and biological soil reclamation. Animals play an important role in harvesting and relocating nutrient, significantly improving soil fertility and crop yields.
- Economic - through product diversification and higher yields and quality at less cost;
  It is quick, efficient and economically viable because grain crops can be produced in four to six months, and pasture formation after cropping is rapid and inexpensive. It helps increase profits by reducing production costs. Poor farmers can use fertilizer from livestock operations.
- Ecological - through the reduction of crop pests (less pesticide use and better soil erosion control);
  It results in greater soil water storage capacity, mainly because of biological aeration and the increase in the level of organic matter.
- Social - through the reduction of rural-urban migration and the creation of new job opportunities in rural areas.
  It provides diversified income sources, guaranteeing a buffer against trade, price and climate fluctuations.

2.3.2 Constraints

- Nutritional values of crop residues are generally low in digestibility and protein content. Improving intake and digestibility of crop residues by physical and chemical treatments is technically possible but not feasible for poor small farmers because they require machinery and chemicals that are expensive or not readily available.

- Crop residues are primarily soil regenerators, but too often they are either disregarded or misapplied.
- Intensive recycling can cause nutrient losses.
- If manure nutrient use efficiencies are not improved or properly applied, the import of nutrients in feeds and fertilizers will remain high, as will the costs and energy needs for production and transportation, and the surpluses lost in the environment.
- Farmers prefer to use chemical fertilizer instead of manure because it acts faster and is easier to use.
- Resource investments are required to improve intake and digestibility of crop residues.
- Mixed farms are prone to use more manure than crop farms do. Manure transportation is an important factor affecting manure use.

2.3.3 Challenges

1. Develop strategies and promote crop-livestock synergies and interactions that aim to: (a) integrate crops and livestock effectively with careful land use; (b) raise the productivity of specific mixed crop-livestock systems; (c) facilitate expansion of food production; and (d) simultaneously safeguard the environment with prudent and efficient use of natural resources

2. Devise measures (for instance, facilitating large-scale dissemination of biodigesters) to implement more efficient use of biomass, reducing pressures on natural resources; and develop sustainable livestock manure management system to control environmental losses and contaminant spreading.

Key Principles:

- **Cyclic.** The farming system is essentially cyclic (organic resources – livestock – land – crops). Therefore, management decisions related to one component may affect the others.
- **Rational.** Using crop residues more rationally is an important route out of poverty. For resource-poor farmers, the correct management of crop residues, together with an optimal allocation of scarce resources, leads to sustainable production.
- **Ecologically sustainable.** Combining ecological sustainability and economic viability, the integrated livestock-farming system maintains and improves agricultural productivity while reducing negative environmental impacts.

3. CROP-LIVESTOCK SYSTEMS IN SRI LANKA

Six main farming systems that integrate crop and livestock could be identified as follows in Sri Lanka (Kodituawakku A O,2002)

3.1 Main Crop-Livestock Farming systems in Sri Lanka

The hill country system
This area lies 1200m above sea level and is characterized by tea plantations and dairy production from cattle kept in two systems; the plantation-estate and village-based systems. The dairy cattle are European breeds and their crosses. In the estate system, cattle are reared by landless estate workers who depend on estate land and roadside pastures for feeding their cattle. In the village-based system, the majority of smallholders are crop-livestock farmers growing vegetables and rice, and rearing cattle and buffalo to supplement their income. Dairying provides milk and manure, and most of the manure is sold for vegetable cultivation.

The mid-country system
This system is characterized by medium-intensity dairy production, based on crossbreds and Zebu cattle, and local buffalo. The small-scale farms combine a homestead tree-garden system with rice production in lowland areas. This is a crop-livestock system with different categories of crops grown on a limited land area. Export crops such as cloves, pepper, coffee and cocoa are grown in the home-gardens.

The low country, wet zone system
This area forms the peri-urban dairy system, which has both crossbred cattle and improved buffaloes. Cattle and buffalo are an integral part of the farming system providing manure and buffaloes being used for draught purposes. There is wide variation in the integration of crop and livestock.

The coconut triangle system
In this system, the main crop is coconut which is inter-cropped with export crops such as pepper, banana and pineapple; and root crops such as ginger, turmeric, and sweet potato. Small to medium herds of crossbred cattle and buffalo are reared in this system for milk and the provision of draught power. In this and the wetland zone, cattle and buffalo graze or are tethered on harvested rice lands. The animals are also fed on the native pastures in the coconut plantations.

The dry zone system
This is the largest zone, which includes irrigated rice, forest, and scrubland. The majority of cattle and buffalo in this region are of the indigenous type. The animals graze most of the year on rice lands after harvest, and are moved to the scrubland during the cultivation season. Most of the farmer settlements in the dry zone are serviced by a large number of major and minor irrigation schemes. Under irrigation, rice is grown in both monsoon seasons, with cash crops such as chilies and other vegetables being cultivated during the off-season. Under rainfed conditions, rice is grown only during the North-east monsoon season.

Under major settlement schemes, settlers maintain their homestead with one or two cattle and buffalo, a few goats, chickens, paddy rice land, and tree crops including some coconut palms. In the southern part of the dry zone, where irrigation is not available, the farmers cultivate only during the North-east monsoon season. During this period, cattle and buffalo are sent into the native vegetation unattended. During the dry period, the slash and burn (Chena) system is practiced and short-duration annual crops are grown. Once harvesting is over, animals are brought back to the villages.

The Jaffna peninsular system
This is a highly intensive, small-scale, cash-crop and vegetable-based system, where crossbred cattle are reared under intensive management. Dairy animals are kept mainly for milk and manure.

According to one study (Kodituawakku A O, 2002) there are 48 crop-livestock combinations within the country, consisting of eight crop and six livestock types. According to the study, 62% of all farms involved in annual and perennial cropping keep livestock. In 64% of livestock farms, the animals most commonly kept were cattle and poultry.

3.2 Empirical Evidence of Crop-Livestock Integrated Organic Farming Systems in the Hill Country.

Case study

District: Nuwaraeliya
Scale (Farm Size): ½ Ac
Family: 3 adults and 3 children
Production sub system: Crops, livestock and Bio gas unit
Crops: up country vegetables, banana, passion fruit, maize, pasture and fodder, live fence, fish pond
Livestock: Cattle – 1 Jersy milch cow and 8 months old Fresian calf, Goat
Animal feed: pasture and fodder (own farm and outside), Concentrates and Feed Additives
Crop Fertilisation: compost produced with farmyard manure, bio slurry and organic manure bought from outside, liquid fertiliser prepared with herbs, green manure harvested from live fence and forest
Labour: 1 full time farmer and 1 part time helper
15 man days per season is hired
Agronomic practices: crop rotation, fallowing, mixed cropping
Soil conservation measures: contour terraced plots surrounded by pasture, drainage channels with slit pits, forest at the lowest elevation, live fence, no weeding, land preparation and harvesting during rainy season, minimum tillage

Source: Weerakkody P.R, 2002

This is a conventional small farm that was gradually converted to an organic farm. Presently it totally depends on organic materials to fertilise crops. A direct involvement of a NGO has contributed in making this farm conversion from conventional to organic. This farming system is an integrated crop livestock system that depends on low external input. Compost produced with farmyard manure, bio slurry and organic manure bought from outside, liquid fertiliser prepared with herbs, green manure harvested from live fence and forest are the organic matters used by the farmer to fertilise his crop. Several agronomic practices and soil conservation measures have been adopted to make the system viable and sustainable.

4. SOME LESSONS LEARNED AND RECOMMENDATIONS

The maintenance of an integrated crop-livestock system depends on the availability of adequate nutrients to sustain animals and plants and to maintain soil fertility. Animal manure alone cannot meet crop requirements, even if it does contain the required kind of nutrients. This is because of its relatively low nutrient density and the limited quantity available to small-scale farmers. Alternative sources for the nutrients need to be found.

Growing fodder legumes and using them as a supplement to crop residue are the most practical and cost-effective method for improving the nutritional value of crop residues. This combination is also effective in reducing weight loss in animals, particularly during dry periods.

Given their traditional knowledge and experience, local farmers are able to apply an integrated system. In practice, however, relatively few adopt this system, mainly because they have limited access to credit, technology and knowledge. Particularly during the period of adoption of an integrated system, NGOs can play a proactive role.

Veterinary services generally do not reach poor small farmers in remote areas. Therefore, for livestock production to be improved, more attention needs to be paid to making veterinary care accessible, particularly in terms of prevention of illnesses.

Better livestock management is needed to safeguard water. Livestock water demand includes water for drinking and for feed production and processing. Livestock also have an impact on water, contaminating it with manure and urine. All of these aspects need to be given due consideration.

Intensification of agriculture through appropriate incorporation of small livestock has the potential to decrease the land needed for agricultural production and relieve the pressure on forests.

4.1 Key Issues/Questions of Concern

The increase in demand for livestock products presents opportunities for small farmers who can increase livestock production and benefit from related income. However, in terms of environmental impact, the growing number of livestock and the increase in livestock processing can have a negative impact on natural resources unless actions are taken to identify farming practices that are economically and ecologically sustainable. Thanks to the dynamic interaction of its various components, the highly improved integrated crop-livestock system can guarantee more sustainable production and therefore constitutes a valid new approach.

Experience in the use of this system has shown that: (a) adopting sustainable management practices can improve production while preserving the environment; (b) residues, wastes and by-products of each component serve as resources for the others; and (c) poor farmers have the traditional knowledge needed to integrate livestock and crop production, but because of their limited access to knowledge, assets and inputs, relatively few adopt an integrated system.

The challenge for development practitioners is to ensure that poor small farmers can increase the productivity of traditional farming systems, adopting an effective integrated system that produces usable biomass while conserving natural resources, and can therefore be sustainable in the long term.

4.2 Integrated Plant Nutrition Systems (IPNS)

Integrated Plant Nutrition System is a holistic approach to plant nutrition by obtaining the nutrients from both inorganic and organic sources to maintain and sustain soil fertility and enhance crop productivity in a framework of an ecologically compatible, socially acceptable and economically viable situation.

Organic manures sustain soil fertility at a low level of production. Chemical fertilizers have concentrated forms of nutrients. Application results in leaching, fixation and build-up of certain nutrients at the expense of others, resulting in nutrient imbalances. Fertilizer use efficiency (FUE) is low in all chemical fertilizers and organic manure when used singularly. Combined use of organic manures and chemical fertilizers increases FUE

Appendix 1

Terms and Technologies Associated with Crop-livestock Integration, Soil Fertility and Animal Nutrition

Anti-erosion bund	A ridge planted (on the edge of a terrace) to avoid runoff
Catch crop	A crop that is planted to "absorb" nutrients in the soil that are released through weathering
Compost	Organic matter (with or without animal excreta) which is decomposed on a heap or in a pit before applying it to the soil
Excreta	A combination of dung and urine
Fallow	Allowing the land to remain idle so that it can rebuild itself in terms of soil fertility, soil structure and soil life; or to ensure reduction disease and weed pressure.
Grain:straw ratio	The ratio between grain and straw, i.e. a grain yield of 2 000 kg/ha associated with a grain:straw ratio of 1.5 which results in a straw yield of 3 000 kg/ha
Harvest index	The proportion of the above ground biomass (in the case of cereals) is found in grains, i.e. a harvest index of 33 percent results in a ratio of 2 kg straw:1 kg grain
Infield	The cropping area around villages or homesteads fertilized with excreta and litter from the outfield
Ley	A cultivated fallow planted with fodder crops that actively suppress weeds germs, bind nitrogen, mobilize phosphorus, and add soil organic matter or reduce runoff, etc.
Manure	Farmyard manure, excreta (the solid part) of animals which is mixed with straws and other leftovers
Mulch	The mix of dry and/or green materials that can be used to cover the soil for prevention of erosion or excessive temperature effects
Outfield	The grazing lands, waste lands and forests around the village where animals are grazed or the faraway crop fields of a village
Soil organic matter	Organic matter originating from plants and/or dung that occurs in several degrees of decomposition in the soil, and in different degrees of solubility. It serves to enhance structure (on heavy soils) and water/nutrient holding capacity (on light soils)
Stover	The mature stems and leaves of coarse cereals such as maize, sorghums and millets
Straw	The stems and leaves of mature fine cereals such as rice, wheat, barley, oats and rye
Zero grazing	The keeping of animals in a shed, based on feed that is brought in from elsewhere (on-farm and/or off-farm)

Appendix 11

Empirical Evidence of Crop-livestock Systems with Different Management Practices

1. Case Study from India

A study for Low External Input Agriculture (LEIA) conditions in India with different crop-animal combinations has shown that the use of cows with individual productions of 10 litres/animal/day led to higher total farm outputs than those producing 16 litres/animal/day. The high- producing dairy cows cannot be fed with fibrous crop residues such as straw. The goal of high milk yield per cow would reduce total farm income, thus losing an opportunity to use these resources.

Optimum crop combinations, herd size and production at different individual cow productions with or without treatment of stover, when the farmer also has access to a small fixed area of good quality fodder

Individual production	Total production (litres/day/system)	Herd size (cows/farm)	Cotton (ha)	Total income from milk and crop (litres/day/cow) (Rs/day/farm)
2.0	5.1	2.5	0	22.2
6.0	9.5	1.6	0	35.4
10.0	10.6	1.1	0.4	39.1
16.0	6.6	0.4	1.0	27.6

Notes: Total area is 1 ha, i.e. 0 ha cotton implies 1 ha of sorghum, 0.4 ha cotton implies 0.6 ha sorghum.

The cows used in this modelling are "tropical" cows; they are smaller than their temperate cousins. A milk yield of 10 litres for an animal of 350 kg is comparable with a yield of 20-25 litres for a temperate cow.
Source: Based on Patil, Rangnekar and Schiere (1993).

2. Case Study from Kenya

A study of crop-livestock combinations in Kenya shows an added issue, i.e. the optimum combination of animals and crops. The large farmer benefits more from grade cows (high yielding) and the small farmer is better off with crossbreeds.

Optimal Farm Crop Areas as Calculated with Linear Programming for an Area with Mixed Crop-livestock Systems in Kenya

	Large farm holding	**Small farm holding**
Gross margin (Kenyan shilling)	7 952	6 560
Land used (ha)	7.98	3.9
Grade cows (cow/farm)	7	-
Crossbred cows (cow/farm)	-	5
Coffee (ha)	0.06	-
Maize (ha)	0.28	0.52
Beans (ha)	1.03	1.34
Potato (ha)	0.03	0.04
Banana (ha)	-	0.15

Source: Based on Kidane (1984).

Farm Yard Manure

The amount and quality of urine and dung produced depends on the type of animal, its size and the type of feed as well as on the management of the farmer. One way to calculate the amount of manure produced is:

- One animal of 250 kg live weight has a feed intake that averages 2.5 percent dry matter of its live weight. It therefore consumes 250*365*0.025 = 2 280 kg of dry matter. With an average digestibility of 55 percent, the animal will produce 0.45*2 280 = 1 026 kg of dung every year.
- Small ruminants weighing 25 kg and feeding 3.2 per cent daily on average of their live weight, consume 25*365*0.032 = 292 kg dry matter. If their average digestibility of the feed is estimated at 60 percent it can be calculated that one small ruminant produces some 117 kg of dry matter faeces per year (Defoer *et al.*, 2000).

The amount and proportion of nitrogen excreted depend on animal diet. The urine and solid dung of animals fed with highly digestible diets with a lot of protein contain much more nitrogen and, therefore, are more susceptible to nitrogen losses than excreta from diets containing greater amounts of roughage. Much of the urine nitrogen is lost via ammonia volatilization. Where animal management tends towards increased stall-feeding, the composting of fresh manure will have to play a greater role in minimizing nutrient losses. Pits or heaps that capture feed refusals, manure and urine and household waste need to be designed to minimize nutrient losses. Low-cost appropriate implements to spread the compost at the appropriate time over large cultivated areas such as the Sahel are also needed (based on Powell and Williams, 1993).

Nutrient Contents of Manure and Other Organic Fertilizers (percentage)

Organic fertilizer	N	P	K	Dry matter
Cattle				
Fresh manure	1.4-2.8	0.5-1.01	0.5-0.6	15-25
Kraal (litter)	0.5-2.3	0.22-0.81	0.77-5.44	40-60
Kraal (no litter)	1.5-2.5	0.2-0.6	1.5-2.0	30-50
Goat and sheep				
Fresh manure	2.2-3.7	0.25-1.87	0.88-1.25	50-70

Source: Based on a compilation by Defoer *et al.* (2000).

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