CROP-LIVESTOCK INTERACTIONS IN THE ETHIOPIAN HIGHLANDS AND EFFECTS ON SUSTAINABILITY OF MIXED FARMING: A CASE STUDY FROM ADA DISTRICT

BY

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DECLARATION

I, the undersigned, hereby declare to the Agricultural University of Norway that this thesis is my own original work and all other sources of materials are duly acknowledged and that it has not been submitted to any other university for any academic degree awards.

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LIST OF ACRONYMS, SIGNS AND UNITS

BOSTID	Board on Science and Technology for International Development
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Centre
CSA	Central Statistical Agency (Ethiopia)
EMA	Ethiopian Mapping Agency
FAO	Food and Agricultural Organization of the United Nations
GOE	Government of Ethiopia
IAR	Institute of Agricultural Research (Ethiopia)
ICRISAT	International Crops Research Institute for the Semi-arid Tropics
IIED	International Institute for Environment and Development
ILCA	International Livestock Centre for Africa
IUCN	International Union for Conservation of Nature and Natural Resources
MOA	Ministry of Agriculture (Ethiopia)
NORAD	Norwegian Agency for Development Co-operation
NORAGRIC	Norwegian Centre for International Agricultural Development
ONCCP	Office of the National Committee for Central Planning (Ethiopia)
PA(s)	Peasant Association (s), PC = Producers' Cooperative
TAC	Technical Advisory Committee of the CGIAR
WCOED	World Commission on Environment and Development (The Brundtland Commission)
WHO	World Health Organization
WMO	World Meteorological Organization
Kert	A quarter of a hectare (2500 m^2)
DM	Dry Matter, CP = Crude Protein
Kcal	Kilo calories (1000 calories)
MJ	Mega joule
N	Number of observations, ppm = Parts per million

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'' Agriculture will be found to be sustainable when ways are discovered to meet future demand for foodstuffs without imposing on society real increases in social costs of production and without causing the distribution of opportunities to worsen'' (Douglass, 1984 P 25).

''Integration of plant and animal resources to achieve optimal biomass output within a given ecological and socioeconomic setting should be the ultimate goal for sustainable farming systems'' (Parker, 1990 PP 238-239).

ABSTRACT

This study, carried out in the former Ada district of Ethiopia, assesses the cause and effects of competitive crop-livestock interactions at a Macro (district) level and complementary interactions at a Micro (PA) level on sustainability of mixed farming in the Ethiopian highlands. At a macro-level, the effects of crop encroachment and population pressure on disappearance of grazing areas and fallow lands and extension of cropping into marginal areas was looked into. Furthermore, disparities in feed supply and demand and current feeding systems in the district were assessed.

It is argued that incursion of cropping into grazing grounds as a cumulative effect of demographic and non-demographic factors has led to increasing disappearance of natural pastures and extension of permanent cropping and livestock husbandry into fragile environments. This has led to increasing competition for land between cropping and livestock production and raising of stock at sub-maintenance diets even after a virtually complete diversion of crop residues for animal feeding. The environmental effects of the tightening resource use conflicts in mixed farming is highlighted.

The study further goes on investigating complementary effects of crop-livestock integration for sustainability of mixed farming. Some of the key integration effects of maintaining animals in mixed farming are compared and argued in terms of sustainability of the system. It illuminates the role of livestock towards sustainable development in subsistence-oriented mixed farming in the highlands. It elaborates how complementary interactions could benefit the crop and livestock sub-sectors without jeopardizing sustainability when cultivation densities and herd sizes are kept below certain critical levels. However, the study does not attempt to be exhaustive and conclusive as it relies on input-output relations of one cropping year in mixed farming.

1.0 INTRODUCTION

1.1 The role of agriculture in the Ethiopian economy

Ethiopia, situated between 3 and 18^0 N latitudes and 33 and 48^0 E longitudes, has a total area of 1.222 million square kilometers. The country has a fairly good endowment of physical and biological resources including soils, water, climate, flora and fauna suitable for agricultural production. About 68% of the total area is considered propitious for agriculture (GOE, 1988).

Ethiopian agriculture provides a means of living for the majority (85%) of the population (GOE/IUCN, 1990). In 1989, about 75% of the economically active population was engaged in the agricultural sector (FAO, 1990). Between the years 1983/84 and 1987/88, agriculture generated about 44% of the GDP at current factor costs and 88% of the export revenue (GOE, 1988).

As a result, agriculture remains to be the single most important sector in the Ethiopian economy. However, the performance of this sector has not kept in pace with the undeterred population growth of 2.9% per annum. During the first four years of the Ten Year Perspective Plan (TYPP) 1984/85-1987/88, agricultural production in general and food production in particular grew at -0.4% and -0.7% per annum respectively (GOE, 1988). This means that between the same period per capita food crop production has declined by 3.6% per annum. According to FAO (1989b) estimates per caput dietary energy supplies declined from 1748 calories in 1978-80 to 1661 calories in 1984-86.

Ethiopian agriculture is primarily subsistence oriented dominated by peasant low-level production technology in both crop and livestock production. The overwhelming proportion of agricultural production in the country originates from private smallholder farmers which own about 93% and 98% of the cultivated land and livestock and produce 90% and 98% of the crop and livestock output at any one year respectively. Peasants cultivate fragmented small holdings with an average size of 1.32 ha. Until the time when cooperativization policy was repealed in 1990, Producers Cooperatives (PCs) and State Farms jointly owned 7% and 2% of the cultivated land and livestock and produced about 10% and 2% of the crop and livestock output respectively (GOE, 1988). By and large, private smallholder mixed farming remains to be the dominant sector of Ethiopian agriculture and the entire economy.

1.2 Potential of the highlands in the economy

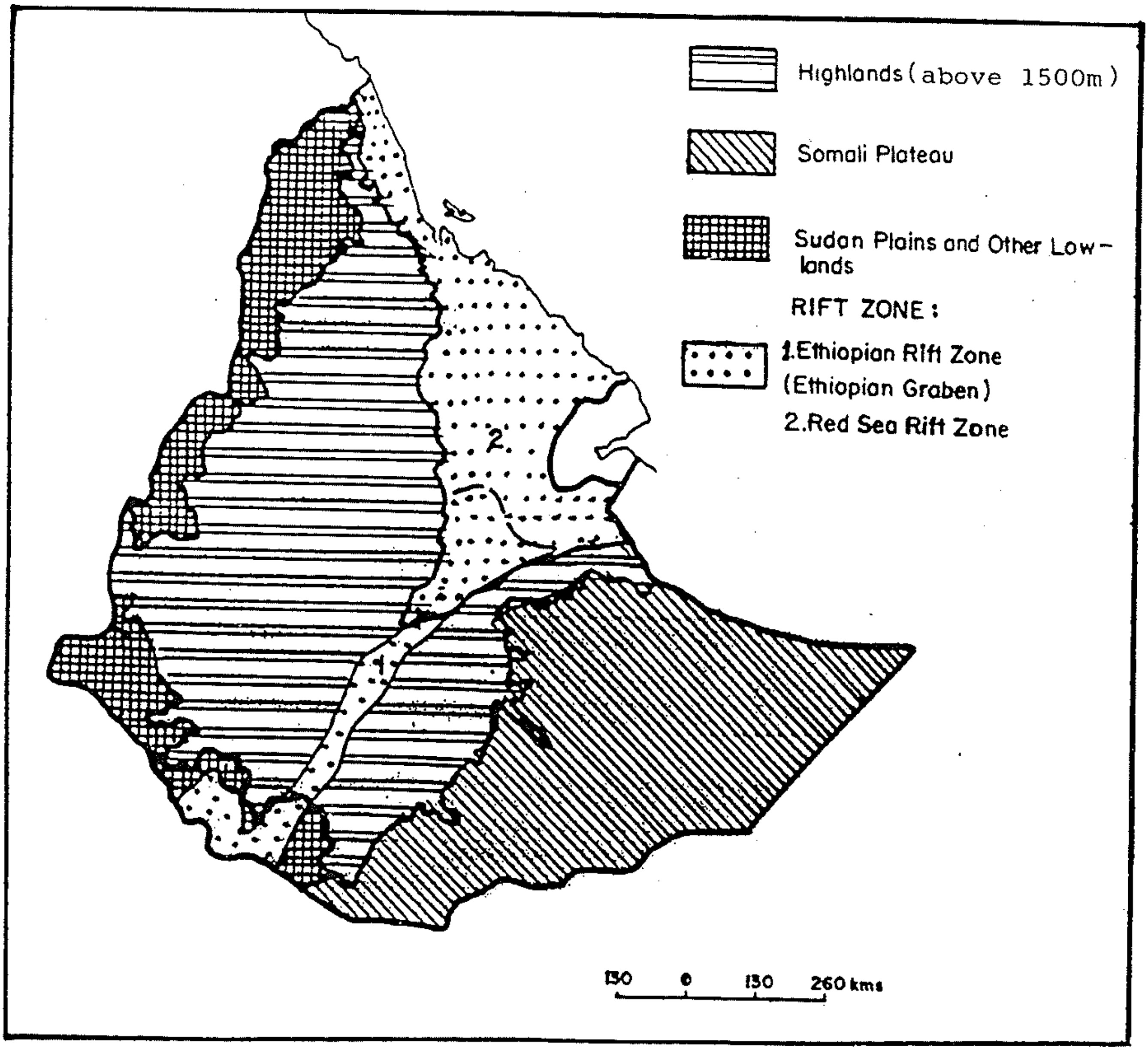
The highlands of sub-Saharan Africa defined as areas above 1500 m elevation or with mean daily temperatures of less than 20° C during the growing period include approximately 1 million km^2 or some 4% of the land area of sub-Saharan Africa. About 75% of the highlands are located in eastern Africa (Jahnke, 1982).

Ethiopia has the largest (50%) highland area of the continent, divided by the Ethiopian rift system into two, a larger landmass in the west and a smaller one in the east (see Figure 1) covering some 536,000 km^2 or 44% of the country and almost half of the total African highland area as a result of which Ethiopia is referred to as the 'Roof of Africa'(FAO, 1986; Amare Getahun, 1978a; Gryseels and Anderson, 1983).

In Ethiopia, Kenya and Tanzania, the highlands account for the great majority of the human and livestock populations. Even though there is a critical shortage of information apart from its variability about the exact land use situation and potentials of the different altitudinal zones, available crude data indicate that the Ethiopian highlands constitute 88% of the total population, over 95% of its regularly cultivated lands, about 75% of its livestock, about 91% of its forest cover and account for more than 90% of the country's economic activity (FAO, 1986; GOE, 1988; GOE/IUCN, 1990).

Several factors contribute for concentration of people and their livestock in the highlands, the most important of which are

Figure 1. Topographic map of Ethiopia.



Source: Adapted from FAO(1986).

favorable climate and ecological conditions for smallholder mixed farming (good soils, moderate temperatures, ample radiation andrainfall); comparatively high levels of fodder production and reduced incidence of diseases like trypanosomiasis and sleeping sickness.

While the productivity of crop and livestock in the highlands is higher than the lower altitudes, concentration of people and their crops and livestock over a millennia in the past has resulted in substantial land degradation. Because Ethiopia's development depends on the effective utilization of its higher altitudes, degradation of the resource base severely threatens the national economy.

1.3 Crop-livestock interactions in the Highlands

1.3.1 The crop and livestock sub-sectors

As it has been presented above, agriculture occupies a pivotal position in the Ethiopian economy. The majority of the agricultural produce emerges from mixed smallholder farmers of the highlands where livestock production is a component part of the farm management unit. The productivity of both crop and livestock enterprises is very low.

Although livestock serve several functions to the cropping sub-system in the highlands, the primary emphasis of the highland mixed farmer is to secure a sufficient crop output to feed the family, while livestock production is very often a means to that end.

This situation has been also reflected in the agricultural policy of the government which gives top most priority in the TYPP (1984/85-1993/94) to the crop subsector. For example, during the first five years of the TYPP, the peasant and state crop and livestock sectors are jointly envisaged to share 77.2% and 16.6% of the agricultural investment respectively (GOE, 1984). This is mainly because of the recent drive towards self sufficiency in food crop production and a higher current contribution of the crop enterprise to the agricultural GDP and export earnings.

However, any campaign for self sufficiency in food production seems to be highly inseparable to livestock production since the latter are the ones which convert inedible and useless lignocellulose to a high quality edible protein, and provide the crucial traction and transport input to the cropping subsector. Thus, livestock can not be undervalued in any attempt to promote food crop production.

According to the latest FAO (1990) estimates, Ethiopia possesses about 28.9 million cattle, 24 million sheep, 18 million goats, 4.9 million donkeys, 2.6 million horses, 0.57 million mules, 1.07 million camels, and 57 million chicken. This is a very huge potential wealth to the country's national economy which places Ethiopia at the forefront in livestock population in Africa. Despite this tremendous livestock potential, the sub-sector's productivity and contribution to the national economy has been disproportionately low.

As a result, livestock contribute only about 15% of the GDP (Gizaw Nigussie, 1987), while the remaining 29% of the agricultural sector emerges from the cropping subsector. Put differently, livestock and crop production contribute about 34 and 66% of the agricultural GDP (Jahnke, 1982).

1.3.2 Interdependence between crop and livestock sub-systems

In the Ethiopian highlands, mixed farming is a fact of life and crop and livestock production are synergistically linked together under the same farm management unit. Apart from provision of output functions (milk, meat, wool, skin and hides) to the mixed farmer, livestock predominantly provide several indispensable input and integrative functions to the cropping sub-system.

The major input functions of livestock to the cropping sub-system include provision of traction, threshing and transport power, and manure for maintenance of soil fertility in areas where its high opportunity cost for fuel does not constrain its soil ameliorative function. In some areas of the highlands, livestock also provide power for trampling cultivated fields as a final preparation of the seed-bed before planting especially for teff and finger millet.

The farm integrative function of livestock includes all the different effects livestock may have on the productivity of resources engaged in agriculture. Through the investment linkages, income from sale of livestock may be invested in cropping and vice versa. Livestock also serve a buffering effect to the mixed smallholder there by providing security against crop failures. Complementary interactions are also observed when idle labor is used in livestock during slack periods in cropping, or in use of skin and hides for storage of grains or when a fallow land is used for grazing. The cropping sub-system predominantly provides crop residues as byproducts of threshing and stubbles as byproducts of harvesting which now serve as important sources of animal feed in the highlands.

1.3.3 Conflicts between crop and livestock sub-systems

Because of favourable agricultural conditions (fertile soils, climate propitious for a variety of crops, diverse topography, and reduced disease incidence), the human and livestock population densities of the highlands have been gradually building up ever since agriculture became known to mankind. This has made highlands centres of proliferation for human and livestock populations.

At present, human and livestock population density of the highlands is higher than any other agroecosystem in Africa. According to Jahnke (1982), almost 20% of the rural human and livestock populations of sub-Saharan Africa are concentrated in the highlands. The human population density of approximately 44 persons per km^2 and the animal stocking density of 23.9 LU per km^2 is almost four times the average for sub-Saharan Africa.[1]

Partly because livestock are integral parts of the highland mixed farming complex, and because of reasons mentioned above, about 75% of the livestock population of the country is found in the highlands which also contains 88% of the population and 95% of the country's regularly cultivated fields. This issue is paradoxical when one observes that 68% of the country's grazing lands are found in the lowlands which now support only 25% of the livestock population. In other words, 75% of the country's livestock are concentrated only in 32% of the grazing lands (GOE, 1988). In the lowlands livestock are parts of the pastoral economy, while in the highlands they are integral parts of mixed cultivation complex (see Table 1.1).

Even though the country lacks a comprehensive land use map showing the exact altitudinal distribution of human and livestock populations and the resource use situation, population densities of the highlands are by far higher than the country's average and that of the lowlands. This may imply that land use in Ethiopia is unbalanced with respect to spatial distribution of resources and potentials in different altitudinal zones. Land use pressure is substantially high in the highlands with a better resource endowment as compared to the lowlands.

Land use pattern and human and livestock densities also vary within the different agroecosystems of the highlands. Several authors have attempted to describe traditional agricultural systems in Ethiopia and the highlands (Westphal, 1975; Amare Getahun, 1978a and 1978b; FAO, 1986). Adopting the type of soil, climate, length of the growing period and farming systems criteria, FAO (1986), based on Amare Getahun (1978a), classified the highlands in to three agroecological zones. These are:

[1] These aggregate figures conceal significant variations in settlement and land use density within each agroecosystem. Some pockets in the highlands, of course, harbour population densities much higher than the average given for sub-Saharan Africa (eg. Kembata, Hadiya, and Wolayita highlands of Ethiopia support a population density over 100 persons Km^{-2}).

- High potential perennial (HPP)
- High potential cereal (HPC)
- Low potential cereal (LPC) zones covering 36.4%, 30% and 33.6% of the total highland area respectively. Estimated livestock population of each zone is given in Table 1.2.

Table 1.1 Land use pattern and altitudinal distribution of human and livestock population in Ethiopia (1988).

Land use/population	Total	Highland	%	Lowland	%
Area ('000ha)	122456	54104	44	68352	56
Cultivated land ('000ha)	18487	16737	90	1750	10
Forest land ('000ha)	4470	4070	91	400	9
Grazing land ('000ha)	62404	20096	32	42308	68
Human pop. ('000 persons)	47300	39100	83	8200	17
Livestock pop. ('000 TLU)[a]	29760	20941	71	8819	29
Stocking density (TLU Km^{-2})	24	38	-	13	-
Stocking in grazing land(TLU km^{-2})	48	104	-	21	-

[a] TLU is a ruminant livestock of 250 kg live weight. In this calculations the 1988 population estimates of FAO Production Yearbook 1989 were used with the estimates of Jahnke and Getachew (1984) in which 75%, 75%, 27%, 80% and 0% of cattle, sheep, goats, equine and camels are found in the highlands. TLU conversion factors are according to Jahnke (1982).
Source: Compiled by Author mainly based on GOE (1988) and GOE/IUCN (1990).

Livestock are distributed in the different zones of the highlands according to their importance in each zone, their feeding behavior and habitat preferences. Cattle and equine, which are able to survive on a diet consisting of a higher ratio of crop residues, are concentrated in the highlands where they are badly needed for provision of draught and transport power. All the camels and the majority of the goat are in the lowlands since they are intermediate feeders preferring browsing on rangeland flora.

Table 1.2 Livestock population of the highlands by zone.

Species	Ethiopia [a] ('000 heads)	Highlands ('000 heads)				
		%[b]	total	HPPL	HPPC	LPCL
Cattle	27000	75	20250	6682	8302	5265[c]
Sheep	24000	75	18000	3240	8100	6660[d]
Goats	18000	27	4860	874	1895	2089[d]
Equine	8000	80	6400	448	2945	3000[d]
Camels	1060	0	0	0	0	0[2]

Source: compiled by author based on:
[a] the 1988 livestock population estimates of FAO production year book 1989.
[b] estimates for highlands given by Jahnke and Getachew (1984).
[c] estimates given by AACM (1984).
[d] estimates given by FAO (1986).

Besides, the camel, which can best utilize plants from highly saline areas and have distinguished ability to conserve water, is the most suitable domestic species in arid and semi-arid areas. The goat with its high selectivity and short rumen retention time can not utilize low quality roughages as efficiently as cattle and sheep, thus it is at a disadvantage where crop residues represent the main feed sources. The highland human and livestock population densities are given in Table 1.3.

Even though, aggregation of average figures on a larger zone may conceal more than it reveals significant variation with in one

[2] In reality, the assumption that there are no camels in the highlands is not always true because of seasonal movements into the system apart from existing low populations.

zone, the well-endowed high potential perennial-livestock zone has the smallest human and livestock densities. The high potential cereal-livestock zone has the highest densities for both human and livestock populations. In both zones, livestock densities are closely correlated to human settlement patterns which implies that areas of high subsistence demand are at the same time areas of high animal density which further intensifies land use pressure on the natural resource base.

Table 1.3 Highland human and livestock population densities by zone.

Zone	Area[a] ('000km^2)	%	Popul[b]. (mill.)	%[a]	Density (pers./km^2)	Livestock[c]. ('000TLU)	%	Density (TLU/km^2)
HPPL	195	36.4	13.7	33	70	5402	26	28
HPCL	161	30.0	13.7	33	85	8872	42	55
LPCL	180	33.6	14.2	34	79	6667	32	37
Total	536	100	41.6	100	-	20941	100	-

Source:- Compiled by the author based on:
[a] land area and population distribution of highland zone given by FAO (1986).
[b] assuming that 88% of the 1988 population of 47.3 million is in the highlands.
[c] livestock distribution given in Table 1.2.

Maximization of contributions of livestock in the highlands is much more readily achieved by maximizing numbers than production per animal. On the top of these, the fact that a larger part of the grazing land is communal while all livestock are privately owned adds to the above syndrome of expanding herd/flock size. Where local institutions are undermined often because of external interference, there is no mechanism that would prevent an individual farmer from increasing his number of animals. While the benefits from increasing herd size are private, the costs in terms of lower productivity of the total herd/flock and the total grazing resources are shared by all because no one has the incentive to invest on improvement of a communal grazing land which is now virtually an open access resource. This generally results in stocking rates above the optimum on the scarce grazing resources disappearing from expansion of cropping and incursion in to the already overgrazed pastures.

In this confrontation, one unintelligible paradox is uncovered. While the functions of livestock in the highlands encourage expansion of herd/flock sizes, the available grazing areas are disappearing because of declining fallow periods and crop encroachment. The major sources of feed now in the highlands are valley bottoms that quite often because of water logging are not suitable for cropping, steep mountains where oxen can not climb for cultivation, stubble grazing, crop residues and roadside grazing. The remaining grazing resources are highly overgrazed and can barely meet the maintenance requirements of the huge livestock populations of the highlands.

With increasing competition for land, more and more unsuitable land is brought into cultivation, fallow periods decline to zero with the cropping index approaching 100%, livestock are crowded on small areas on the hillside or near waterlogged areas or become largely dependant on crop residues, thus land degradation becomes a fact.

As the resource base deteriorates because of alarming rates of soil erosion, crop yields decline and reach the low level steady state equilibrium which also reduces the supply of crop residues. Crop yields also decline because the input function of livestock (supply of power for traction, threshing, and transport, and manure for maintenance of soil fertility) will decline with a decline in the supply of animal feed. The result is that productivity of livestock by all indicators including offtake is very low and livestock populations are not capable of growth.

Although the central theme of this study focusses on Complementary interactions and competition for land in crop-livestock systems, the two enterprises also compete for all factors of production including labour, capital and managerial capability of the farmer. Competition for labour becomes intense during peak land preparation (cultivation), seeding, weeding and harvesting seasons. During slack periods, however, competition for labour may turn to complementarity as idle labour is used in the livestock enterprise. The major labour requirements of the livestock system in mixed smallholder farming are herding, shifting/cleaning the kraals, feeding (mainly transport of crop residue to the homestead), milking, marketing, etc.

Because the farmer is confronted with a variety of competing ends for scarce input factors, as the manager of the enterprises he has to allocate scarce factors in the best possible combination which provides the highest return per unit of input factor used.

1.4 Justification and objectives of the study

1.4.1 Justification

Although agriculture has remained to be the back bone of the Ethiopian economy of which the smallholder mixed farming of the highlands represents more than 90% of the cropped land and two-third of the livestock population, the performance of this sector has been generally stagnating and dismal. One possible reason for low productivity is deterioration of the natural resource base mainly because of unwise use and management of land resources.

Now a days, Ethiopian highlands represent one of the largest areas of ecological degradation in Africa (FAO, 1986). Environmental conditions have worsened to such an extent that in some parts of the highlands millions are now scarcely able to subsist even in years of good rainfall. Years of less-than- average rainfall threaten famine with increasing severity and extent thus making the disadvantaged rural poor vulnerable to the effects of drought. The country is already importer of some 5 million quintals of food during years of 'good' rainfall, while imports may rise up to 11 million quintals during years of drought or lean rainfall

(GOE, 1988).

An increasing subsistence demand because of outward expansion of cropping areas under conditions where soil fertility enhancing practices are virtually absent (only 10% of farmers use chemical fertilizers while animal manure is mainly used as fuel) and fallow periods are hardly observed, indeed gradually leads to overgrazing and land degradation. This will result in livestock raising under sub-maintenance diets in turn leading to a decline in the productivity of both crop and livestock sectors. The standard of living of the rural mixed farmer will progressively decline accordingly.

Oxen provide the traction power to cultivate about 95% of some 7 million ha (estimates vary between 7 and 18 million ha) cultivated every year (GOE, 1988; GOE/IUCN, 1990). Moreover, livestock provide other important input and integrative functions to the cropping sub-system.

While it becomes difficult to overemphasize the value of livestock in the mixed smallholder system of the highlands, it is incontestable that livestock production is being relegated to marginal areas unsuitable for cropping with severe impacts on the environment and productivity of the two enterprises.

Despite the fact that oxen provide tractive power virtually for all regularly cultivated fields in any one year, draught oxen availability is a crucial handicap to the smallholder mixed farmers. According to the available statistics of MOA (1980), nationally around 29% of the farmers have no oxen, 34% have one, 29% have two and only 8% have three or more oxen. Since only pairs can be traditionally used for cultivation those with single oxen have to enter in to different kinds of arrangements for pairing, and those without oxen are either dependent on hoe cultivation or hire out labour to those who had the traction power. This will be reflected eventually by lower productivity of land, labour and livestock and thus poverty and famine become persistent.

The essential functions of livestock in mixed farming systems as they can only be efficiently maximized by a sheer increase in numbers than improving productivity per animal unit, compel the farmer to increase his herd/flock size. However, increasing subsistence demand and outward expansion of cropping to compensate for declining productivity of land are compromising sustainability of the system by turning symbiotic interactions into competitive and mutually exclusive interactions in the long run.

1.4.2 Objectives

Having all these notable justifications, this study was carried out with the following major objectives.

1. To assess trends in land use and degree of incursion in to grazing lands as a result of population pressure, crop encroachment, changes in rainfall and institutional factors.
2. To assess prevailing disparities between feed supply and demand.
3. To investigate the impacts of draught oxen availability and size of livestock holdings on sustainability of agriculture in the highlands.

2.0 REVIEW OF LITERATURE

2.1 The structure and dynamics of agroecosystems

2.1.1 Natural systems versus agroecosystems

The biological systems which make up the Earth's biosphere have functioned systematically and have gradually been modified through time ever since the most primitive forms of life first appeared on this planet.

During ancient times, mankind used to obtain the basic food and shelter requirements in the natural ecosystem as a hunter and/or gatherer without unduly upsetting the ecological balance. This is as long as the limit of spontaneous recovery is not surpassed and the extraction and transfer of energy and nutrients out of the system are kept at a very low level (WMO, 1986).

When exploitive technology evolves, crop growing and livestock raising are introduced and develop into highly specialized forms of land use, biological systems are created which differ greatly from natural systems. This systems which have been variously called agricultural systems, agricultural ecosystems, agroecosystems, or simply agrosystems continuously replaced vast areas of natural ecosystems ever since agriculture has become known to human kind. From its beginning, agriculture has been a crucial test of the resiliency of nature (Altieri *et al*, 1984; WMO, 1986).

The basic principle of farming is to change the natural unproductive system into one which produces more of the goods desired by man. The man-made system is an artificial construction which requires economic inputs obtained from the environment to maintain its output level (Ruthenberg, 1981). To maintain the 'man-made order' of simplified agricultural systems against the natural tendency toward entropy, diversity, and stability, requires energy and resource inputs (Altieri *et al*, 1984).

Therefore, there exist marked differences between natural ecosystems and agroecosystems (see Table 2.1). The scale of environmental, chemical and physical processes in natural ecosystems is local, the exchange flux being predominantly vertical in direction. The agricultural artificial ecosystems have marked horizontal exchange as they obtain substantial quantities of energy subsidies. The energy and chemical elements integrated in the crops are dissipated and consumed in places which are very far from the origin. Likewise, the energy to produce the crop is external to the system (WMO, 1986).

Table 2.1 Structural and functional differences between natural ecosystems and agroecosystems.

Characteristic	Agroecosystem	Natural Ecosystem
Net productivity	High	Medium
Trophic chains	Simple,linear	Complex
Species diversity	Low	High
Genetic diversity	Low	High
Mineral cycles	Open	Closed
Resilience	Low	High
Entropy	Low	High
Human control	Definite	Not needed
Temporal permanence	Short	Long
Habitat hetrogenity	Simple	Complex
Phenology	Synchronized	Seasonal

Source:- Cox and Atkins (1979).

Unlike the natural ecosystems, mans activities have a dominant and decisive influence on the evolution and productivity of agroecosystems. This means that besides, biological, physical, physicochemical factors influencing them, economic and social factors also have their impact. Factors such as production costs, land tenure, land use patterns, etc can limit or favor the development of a particular agroecosystem (WMO, 1986; Harper, 1974).

Man has modified and simplified agroecosystems in ways generally favorable to himself by intentional or accidental elimination of plant and animal species. However, progressive simplification of natural ecosystems carries with it the risk of disruption and breakdown as the simplified ecosystem is unstable and less resilient (Harper, 1974).

The stability of natural ecosystems has been, however, the subject of some controversy. Some associate the higher stability of natural systems to the complex range of organisms and micro-environments of which they are composed; while others suggest the local balance of energy and nutrient influxes assures their stability. The instability of agro-ecosystems on the other hand, is attributed to the monomorphism acquired by the cultivated community, which favours the increase of parasites and diseases and the loss of soil fertility and continuous drain of nutrients that can not be replaced altogether by farmers (Harper, 1974).

Without sufficient human effort, artificial systems inevitably fall back either to the original natural unproductive state or, very often, into another state which is less productive than the original one. The change from one system to another is accompanied by the amount of dry matter produced and the percentage of it which is edible. A change from shifting cultivation (largely self-contained and not very different from natural systems) towards more intensive systems with a decline in the fallow period in upland cultivation without modern technology and its related support energies, increases edible dry matter until the low-level 'steady state' is attained, while total dry matter production is significantly down. The tendency is towards depleted soils, low yields, and a very much reduced fallow weed vegetation (Ruthenberg, 1981).

In total, artificially created agroecosystems unlike natural systems, are prone to massive ecological disruption because of their inherent instability with humanities attempt towards agricultural intensification without sufficient effort to restore the flow of energy and nutrient cycles.

2.1.2 The carrying capacity concept

The term carrying capacity has been variously defined by different authors and is somewhat argumentive in meaning. The carrying capacity debate has emerged mainly because of the following reasons:-

i. carrying capacity in reality is difficult to ascertain for a single species since all species of plants and animals including humans interact together in the ecosystem,

ii. populations of a species fluctuates over space and time, thus making it difficult to fix the sustainable population size,

iii. carrying capacity varies with changes in climate, technology, trade, etc,

iv. as it relates natural resource endowment to population size it becomes worthless in meaning as regions/countries with meager natural resource bases have supported higher population densities than what could be expected from the potentials of their lands, and

v. aside from poor quality of available natural resource data, natural resource accounting and valuation techniques are not well defined to make reliable carrying capacity estimates.

With all these limitations, Krickner *et al* (1985), defined carrying capacity of a particular region as the *maximum population of a given species that can be supported indefinitely, allowing for seasonal and random changes, without any degradation of the natural resource base that would diminish this maximum population in the future.* In land evaluation for extensive grazing, FAO (1988) defined carrying capacity as the maximum number of animals that can survive the greatest period of stress each year on a given land area (without referring to sustainable production); while *grazing capacity is defined as the maximum stocking rate of an animal type with specific production objectives that a certain land unit can support without deterioration (at a sustainable basis) during a defined grazing season.*

The carrying capacity of a region is also differently defined in natural ecosystems and ecosystems managed by humans. In natural ecosystems, carrying capacity is determined by cyclical flactuations in food supply. In this situation, the carrying capacity of the bound environment can be defined as the maximum number of members of that species that can maintain a minimum diet. As the carrying capacity determined by natural food supply fluctuates, different species adjust to the environment in different ways. When population of a species exceeds the food supply, the surplus will be removed by starvation (if not by predation and disease outbreaks) (Krickner *et al*, 1985; Muscat, 1985).

At the point where animal populations are forced to adopt behavior reducing its members in response to reduced food supply, its population has exceeded the short-run carrying capacity of its environment. Mortality increases, however, are inherent in a population's coping behavior, thus, do not indicate that the population has exceeded the long-run carrying capacity of the environment (Muscat, 1985).

In ecosystems managed by humans, it is evident that carrying capacity can be expanded using technological innovations, accumulation of capital, and trade which generally reduces total dependence of human populations on the inherent fertility and natural resource endowment of their particular environments (Krickner *et al*, 1985; Muscat, 1985).

In cases where all arable land is put into cultivation; international or inter-regional trade plays minor role; productivity of agriculture is declining; and changes in agricultural technology are stagnating and capital to increase the effectiveness of the existing technologies is limiting; communities face a serious resource constraint and react by out-migration, intensification of cropping systems, and cultural adaptations like restrictions on marriage. When all these adjustment mechanisms fail, the carrying capacity of the region is temporarily exceeded causing damage to soil productivity, which ultimately reduces population size of the region as a result of a serious food supply constraint (Muscat, 1985).

However, the failure of food supply to keep pace with population growth, can not be always completely ascribed to inherent production limitations of the land, since policy disincentives and institutional shortfalls may become handicaps for expanding food production. Thus, simple comparison of domestic food supply with population size at one point in time, and the labelling of the output as the carrying capacity for the relevant area can be quite misleading (Muscat, 1985).

In the above discussion, carrying capacity of a region is defined as the maximum value of the ratio of population to food production. However, if food is readily available through trade with outlying areas, the carrying capacity is often determined by other factors like availability of living space, availability of cooking wood fuel or ability to dispose wastes and pollutants. *As a result, a region's carrying capacity is ultimately determined by the scarcest vital resource* (Krickner *et al*, 1985; Muscat, 1985).

2.1.3 Primary production from grazing lands

Pasture production depends on several factors, such as climate, nature of soil, botanical composition and vegetation structure, type and intensity of management like grazing patterns and stocking rate, fire and wildlife (Houerou and Hoste, 1977).

In this respect, grasses (C_4 species) tend to accumulate more biomass of low nitrogen (N) and phosphorus (P) content than legumes (C_3 species) largely because of differences in photosynthetic efficiency at high light intensities; woody species and perennial grasses produce slightly more each year than annual species mainly because of an early start of growth after the first rains (Breman and de Wit, 1983); moderate grazing on grass vegetation by inducing compensatory photosynthesis and quick replacement of removed shoots may lead to increased production of green biomass (Skarpe, 1990).

Estimation of edible dry matter production from grazing systems is not without problems. Forage standing crop, defined by FAO (1988) as that amount of the above ground biomass of one or more plant species, or the vegetation within an area at a specific moment, can be measured by harvest techniques which are, however, time consuming and expensive. Alternatively, radiometric reflectance of herbage standing crop has been measured (red, infrared or composite parameters such as normalized difference vegetation index:NDVI). Reasonable results are reported from ground measurements only when reflectance was calibrated against standing crop separately for each vegetation type and each phase of the vegetation and when reflectance was measured at the same time of the day or corrected for sun angle (Tucker *et al*, 1983). In other cases however, ground reflectance parameters were not satisfactorily correlated with standing crop (Essenlik and Gils, 1985 cited by FAO, 1988a).

Biomass annually produced, however, depends mainly on the absolute availability of growth-limiting factors. The availability of water relative to that of nitrogen and phosphorus determines quantity and quality of forage produced. In the Sahel countries, water limits growth at the border of the Sahara. This changes to growth limited by nitrogen (and phosphorus) with increasing rainfall to the south. Biomass production increases with precipitation but the protein content decreases. With water availability rising from 50 to 1000 mm annually, the total mean production increased from nearly 0 to 4 metric tons per hectare; but protein content decreased from 12 to 3%. Thus, low water availability produces biomass of good quality, and higher water availability results in more biomass of increasingly lower quality (Breman and de Wit, 1983).

Where rainfall occurs seasonally, and a clear break in vegetative growth is similarly affected by this and temperature changes, a rough formula called dry matter production index (DPI), can be applied as a guide to the expected total dry mass of vegetative growth of herbage on the range related to precipitation per mm (Chandler, 1984).

Therefore, an attempt was made to correlate forage standing crop with average annual rainfall in Mediterranean basin and in the African Sahelo-Sudanian zone to come up with a single mathematical model for assessing potential yield of grazing lands (Houerou and Hoste, 1977). In this exercise, regression equations of the type below are developed:

$$Y = a + bx$$

where, Y = Dry matter in Kg ha^{-1} yr^{-1}

x = Average annual rainfall in mm yr^{-1}

a = Intercept

b = Slope

Mean annual rainfall and equations developed for prediction of forage standing crop dry matter are shown in Table 2.2.

Table 2.2 Mean annual rainfall as a predictor of forage standing crop dry matter.

Region	Type of herbage		Rainfall range(mm)	Intercept (a)	Slope (b)
	herbage only	herbage & browse			
Mediterranean[1]		+	20-900	-415	8.68
Sahelo-sudanian[1]	+		100-1500	105	2.58
East and- south Africa[2]		+	500-800	-200	8.5

Source:- [1] From Houerou and Hoste (1977).
[2] From Deshmukh and Baig (1983) as adapted by FAO (1988).

Fodder predictive equations of Houerou and Hoste (1977) for the low summer rainfall region of south of the sahara, suggest that winter rainfall is more effective than summer rainfall in fodder production. 1 mm rainfall in Mediterranean basin produced about 8.5 Kg ha^{-1} whereas in the Sahelo-Sudanian zone 1 mm produced 2.5 Kg ha^{-1} . Consumable dry matter (Kg ha^{-1}) prediction equations developed by this authors were **2.17x - 103.7** for winter rainfall, and **1.03x + 42.2** for summer rainfall regions.

Obviously, these rainfall-based models do not include essential input factors as vegetation composition, competition between grass and woody species and between annuals and perennial, the rangeland condition, herbivore-rangeland interactions, fire and flooding. Nevertheless, can provide a good approximation of forage standing crop produced in areas relatively homogenous in soil, temperature and other environmental factors (FAO, 1980).

Total primary production of fodder from natural grassland communities is generally low. This can be attributed to the limitations imposed by essential nutrients (like N and P) and water, and where woody plants are present, to competition for these resources and light (FAO, 1980).

In the Ethiopian highlands where overgrazed natural pastures provide not less than 90% of the feed supply, annual pasture yields range from 1 to 2 t ha^{-1} dry matter on freely drained, relatively infertile soils, up to 4 to 6 t ha^{-1} from seasonally waterlogged fertile areas (Lulseged G/Hiwot, 1987). In low land areas native pastures yield only 1 t ha^{-1} dry matter or less; at mid- and high altitudes on freely drained soils yields are 3 t ha^{-1} dry matter (Alemayehu Mengistu, 1987). Jutzi *et al* (1987) from simulation experiments of overgrazing indicated that the dry matter yields of heavily grazed grasslands probably do not exceed 1.5 t ha^{-1} (half of that recorded under protected conditions) in the highlands above 2500 m and will not exceed about 2.5 t ha^{-1} below this altitude.

By and large, pasture standing crop is higher at intermediate grazing intensities but diminishes with further grazing pressure. From primary productivity and herbivory studies in Tanzania and Kenya, McNaughton (1985) reported that grazing stimulated net primary productivity with the maximum stimulation at intermediate grazing intensities. Part of the stimulation of grassland productivity by grazing was due to maintenance of vegetation in an immature, rapidly growing state similar to that at the beginning of the rainy season. Rate of energy flow per unit of plant biomass was also much higher in grazed vegetation.

According to Skarpe (1990), compensatory photosynthesis and quick replacement of removed shoots may lead to increased production of green biomass in moderate grazing pressure, while the plant is continuously weakened in heavy grazing pressure as nutrients required for quick compensation are taken from the roots and rhizomes and a large part of the root system dies back after frequent defoliation.

2.1.4 Evaluation techniques for availability of feed in mixed farming systems

In order to support the body's processes and promote production, animals must have regular supplies of nutrients. These nutrients may be broadly defined as energy, protein, minerals, vitamins and water.

The animal's nutrient requirements differ with species, age and with type and levels of production. Ruminants are able to digest bulky cellulose-rich plant material, while animals with single compartment digestive system (monogastrics) can not utilize plant fiber.

Animal food requirements are frequently divided into that required for maintenance of body functions and that required for production (growth, work, milk secretion, and reproduction), the latter requiring fodder of better quality than is required for the former. When the nutritive quality falls below that required for maintenance, the animals body tissues are depleted and there is loss of weight (FAO, 1988; Topps, 1969).

Feed availability and scarcity can be measured by balancing dry matter requirements and dry matter supply in the system. Taking dry matter requirements as a base for calculating grazing capacities assumes that energy is the main limiting factor for animal maintenance and production (FAO, 1988). Dry matter requirement of an animal is given as 2.5 Kg per 100 Kg live weight or 6.25 Kg dry matter per TLU. Energy requirements are also calculated in terms of feed units (FU) which are comparable to the starch equivalent system. Maintenance requirement of a TLU is 2.9 FU (FAO, 1980; Boudet, 1975; Houerou and Hoste, 1977).

Various formulae have been used for calculation of carrying capacity based on supply and demand of forage production (FAO, 1988; Boudet,1975).

$$G = \frac{F \text{ (the lowest of } g \text{ or } 1-l \text{ or } p)}{R}$$

Where, **G** = grazing capacity (equivalent to carrying capacity in section 2.1.2) in TLU per area unit for a specified season (TLU ha^{-1})

F = dry matter production in weight per unit area during the grazing season (Kg DM ha^{-1})

g = grazing efficiency (proportion of forage standing crop that is ingested by the animal)

l = the loss factor (proportion of forage standing crop lost for grazing due to trampling, fouling by excreta and decomposition)

p = the proper use factor (the maximum proportion of the forage that may be grazed without causing grassland deterioration).

R = the animal requirement of dry matter per TLU during the grazing season (Kg DM TLU^{-1})

The present stocking rate of the range land is given by chandler (1984) as:

$$S = A/T$$

Where, S = Stocking rate (TLU ha^{-1})

A = Total area of grazing land (ha)

T = Total weight of animals (TLU)

For a variety of reasons only a proportion of potential yield of fodder plants will be consumed by animals (Chandler, 1984). Fodder is avoided because of its low palatability; forage is lost by trampling, wind, fire and is also consumed by invertebrate animals. Between a third and a half of the potential ungrazed yield of an area will be utilized in the growing season, and that during the dry season only half of the potential yield may be consumed (FAO, 1980). According to Chandler (1984), the actual percentage utilized by the animal varies between 22 and 35%.

McNaughton (1985) reports the average proportion of annual above ground primary production that was consumed by herbivores as 66%, with a minimum of 15% and a maximum of 94% in the Serengeti grazing ecosystem. Houerou and Hoste (1977) estimated rates of forage consumption of 50% and 40% of the annual production for Mediterranean and Sahelo-Sudanian zones of Africa respectively. The same authors estimate 70% and 30% rates of forage consumption of the annual production during the wet and dry season in the Sahelo-Sudanian zone respectively. Estimates of Breman (1975) for ratio of consumable dry matter in Malian grasslands are 50% of the primary production in the course of any given season (either rainy or dry season). Boudet (1975) also estimates a consumption rate of about 50% of the potential yield.

Therefore, the actual carrying capacity is less than the potential carrying capacity since consumable forage production is less than forage standing crop. Moreover, it is necessary to set aside a certain proportion of forage dry matter to offset undesirable effects of grazing pressure and to increase the survivability of palatable species and to maintain the ultimate potential of the land.

However, as often as not, the dynamics of grazing ecosystems is insufficiently understood to be able to say which species can realistically, be encouraged by the manipulation of grazing pressure. But, in cases of uncertainty it is always better to err on the conservative side (Pratt, 1975; Boudet,1975).

The proper use multiplier, therefore, should consider the hazard of nutrient depletion (eg.loss of N from the plant-soil system) by grazing, potential decrease in vegetation cover or the encroachment of undesirable vegetation, and resilience of the main forage species (FAO, 1988).

Ministry of Agriculture, Fisheries and Food, UK (1975) also provides formulae for calculation of energy requirements for maintenance, growth, milk production and gestation. Apart from energy requirements, protein requirements of a TLU for maintenance are given as 160 gm (FAO, 1980) and 156 gm (Houerou and Hoste, 1977) digestible protein per day. For a weight gain of 500 gm per day, digestible protein requirements are 90 gm (FAO, 1980) and 125 gm per day (Houerou and Hoste, 1977).

The other important sources of feed in a mixed farming system, apart from natural pastures, are crop residues and stubble (aftermath) grazing. The availability of crop residues is closely related to the farming system, the type of the crop produced and the intensity of cultivation. The use of crop residues as animal feed is mainly limited to ruminants.

The amount of crop residue produced in any system is estimated by use of multipliers developed from experiments on grain-residue ratios. The harvest index (proportion of the edible above ground dry matter) varies with soil type, climate, species and variety of crops. However, some conversion factors are developed for estimation of straw yield (Kossila, 1988; Chandler, 1984).

The main crop residues in the Ethiopian highlands used as animal feed include cereal residues of teff (*Eragrostis tef*), wheat, barley, maize, sorghum, and finger millet and pulse residues of chickpeas, horse beans, field peas, lentils and rough peas the stubbles of which are also used for grazing. Multipliers used for conversion of grain yield of these crops in to their fibrous products is given in Table 2.3 below.

The energy and crude protein content of crop residues is low and seldom adequate even for livestock maintenance requirements. Crop residues contain metabolizable energy of 7.5 MJ or less per Kg dry matter and less than 5% crude protein and organic matter digestibility of about 50% (Mukasa Mugerwa, 1981; Seyoum Bediye *et* *al*, 1988; McDowell, 1988).

Table 2.3 Multipliers used for estimation of yield of crop residue dry matter.

Crop	Region/country	Grain:Straw ratio	Multiplier
Teff[a]	Ethiopia	1.00	1.00
Wheat[b]	Ethiopia	0.69	1.45
Wheat[c]	Africa	0.50	2.00
Barley[b]	Ethiopia	0.72	1.39
Barley[c]	Africa	0.67	1.50
Maize[c]	Africa	0.33	3.00
Maize[d]	Botswana	0.75	1.34
Sorghum[c]	Africa	0.20	5.00
Sorghum[d]	Botswana	0.43	2.33
Pulses(dry)[c]	-	0.25	4.00
Field peas[b]	Ethiopia	0.69	1.45
Horse beans[b]	Ethiopia	0.87	1.15
Lentils[b]	Ethiopia	0.64	1.56

Source:- [a] Mukasa-Mugerwa (1981).
[b] Gryseels *et al* (1988).
[c] Kossila (1988).
[d] Chandler (1984).

As a result, digestion is low, rate of passage is slow and voluntary intake is limited. Ruminants require apparent digestibility value of above 70% in the entire ration in order to express their full genetic potential for performance. The minimum range in apparent digestibility to sustain body maintenance needs is 42-45% (McDowell, 1988). Chemical composition of major feedstuffs of the Ethiopian highlands is given in Table 2.4.

2.2 Crop-livestock interactions

Crop-livestock interaction is defined as the use of crop output in livestock production and vice versa, and the exchange of products or factors of production between the two sectors. Crop-livestock integration is defined as the merger of the two sectors on one farm, in what is called mixed farming (McIntire *et al*, 1989). As such crop-livestock interactions take place in segregated systems (without integration) and in integrated systems.

Table 2.4 Average feed composition of partly air-dried feedstuffs around ILCA Debre Zeit station.

Feedstuff	DM(%)	CP(%)	Met.Energy (MJ/Kg DM)	DOM
Natural pasture (pooled)	92.40	7.48	7.3	53.6
Barley straw	92.63	3.96	6.8	49.3
Red teff straw	92.74	3.64	7.3	52.6
White teff straw	92.57	5.05	7.3	53.3
Wheat straw	92.63	4.25	7.3	52.8
Pulse straw(general aver)	92.26	5.70	7.1	51.9
Red teff stubble	92.62	5.21	7.7	48.8
White teff stubble	92.70	4.23	6.5	47.0
Pulse stubble	92.40	8.59	6.8	50.2
Wheat stubble	93.00	3.56	5.7	41.7

DM = Dry matter, CP = Crude protein,
DOM = Digestible organic matter

Source:- Adapted from Mukasa-Mugerwa (1981).

Interactions in segregated systems are observed like when herders grow crops or farmers own animals without integration; and when farmers entrust cattle to herders for use of milk by the latter; or when farmers receive manure for soil restitution from cattle herders in return for grazing rights on crop residues or pastures during the dry season.

Interactions in integrated systems include widespread use of animal power for cultivation and transport; recovery of animal manure for soil restitution; animal feeding from crop residues, fodder crops and fallows; investment of income and profits from one sector to another as occurs when farmers income from sale of milk and milk byproducts is used for purchase of inputs in cropping. In Africa, integrated interactions are common in the highlands of

Ethiopia, Madagascar and Kenya (with animal traction) and highlands of Zimbabwe, Rwanda, Burundi and sub-humid and semi-arid zones of Mali, Senegal and Burkina (without animal traction) (McIntire and Gryseels, 1987; McIntire *et al*, 1989).

In the tropics crop-livestock interactions are generally expressed as multi-faceted complementary linkages and conflicts/competitions for use of resources. The summary of complementary linkages as compiled from various sources (Bayer and Bayer, 1989; McIntire *et al*, 1989; Tesfaye Assefa, 1989; Hart, 1985; McDowell, 1985) is described below:

i. **Food linkages:** As no farming system is completely dependent on crops or livestock products for supply of food, farmers consume animal products and nomads consume cereals.

ii. **Investment linkage:** Income from crops is used to purchase livestock; and animals, their products and byproducts are sold to finance cropping inputs.

iii. **Draft power linkage:** Animal power is used for cultivation, threshing and transport.

iv. **Manure linkage:** Animal manure is used to fertilize cultivated fields and home gardens in smallholder farms as well as large-scale commercial farms.

v. **Forage linkage:** Crop residues, stubbles, and fallow fields are used as fodder and pasture. This also includes yield increasing effects of sown forage legumes when they form part of the crop rotation cycle.

vi. **Employment linkage:** As occurs when pastoralists keep animals entrusted to them by farmers or when family labor and management resources are fully employed in animal production during slack periods of crop production.

vii. **Capital linkage:** When the grain storage facility is used for storing animal feed during low level of grain inventory.

viii. **By-product linkage:** When hides and skins are used for storage and transport of crop products.

Competitions and conflicting crop-livestock interactions occur for a pool of scarce resources common to both enterprises (land, labor, capital and management). Conflicts also occur when livestock cause crop damages, or as a result of externally induced changes like when grazing reserves are established in areas where farmers claim land rights, or when mechanized cropping reduces available grazing areas. Promotion of external inputs (like fertilizers and herbicides) may also weaken existing crop-livestock interactions as occurs when farmers abandon use of animal manure and feeding of weeds because of increased use of fertilizers and herbicides (Bayer and Bayer, 1989; McIntire *et al*, 1989).

Another potential source of conflict arises in the process of land use intensification when crop residues are used for animal feeding which deprives the soil its essential nutrients or a protective cover against erosive forces of wind and water. This problem is critical in mixed farming systems of the highlands with high population densities where crop residues increasingly assume the prominent sources of animal feed in the face of declining fallows and grazing lands (McIntire *et al*, 1989; Sandford, 1989).

In sum, literature in crop-livestock interactions have prominently two-pronged approaches. The first approach argues about the inevitable resource competition, especially for land, with escalating population pressure and inclining intensification which may in the long- or short-run induce destocking and reduce crop-livestock interactions. The second argument is concerned with complementarity between crops and animals. Complementary inputs are regarded to be most efficient when crop and livestock production are integrated on the farm. It is argued repeatedly in the literature that lack of integration is a serious inefficiency in African agriculture because it wastes cheap inputs (McIntire *et al*, 1989; Tesfaye Assefa, 1989).

2.2.1 Causes of land use conflicts in mixed farming

One of the serious conflicts between crop and livestock systems in mixed farming originates from increasing competition for a fixed land resource. Several factors contribute to the emergence of negative crop-livestock interactions in land use in integrated systems. The most prominent causes are population pressure (and crop encroachment) and institutional or non demographic factors which may lead to diminishing grazing grounds or breakdown of traditional resource management systems.

2.2.1.1 Population pressure and crop encroachment

In sub-Saharan Africa, mixed farming is mainly prevalent in semi-arid and highland zones where the disease pressure is low, fairly good quality fodder is available, and population pressure is high. Transition from specialized farming and herding into mixed farming took place when opportunities for using less labor intensive techniques of soil fertility maintenance are exhausted as population densities increase and as opportunity cost of labor rises (McIntire *et al*, 1989).

Land use is determined by soil quality, especially moisture holding capacity and seasonal distribution of moisture. In a progression from a summit to a valley, soils become deeper and richer in organic matter content, and water holding capacity increases. Under most arid conditions, the lower slopes and depressions are the only lands cultivated because only there is water holding capacity sufficient to allow cropping. These valley bottoms in arid areas are often indispensable to livestock during the dry season when water is the limiting resource. In semi-arid areas and the highlands, the mid slopes are the first to be cultivated as the lower slopes are difficult to work on and become waterlogged during the cropping season. However, with increasing subsistence demand, cultivation extends to the previously inaccessible slopes and valley bottoms which were invaluable sources of animal feed (McIntire *et al*, 1989; Jahnke, 1982).

With increasing population pressure, the land hungry farmers clear more vegetation to obtain land for cultivation or put into cultivation areas previously used for grazing. This phase of traditional land use is termed as 'outward expansion'(Jahnke, 1982).

From the farmers' point of view, as the cost of manuring rises because of fragmentation of holdings while yield increasing support energies are largely unavailable, this is the safest reaction as it allows the application of the same proven techniques of land use on simply a larger area.

As the effort and cost of taking new land into cultivation becomes too great or when potentially cultivable land is exhausted, farmers try to intensify land use on the existing plots. This latest phase of traditional land use in response to population pressure is referred to as 'inward expansion'. In this phase, as the cropping index increases, fallow periods are hardly observed, use of animal manure and fertilizers becomes common, and animals are kept at sub-maintenance diets of crop residues, and grazing grounds are pushed up-or down-the-hill to areas extremely unsuitable for cropping (Jahnke, 1982; Jahnke and Getachew Assamenew,1984).

In this condition, livestock are squeezed between marginal areas at the fringe of the desert and cultivated fields; grazing areas are shifted to marginal grounds with little resilience, and feed has developed a scarcity value.

2.2.1.2 Institutional factors

Population pressure is widely blamed for deterioration and depletion of valuable natural resources in the developing countries. Growing rural populations and rising subsistence demands have, of course, resulted in the expansion of cultivation on to increasingly marginal soils and have shortened periods of fallow leading to increasing conflicts between crops and animals and loss of soil fertility. Nevertheless, to view the problem of environmental deterioration and resource use conflicts as a consequence of growing population and rising subsistence requirements is to oversimplify and, in some ways, is to mistake the current situation. In many regions the problems are considerably worse than would follow from the sheer increase in numbers (Repetto and Holmes, 1983).

Therefore, it is not just an increase in subsistence demand that is compromising complementary interactions between crops and livestock; rather population growth in conjunction with other non demographic factors is leading to much more rapid deterioration.

According to Shaw (1989), there exist ultimate and proximate causes to environmental degradation. The ultimate, 'deeper' causes which perpetuate poverty and environmental degradation include use of ill-adapted technologies, urban bias, low producer prices, land tenure policies, etc. Proximate causes which are more situation specific, contemporary and of confounding nature include factors like population growth.

Non-demographic factors which may cause land use conflicts include inequalities in access for land, promotion of commercial crops or ranching, settlement on areas used for grazing, undermining of traditional resource management systems, adoption of inappropriate conservation and development policies, low farm-gate prices, etc (Reppeto and Holmes, 1983) and for Ethiopian conditions (GOE/IUCN, 1990).

Nevertheless, as Shaw (1989) discusses, control of ultimate causes of environmental degradation remains out of reach as they have resisted change, then the need to tackle the exacerbating effect of more proximate causes like population growth takes an urgency.

2.2.2 Impacts of land use conflicts on the environment

Because of increasing intensification, natural systems are increasingly converted to agro-ecosystems with little inherent stability and resilience. This is particularly disastrous in the tropics and sub-tropics characterized as relatively unstable agricultural ecosystems which can merely be modified, but if at all possible, should not be transformed (Espig, 1989).

Because of demographic and non-demographic factors, grazing areas shrink down and are relegated to marginal hill-sides which cannot sustain high population densities of animals.

In permanent mixed farming increasing pressure on land from concentration of animal and human populations is reinforced by scarcity of fertility enhancing practices since chemical fertilizers are increasingly expensive to a subsistence farmer and manure is used as fuel while virtually all crop residues are not returned to the soil.

A decline in the area and productivity of grazing lands is inspite of the essential functions of livestock in mixed farming systems (traction, manure and transport) which can be easily maximized by increasing numbers than increasing efficiency per animal (Jahnke and Getachew Assamenew, 1984). An increase in human population density in mixed farming systems also calls for an increase in livestock density simply because animals are integral parts of the system by which farmers achieve security in food production. In the tsetse free zone of Ethiopia, Bourn (1978) found a correlation coefficient of 73% between log transformed variables of human density and cattle biomass. This implies that areas of high cultivation density are at the same time areas of high livestock density.

However, the role of livestock in land degradation is not unarguable. It is a common belief of many that livestock are the root causes of overgrazing and land degradation. In several cases of land use conflicts and resource degradation, livestock *per se* do not seem to be the real causes of ecological disruption. Land degradation caused by livestock raising in mixed smallholder farming, if any, is entrenched in the system by which communal pastures are managed and the expansion of herds to meet the particular functions of animals in the system while the area and productivity of pastures is declining (Jahnke and Getachew Assamenew, 1984).

The process of degradation which is already underway because of increasing cultivation intensities and removal of forests is accompanied by overgrazing resulting from crowding of animals on a very small area on the hill-sides. The effects of high grazing intensities on the ecosystem are manifold, including the removal of green biomass, trampling and compaction there by reducing moisture holding capacity, change in the species composition of the grassland towards successively poor species, decreased ground cover and increased erosion (Skarpe, 1987). New land brought under the plow because of outward expansion is often shallow in depth, poor in moisture holding capacity, and low in organic matter and generally less fertile than the already cultivated fields; thus is highly susceptible to ravine erosion.

Diversion of crop residues as a prominent source of animal feed in mixed farming systems also precludes the use of same for soil and water conservation. According to Papendick and Parr (1989), 1000 Kg ha^{-1} of grain residues left on surface during the non-cropping season in dry land areas of USA are worth up to 85 Kg wheat in terms of water conserved for the next crop. Sorghum yield increases from water conserved were also considerably high. Besides, residues provided adequate surface cover against erosive rainfall, thus preventing runoff and enhancing water holding capacity.

According to Sandford (1989) if crop residue is incorporated into the soil instead of being used as animal feed or fuelwood, 29% less farm manure is required to replace the most constraining nutrients (NPK) to maintain the desired level of cereal output.

Generally speaking, a number of ecological 'diseases' ('diseases' affecting the biogeostructural component of agroecosystems) are associated with increasing intensification of food production. 'Diseases' of the ecotope such as erosion, loss of soil fertility, depletion of nutrient reserves, salinization and alkalinization; and 'diseases' of the biocoenosis such as loss of crop, wild plant and animal genetic resources, pest resurgence and genetic resistance are all in one way or the other related to increasing intensification of land use (Altieri *et al*, 1984).

2.2.3 Complementarity of crop-livestock systems

As presented else where in this manuscript, apart from increasing competitive interactions for a pool of scarce input factors, there exist incredibly complex and valuable complementary interactions between cropping and livestock production. These are addressed in the next sections according to their effect on each sub-system.

2.2.3.1 Effects of interactions on crop output

In mixed farming systems livestock fulfill several functions like the output function (subsistence, income and nutrition), the input function (crop inputs and farm integration), the asset and security function, and the social and cultural functions (Jahnke, 1982). A livestock function which has a direct impact on crop output is the input function. The farm integrative function of livestock refers to all the different effects livestock may have on the productivity of resources engaged in agriculture there by rendering the farm more productive than it would be without the livestock enterprise.

Animal power and its impact: In mixed farming, livestock provide mainly traction power for cultivation and transport power for translocation of loads. Besides, animals are also used to provide threshing power virtually for all kinds of crops cultivated and power for trampling to prepare the seed -bed before seeding (as observed in the Ethiopian highlands before seeding of teff, and finger millet). Although it is difficult to quantify the effect of all kinds of animal power used in cropping, they remain indispensable assets to the mixed farmer.

However, some investigations on the effect of animal traction in cropping indicate that animal traction, among other things, may have an *area effect*, in terms of increasing the area cultivated; *yield effect*, where availability of draught power may affect yield per unit area through better and timely cultivation, and total yield through the combined effect with area cultivated; *cropping pattern effect*, where availability of animal traction may change the mix or succession of crops and in particular leads to growing of higher value or more market-oriented crops; *labour saving effect*, where mechanization reduces labor costs per unit area (Sandford, 1989; McIntire *et al*, 1989; Gryseels *et al*, 1984; Gryseels *et al*, 1987).

According to ILCA (1981), area cultivated on farm in Senegal and Mali using animal traction was on average twice higher than those without animal traction. From the review of 22 animal traction studies in Africa, Pingali *et al* (1987) report that area cultivated per family member was 25% greater where animals were used for cropping. In Ethiopian highlands Gryseels *et al* (1987) found significant effects of draught power availability on area cultivated at Debre Berhan and Debre Zeit. Farmers owning two or more oxen cultivated 32% and 59% more land than those owning fewer oxen at Debre berhan and Debre zeit respectively. Area and cropping pattern effect of oxen ownership is summarized in Table 2.5.

Table 2.5 Area and cropping pattern effect of oxen ownership at Debre Zeit,1980.

No of oxen owned by farmers	Average area cropped per farm (ha)	Area sown to cereals (%)	Area sown to pulses (%)
None	1.2	54	46
One	1.9	44	56
Two	2.7	67	33
Three or more	3.6	92	8

Source:- Gryseels *et al* (1984).

Yield increases are difficult to measure as they are confounded with other changes in farming systems. However, more thorough, more timely and better tillage leads to more timely planting, lower soil bulk density, incorporation of organic matter, better weed control, and better pre- and post-harvest moisture conservation. These lift average levels of yields and reduce downward fluctuations in years of lean rainfall (Sandford, 1989).

However, Pingali *et al* (1987) reported that association of animal traction to increased yields is indeterminate. In Ethiopia, Gryseels *et al* (1987) reported insignificant effect of oxen ownership on yields per hectare at Debre Zeit, while farmers with two or more oxen had net cereal yields per hectare over 48% greater than farmers owning fewer oxen.

Out of 22 animal traction studies reviewed, Pingali *et al* (1987) reported 67% of the cases having a significant cropping pattern effect. In Ethiopia (Gryseels *et al*, 1984) as shown in Table 2.5, farmers with fewer oxen cultivated less of cereals and more of pulses, the former requiring more intensive land preparation and therefore, higher labor input and draught power.

Animal manure and its impact: The value of livestock droppings for soil fertility is recognized by most tropical farmers and livestock herder. In addition, manure is used for fuel and as a building material (Jahnke, 1982). Schleich (1986), citing different sources reported that a TLU can produce 2 to 4 Kg dry matter of pure dung per day. Jahnke and Getachew (1984), estimate a production of 1 t of dry manure per TLU per year.

According to Jahnke (1982), manure from two livestock units would increase crop yields at low levels (say 600 Kg) by 50%. One manure effective TLU can, therefore, be attributed the value of 150 Kg of grain equivalent for its manure production alone.

As Schliech (1986) reports, composition of cattle dung is highly variable; at 24 sites in Mali, the N content varied from 0 to 2.5%, P_2O_5 content from 0.31 to 1.45% and the K_2O content from

0.31 to 5.02%. For optimal fertilization, at least 10 t and as much as 30 t of manure (with 30% moisture content) is needed per hectare depending on the type of crop. Therefore, 5 t dry matter (corresponding to a fresh mass of 10 to 15 t) can be taken as a guide for the minimum level of manuring needed for an adequate result.

According to McIntire *et al* (1989), manure produces weak crop response; a ton of fresh manure probably producing about 50 Kg of grain in the short term. The weak response and low concentration of manure makes it less efficient in terms of transport and application costs than chemical fertilizers. Thus, a fresh manure containing 0.75% N would give 6 to 7 Kg of grain per Kg of N assuming 50 Kg per ton of material. Schliech (1986) reported, an absolute additional yield of 29 to 237 Kg ha^{-1} related to application of 1 t ha^{-1} of dry manure.

Generally speaking, the benefits that livestock manure can bring can be divided into two classes: the physical and physicochemical effects on the soil, and the provision of plant nutrients (Sandford, 1989).

Apart from the various effects of traction power and animal manure to the cropping system, inclusion of forage crops (especially forage legumes) in the rotation cycle may contribute for increasing yields. According to Francis and Clegg (1990), forage legumes in the rotation cycle, provide N to the succeeding crop, increase soil water holding capacity and microbial biomass, provide environmentally sound control against insects and plant pathogens having specific host ranges, reduce damage by nematode species, and provide cultural control against noxious weeds.

At the aggregate level, Sandford (1989) reports that larger herds are associated with higher crop output, and this observation at the household level is confirmed at the regional or national level.

Through the investment linkage, animal sales are also used to finance the cropping sector for purchase of yield increasing inputs like fertilizers and oxen.

Livestock also provide subsistence security to crop farmers against periods of drought or lean rainfall. Diversification in to livestock keeping extends the risk reducing strategies of crop farmers beyond mixed-species cropping (Jahnke, 1982; Sandford, 1989; Bayer and Bayer, 1989).

2.2.3.2 Effects of interactions on livestock output

Crop-livestock interactions in mixed farming determine livestock output in several pathways. The most predominant interactions are effects of crops on livestock production through their effect on the feeding characteristics of domestic livestock, availability and quality of crop residues and other sources of fodder for livestock (Mcdowell, 1985).

Effects of crops on feeding behavior of livestock: Strong interactions often exist between plant types and types of livestock which influences the utilization of natural grasslands, cultivated forages and crop residues. Variations among species in their ability to utilize different plant species determines to a large extent the main areas of animal concentration, and frequently determines the crops grown and vice versa. Type of crops grown and quantity and quality of crop residues produced more often than not affect livestock production through their impact on the feeding behavior of animals (McDowell, 1985).

The relationship between body size, gut capacity (GC), and metabolic rate (MR) appears to have a strong influence on the feeding strategies of ruminants. MR is a function of body size to the 0.75 power, while GC is a function of body weight to the power of one (Demment and Van soest, 1983 cited by McDowell, 1985). Small ruminants such as goats and sheep, have a high MR relative to gut capacity. They must, therefore, consume high quality feed which can be digested quickly. Rumen retention time increases with increasing gut capacity which enables animals to undergo microbial fermentation to utilize fibrous feeds (McDowell, 1985).

Although all species would tend to increase feed retention time during the dry season when they subsist on poor quality fodder, the increasing order of feed retention time in domestic livestock is goat - sheep - cattle - camels - buffalo (McDowell, 1985; McDowell, 1988).

Animals also differ in their selectivity within and between plants in their feeding behavior. Dentition, muzzle width and approach to browsing or grazing are important in ease with which ruminants can select plants with different morphology. Goats have prehensile lips and narrow muzzles which permit easier selection of nutritious and palatable parts of plants. In contrast, the broad muzzle and large tongue of cattle allow rapid harvesting of plants with little selectivity. The increasing order of feed selectivity between plants and parts is cattle - camels - sheep - goat (McDowel, 1985).

Ability to digest fibrous feeds increases with increasing feed retention time in the rumen. A buffalo with its high rate of intake and slower rate of passage is able to survive on rice straw, the lowest of the cereal grains in nutritive value. Thus, the best niche of the buffalo appears to be as a user of crop residues in mixed farming systems (McDowell, 1985).

From cattle, there are differences in morphological traits of the two species *Bos indicus* (Zebu or humped) and *Bos taurus* (non-humped). Zebu types, with a longer and more narrow head and smaller muzzle, are slower and more selective feeders than non-humped types which are rapid feeders with low selectivity (McDowell, 1988). The Zebu cattle has also a higher ability to digest cheap quality fodder than non-humped types. These properties of Zebu make it suited for utilization of low quality crop residues. Therefore, the Zebu is the main integrator of pastoralism and crop cultivation.

The goat, with its high selectivity is at an advantage under conditions where there is a broad range in digestibility of the available feeds to pick highly nutritious parts and to reject materials low in quality. The goat is poorly suited for feeding with crop residue. It will not survive on a diet of more than 50%

straw, a diet which could keep both sheep and cattle alive. The best habitat of sheep is in natural range lands of medium to low rainfall areas and grazing of cereal grain stubble (McDowell, 1985; McDowell, 1988).

The camel, with its high feed retention time and selectivity together with its distinguished ability for heat and drought tolerance and feeds with high salt content, is at an advantage in dry lands with a predominant bush vegetation (McDowell, 1985).

Effects of availability and quality of crop residues: Other important crop-livestock interactions which affect animal output, apart from the feeding characteristics of domestic livestock, are the availability and quality of crop residues. Crop residues are important sources of feed in integrated systems. In sub-Saharan Africa, crop residues may be referred to as the main 'cultivated forages'(McIntire *et al*, 1989).

Crop residues are either grazed after the crop has been harvested or deliberately transported to the homestead and stacked for use during the dry season when feed supply from natural pastures is reduced to its minimum.

However, intensive selection and breeding of cereals for high fertilizer response, resistance to lodging and straw stiffness, have reduced the feeding value of byproducts and impaired complementary crop-livestock interactions in mixed farming systems. Cereal grain residues of native varieties have a digestibility in the range of 42 to 56%, while most of the improved green revolution varieties have digestibility values of 35 to 45% (McDowell, 1985).

Furthermore, because of the investment links between crops and livestock, income from sale of crops can be used for buying more animals. Sandford (1989) and McIntire *et al* (1989) cite several examples in which mixed farmers whose crop out put is in excess of their subsistent needs investing surplus in livestock.

2.3 Sustainability of agricultural production systems

Now a days, sustainability is an internationally used banner word, though neither its concepts and characteristics are sufficiently understood nor its achievements could be measured or monitored (Daly, 1990; Shanmugaratnam, 1990).

Sustainability in its dynamic sense refers to the question of understanding and handling contradictions and interdependencies of the vital roles of nature (supply of natural resources, absorption and recycling of wastes, sustenance of life through essential ecological processes and natural life support systems, and serving as habitat for humankind) without letting them turn into irreconcilable antagonism (Shanmugaratnam, 1990).

The WCED (1987), defines sustainable development as a process of change in which the exploitation of resources, the direction of investment, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potentials to meet human needs and aspirations. This is, however, a broad and open-ended definition which may be elaborated on or criticized from different ideological positions (Shanmugaratnam, 1990).

According to Daly (1990), there are two operational principles for sustainable use of renewable resources. First, the harvest rates should equal regeneration rates, and second, waste emission rates should equal the natural assimilative capacities of ecosystems. As the same author points, non renewable resources can be managed in a quasi-sustainable manner by limiting their rate of depletion to the rate of creation of renewable resources. According to WECD (1987), sustainable non-renewable resource management should consider the criticality of the resource, the availability of technologies for minimizing depletion, and the likelihood of substitutes being available i.e. rate of depletion of non-renewable resources should foreclose a few future options as possible.

Although there exist now a fairly sophisticated theoretical understanding of sustainable development, there is a critical shortage of methodologies and techniques of measurement for translating this into practice (Simon, 1989).

2.3.1 The concept of agricultural sustainability

Lack of clearly defined concepts, techniques and methodologies for measuring and monitoring achievements of sustainable development is also reflected in lack of same in agricultural sustainability.

Therefore, various definitions have been given to agricultural sustainability. Okigbo (1990) defined a sustainable agricultural system as a dynamically stable and continuous production system that achieves a level of productivity satisfying prevailing needs and is adapted continuously to meet future pressing demands for increasing the carrying capacity of the resource base.

Lal (1987) considers sustainable agriculture as a science-driven resource management strategy aimed at balancing the inherent soil resources and crop requirements with innovative soil and crop management techniques and renewable external inputs to maintain a healthy equilibrium in the soil-food-people-environment continuum, and to reserve the resource base. As Lal elborates it, it involves the most appropriate crops and animals and crop-livestock combinations, improved crop cultivars, liberal use of organic matter and mulches, maintenance of soil fertility through legumes and agroforestry techniques, etc. The emphasis is on optimizing the resource use, preserving its productive potential, minimizing degradation of soil and environment and reducing the dependence on inputs not locally available.

TAC's concept of agricultural sustainability involves successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources (FAO, 1989a).

Douglass (1984) in his discussion of the meaning of agricultural sustainability, after reviewing various proposed definitions including sustainability as food self-sufficiency, as stewardship, and as a community, eventually provides a composite definition. The composite definition reads: *agriculture will be found to be sustainable when ways are discovered to meet future* *demand for foodstuffs without imposing on society real increases in social costs of production and without causing the distribution of opportunities or incomes to worsen.*

2.3.2 Sustainable agricultural systems

A lot of time was used initially in an effort to define sustainable agriculture some times also called as eco-farming or ecological agriculture. People have generally stopped now with the definitions, except to list the characteristics common virtually in all definitions.

However listing of characteristics and requirements of sustainable agriculture is of limited value because an agricultural system must be ecologically adapted to the local soil, water and biota present (Ragland, 1991). One attribute of a sustainable system is its *variability*, which is dependent on specific local conditions like the natural resource base, climatic factors, cropping patterns, infrastructure, and social economic and political framework. Therefore the real and complete meaning of sustainable agriculture is not easy to describe and yet object of differing interpretation among scientists, farmers and the public (GFID/FADC, 1988). However, several authors provide some basic elements (requirements) of sustainable agricultural systems valid for any location.

According to GFID/FADC (1988), elements of sustainable agriculture include:

i. Improvement or at least preservation of natural resources such as soil fertility, water resources, forests or tree cultures necessary for favourable macro- and micro-climatic conditions.

ii. Intensification of agricultural production through integration of crop production, horticulture, agroforestry components and animal husbandry into a manifold ecological farming.

iii. Use of all wastes, recycling of all nutrients and biomass produced within the system.

iv. Reduction and where ever possible, elimination of pesticides and mineral fertilizers by adoption of biological control measures, resistant varieties and organic fertilizers.

v. Use of appropriate technology designed for special needs and working conditions of the farmer.

vi. Avoidance of production risks and strengthening of self-sufficiency of farms and rural communities.

vii. Adjustment of production system to social, cultural, economic and political conditions and peculiarities of each location.

Characteristics of a sustainable system provided by Ragland (1991) are also related to the aforementioned elements as they prescribe agriculture which is environmentally, socially and economically compatible. Among other things, they include factors like:

i. Adequate economic returns to farmers

ii. Maintenance of natural resources and productivity indefinitely.

iii. Minimal adverse environmental impacts.

iv. Optimal production with minimal external inputs.

v. Satisfaction of human needs for food and income.

vi. Provision for social needs of farm families.

In their discussion of the requirements of sustainable agroecosystems, Altieri *et al* (1984) describe elements of an ecologically healthy agricultural system as the one which:

i. reduces energy and resource overuse.

ii. facilitates the operation of production methods that restore homeostatic mechanisms conducive to community stability; optimize the rate of turnover and recycling of matter and nutrients, maximize the multiple use of capacity of landscape and ensure an efficient energy flow.

iii. encourages local production of food items adapted to the natural and socioeconomic setting.

In general, the requirements of sustainable agroecosystems are social, economic, and political as well as biological or technical, indeed, they illustrate the requirements of a sustainable society.

Ecological changes in agriculture must be also accompanied by compatible changes in all other interrelated spheres. The final requirement of a sustainable system is that humanity develops an attitude towards nature of coexistence rather than exploitation (Altieri *et al*, 1984).

FAO (1989a), distinguishes agricultural sustainability from stability and productivity. Thus, stability implied limited change in the general sense, as environmental stability. It can also be used to mean limited fluctuation as in yield stability. Unstable yields caused by environmental fluctuation can, however, be entirely sustainable. Although, an adequate level of productivity is necessary for sustainability, it is not by itself sufficient to achieve sustainable agricultural development.

According to Smith (1990), sustainability is not synonymous to low input agriculture and both modern science and traditional knowledge are required for sustainability.

2.3.3 Livestock and sustainability of mixed farming

Livestock contribute to sustainability of mixed farming in several pathways. The most important contributions come through their buffering effect and increasing subsistence security, use of forage legumes and animal manure for restitution of soil fertility, transfer and recycling of energy, increasing income and yields to farming families which will be invested on agricultural inputs, and all other integrative and synergistic effects on cropping (Parker, 1990; Bayer and Bayer, 1989).

Diversification in to livestock-keeping extends the risk reduction strategies of crop farmers beyond mixed-species cropping, and extends the risk reduction strategies of pastoralist beyond mixed-herding. Livestock serve as buffers; an animal can be slaughtered for home consumption or sold to buy food when crop yields do not meet family needs (Parker, 1990).

Crop-livestock interactions provide a key to ecological sustainability by intensifying nutrient and energy cycles.

Inclusion of forage legumes in to crop rotations provides a means for solar energy maximization, nutrient cycling, utilizing non-competitive renewable resources, and soil-water conservation (Parker, 1990; Okigbo, 1990).

Manuring is an important process for recycling of nutrients to maintain or improve soil fertility, especially in those intensively cropped locations where chemical fertilizers are limited. Animals by utilizing inedible and low quality lignocellulose of crop residues and other roughages, provide high quality, value-added food for human consumption, power indispensable for smallholder farming, and animal manure for maintenance of soil fertility (Parker, 1990; Edwards, 1990; Bayer and Bayer, 1989).

Integration of crop and livestock production into compatible and ecologically stable farming systems is thus one of the requirements of sustainable agroecosystems (see section 2.3.2). Therefore, integration of plant and animal resources to achieve optimal biomass output within a given ecological and socioeconomic setting should be the ultimate goal for sustainable farming systems (Parker, 1990).

3.0 DESCRIPTION OF THE STUDY AREA

3.1 Geographic location and representativeness

This study was carried out in the former Ada district of the Shewa Administrative region of Ethiopia. According to the old system of disaggregation of administrative structure, Ethiopia was divided into 14 Administrative regions (*Kifle Hager*) of which Shewa is one.[3] In turn this regions are divided into *Awrajas* which are themselves divided into districts (*Woreda*). In the rural areas, several peasant Associations form a district. Ada district, where the present study was undertaken, is located in the former Yerer and Kereyu Awraja of the Shewa Administrative Region (see Figure 2).

Ada district is situated about 45 Kms east-south-east of Addis Ababa. There were 91 Peasant Associations in Ada district with a total of 18,760 registered families in 1989. In the same year, the total population of Ada district is estimated at 204,742 of which 30% are residents of the principal town, Debre Zeit, located some 50 Kms east-south-east of Addis Ababa along the main high way to Nazareth.

The district covers some 1750 Km^2 stretching, in a fairly oblong fashion, from just east of Bole International Airport to the north-west corner of Koka dam. The altitude of the area ranges from about 1500 m in the arid, eroded area of the rift valley in the south near the river Awash, to over 2000 m in the Routh plateau of the north (Vincent, 1977; Mukasa-Mugerwa, 1981; Gryseels and Anderson, 1983). The ILCA experiment station at Debre Zeit is located at an elevation of 1850 m and latitudes 8^0 44' N and longitudes 38^0 58' E some 50 Kms east of Addis Ababa

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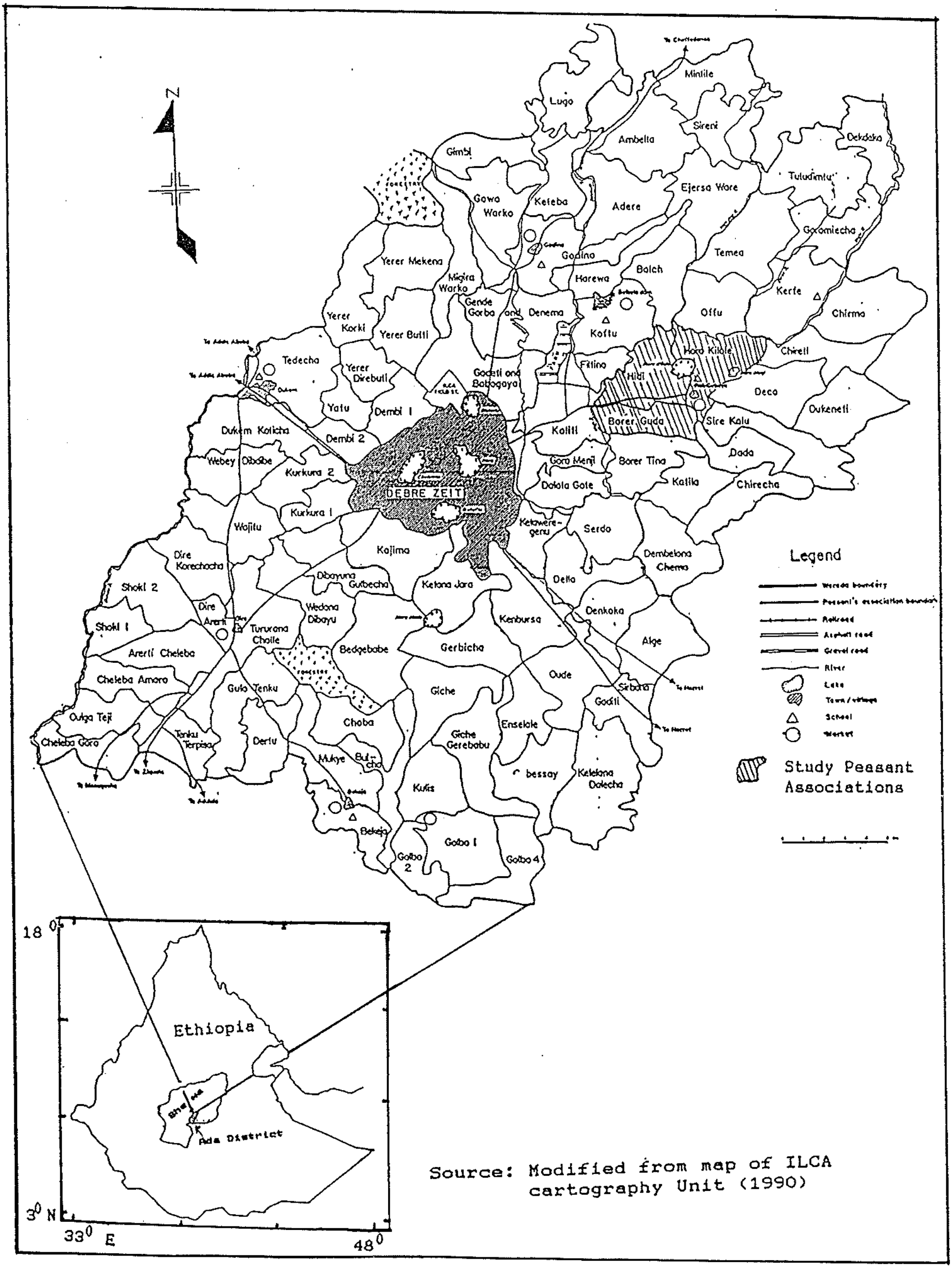
[3] Presently, Ethiopia is disaggregated into 30 Administrative Regions of which five are autonomous. According to this new system, the former Ada district (*Woreda*) is promoted to the level of *Awraja* containing 193 PAs and is located in the Misrak Shewa Administrative Region.

Figure 2. Locational map of the study area (Ada district).



Source: Modified from map of ILCA cartography Unit (1990)

(Gryseels and Anderson, 1983).

The three Peasant Associations (Hidi, Borer Guda and Hora Kilole) where the micro-level survey for investigation of the roles of integration for sustainability of mixed farming was carried out, are located near the ILCA on-farm verification site at Hidi some 15 Kms north-east of Debre Zeit at an altitude of 1950 m (see Figure 2). The three PAs, all share a common boundary and are presumed to have similar farming, soil, climate and other environmental conditions.

Ada district is fairly well endowed with development infrastructure in relation to other districts in Ethiopia. The Ethio-Djibouti Rail Way Line and the main high way from Addis Ababa branching later into different places, all cross the district and the capital town, Debre Zeit. It is also well supplied with telecommunication facilities, and fairly well staffed with Development Agents of the Ministry of Agriculture. There are also a few dry-weather roads branching to different parts of the district from Debre Zeit town. Apart from ILCA, the National Veterinary Research Institute, the Faculty of Veterinary Medicine and the Debre Zeit Agricultural Research Center of Alemaya University of Agriculture are the main scientific institutions situated in Debre Zeit mandated with agricultural research.

Ada district is typical of the traditional mixed farming system of the central highlands. More than half of Ada represents the high potential cereal/livestock zone (Mukasa-Mugerwa, 1981) where animal power is invaribly used for traction and transport, and cereals are the main cultivated crops under high human and livestock population pressure.

All these factors combined together made Ada district a logistically appropriate and representative study site for the purpose of this survey.

3.2 The natural resource base

3.2.1 Climate

The Debre Zeit Air Force maintains the nearest weather monitoring station which has recorded climatic data since the

1950's. ILCA and the Debre Zeit Agricultural Research Center also had weather monitoring stations from 1970's.

According to Mukasa-Mugerwa (1981), three fairly distinct climatological zones are recognizable in Ada: the rift valley which covers some 600 Km^2 (34%) at 1500-1800 m; the mountain zone covering 150 Km^2 (9%) at above 2000 m; and the true highland zone extending over 1000 Km^2 (57%) at the intermediate 1800-2000 m elevation.

As data received from National Meteorological Services Agency (1990) indicates, the average rainfall of Debre Zeit for complete data sets of years 1951-1988 was 884 $\pm$ 196 mm per year. The mean monthly rainfall and minimum and maximum temperatures for years 1951-1988 in Debre Zeit are shown in Figure 3a, while reliability of monthly rainfall (standard deviation as percentage of the mean) for years 1971-1988 is depicted in Figure 3b.

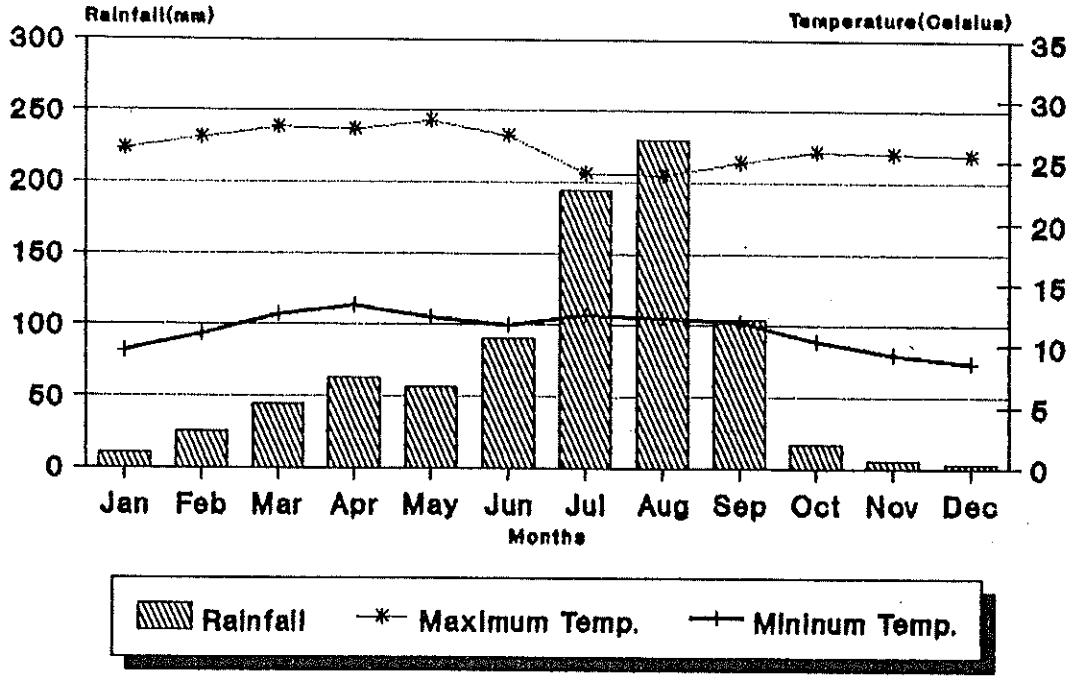
Climate in Ada is generally mild with a nearly unimodal rainfall pattern. The light and less reliable short (*Belg*) rains come down in February to May, while the more reliable heavy (*Meher*) rains which account about 74% of the annual precipitation come down in June to September.

In Ada, March, April and May are the hottest months, while November and December are the coldest months. For years 1951-1988, the mean annual maximum and minimum temperatures were 26.2 $\pm$ 0.35^0 C, and 11.4 $\pm$ 0.5^0 C respectively. According to Mukasa-Mugerwa (1981), no frosts are known at the ground levels of the areas at low elevation.

3.2.2 Soils

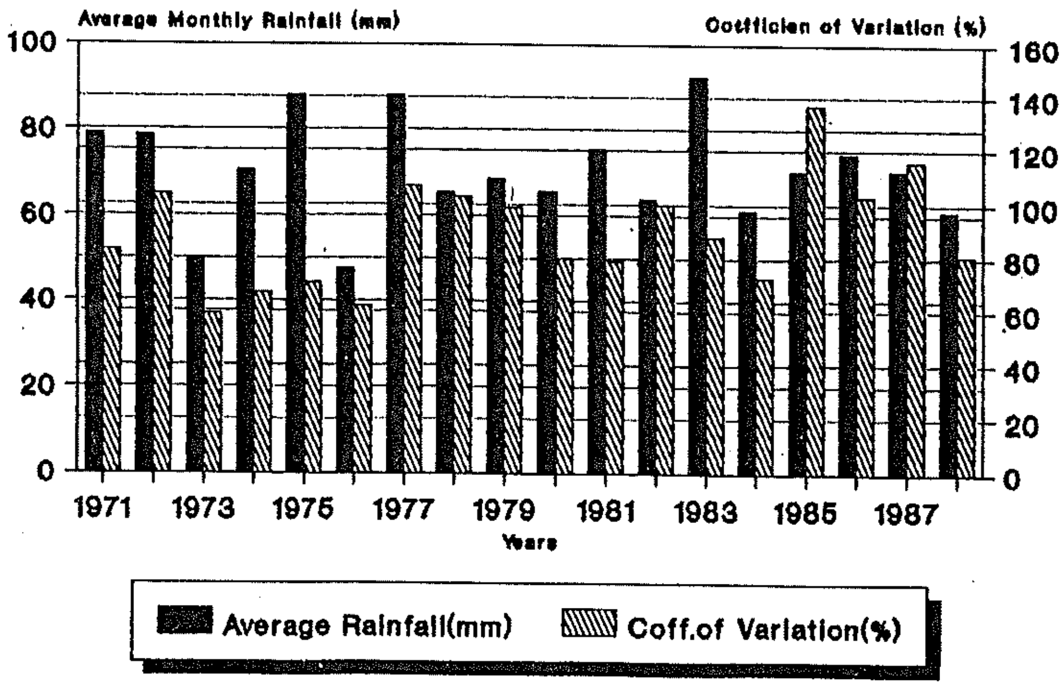
Since detailed soil classification and investigation in Ethiopia has been carried out only for limited areas, information on soil types and soil fertility is mostly very general and some times inconsistent (Pulscen, 1990). According to FAO (1986), the seven dominant soil types which comprise 88% of the highlands are

Figure 3a. Average monthly rainfall and temperature in Debre Zeit (1951-1988)



Source: Compiled by author from data of NMSA (1990).

Figure 3b. Reliability of Average Mounthly Rainfall in Debre Zeit (1971-1988).



Source: Compiled by author from data of NMSA (1990).

vertisols, nitosols, luvisols, acrisols, cambisols, phaeozomes,and lithosols all derived from volcanic parent material but cambisols and lithosols. The HPP zone is dominated by nitosols (39%) and acrisols (36%). The HPC zone is much more varied, with vertisols covering 20%, followed by luvisols, nitosols and cambisols. The LPC zone is also varied, cambisols (32%) being most widespread, followed by lithosols (degraded soils), luvisols and others. Around half of the vertisols are in the HPC zone and practically all the phaeozomes in the HPC and LPC zone.

On the ILCA station at Debre Zeit, soils vary from red sandy loams to clay and clay loams. Soil fertility on the station is adequate with respect to phosphorus, at 35-70 ppm in upper soil layers, while the potassium content is relatively high. Both the organic matter fraction at 1.5-2.5%, and nitrogen (0.1-0.2%), are low in the upper layers (Houerou, 1976).

According to Mukasa-Mugerwa (1981), various gradations of the two principal soil types of Ada, black heavy, and red light soils, are traditionally known and their fertility variation well accepted. These are,

* *Koticha*: black clayey soils,
* *Gombore*: light hillside well-drained sandy soils,
* *Abolse* : a mixture of black and red light soils, and
* *Cheri* : stony soils.

In the highland soils, by international standards, nitrogen, cathion exchange capacity and organic matter contents are generally high, but phosphorus is low, and calcium and magnesium at average levels. With the exception of vertisols and lithosols all the major soils of the highlands have good workability, good drainage and adequate soil depth. Lithosols are already degraded infertile soils, while vertisols are inherently fertile with good moisture holding characteristics but have narrow moisture range outside of which they are hard and cracked when dry, and sticky when wet (FAO, 1986).

3.2.3 Vegetation

Because of the widespread devegetation and remarkable human influence on the land scape, only little of the natural vegetation of the highlands remains today. The country, which was at the turn of this century covered with 40% forest, has now remained with less than 4%. Forests are now being cleared at a rate (200,000 ha $year^{-1}$) in excess of their annual growth which is estimated twice the regeneration rate (FAO, 1986; GOE/IUCN, 1990).

In Ada district, the natural vegetation before a decade ago represented less than 15% (Gryseels and Anderson, 1983). Because of extensive destruction of vegetative cover, fuel wood is now a very limiting resource. As a result, animal manure is invariably used as household fuel and has lost its integrative soil fertility maintenance function. According to Ada Awraja Agricultural Development Office (1990), about 10,000 ha (6%) is considered under natural or man-made forests.

The farmers of Ada have deliberately left *Acacia albida* in all cultivated fields since it is highly valued for firewood, animal feed, maintenance of soil fertility and fencing. The acacia trees are regularly pruned every 2 to 3 years to reduce shadowing effect on the crops and to encourage new growth of shoots while the cuttings are used for various purposes. *A. albida* seems an important traditional multipurpose tree in Ada. Moreover, *Sasevieria spp* and *Ziziphus abyssinica* are widely used as live fences around the homestead and cultivated fields.

The remaining highland forests comprise species like *Podocarpus gracilias*, *Juniperus procera*, *Cordia africana*, *Olea africana*, and *Ficus spp*.

The grasslands are highly overgrazed and most of the remaining species are screened for generations for resistance to grazing and unpalatability to herbivores. Continued overgrazing has reduced the more palatable species of *Cynodon*, *Cenchrus*, *Chloris*, *Panicum*, and *Trifolium*. These species have been surplanted by *Pennisetum schimperi*, *P. glabrum*, *Setaria atrata*, *Andropogon chrysostachys*, and other unpalatable species of *Eragostis*, *Aristida*, *Heteropogon*, *and Cyperus* (Archer and

Solomon Demeke, 1984).

3.2.4 Hydrology

The hydrology of the highlands is dominated by a variable rainy season with corresponding large variations in surface water flows, relatively few rivers being perennial. The physiography of the highlands and its exposure to seasonally abundant rainfall has created an extensive network of rivers and streams to such an extent that many rivers starting from the highlands are major sources of Ethiopia's increasingly enormous 'foreign aid' of fertile top soil and water to the neighboring countries.

Like most of the highland rivers, a few rivers of Ada district are mountain streams over much of their length. A few first order streams available north of Debre Zeit town are highly intermittent depending on the amount of rainfall received on slopes along their course. The largest of the rivers in Ada, river Mojo, is now being diverted by Ministry of Agriculture to pour its contents to lake Hora Kilole in an attempt to irrigate the nearby cultivated fields. All the small streams and rivers are important sources of drinking water to the rural families and their livestock.

Ada is more blessed for its marvelous crater lakes, which depict the real beauty of nature, than for its scanty rivers. There are four such lakes only within the main town of Debre Zeit and a few others north and south of the town. These lakes are indispensable gifts of nature as they are important sources of fish, drinking water for animals, and serve as centers of tourist attraction and recreation. During the non-cropping season, all the lakes are used as watering points for animals coming from all direction. During some seasons (like *erecha* when various rituals are also performed), the Oromo, because of their belief in medicinal value of watering and dipping in lake Hora (Debre Zeit), trek their animals from long distances.

3.3 Farming systems

As it has been described in section 1.3.3, several authors have attempted to characterize farming systems in Ethiopia and in the highlands. Westphal (1975) distinguished four agricultural systems: the seed farming complex, the ensete planting complex, shifting cultivation and pastoral complex.

An important system in the central highlands of Ethiopia is the seed farming complex. The main characteristic of this system is reproduction of nearly all crops by seed (mainly cereals, pulses, and oil crops), while perennial and tuber crops are much less important. Fields are cultivated using draught power where by a pair of oxen and a traditional wooden ard called the *maresha*[4] is used.

According to Westphal(1975), the seed farming complex is found in the central, northern, and eastern highlands and in the Konso and adjacent regions.

From an economic view point, the development potential and the resource base of the highlands, Amare Getahun (1978a and 1978b) differentiated the high potential cereal/livestock (HPCL), the low potential cereal/livestock (LPCL) and high potential horticulture/livestock (here referred to as the high potential perennial/livestock (HPPL)) zones within the mixed farming system of the highlands[5].

The HPCL zone covers some 140,000 Km^2 (29%) comprising the Central highlands, the Arsi-Bale Massif, the Harar Highlands, the north-eastern highland valleys and the lake Tana Basin. This zone is important in terms of human and livestock densities and production of food crops. The zone is suffering from gradual ecological degradation from increasing population pressures. The growing period is usually over 180 days. Throughout the zone, oxen provide the necessary traction power and the *maresha* is the

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[4] Unlike the conventional mouldboard plow, the *maresha* does not turn the soil, instead it barely breaks and disturbs it. The implement is locally made by the farmer from wood and has a metal tip for penetrating the soil. It consists of bent wooden beam; a pair of rectangular pieces of wood, one on each side, serving as a sledge; and a yoke infront of the beam with two V-shaped pieces of wood, one on each side, where oxen are to be engaged.

[5] FAO (1986), slightly modified these agricultural systems and retained the names as High Potential Cereal(HPC), Low Potential Cereal(LPC) and High Potential Perennial(HPP) zones.

main implement.

The LPCL zone covers 162,920 Km^2 (33%) consisting of degraded high-altitude highlands (climatically parts of the HPCL zone), and the plateaux and escarpments lying between the lowland and the more temperate highlands. Human and livestock pressure is high in relation to the resource base, yields are low, and there is a shortage of arable land and pasture. The resource base is deteriorating rapidly. The growing period is short (90-150 days). Traction is common and again the marsha is the main agricultural tool.

The HPPL zone covering 186,300 km^2 (33%), has high annual rainfall, an extended wet season with the growing period of over 240 days and a moderate warm climate. In this zone perennial crops like coffee, tea and chat (*Catha edulis*) are important commercial crops while ensete (*Ensete ventricosum)*, root crops and maize are important food crops. Animal traction is very rare, and the hoe is the main agricultural tool.

In the central highlands, the main crops grown are teff (*Eragrostis teff*), wheat, barley, maize, sorghum, horse beans, chickpeas and field peas. Farm sizes average from 0.5 to 5 ha and around 80% of all the farm produce is used for subsistence consumption. Grain yields average between 0.5 and 1 t ha^{-1}, and access to modern inputs is limited (fewer than 10%, and 2% of the farmers regularly use chemical fertilizers and improved seeds respectively) (Gryseels *et al*, 1984; Gryseels and Anderson, 1983).

The Yerer-Kereyu highlands of Shewa, where Ada district is located, represent one of the regularly cultivated important grain regions of the central highlands. In Ada, the main cereals grown are teff (white, mixed and red varieties), durum wheat (*Triticum durum*), bread wheat (*Triticum aestivum*), and barley (*Hordium vulgarae*), while maize (*Zea mays*) and sorghum (*Sorghum bicolor*) are also important at the lower altitudes with lower precipitation. The most important grain legumes are chickpeas (*Cicer arietinum*), horse beans (*Vicia faba*), field peas (*Pisum sativum*), Rough peas

(*Lathyrus sativus*) and lentils (*Lens esculanta*). Some times fenugreek (*Trigonella foenum-graecum*) and safflower (*Carthamus tinctorius*) and niger seed (*Guizotia abyssinica*) are also grown.

In the crop rotation cycle of Ada, usually pulses precede the cereals for their residual soil fertility enhancing effect for the next crop. The farmers intentionally grow horse beans, field peas or lentils on red light upland soils and chickpeas or rough peas on vertisols of the valley bottoms on lands which will be the next seasons teff fields.

In Ada, a typical farm contains 2.5 ha, two-thirds of which is sown to cereals and the remainder to pulses, and a typical livestock inventory shows a pair of oxen, a cow, a few sheep and a donkey (Gryseels and Anderson, 1983). More than 90% of the land holding is annually cultivated and there is very little tendency for any fallow (Mukasa-Mugerwa, 1981), thus, pressure is increasing on the available arable land for subsistence crop production. Grazing on communal lands, stubbles and crop residues is the main source of feed. Food grain needs of the rising rural population are resulting in progressive extension of the area under cultivation and a consequent reduction of fallow areas, leading to increased use of the limited grazing resources that remain.

4.0 RESEARCH DESIGN AND METHODOLOGY

This study which was carried out in Ada district of Ethiopia from August-January 1990, has macro- and micro-components. The macro-component of the study was concerned with assessment of competitive crop-livestock interactions in terms of land use conflicts for livestock production at the district level. In this part of the study, aspects of temporal changes in population pressure, size of land under cultivation for various crops, and size of land under other categories and their effect on the limited grazing resources of the district was looked into.

In the micro-component of the study, identification of the roles of crop-livestock integration (complementary interactions) for sustainability of highland agriculture was the center-piece of the program. This aspect of the study was carried out in the three highland PAs namely Hidi, Hora Kilole and Borer Guda located in Ada (see section 3.1).

4.1 Research design and data collection

4.1.1 Sampling design

4.1.1.1 Farm stratification criterion

As it has been described elsewhere in this manuscript, crop and livestock sub-systems of the highlands have historical symbiotic interactions. The input and farm integration function of livestock outweighs the objectives of the mixed smallholder farmer in maintaining animals in the farm. Because of widespread destruction of vegetative cover in the highlands, animal manure is now increasingly used as an important source of household fuel and thus has lost its soil improving input and integrative function. Therefore, according to Gryseels and Anderson (1983) and Gryseels *et al* (1984) among the input functions of livestock, provision of draft power for cultivation and threshing is the major contribution of cattle to agriculture in the Ethiopian highlands.

Animal power (not including power supplied by donkeys which are mainly used for transport of agricultural produce) used for crop related work in the highlands averaged more than 1000 hr $farm^{-1}$ $year^{-1}$; most of this power supplied by oxen, but other cattle also employed for threshing. About 60-70% of the total animal power input was for seed-bed preparation and planting, with approximately 350 hr per oxen pair used for traction (Gryseels *et al*, 1984).

Use of oxen as draft animals is, therefore, the main integrator of crop and livestock production in highland agriculture. Besides, total livestock holding of the farm is an important integrator since availability of other categories of cattle, equine and small ruminants (sheep and goats = shoats) increases farm income, total manure output, transport power and subsistence security of the rural poor. Higher livestock holdings may also lead to efficient use of otherwise unusable resources thereby enhancing efficiency and productivity of the farm.

Mixed smallholder farmers of Ada can thus be effectively differentiated for degree of integration of crop and livestock sub-systems by looking into the size of livestock holdings and number of draft oxen they employ for cultivation. Therefore, number of draft oxen and size of livestock holdings of each farm were adopted as the main criteria for stratifying mixed farmers into varying levels of integration. Other criteria like size of grazing land and/or size of cultivated land of each farm may also be used for partitioning farmers, but in many cases, property rights about grazing lands are not clear, and if distinct enough, they are common properties with restricted access making it impossible to adopt this criteria.

4.1.1.2 Sample selection

After a preliminary survey of the study area has been carried out, the micro-level study was conducted around the three PAs of the ILCA's on-farm verification site at Hidi. While a questionnaire was ready to study status of livestock and draft oxen holdings of the study PAs, the 1989/90 data was obtained from a survey conducted by Development Agents of the Ministry of Agriculture.

Livestock holding of each farmer in the study PAs (except those who were members of Producers' Cooperatives (PCs)) were converted into a standard livestock unit also called tropical livestock unit (TLU). Conversion into livestock standard unit in tropical Africa varies with breeds and species of livestock in each zone. As the study conducted in Ada district by Mukasa-Mugerwa (1981) indicates, the average live weight (Kg) for different species of livestock is as follows: Cows 250, oxen 275, mature female shoats 25, mature male shoats 30, young donkeys (less than 3 years) 50, and mature donkeys 125-130.

Based on average weights for each class and species of stock, the following TLU conversion factors (summarized in Table 4.1) were developed and subsequently used as desired throughout the course of the study.

Table 4.1 TLU conversion factors used in the survey.

Class/Species	Average Weight(Kg)	TLU Conversion Factor
Oxen	275	1.1
Cows	250	1.0
Heifer	125	0.5
Young bulls	150	0.6
Calves	50	0.2
Sheep	25	0.1
Goats	25	0.1
Donkeys	125	0.5
Horses	200	0.8
Mules	175	0.7

Source:- Compiled by author mainly based on average live weights of livestock in Ada given by Mukasa-Mugerwa (1981).

All the livestock possessions of the mixed smallholder farmers of the study PAs were converted into this standard unit, TLU. Based on this, oxen ownership and livestock holdings of three PAs in

1989/90 is summarized in Table 4.2.

Table 4.2 Oxen ownership and livestock holdings (TLU) of the study Peasant Associations (1989/90).

PA	Members[a]	More than two oxen (%)	Pair of oxen (%)	One ox (%)	No ox (%)	No live-stock (%)	Total TLU	Average[b] TLU
Hidi	132	2	44	27	27	22	312.5	3.03
Hora-Kilole	105	2	61	27	10	7	265.1	2.71
Borer-Guda	126	3	48	27	21	16	220.1	2.07

[a] This does not include farmers who were members of PCs in 1989/90.
[b] Average TLU as calculated for all members but those without livestock.

As shown in this table, livestock and oxen holdings are not very different between the three PAs. About 15% of the farmers do not have livestock, thus were not considered as integrators and were excluded from the sample. About 19% of the farmers do not have the necessary traction power, and about 27% had only one ox. The average livestock holding for the three PAs was 2.6 TLU, while the average oxen holding was 1.6.

To investigate the role of crop-livestock integration for sustainability of mixed farming, two groups of farmers (A and B) above and below the average livestock and oxen holdings were identified. *Group A, representing a high level of integration, contained mixed farmers with a minimum of two oxen and two other TLU. Group B, representing a low-level of integration, contained mixed farmers with a maximum of one ox and two other TLU.* Those farmers which did not lie either in Group A or B were avoided from the population from which samples were selected.

From the three PAs, 77 and 95 farmers were found to be in Group A and Group B respectively from which a simple random sample of 42 farmers were drawn for a detailed investigation (see Table

4.3). Although all the three PAs were considered to have similar social, economic and biophysical conditions, farmers in each Group were about evenly distributed in the three PAs. Inclusion of three PAs into the study program was to widen the scope of the study and to provide more flexibility for selection of representative farmers (ie. to avoid exertion of high selection pressure in drawing samples).

Table 4.3 Population of farmers in each group and size of selected samples from each Peasant Association.

PAs	Population		Sample	
	Group A	Group B	Group A	Group B
Hidi	27	38	17	14
Hora-Kilole	33	23.	13	9
Borer-Guda	17	34	12	19
Total	77	95	42	42

4.1.2 Data collection

4.1.2.1 Micro-level survey

After representative samples have been selected for each group, detailed farm management data were collected using a questionnaire (see Appendix 9) for the year 1989/90 cropping season. The questionnaire was developed according to the key areas of crop-livestock integration and in ways relevant to sustainability issues of highland agriculture. The questionnaire was tested first in the field for its appropriateness, and changed and adjusted as the case may be.

A grade twelve complete and experienced enumerator assisted in aquisition of the required information using the questionnaires. When ever necessary, an interpreter was used to minimize the problem of the language barrier. Farmers were usually surveyed in the morning (between 7 and 8 AM) and late in the afternoon (after 5 PM) during the working days of the week and at any time (8 AM-6 PM) on the weekends and other non working days of the week depending on the farmer's convenience.[6]

For matters related to socioeconomic changes, social division of labor, cultural practices and property rights to grazing lands group interview of knowledgeable farmers was used. Interviews were always made with the household head (very often the husband) and the housewife was consulted for issues relating to women's duties in the farm. For the farmer's convenience, local units for area, weight and volume measurements were used in the study.

Farmers were briefed about the objective of the study program and were advised to respond to all types of questions to the best of their knowledge, and unreserved effort was made to obtain the required information through indirect and informal approaches.

4.1.2.2 Macro-level survey

In an attempt to assess the land use pattern as influenced by demographic and non-demographic factors and their inevitable effect on spatial availability of grazing areas and demand and supply disparities of forage produced in the system, eleven-years' (1979/80-1989/90) data was received from the local office of the Ministry of Agriculture (Ada Awraja Agricultural Development Office). Land use data were cross-checked for their validity with various estimates available from literature and were adjusted accordingly as felt necessary. Data included yearly changes in area of cultivated land for each crop, grazing land, fallow, and other categories of land. Livestock (by class and species) and human population data of eleven years was also obtained from the same

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[6] Orthodox christian farmers of the highlands observe up to 200 religious holidays every year (3-4 days a week) which prohibits field work (mainly breaking the ground). All farmers, however, do not attest to the same saints such that when one is ploughing on a given day, another is weeding or fencing.

source.

4.2 Data management and analysis techniques

4.2.1 Data management and assumptions

In the micro-level survey, after the desired information was acquired using the questionnaires and informal discussions, a number of assumptions and transformations were required before the data awaits statistical analysis.

Among other things, transformations were needed for converting family sizes into standard consumer unit, family labor into comparable labor units, and grain carry-over stocks into grain equivalents for ease of comparability between the two groups. Family sizes were converted into consumer units adopting the FAO/WHO coefficients (see Appendix 1). In lack of any standard conversion factors, family labor was converted into labor units according to an elaborate conversion table (see Appendix 2) developed for Ada conditions based on division of labor (see Appendix 3) and time spent on farm work by a family member.

Carry-over stocks, amount of grain left from last season just before the next harvest, were converted into Grain Equivalents (GE) based on average market prices (see Appendix 4) for three years (1986,1987,1989). The conversion factor was developed as the ratio of the average market price of each crop and the average price of all the crops. Therefore, GE kg of each crop is the product of Kg reserve and its respective conversion factor.

Several other criteria like calorific value and proportion of each crop in the farm may be used for conversion of grain reserve into grain equivalent. Adoption of the relative price criterion for this study was in lack of good correlations between nutrient composition (energy and protein content), spatial proportion of each crop in the farm and market prices. Relative market prices attach a good measure of weight to each crop and reflect the opportunity cost of acquiring that crop from markets for home consumption. Average market prices of all the crops were preferred to be the denominators since the family combines cereals, pulses and other crops in its food habits. Price of each crop can also be expressed as the ratio of say the price of teff, but this reduces grain equivalents into teff equivalents.

Calculation of crop yields: crop yields for Group B farmers which have paid the opportunity cost of using some one's oxen were calculated as:

$$\text{Yield (Kg ha}^{-1}) = \frac{\text{Total Yield - Ox Rent}}{\text{Crop Area}}$$

In Ada district, there are several strategies by which farmers having less than a pair of oxen can work with pairs. The most common traditional ox-pairing strategies are the *mekenajo* agreement by which two farmers with one ox come together and the two oxen are used on the partners' fields on alternate days, and the *minda* agreement by which farmers rent one or two oxen in exchange for grain or human labor. There are also some departures from these two common types of oxen-pairing strategies like when a farmer receives oxen without any form of payment for the whole or part of the production season.

For some types of *minda* arrangements for which payment is not made in the form of crops, or cash (or labor) and *mekenajo* agreement, ox rent is paid in terms of the farmer's time forgone for use of oxen or labor on the partner's field. This is argued to be reflected in reduced yields as a result of delayed planting as the cropping season is short, infrequent ploughing and insufficient preparation of the seed-bed, reduction in the area cultivated and decline in tractive power generated from changing of handlers and pairing of different animals. Therefore, in yield calculations, ox rent was considered to be zero for farmers using these types of arrangements.

Nonetheless, for all kinds of *minda* types of agreements involving payment in the form of crops, the amount paid as the opportunity cost of using some one's oxen was deducted from the total yield of that crop. This is because that part of the total yield paid as ox rent is no more available to the farmer simply for lack of the necessary traction power. For farmers obtaining traction power free of charge, ox rent was estimated from the average paid by the others for one or two oxen.

Calculation of gross margins: A number of transformations and assumptions were also required for calculating gross margins for crop and livestock enterprises. Gross margins, difference between gross income earned and the variable costs incurred, were calculated according to Makeham and Malkolm (1986) which can be described as:

Gross margin from crops (GMC) = Total value of crops + value of crop residues - cost of purchased variable inputs.

where, *Total value of crops* = sum of the product of yield and the 1989 market price of each crop (see Appendix 4),

Value of crop residues = 160 (tons of crop residue produced) 0.75

Amount of crop residue produced was estimated by using multipliers developed from the grain:seed ratio. Multipliers used in this study for estimation of crop residue yield are summarized in Table 4.4. After the crop residue yield is estimated, it was assumed that 75% of all produced will disappear every year.

Crop residues are mainly used as animal feed during the dry season, but may also serve as firewood or as building material (mixed with mud for plastering walls). Crop residue may have market values for each of these intended end uses. According to Mukasa-Mugerwa (1981), a donkey load (25-30 Kg) of crop residue costs 4-5 Birr, thus 160 Birr t^{-1} is used in this study.

Cost of variable inputs = cost of fertilizer used + seed expenses + cost of pesticide used + cost of hired labor

+ cost of agricultural tools + ox rent expenses.

In this equation seed expenses were estimated as a product of Kg of seed used and the 1989 market price of the crop. An average seed rate (see Appendix 5) per *kert* (2500 m^2) estimated from a questionnaire developed for seed rate survey was used as a basis for calculating amount of seed used for area cultivated of each crop.

Table 4.4 Multipliers used for converting grain yield to its crop residue equivalent.

Crop	Average Grain-Straw Ratio	Multiplier	Source
Teff	0.45	2.22	Own experiment[a]
Wheat	0.67	1.48	,,
Barley	0.72	1.39	Gryseels *et al*,1988
Chickpeas	0.65	1.54	Own estimate
Field peas	0.69	1.45	Gryseels *et al*,1988
Horse beans	0.87	1.15	,,
Lentils	0.64	1.56	,,
Rough peas	0.65	1.54	Own estimate

[a] Average of 18 and 7 samples, each one kilo, for white teff (hand threshed) and bread wheat (machine threshed) at ILCA Debre Zeit station respectively. This was done in lack of reliable estimates especially for teff.

Ox rent expenses refer to market value of crop payments made for *minda* arrangements or payments estimated as opportunity cost of use of oxen without payment.

Gross margin from animals (GMA) = Value of change in stock (±) + revenue from sale of animals reared in the farm + value of milk produced + value of traction power + transport value of equine + value of animal manure - variable costs in animal husbandry.

Where, *value of change in stock* = inventory changes at the beginning and end of the year because of births and deaths valued at 1989 market prices (see Appendix 6), *Value of milk* = (Kg of milk produced) 0.70 Birr,

Revenue from animal sale = sum of revenue from sale of animals reared in the farm,

Value of traction power = 209.45 Birr for renting one ox or 635.90 Birr for renting a pair of oxen.

This was estimated from ox rental markets of the survey farmers as average market value of crops paid for use of a single or a pair of oxen. The traction value of three oxen is estimated as the sum of rent payments for a pair and single ox.

Transport value of a donkey = 720 Birr $year^{-1}$. This was estimated under the following assumptions. Between the period December and March, donkeys are used every day for 120 days. During the harvest period, donkeys convey all crops from the field to the stacking ground near the homesteads to await threshing if not immediate. All the threshed crops are also conveyed to stores by use of donkeys. The average farm distance is assumed to be 1 Km. Besides donkeys are used for transport to markets, for fetching water by jerry-cans or traditional clay pots (20-40 litres) seated in specially constructed saddles. For the rest of the time (36 weeks) donkeys are used only for 5 days a week for marketing, fetching water, transport to milling machines, etc.

In summary a donkey can be assumed to transport:

i. 0.5 t over 10 Km for 120 days (December-March) ie. if a donkey travels 10 times in the farm carrying 50 kg,

ii. 50 Kg over 15 Km for 52 days ie. if a donkey travels to markets carrying 50 Kg,

iii. 50 Kg over 2 Km for 128 days for fetching water and other services.

Under these assumptions, a donkey on average carries 0.23 t over 7.5 Km for 300 days every year. Put differently, a donkey carries 0.12 t over 15 Km for 300 days a year. According to Mukasa-Mugerwa (1981) and from this survey, on average 0.50-1.00 Birr is charged to transport one's load for 5-7 Km per day. The market rent rate for translocation of 100 Kg load over some 15 Km (say to Debre

Zeit market) is 2.00 Birr. Therefore, a donkey's daily load of 120 Kg can be conservatively estimated at 2.40 Birr, which amounts to 720.00 Birr per year.

An estimate of 0.23 t over 7.5 Km (equivalent to 1.3 ton Km), is conservative compared to 2-5 ton Km estimated for equine by Jahnke and Getachew Assamenew (1984).

Transport value of horses was estimated as income received by the owner from horse cart. Transport value of mules was estimated assuming that a mule will be used two days a week over a distance of 30 km. The equivalent market rate of 4.00 Birr for an alternative source of transport using horse carts which amounts to 415.00 Birr a year is used in this study.

For estimation of the value of animal manure, a dry manure production of 1% of body weight (2.5 Kg TLU^{-1}) and a 30% loss in collection and a price of 0.05 Birr per Kg dry matter was adopted.

Variable costs in animal husbandry = depreciation cost of purchased oxen + cost of replacement stock + feed costs + veterinary expenses + cost of hired labor.

Depreciation cost of purchased oxen was estimated using the following assumptions also indicated by farmers:

i. Average economic life time of oxen is 5 years.

ii. Expected sale price (ESP) after 5 years is a quarter of the purchase price.

iii. Expected replacement cost (ERC) after five years is ERC = purchase price + 5(annual growth rate in prices x purchase price).

From 1980 average Ada district prices which were Birr 350.00 (Mukasa-Mugerwa, 1981) and average 1989 prices which were Birr 528.00 (Getachew Assamenew, 1991), annual growth rate of price of oxen for the last decade was estimated at 5.7%.

Therefore, total depreciation = ERC - ESP, and

$$\text{Anual depreciation} = \frac{\text{total depreciation}}{\text{economic life time}}$$

Calculation of farm income: farm income was calculated as the sum of GMC and GMA.

Calculation of household income: household income was calculated as the sum of farm income and off-farm income.

4.2.2 Data analysis techniques

After a series of transformations and assumptions, data were analyzed by a computer using SAS release version 6.03 and 6.04 (SAS Institute, 1987a, 1987b, 1988) and Harvard Graphics version 2.10 (Soft Ware Publishing Corp., 1987). The following major statistical procedures were used in data analyses.

i. T-tests (independent groups) and Analysis of Variance (One- and Two-Way ANOVA) to test hypotheses regarding mean differences for a number of comparative parameters in the micro-level study between the two levels of integration (Group A and B).

T-tests, among other things, were used to test the mean difference in total area cultivated and for each crop, yield of each crop, cropping pattern effects, crop and animal gross margins, productivity of factor inputs (land and labor), expenses on agricultural inputs, amount of grain reserve (carry-over stock), amount of ferilizer use (toatl and per unit area of land), number of passes with the *maresha* for each crop, family size and farm labor, etc.

Since sample sizes of the two levels of integration were not equal between PAs, the General Linear Models (GLM) procedure of two-way analysis of variance was used to test the effect of PAs and effects of PA-Group interactions on parameters used in the T-test procedure. Duncans Multiple Range Test was used in two-way ANOVA to indicate the mean difference between PAs, Groups and Interactions.

ii. Simple and multiple correlation and regression were used to estimate the degree of relationship between variables and for prediction of the measurement (response) variable.

Correlation matrices were used to investigate the degree of association between a number of variables, and highly correlated estimators were avoided from use in a regression model because of problems of multicollinearity.

Where ever several predictor variables are used in a multiple regression equation, a SAS procedure (PROC RSQUARE) was employed for model building based on the best subset size calculated from equations of all possible combinations of estimators. This optimum subset sizes (with high coefficient of determination or the least residual sum of squares) were subsequently used in a regression model.

Regression was used to assess land use conflicts between cropping and livestock production at a macro-level. It was also used in the micro-level study, among other things, to test the effects of family labor, farm size, livestock holdings, amount of harvest, expenditure on agricultural inputs, etc on gross margins from crops and livestock; to test effects of family size, family labor, livestock and oxen holdings, etc on area cultivated of crops; to test the effects of farm size, yield of crops, fertilizer use, livestock and oxen holdings on grain reserves, income from sale of crops and availability of crop residues.

iii. Group means, ranges, percentages and charts were used as desired.

iv. Absolute frequencies, cumulative frequencies and cumulative percents were employed for analysis of rankings on farming system constraints. In addition to these, the chi-square test was used as a test for homogeneity of the different ranks (ranging from rank 1 to rank 3 and all others) on farming system constraints as percieved by the farmers them selves between the two categories of survey farmers (Group A & B). The chi-square test was also used to test for homogeneity of farmers growing each crop between the two Groups.

All the hypotheses were tested by using a significance probability of 5%, 1% or 0.1% ($P<0.05$, $P<0.01$, $P<0.001$) respectively.

5.0 RESULTS AND DISCUSSIONS

5.1 Macro-level study

5.1.1 Land use conflict - a competitive interaction

As it has been addressed in section 2.2.1, competitive interactions for a pool of resources especially for a fixed land resource in mixed farming may arise because of several factors like crop encroachment into natural pastures, decline in fallow periods and extensive use of crop residues for feeding. All these may arise from increasing subsistence demand and escalating population growth or because of non-demographic factors which may undermine traditional resource management systems.

In this part of the study, land use conflicts between crop and livestock systems and its possible causes and effects in Ada district are presented and discussed.

5.1.1.1 Cultivated lands versus grazing lands

Ada district has a total area of 1750 km^2. The district mainly consists of undulating plains with scattered crater hills, but can generally be divided into three altitudinal zones: the major cereal/livestock zone covering an area of 1000 km^2 (57%) between altitudes 1800 and 2000m; the rift valley (low potential cereal/livestock) zone covering an area of 600 km^2 (34%) between altitudes 1500 and 1800m; and the mountain zone covering 150 km^2 (9%) at altitudes over 2000m with peaks rising up to 3100m (Gryseels and Anderson, 1983; Mukasa-Mugerwa, 1981).

Haywood *et al* (1979) report that 60% of the district is regularly cultivated, and 25% is seriously affected with ravine erosion and is unsuitable for cultivation, and less than 15% is natural vegetation. According to this authors, of the total area, only 19% is high-potential farm land and a further 36% is a medium potential. Low-potential crop land and degraded natural vegetation on steep slopes account for 16%, while the remaining 29% incudes forest, natural bush and grass land, urban areas, villages, etc a major part of which is also subject to sheet and ravine erosion.

These comprehensive figures, however, reflect only the overall land use pattern of the whole geographic area of the district including areas now under various state farms (poultry, swine, horticulture, fattening), other parastatal organizations and ILCA. As this land use pattern (which represents an estimated 30% of the total area) is not part of the agrarian smallholder farming, it has been excluded from this study. Only land areas registered under the Ministry of Agriculture, 122,300 ha (70%), is considered to be part of the rural smallholder farming.

Estimated land use pattern of 11 years (1979/80-1989/90) is summarized in Appendix 7. According to the latest five years (1985/86-89/90), regularly cultivated fields account 43%, natural pastures 11%, forests 7%, and other areas 39%.[7] The proportion of fallows is highly insignificant confirming the transition of the farming system towards permanent cropping. This is in agreement to observations of Mukasa-Mugerwa (1981) and Gryseels and Anderson (1983).

Between years 1979/80 and 1989/90, the area under cultivation has expanded by 2.5% a year, while the area under grazing has declined by 5.2%. As such, cultivated land which was 42,479 ha (35%) in 1979/80, has grown to 54,503 ha (45%) in 1989/90. On the other hand, the area under grazing, which was 20,077 ha (16%) in 1979/80, has declined to 11,862 ha (10%) in 1989/90.

Expansion in area under cultivation has a high negative correlation of 99% ($P<0.001$) with contraction of area under grazing. There was also a high negative correlation of 98% ($P<0.001$) between expansion of cultivated areas and the decline in fallow areas. For this 11 year data, a decline in the area of

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[7] land under other categories includes roads, villages, towns, lakes, mountain peaks, degraded land and other waste land now left as unsuitable for cultivation.

grazing lands was significantly negatively correlated ($P<0.001$) with area under teff (96%), wheat (86%), barley (75%), horse beans (90%) and field peas (94%). Conversely, area under cultivation was equally positively correlated ($P<0.001$) with area of these same crops. However, the decline in area under natural pastures or expansion of area under the plow was not significantly correlated ($P>0.05$) with area under maize, sorghum, chick peas, lentils and all other crops.

Ada district is nationally very well known for its high quality teff (the main source of the reputable national dish, *injera*) and on top of this, its strategic geographic location between the urban centers of Debre Zeit, Nazareth and Addis Ababa, all within 50 km, have created favourable markets for this cereal. All available time series data attest to evident increases in the area under this crop (see Table 5.1).

Table 5.1 Land allocation trends in Ada district (*percentage of total area under crops*).

Crop	Crop Year(s)					
	1973[a]	1975[a]	1978[b]	1979[b]	1980[b]	1985-89[c]
Teff	37	44	49	56	50	55
Wheat	15	15	6	7	7	23
Other cereals	23	10	5	5	4	6
Pulses	24	30	37	31	36	15
Others	1	1	3	1	3	1

Source: [a] From Vincent (1977).
[b] From Gryseels and Anderson (1983).
[c] From Ada Agricultural Development Office, MOA,(1990) and present study.

In 1980s, it seems that the area under wheat has expanded perhaps because of extensive adoption of high yielding varieties of durum and bread wheat which are now common in Ada. Another interesting observation is shrinkage of area under pulses. All estimates before 1980 seem to agree fairly well, but in fact the area under these crops is declining as farmers confer high priority to food cereals with a progressive decline in average land holdings. This has been confirmed from the micro-level survey and awaits thorough treatment later.

For data of 11 years, total population, total cultivated land, fallows, area under teff, and area under wheat have highly significant effects (P<0.001) on contraction of grazing lands (natural pastures) when used separately in a linear regression model. Development of a multiple regression model for explaining the observed reduction in grazing areas was difficult because of a high degree of multicollinearity among regressors. However, a SAS procedure was used to find out the optimum subset size by computing equations for all possible combinations. The best model so developed was highly significant (P<0.001) and explained almost 100% of the observed decline in grazing areas. This multiple regression model was:

Grazing land = 82,335 - 0.7 cultivated land - 0.62 land under other categories - 0.2 area under wheat.

According to this model, extension of area under cultivation by 1 ha has on average reduced grazing areas by 0.7 ha; an increase in the area of land under other categories (villages, waste land, etc) by 1 ha has on average reduced grazing lands by 0.6 ha; and increase in the area of wheat by 1 ha has on average reduced grazing areas by 0.2 ha, all other estimators kept constant in each case.

Although this was found to be the best equation because of the high multiple coefficient of determination (or small residual sum of squares) for predictors included in the model, a bivariate regression model for estimation of the observed decline in grazing lands by extension of area under cultivation also explained more than 99% of the variation and was highly significant (P<0.001). The same conclusions given above can be made by using this model:

Grazing land = 49,531 - 0.699 cultivated land.

5.1.1.2 The role of population pressure

Between the period 1979/80-89/90, the number of farm households registered by PAs on average increased by 1.3% a year, thus the total registered PA members increased from 16,500 to 18,760 in the same period. Increase in the total rural population (2.2% per annum) was 1.7 times the rate of increase in farm households. The total rural population increased from 115,090 to 143,700 during the same 11 year period. Although both were highly negatively correlated ($P<0.001$) to the decline in the area of grazing lands, a rise in the total population was slightly more correlated(95%) than an increase in the number of farm households (92%). An increase in the total rural population was also highly negatively correlated at 94% ($P<0.001$) with the observed decline in fallow areas but highly positively correlated at 95% ($P<0.001$) with extension of area under cultivation.

The least squares straight line regression model developed for investigating the effect of population pressure on the observed decline on grazing areas was highly significant ($P<0.001$) and explained over 90% of the variation. This equation was:
Grazing lands = 58,064 - 0.32 total rural population.

This may be interpreted as an increase of the rural population by one person during the last decade has on average led to the reduction of natural pastures by 0.3 ha. Therefore, unbridled growth of the rural population at a rate of 2.2% over the last decade was indeed a significant exacerbating factor for the decline in grazing areas.

Increase in rural population has caused a decline in the area of grazing lands by adding to the increasing degree of fragmentation of holdings and when landless peasants bring into cultivation areas previously meant for grazing or when peasants with higher family members have now to bring new land under the plow to meet subsistence requirements.

The linear effect of increase in total rural population on expansion of area under cultivation was highly significant

($P<0.001$) and explained over 90% of the variation. This straight line regression equation for the available data of 11 years was: *Cultivated land = -11,937 + 0.46 total rural population.*

An increase of population by one person for the last decade has on average led to outward expansion of cultivated areas by 0.4 ha which is similar to the annual contraction of grazing areas.

The best linear regression equation developed for explanation of expansion in cultivated areas explained almost all the variation and was highly significant ($P<0.001$). This equation was:

Cultivated land = 124,163 - 1.03 grazing lands - 1.06 forests - 1.02 other categories of land.

Taken one estimator at a time, increase in population, decline in grazing areas, decline in fallow areas, decline in land under other categories, an increase in the areas of teff, wheat, barley, horse beans, and field peas had all significant effects ($P<0.001$) on outward expansion of cultivated areas.

The observed decline in grazing or fallow areas or expansion of cultivated areas was not, however, significantly correlated ($P>0.05$) to changes in average monthly rainfall, total annual rainfall or its coefficient of variation for the same period of 11 years.

Therefore, based on the available data of 11 years unfavourable or propitious climatic factors do not seem to have significant effects on the expansion of area under cultivation. This may be because of the already low average land holdings which the farmer has to cultivate year-in and year-out giving him little opportunity to respond to climatic factors. As a result, expansion of microholdings, land entitlement failures and fragmentation coupled with lack of yield increasing inputs make risk managent more difficult. With lack of risk spreading strategies vulnerability to crop failures and famine will increase.

5.1.1.3 Fallow lands and incursion of cropping into marginal areas

With a rapid increase in the rural population, the first response of traditional farming was outward expansion of cultivated areas up until all the slopes which an ox could climb are brought under cultivation. This was mainly because when yields stabilize at a low level steady state, the farmer can only expand the area under crops so as to secure a sufficient subsistence crop output to the family by applying the same proven traditional techniques of production on a larger area. As such cultivation now becomes a fact of life on marginal areas with little ability to absorb the stress from permanent cropping.

When additional effort and costs required to bring new land under the plow become high compared to intensification of cropping on the existing plots, family holdings are regularly cultivated and fallow periods will gradually disappear. At this phase of traditional farming, reduced yields are compensated for by intensification of cropping by introduction of multiple cropping systems (with or without irrigation depending on whether precipitation is a limiting factor), use of fertilizers (or animal manure) and high yielding varieties or by increasing cultural practices of weeding, plowing, etc for each crop.

Under the circumstances of most of the Ethiopian highlands and particularly in Ada district where the nearly unimodal rainfall pattern is unfavourable for multiple cropping, irrigation is not an alternative way out, animal manure is used as cooking fuel and high yielding varieties are largely unavailable, farming can only continue on the ever declining and regularly cultivated holdings of the farmer.

In Ada district, a decline in fallow areas was closely correlated with expansion of area under different crops. A high negative correlation of 95% ($P<0.001$), 82% ($P<0.01$), 74% ($P<0.01$), 93% ($P<0.001$) and 94% ($P<0.001$) was found between a decline in fallow areas and outward extension of area of teff, wheat, barley, horse beans and field peas respectively. An increasing population pressure with a high negative correlation of 94% ($P<0.001$) seems to be a significant factor for expansion of cropping and the decline in fallow periods.

Decline in land registered under other categories was only moderately negatively correlated (79%) with expansion of area under wheat. This may imply that the area under this crop has been encroaching into marginal areas often located on hilltops and steep hillsides vulnerable to the ravages of water erosion. This sounds true considering teff and wheat as the two principal cereals of Ada, the former demanding fertile black soils near valley bottoms, while the latter grows fairly well on shallow upland red soils. This also implies a kind of specialization of cropping according to soil types as vertic soils are allotted for teff often preceeded by chickpeas or rough peas while infertile red hillside soils are increasingly left for wheat. Of course, teff is also grown on hillsides as a succeeding crop after grain legumes like horse beans or field peas. As such, it seems that the two major cereals have been expanding in opposite directions along the slope engulfing new areas previously used for grazing and increasingly unsuitable for permanent cropping.

An increase in area under crops, total population, area under teff, and area under wheat had all highly significant effects ($P<0.001$) on the observed decline in fallow areas and explained 98%, 88%, 90%, and 68% of the variation respectively when each of these estimators are used separately. The best of these equations is given below:

Fallow land = 1855 - 0.03 cultivated land.

This can be interpreted as an outward extension of cropping by 1 ha during the last decade has on average led to the reduction of fallow areas by 0.03 ha.

Area under crops, grazing, wheat and increase in total population had all significant effects ($P<0.05$) on the observed changes in the area of land under other categories when used in a partial regression model. The best of multiple regression equations for a combination of all these estimators was highly significant ($P<0.001$) and explained about 96% of the variation. This equation was:

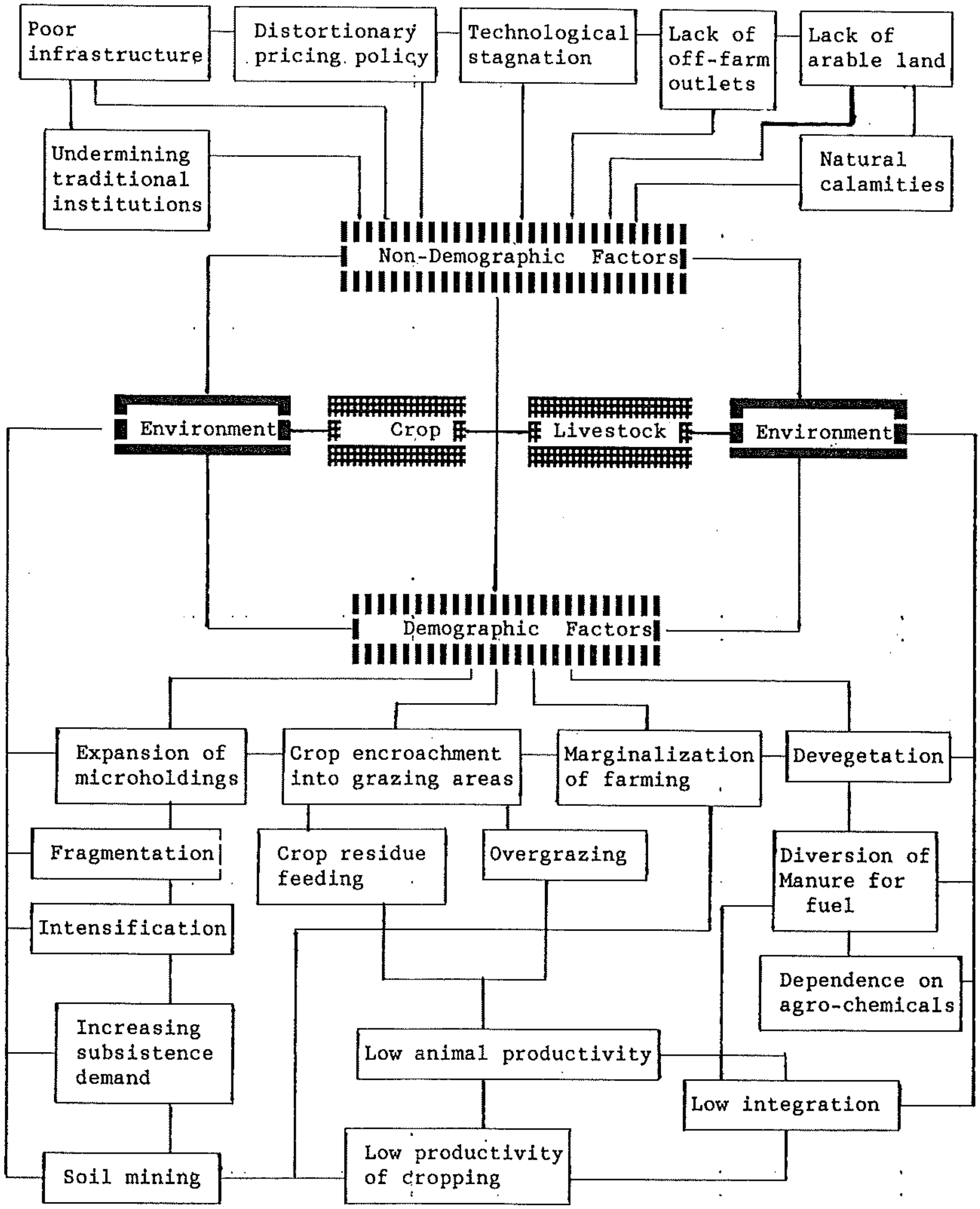
Other land = 123,753 - 1.0 cultivated land - 1.4 grazing land - 0.35 area under wheat.

In total, outward expansion of cultivated lands in response to aggregate effects of demographic and non-demographic factors (schematically modeled in Figure 4) have resulted in acute land use conflicts between crop and livestock systems. This has brought about tremendous declines in grazing areas and reduced fallows to a trivial proportion. Furthermore, cultivation has extended to fragile environments with little resilience which can not withstand all the stresses of permanent cropping. With it, ecological disruption is an inevitable reality as livestock are confined on smaller and smaller areas than ever before and bare soils on marginal cultivated lands are washed down with a torrential downpour.

At this stage, symbiotic interactions which were beneficial to both sub-systems under low cropping and livestock densities have turned out to be largely competitive. With increasing pressure on the land, complementary interactions are increasingly overshadowed by competitive interactions. Availability of animal feed has become a limiting subsistence constraint to the smallholder even to maintain the minimum stock size required for replacement of a pair of oxen badly needed for sustainability of the system. Therefore, crop residues are diverted to their increasing use as stock feed. As a result, animals are undernourished and maintained under diets of low quality roughages for large part of the year which further depresses complementary interactions in the long run.

Apart from widespread use of crop residues as animal feed, animal manure has also lost its integrative soil restitution value because of its high opportunity cost as a source of household fuel. While all the inedible crop dry matter is used by the animal, manure is not recycled in the farm for maintenance of soil

Figure 4. Cumulative causation of a resource use conflict in crop-livestock systems and its environmental effects.



fertility. This has resulted in excessive loss of organic matter out of the system exacerbating ecological effects of soil erosion. Furthermore, it has made farmers to be increasingly dependent on external inputs for restoration of soil fertility. Bureaucratic delays in the availability of fertilizers coupled with lack of the required tractive power are the major reasons for off-season cropping. Lack of these inputs during the peak demand season will severely affect the farming operation particularly in areas of short growing periods.

Farmers are not irrational when they expand cultivation into areas previously used for grazing or when they fail to introduce cultivated forages into the system as a substitute for what is lost by expansion of cropping. This is because when the already fragmented land holdings are further reduced by an attempt to feed more mouths or by introduction of alien development policies, the destitute farmer has no options other than trying to eke out a living by expanding cultivation into the available marginal grounds. Expansion of microholdings, fragmentation and technological stagnation reinforce the effects of increasing subsistence demand.

The marginalized peasant in his present day survival strategy adopts a high rate of time preference for costs and benefits which may accrue in the future. In the strive for maximum welfare in the short term, actions of peasants with no other options lead to environmental damages which may affect the present and future generations. Struggle for survival and the resulting high rates of time preference mean that present generations are not prepared to accept responsibility for the state of the system in future periods which militates against the integrity and sustainability of the agroecosystem.

The fact that any new crop competes for scarce land resources having high opportunity costs for food crops signifies that forages will not be adopted in densely populated arable environments unless the return to land in forage production exceeds that in alternative crops. In mixed farming zones with elevated population densities land scarcity has also made feeding of crop residues much cheaper than introduced forages.

As a result, a crucial subsistence constraint is set up because of breakdowns in complementary interactions and predominance of competitive interactions between cropping and livestock production. Because of the unabated rural population growth still trending upwards and a pool of interrelated non-demographic factors fortifying the effects of the former, increasing areas of grazing and marginal soils are brought under the plow, crop residues are already replacing natural pastures as principal diet of stock, and manure is developing a scarcity value all undermining sustainability of mixed farming in the highlands unless steps are now sought to ward off the foreseeable crisis.

If the hypothesis of continuous disappearance of grazing areas is true while maximization of the livestock functions in the highlands encourages increasing herd sizes, then one should question the availability of stock feed in the system. Therefore, an attempt is made to look into any disparities between feed supply and demand in the next sections.

5.1.2 Disparities between feed supply and demand in Ada district

Existing disparities between feed supply and requirements were assessed by equating the estimated total consumable dry matter(DM) and protein supply to the total availability of the same nutrients for the whole livestock population of the district converted into Tropical Livestock Units (TLU). The average livestock population, area of grazing lands, fallows and area under crops for the latest five years (1985/86-89/90) of the estimated figures given by Ada Agricultural Development Office, MOA (1990) were used in calculation of feed supply and requirements (see Appendices 7 and 8). Conversion of livestock into standard TLU was made according to Table 4.1.

5.1.2.1 Feed requirements

An animal's nutrient requirements are often partitioned into maintenance and production requirements. In this study, nutrient requirements per TLU are calculated for the two major nutrients, energy and protein. Dry matter requirement were calculated based on MJ of metabolizable energy (ME) per TLU per day. An average ME content of 7 MJ kg^{-1} DM of feeds produced in Ada district (see Table 2.4) is used all over for computations of daily dry matter requirements of animals.

Energy Requirement: Metabolizable energy requirements of livestock were calculated according to the methodology given by Ministry of Agriculture Fisheries and Food, UK (1975).

i. *Maintenance requirements:* Maintenance requirement of an animal is the ratio of the fasting metabolism(FM), representing the animal requirement for energy to maintain the animal, and the efficiency with which the ME is used for maintenance (Km) which is related to the energy concentration of the ration.

$$Fm\ (MJ\ day^{-1}) = 5.67 + 0.061W$$

W = live weight in Kg.

$$Km = 0.55 + 0.016\ M/D$$

where, M/D = MJ per Kg DM

Maintenance requirement of a TLU is therefore Fm/Km and is estimated at 31.6 MJ per day. In Ada district this energy maintenance requirement can be thus met if the animal consumes 4.5 Kg DM day^{-1} . For the total livestock population of Ada district estimated at 73,202 TLU, the total requirement will be 329.5 t DM day^{-1} or 121 thousand t DM $year^{-1}$.

ii. *Growth (live weight gain) requirements:* The net energy requirement for gain (Eg) is the energy content of the gain and is the product of the weight of the gain (LWG) and its energy value (EVg).

$$Eg\ (MJ) = \frac{LWG\ (6.28 + 0.0188W)\ MJ}{(1 - 0.3\ LWG)}$$

where , W = live weight of the animal

$$ME\ requirement\ (MJ) = Eg/Kg$$

where, Eg = as defined above,

Kg = Efficiency of utilization of ME for body gain given by the formula 0.0435 M/D.

The growth requirement of a TLU gaining 250 g day^{-1} is thus calculated to be 9.75 MJ day^{-1} . This is equivalent to 1.4 Kg DM per day or 0.5 t DM per year. Assuming that 50% of the livestock biomass is still growing, the total growth energy requirement will be estimated at 51.2 t DM day^{-1} or 18.7 thousand t DM $year^{-1}$.

iii. *Pregnancy requirement*: Metabolizable energy requirement of a pregnant cow (here considered as 1 TLU) is given by :

$$Ec + 1.19\ HIG \quad \text{which is equal to } 1.08\ e^{0.0106(t)}\ MJ/day.$$

where, Ec = Uterine deposition of energy,

HIG = Heat increment of gestation,

t = number of days after conception,

e = 2.718, the base of the natural logarithm.

Energy requirement of pregnancy for a 250 kg cow with gestation period of 270 days is estimated at 18.9 MJ day^{-1} equivalent to 2.7 Kg DM. Adopting a calving rate of 50% per year for indigenous Zebu cows (after Mukasa-Mugerwa, 1981), the ME requirement of gestation for cows will be 6.9 thousand t DM per year (270 days).

iii. *Milk production requirement:* The minimum requirement of energy for milk production (El)is the product of the weight of milk (Y) in Kg and its energy value (EVl). For cows milk energy value is given as :

$$EVl\ (MJ/Kg) = 0.0386\ BF + 0.0205\ SNF - 0.236.$$

where, BF = Butterfat content of the milk (g/Kg), SNF = Solids-not-fat content (g/Kg).

The ME requirement for production of 1 Kg of milk is the ratio of EVl to the efficiency of utilization of ME for milk production (given on average to be 0.62). Therefore, the total ME requirement for production of Y Kg of milk is given by:

$$Ml\ (MJ) = \frac{(EVl)Y}{0.62} = 1.61\ EVl\ (Y).$$

Although milk composition of different breeds of local cows is slightly variable, butterfat and SNF content of milk from indigenous Zebu cows at different stages of lactation in southern Ethiopia given by Fekadu Beyene (1991) is used for computations in this study. This was in lack of milk composition tables for local cows of the central highlands. The composition of milk of local cows of southern Ethiopia (average of 81 random samples of cows at different stages of lactation) was total solids (dry matter) 13.75%, crude protein 3.21%, butterfat 4.94%, lactose 4.92%, ash 0.68% and solids-not-fat 8.81%.

Therefore, the ME requirement of a local Zebu cow producing 2 litres of milk per day with a butterfat and solids-not-fat content of 49.4 and 88.1 g Kg^{-1} of milk respectively is estimated at 11.2 MJ day^{-1} equivalent to 1.6 Kg DM. With a calving rate of 50% per year, the total requirement of cows for milk production in Ada is 15.1 t DM day^{-1} or 5.5 thousand t DM $year^{-1}$. The overall DM requirement as calculated from ME requirements of livestock in Ada district is summarized in Table 5.2.

Protein Requirement: A digestible protein requirement of 160 g and 100 g TLU^{-1} day^{-1} for maintenance and growth (for a TLU gaining 250 g/day) respectively is used for estimating total requirements of livestock in the district (see section 2.1.4). The total digestible protein requirement so estimated for maintenance and production (growth) for the total livestock population of the district is summarized in Table 5.3.

Table 5.2 Estimated dry matter requirement of livestock in Ada district.[a]

Function	Effective TLU	Daily requirement (Kg DM TLU^{-1})	Yearly requirement ('000 t DM)	% total
Maintenance	73,202	4.5	121.0	79.6
Growth	36,601	1.4	18.7	12.3
Pregnancy	9468	2.7	6.9	4.5
Milk production	9468	1.6	5.5	3.6
Total	-	-	152.1	100

[a] For explanations on the estimation of feed energy requirements see text.

Table 5.3 Estimated digestible protein requirement of livestock in Ada district.

Function	Effective TLU	Requirements		
		g/day/TLU	total t/day	total t/year
Maintenance	73,202	160	11.7	4270
Growth	36,601[a]	100	3.7	1350
Total	-	260	15.4	5620

[a] Assuming 50% of the total livestock biomass is still growing.

5.1.2.2 Feed supply

In the Ethiopian highlands, there is no systematic survey of herbage quality or productivity of natural pastures conducted at any significant scale, hence estimates of annual pasture yields vary between 1-2 t DM ha^{-1} on freely drained relatively infertile soils up to 4-6 t DM ha^{-1} on seasonally waterlogged fertile areas (see section 2.1.3). For the purpose of this study, it seems to be fairly reasonable to adopt an annual average primary production of 2 t DM ha^{-1} for the whole grazing areas (including fallows and stubbles) of Ada district containing poorly managed and overgrazed unimproved pastures.

The actual proportion of the forage standing crop (total above ground biomass) utilized by the animal is also variable (see section 2.1.4). Available estimates are highly variable, but annual utilization rates for all estimates rarely exceed 50% of the total primary production.

Utilization rates also depend on the seasons of the year. In Debre Zeit as shown in Figure 3a, the rainfall is essentially unimodal with short (*Belg*) rains starting in March and continuing up to June when the main (*Meher*) rains start and continue up to the end of September. Generally speaking, precipitation exceeds the potential evapotranspiration only during the two main rainy months of July and August. However, in areas where the soil is not shallow, there will be sufficient soil moisture to support plant growth up to November without a need for irrigation. Therefore, the whole year may be roughly divided into two equal wet (soil moisture level is not limiting plant growth) and dry (soil moisture level is a limiting factor for plant growth) seasons.

In this study, it is assumed that 70% and 30% of the forage standing crop (ungrazed yield) will be consumed by the animal during the wet and dry season (6 months each) respectively. The annual forage utilization rate is thus 50% of the total standing crop. This estimate, however, does not set aside a certain proportion of the above ground biomass as a factor for sustainable use of grazing resources. If the proper (sustainable use) multiplier is included, the utilization rate would be less than 50%.

Adopting a total annual primary production of 2 t DM ha^{-1} (for grazing lands and fallows), the actual consumable DM yield is 1 t/ha DM.[8] The natural pastures and fallows provide consumable herbage to herbivores throughout the year hence with a utilization rate of 50% the total consumable yield is estimated at 13,036 t DM

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[8] Consumable dry matter = (Wet season yield = 0.7 x 6/12 x 2) + (Dry season yield = 0.3 x 6/12 x 2).

$year^{-1}$. Stubbles are also grazed during the dry season after all the crops are harvested and threshed. At this time of the year, restricted access to grazing lands of each PA disappears until the fields are cultivated again after the short rains, thus animals can move all over crossing PA boundaries as property rights are now virtually open access.

As aftermath grazing starts after the crops are cleared during the dry season, the utilization rate of 30% is used but this declines to 15% of the total annual ungrazed yield as this continues only over half of the year. This estimates from stubbles may slightly inflate the actual proportion of consumable herbage since some of the fields are already devoid of any leftovers and others may be cultivated as soon as the short rains commence. Therefore, with stubbles assumed to provide an average ungrazed yield of 2 t ha^{-1} $year^{-1}$ and a utilization rate of 30%, the total consumable DM produced is in the order of 15,711 t during the dry season.

Crop residue yields are estimated from multipliers developed based on grain:residue ratios (see Table 4.4). It is assumed that about 70% of all the estimated non-edible portions of the total crop biomass can be utilized by the animal. The total amount of crop residues produced is summarized in Table 5.4. With the assumed 70% utilization rate the total supply of crop residues can be estimated at about 72,254 t $year^{-1}$. This unfortunately assumes that almost all the crop residue is removed and is either used by the animal or the remaining small portion is used as fuel, building material or sold, thus no account is made for recycling of residue organic matter on cultivated fields.

The total amount of consumable feed supply in Ada district is presented in Table 5.5. A total of 101 thousand t DM produced per year is critically in short of the feed requirements estimated at 152 thousand t DM in Table 5.2. Of course, the estimated supply even fails to meet maintenance requirements estimated at 121 thousand t DM $year^{-1}$.

Table 5.4 Estimated crop residue yield from different crops in Ada district.

Crop	Area cultivated (ha)[a]	Crop yield (t/ha)[b]	Crop residue yield (t/ha)[c]	Total residue yield (t)
Teff	28,554	1.05	2.33	66,530
Wheat	12629	1.2	1.78	22,479
Barley	2221	1.1	1.53	3398
Maize	460	1.5	2.01	924
Sorghum	396	1.1	2.56	1013
Chick peas	2321	0.95	1.46	3388
Field peas	2120	0.7	1.02	2162
Horse beans	2024	0.8	0.92	1862
Lentil	1351	0.5	0.78	1053
Others	296	0.9	1.39	411
Total	52372	-	-	103,22

Source: [a] Average area cultivated between 1985/86 and 1989/90 from Ada Agricultural Development Office, MOA (1990).
[b] Average crop yields in Ada district as estimated by author based on Ada Agricultural Development Office (1990), Gryseels and Anderson (1983), and Central Statistical Authority of Ethiopia (1989).
[c] Crop residue dry matter as calculated using conversion factors given in Table 4.4.

The problem is exacerbated by the fact that estimated yields include a very high percentage of poor quality feed in terms of digestible nutrients. Moreover, during the rainy season, the low lying pastures are frequently inundated inhibiting stock moving into some of these areas until the water table recedes, contributing to concentration of animals only on freely drained grazing areas. Farmers also defer crop residues for use by working oxen and lactating cows thus other classes of stock are left to depend on what can be collected from overgrazed pastures.

Surprising enough, the largest proportion of the feed supply (71%) originates from crop residues. This is mainly because grazing lands have been increasingly diminished by crop encroachment to the extent that it now supplies only about 12% of the feed (of which fallows account much less than 1%).

Table 5.5 Total consumable feed dry matter produced in Ada district by origin.

Origin	Total area[a] (ha)	Yield (t/ha)	Utilization rate (%)	Total consumable yield (t DM)	%Total
Grazing land and fallow	13,036	2.0	50	13,036	12.9
Stubbles	52,372	2.0	15	15,711	15.6
Crop residues	52,372	-	70	72,254	71.5
Total	-	-	-	101,001	100

[a] Average of the latest five years (1985/86-89/90) given by Ada Agricultural Development Office, MOA (1990).

As presented in Table 2.4, the crude protein content of crop residues is low (3-5%) and it seldom meets livestock maintenance requirements. If an estimate of consumable crude protein is made based on nutrient composition of different types of feeds in the highlands (given in Table 2.4), natural pastures stubbles and crop residues provide 975, 848, and 3191 t year^{-1} respectively.
The total digestible protein supply (estimated by the formula given by FAO (1980) and Chandler (1984) as **Digestible protein = 0.929 Crude protein - 3.52)** is in the order of 4654 t year^{-1}. Based on this, digestible protein supplies also leave much to be desired to meet animal requirements of 5620 t year^{-1} (given in Table 5.3).

According to this estimate, the actual availability of digestible protein only meets the maintenance needs of animals but only fulfills about 80% of the requirements if the growth requirements are included.

Therefore, it can be argued that both energy and protein are the limiting factors to livestock production in the highlands (this is confirmed at the micro-level survey and deserves discussion later). With declining crude protein content of the feed, voluntary intake is depressed exacerbating the precarious balance between energy supply and demand.

The organic matter digestibility of feeds in Ada district ranges between 40-50% (see Table 2.4). Intake of tropical grasses rapidly declines when crude protein content drops below 7% of the dietary dry matter. Cattle and sheep kept at diets of low organic matter digestibility (45-50%) and low protein content (below 7%) will invariably lose weight (Topps, 1969), hence productivity and offtake is low and livestock populations will not grow. As the crude protein content further declines during the dry season, intake and digestibility are further depressed and animals will continue losing weight.

Crop residues are high in lignin, which inhibits microbial digestion of cellulose and hemicellulose, and low in nitrogen, which limits DM intake, and are deficient in readily available carbohydrates which limits microbial activity in the rumen. Thus, voluntary intake and digestibility of crop residue-based ration will not meet maintenance requirements (Mosi and Butterworth, 1985).

In short, continued expansion of cropping under increasing subsistence demand has substantially engulfed areas previously used for grazing now resulting in overstocking of the district to such an extent that animals are predominantly dependent on the supply of cheap quality crop residues. This has resulted in increasing conflicts in land use between cropping and livestock production with severe damages to the environment.

5.2 Micro-level Survey

In this section, the results of a number of comparative parameters between the two levels of integration measured in the field are presented and discussed. The main objective is to stress on the value of draught oxen availability and livestock holdings to sustainability of crop-livestock systems in the highlands.

5.2.1 Household Size, Consumer Units, and Labor Units

The average family size, consumer units and labor units of the survey farmers of the two levels of integration (A & B) were significantly (P<0.001) higher in Group A than Group B farmers. T-test results for equality of the means between the two Groups are summarized in Table 5.6.

Table 5.6 T-test for mean difference (family size, consumer unit, and labor units) between Groups (A & B).

Variable	Group	N	Mean	Std.Dev	Std. Error	P-value[a]
Family Size	A	42	7.24	2.3	0.36	0.0001
	B	42	4.50	2.3	0.36	
Consumer Unit	A	42	6.30	1.89	0.29	0.0001
	B	42	3.83	1.98	0.30	
Labor Unit	A	42	3.10	0.91	0.14	0.0001
	B	42	2.18	1.09	0.17	

[a] The P-value, the smallest alpha for which the test leads to rejection of H_o, given (through out in this manuscript if not specified otherwise) is for hypotheses tests regarding the mean difference between the two levels of integration. Since SAS provides two P-values for equal and unequal variances, the relevant P-value was chosen and reported based on hypothesis test for equality of variances.

A two-way ANOVA shows that there was no significant ($P>0.05$) PA effect on either family size or labor units. But, there was a significant ($P<0.05$) effect of PA-Group two-way interactions for family size and consumer units indicating that the Group effect was not significant in all the surveyed PAs. This means that family sizes (and consumer units) are not significantly different between PAs, but the Group effect was not significant in all PAs. As a result, while family size and consumer units were significantly ($P<0.05$) different between Groups for Bore Guda and Hidi PAs, it was not significant ($P>0.05$) for Hora Kilole PA. However, neither PA nor PA-Group interactions have significant effects on labor units.

5.2.2 Livestock holdings

As the survey farmers were selected based on total livestock holdings (TLU) and number of oxen, holdings for all classes of animals were significantly ($P<0.05$) higher in Group A than in Group B (see Table 5.7). The total livestock holdings (TLU) were also significantly ($P<0.001$) higher in Group A (6.74 ± 2.1) than in Group B (1.61 ± 0.69). The average holdings for mules are nearly zero for Group A and nil for Group B farmers, thus were not important for consideration.

Table 5.7 T-test for mean difference in livestock holdings (head of animals) between Groups (1989/90).

Group	N	M.Cow	NM.cow	Oxen	Heifer	Y.Bull	Calves	Sheep	Goat	Donkey	Horse
A	42	1.43a	0.48a	2.29a	0.62a	0.62a	1.55a	1.52a	2.17a	1.50a	0.24a
B	42	0.14b	0.12b	0.76b	0.10b	0.0b	0.19b	0.05b	0.45b	0.81b	0.0b

M.cow = Milking Cows, NM.cow = Non-milking cows, Y.Bull = Young Bull.

NB. Column means followed by dissimilar letters are significantly different ($P<0.05$).

5.2.3 Effects of integration and implications for sustainability of mixed farming

5.2.3.1 Area effect[9]

As shown in Table 5.8, the mean area cultivated for Group A (1.83 ± 0.45) was significantly ($P<0.001$) higher than that for Group B (1.27 ± 0.42). Group A farmers on average cultivated 47% higher than Group B farmers. This area effect of integration is in between the findings of Gryseels *et al* (1987) in the Ethiopian highlands at Debre Berhan and Debre Zeit which were 32% and 59% higher for farmers owning more than a pair of oxen respectively.

There was no significant ($P>0.05$) PA effect on average area cultivated, but the PA-Group interaction effect was significant. Hence, mean area cultivated was not significantly ($P>0.05$) different between Groups in Hora Kilole PA, but the Group effect was significant for Hidi and Borer Guda PAs.

However, the mean area cultivated per labor unit was not significantly ($P>0.05$) different between the two Groups. But, area cultivated per family member was significantly ($P<0.05$) higher in Group B (1.5 ± 1.03) than in Group A (1.08 ± 0.35). The major explanation for low productivity of labor in Group A is small land holdings of farmers in the district. Average area cultivated in Group A (1.83) is by far less than what can be ploughed using a pair of oxen.

In Ada district cultivation starts soon after the onset of the short rains in April and continues up to September. If oxen are used for 7 hours every 3 days a week during the cropping season, on average oxen can provide 400 cultivation hours per year. A single pass of 1 ha of land on average requires four oxen days (28 hours). Number of passes until planting/seeding depend on the type of the crop, the soil and availability of draught oxen (eg. teff, the most

[9] All comparisons for area cultivated are given in hectares (ha).

demanding of all the cereals, requires up to six passes or even higher). If one assumes four passes to be on average required for all crops grown by farmers, 112 hours will be needed for every hectare of crop. Therefore, other things being equal, the total oxen hours will be sufficient to crop an area of 3.6 ha, considerably higher than the average area cultivated by Group A farmers.

The observed low productivity of labor in ploughing for Group A is, therefore, attributable to underemployment of oxen resulting from shortage of cultivable land. For every hectare of land cultivated, there exist a large proportion of labor which diminishes the average productivity of every additional unit of this variable factor.

The average area cultivated of farmers is increasingly diminished as a result of undeterred rural population growth (as demonstrated at the district level in section 5.1.1.2) and the cooperativization policy pursued until 1990. According to the farmers perception, the policy privileged PC-members do not only cultivate large areas but also enjoy the fertile spots suitable for a variety of crops. This complaint seems to be valid and in fact the undervalued private farmers had smaller farm sizes than the ex-PC members having average area cultivated per household of more than 2 ha. Although land is redistributed in a few PAs in the district after lifting of the cooperativization policy, it still remains to be a crucial problem demanding urgent solutions in several PAs.

Apart from the total area cultivated per farm, the average area cultivated for white teff ($P<0.001$), bread wheat ($P<0.05$), and chickpeas ($P<0.05$) were significantly higher in Group A than Group B (see Table 5.8). Surprising enough, the frequency count of farmers growing these same crops was also significantly ($P<0.05$) higher in Group A than in Group B (see Table 5.9). However, the average area cultivated and the number of farmers growing all other crops (mixed teff, red teff, durum wheat, barley, field peas, horse beans, lentils and rough peas) were not significantly ($P>0.05$)

different between the two levels of integration.

Table 5.8 T-test for mean difference in area cultivated of crops between the two Groups (A & B).

Area Cultiv.	Group	N	Mean	Std. Dev	Std. Error	P-value
Total	A	42	1.83	0.45	0.07	<0.0001
	B	42	1.27	0.42	0.06	
White Teff	A	42	0.74	0.30	0.05	<0.0001
	B	42	0.40	0.35	0.05	
Bread Wheat	A	42	0.15	0.14	0.02	0.02
	B	42	0.08	0.12	0.02	
Chickpeas	A	42	0.13	0.15	0.02	0.03
	B	42	0.06	0.12	0.02	

There was a significant ($P<0.05$) PA effect on area cultivated of durum wheat, barley, chickpea, horse bean and lentils. As a result, average area cultivated for durum wheat and barley in Borer Guda was significantly ($P<0.05$) lower than all other PAs, but average area cultivated of chickpeas was significantly ($P<0.05$) higher than all other PAs. Average area cultivated for horse bean was significantly different between Hidi and Borer Guda, but was not statistically different between Hidi and Hora or Hora and Guda. Similarly, average area cultivated for lentils in Hora Kilole was significantly ($P<0.05$) higher than all other PAs.

Table 5.9 Number of survey farmers growing each crop in each Group.

Group	W.Tef	M.Tef	R.Tef	D.Wheat	B.Wheat	Barley	C.pea	F.Pea	H.bean	lent	R.pea
A	42a	11a	32a	17a	27a	15a	21a	4a	24a	6a	7a
B	30b	14a	31a	11a	18b	11a	11b	3a	16a	2a	8a

NB. Number of farmers followed by similar letters within a column do not differ significantly (X^2 -Test, P>0.05).

Where, W.tef = White Teff, M.tef = Mixed Teff, R.tef = Red Teff, D.wheat = Durum Wheat, B.wheat = Bread Wheat, C.pea = Chickpea, F.pea = Field Pea, H.bean = Horse Bean, Lent= Lentil, R.pea = Rough Pea.

Total area cultivated was significantly (P<0.001, N=84) positively correlated with oxen holdings (54%) and total livestock holdings (52%). In this respect, it may be argued that the positive area effect of integration may eventually turn out to be competitive when grazing areas are converted to grain fields with unchecked population pressure. Indeed, the positive effect of expansion of area cultivated on sustainability of mixed farming is highly influenced by existing land/man ratios, the rate of population growth and herd size at that particular time, beyond certain critical levels of which negative area effects will overshadow the positive effects.

In this study, area cultivated was significantly (P<0.001, N=84) positively correlated with gross margin from crops (73%), gross margin from animals (49%), amount of grain reserve at the end of the cropping year (56%), income from sale of crops (68%), and total availability of crop residues (80%).

Therefore, other factors being equal, it can be inferred that the well being of the smallholder increases with farm size. In principle, as the size of the farm increases, average total costs will decline until a point is reached where average product per a variable factor is the maximum (average variable cost at minimum). In the long-run, the farm may enjoy economies of scale (increasing returns to scale) from reduction of costs per unit of output resulting from expansion in production over the range of declining long-run average costs.

Under conditions where farm size can be expanded to a point where average product per unit of a variable factor is the highest, both gross margins and productivity of labor will increase with availability of traction power and livestock holdings.

Farm size was also significantly ($P<0.001$) positively correlated with household size (68%, N=84). Although this signifies distribution of land according to household size, it also implies the ability of the farmer to support larger families with increasing farm size.

A linear fit of total area cultivated on family size, family labor, number of oxen and total livestock units (TLU) was significant ($P<0.001$) when each of these regressors were used partially. The best regression model with a minimum effect of multicollinearity comprising the optimum subset size explained about 57% of the observed variation in farm size and was significant ($P<0.001$). This model was:

Cultivated area (ha) = 0.58 + 0.07 family size + 0.11 family labor + 0.18 number of oxen.

According to this model, an increase of family size by one person would on average increase farm size by about 0.07 ha; an increase of family labor by one unit would lead to an increase of farm size by about 0.1 ha; and an increase of oxen holdings by one leads to expansion of farm size by about 0.2 ha, all other factors held constant in each case.

5.2.3.2 Yield effect

Average absolute yields (Kg ha^{-1}) for most of the crops were not significantly ($P>0.05$) different between the two levels of integration, but was significantly higher in Group A for white teff

(P<0.01), bread wheat (P<0.05) and horse beans (P<0.05).[10] There were no significant (P>0.05) PA or PA-Group interaction effect on yield of crops. Average absolute yields for the two levels of integration are summarized in Table 5.10.

Table 5.10 Average yields (Kg ha^{-1}) of crops between the two levels of integration (A & B).[a]

Group	W.tef	M.tef	R.tef	D.wheat	B.wheat	Barley	C.pea	F.pea	H.bean	lent	R.pea
A	1130a	1140a	983a	1060a	1214a	1074a	1057a	1096a	1181a	380a	1357a
B	927b	862a	847a	961a	927b	890a	858a	693a	763b	350a	865a

NB. Column means followed by similar letters do not differ significantly (T-test, P>0.05).
[a] These crop yield levels are conservative since farmers reports, due to several reasons, are often less than the true harvest. For full names of crops refer to Table 5.9.

However, these absolute yields conceal the hard fact that farmers without the necessary traction power (Group B) are required to pay a certain portion of the harvest as opportunity cost of using some one's oxen. Since absolute yields give an impression that the total harvest is available to the farmer, which in reality is not always true, total yields less payments made for ox-rent here referred to as 'net yield' were calculated and compared to see differences in the take-home portion of the total yield.

Therefore, the true level of the harvest available to the farmer from every hectare of land cultivated was found to be significantly higher in Group A for white teff (P<0.01), mixed teff (P<0.05), red teff (P<0.01), durum wheat (P<0.05), bread wheat (P<0.01), chickpea (P<0.05), and horse beans (P<0.01). Nonetheless, 'net yield' was not significantly different (P>0.05) between Groups

[10] Since yields (Kg ha^{-1}) were computed for farmers which grow that particular crop, sample sizes for some crops (mixed teff, barley, field peas, lentils and rough peas) were not large enough for comparison. Thus, results are inconclusive for these crops.

for all other crops (see Table 5.11).

Table 5.11 'Net yields' (Kg ha^{-1}) of crops between the two levels of integration.

Group	W.tef	M.tef	R.tef	D.wheat	B.wheat	Barley	C.pea	F.pea	H.bean	lentl	R.pea
A	1130a	1140a	983a	1060a	1213a	1074a	1057a	1093a	1181a	380a	1356a
B	875b	788b	747b	718b	800b	854a	684b	693a	628b	250a	865a

NB. Column means followed by similar letters are not significantly different (T-test, P>0.05). For full names of crops refer to Table 5.9.

A decline in average yield for Group B farmers is an equivalent cost for not having own draught oxen, while yields remain at higher levels for Group A farmers attributable to savings made for having own traction power. This is an 'invisible income' from livestock to the smallholder insufficiently perceived by many researchers and policy makers.

Therefore, once again livestock contribute to sustenance of mixed farming by enhancing average levels of harvests available to the smallholder farmer. This will offer the farmer a further opportunity to meet his subsistence requirements and to invest the surplus in livestock particularly when the terms of trade in livestock is favourable (crop prices are low and livestock prices high). The net savings made by having own traction power can also be invested on yield-increasing inputs like fertilizers which are now the main nutrient subsidies for maintenance of soil fertility. In the absence of mineral fertilizers (while animal manure and crop residues have been diverted for other uses), permanently cultivated fields are continuously mined and yields will deteriorate with the ultimate result of a collapse in the system.

5.2.3.3 Income effect

i. Gross margin from crops (GMC)[11]

Average GMC as calculated in the conventional way for easily quantifiable products (without considering the value of crop residues) was significantly ($P<0.001$) higher in group A (1429.50 ± 659.7) than in Group B (621.95 ± 332). Productivity of labor in cropping (as measured in GMC per labor unit) was also significantly ($P<0.05$) higher in Group A (474.23 ± 209.27) than in Group B (349.29 ± 241.15). Average productivity of land (as measured in GMC per area cultivated) was also significantly ($P<0.001$) higher in Group A (784.14) than in Group B (489.72). However, average GMC per consumer unit was not significantly ($P>0.05$) different between Groups may be because of lack of significant differences between the two levels for family size and consumer units in Hora Kilole PA.

GMC was considerably improved when estimated value of crop residues was included into comparisons. As crop residues are the prominent sources of animal feed and may also have market values, it is reasonable to include the value of this products in measuring the true worth of each enterprise.

With the value of crop residues included, average GMC was also significantly ($P<0.001$) higher in Group A than in Group B. Average productivity of labor ($P<0.05$) and land ($P<0.001$) were also significantly higher for Group A farmers (see Table 5.12).

There was no significant ($P>0.05$) PA or PA-Group interaction effect on GMC, GMC per labor unit, and GMC per hectare of cultivated land.

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[11] All gross margins and income from sale of crops or livestock are calculated in local currency (Birr). The contemporary exchange rate is 1 US $ to 2.07 Birr.

Table 5.12 T-test for mean difference in gross margin from crops (with value of crop residue).

Variable	Group	N	Mean	Std. Dev	Std. Error	P-value
GMC	A	42	1902.14	844.16	130.26	0.0001
	B	42	883.42	409.38	63.17	
GMC/labor	A	42	633.29	268.60	41.45	0.03
	B	42	493.46	306.39	47.28	
GMC/ha[a]	A	42	1020.70	320.23	49.40	0.0001
	B	42	726.20	342.86	52.90	

[a] Gross margin from crops per hectare of cultivated land.

GMC for the two levels of integration (N=84) was significantly correlated with total yield of various crops less payments made for renting oxen (net yield). There was a significant ($P<0.001$) positive correlation with total net cereal yield (96%), total net pulse yield (55%), total net yield of all crops (98%), total net yield of white teff (87%), red teff (50%), and bread wheat (51%), hence all had significant linear effects on the measurement variable.

There was also a highly significant ($P<0.001$) positive correlation of 53%, 73%, 62%, and 53% of GMC with gross margin from animals, total area cultivated, total livestock holdings (TLU), and expenditure on agricultural inputs.

The best linear fit of GMC on the optimum subset sizes explained more than 97% of the variation and was highly significant ($P<0.001$). This model was:

GMC = -115.55 + 0.91 total 'net yield' of all crops + 0.30 total 'net yield' of white teff.

where, Total 'net yield'(Kg) = Cereal 'net yield'+ Pulse 'net yield', Cereal 'net yield' = Sum of yield less payments for renting oxen of teff, wheat, and barley,

Pulse 'net yield'= sum of yield less payments for renting oxen of chickpeas, field peas, horse beans, lentils and rough peas.

An equally important model which explained about 97% of the variation in GMC was also highly significant (P<0.001). This model was:

GMC = -139.30 + 1.06 cereal 'net yield' + 0.92 pulse 'net yield'.

This equation may be interpreted as an increase of total cereal harvest, less payments made for renting traction power, by 1 Kg on average boosts margins from crops by 1 Birr, other factors held constant. On the other hand, as total pulse yield net of payments for ox rent increases by 1 Kg, crop margins on average increase by 0.90 Birr, other factors being constant.

Both total livestock holdings (TLU) and total area cultivated had significant (P<0.001) effects on GMC. A linear fit of GMC on these two predictors explained about 61% of the total variation and was highly significant (P<0.001). This model was:

GMC = -397.66 + 918.6 total area cultivated + 88.8 livestock holdings (TLU).

As shown in Figure 5a, GMC tends to increase with livestock holdings especially true for Group B farmers. The slope of the trend line is not the same for the two Groups. Average product of livestock in terms of gross margins from crops increases much faster in Group B (as TLU increases from 0.5 to 3.1) than in Group A (as TLU increases from 4.3 to 14.6). This is because of the theory of diminishing marginal returns resulting from increasing number of livestock/oxen used with a given quantity of a fixed factor, land. In Group B, average productivity of a unit TLU increases at an increasing rate, while it increases at a diminishing rate in Group A as there exist more livestock for a fixed area of cultivated land. This is the reason why average productivity of labor in ploughing was not significantly different between Groups, while average area cultivated per family member was higher in Group B. The causal factor again is shortage of cultivable land which prohibited Group A farmers from expanding holdings to the point where average product of labor is the highest.

Since GMC is closely correlated to farm size (see Figure 5b) value of marginal product of additional unit of labor, oxen and other variable factors will eventually decline with a decline in marginal product of same. This is particularly true under conditions of stagnating techniques of production and lack of appropriate technologies which may delay the onset of diminishing returns.

ii. Gross margin from animals (GMA)

GMA is often estimated for easily quantifiable products like meat, milk, skin and hides, eggs, wool and sale of live animals, which have market values. GMA so calculated in the usual manner was significantly ($P<0.001$) higher in Group A (373.8 ± 653.6) than in Group B (14.5 ± 50). Productivity of labor in livestock (GMA per labor unit) was also significantly ($P<0.001$) higher in Group A (150.60 ± 233.1) than in Group B (8.07 ± 126.30).

However, in the Ethiopian highlands the major function of livestock is considered to be provision of traction and transport power to smallholders while the output function is simply a byproduct of this major function. Unfortunately, these major functions of livestock are not market-oriented and thus can not be directly valued in the market, but various available valuation techniques were used in this study (see section 4.2.1).

When GMA so estimated is compared between the two levels of integration, it was significantly ($P<0.001$) higher in Group A than in Group B. Besides, GMA per labor unit and per consumer unit was also significantly ($P<0.001$) higher in Group A than in Group B. But, GMA per livestock unit (TLU) was significantly ($P<0.05$) higher in Group B. Mean difference tests of GMA calculated in the broadest

Figure 5a. Plot of gross margin from crops and farm size versus livestock holdings.

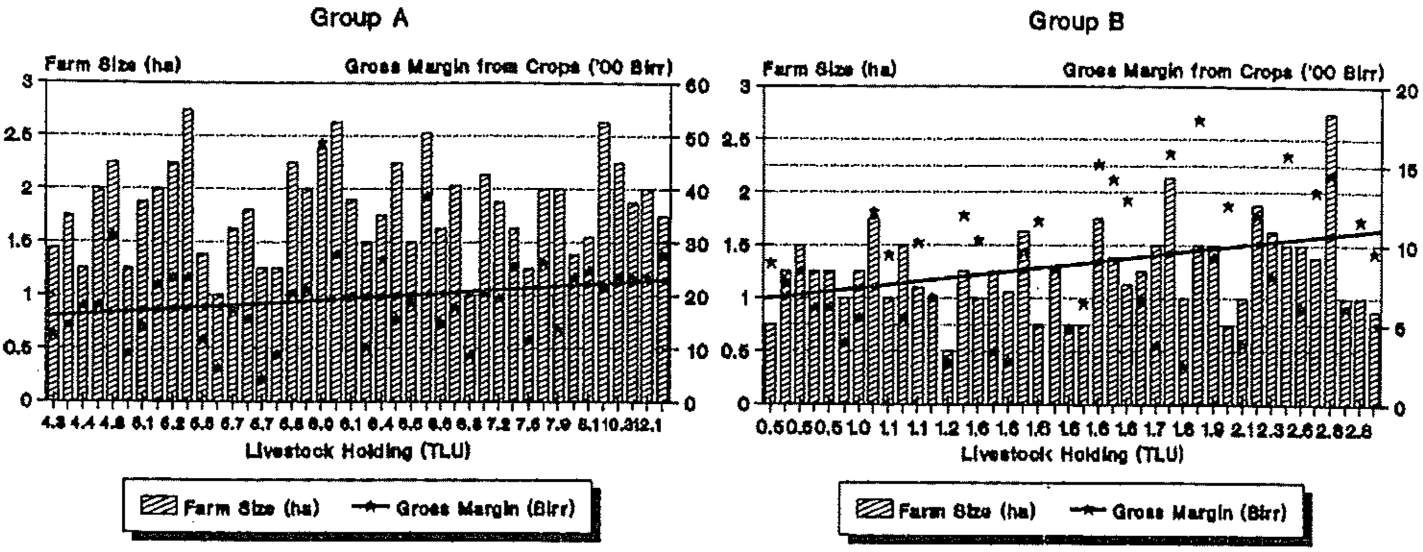
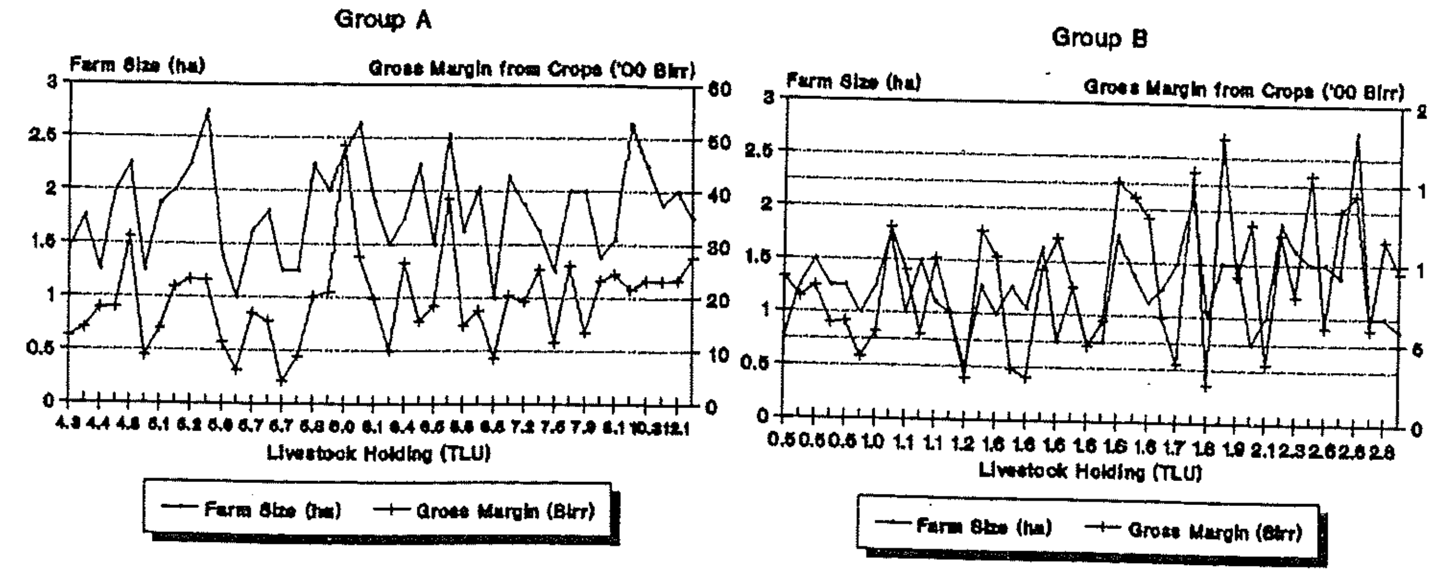


Figure 5b. Changes in gross margin from crops and farm size with livestock holdings.



sense is summarized in Table 5.13.

Table 5.13 Mean difference T-test for gross margin from animals.

Variable	Group	N	Mean	Std. Dev	Std. Error	P-value
GMA	A	42	2432.83	1187.05	183.17	0.0001
	B	42	808.20	394.1	60.81	
GMA/Labor	A	42	896.97	567.74	87.6	0.0001
	B	42	435.99	298.19	46.01	
GMA/consumer	A	42	431.53	262.37	40.49	0.0023
	B	42	266.48	216.70	33.44	

Two-way analysis of variance shows that neither the PA nor the PA-Group interaction effects have significant effects ($P>0.05$) on GMA or its expressions per labor unit or consumer unit.

GMA was significantly ($P<0.001$) positively correlated with GMC (53%), farm size (49%), livestock holdings (73%), total production of crop residues (53%), and expenditure on agricultural inputs (41%), thus all had significant linear effects on this measurement variable.

The best linear fit of GMA containing the optimum subset sizes explained about 55% of the total variation and was significant ($P<0.001$). This equation was:

GMA = -0.49 + 258.2 livestock holding (TLU) + 351.3 area cultivated (ha).

Although a polynomial (Quadratic Response Surface) model (SAS, 1987a) was employed to improve R^2 and the fitness of the equation, neither the quadratic nor the cross-product terms were significant ($P>0.05$). Therefore, according to this available linear fit, an increase of livestock holdings by 1 TLU may on average lead to an increase of GMA by 258 Birr per year, all other factors kept constant. An increase of area cultivated by 1 hectare would be on average expected to boost GMA by 350 Birr per year, all other factors held constant.

Changes in GMA versus livestock holdings are shown in Figure 6a. In both levels of integration, as the trend line shows, GMA seems to be sloping upwards with a rise in livestock holdings. The effect of area cultivated on GMA is depicted in Figure 6b against livestock holdings. For both Groups A and B, changes in GMA are surprisingly interwoven to changes in area cultivated.

iii. Farm income (FI)

FI, calculated as the sum of GMC and GMA in their broadest senses, was significantly (P<0.001) higher in Group A (4334.97 ± 1604.30) than in Group B (1691.62 ± 572.24). The relative share of the cropping and livestock sub-systems to farm income is summarized in Table 5.14.

Table 5.14 Relative share (%) of cropping and livestock to farm income by level of integration.

Group	N	GMC	%	GMA	%	Farm Income
A	42	1902.14a	44	2432.83a	56	4334.97a
B	42	883.42b	52	808.20b	48	1691.62b

NB. Means followed by dissimilar letters within a column are significantly (P<0.001) different.

With increasing degree of integration, the share of livestock to farm income increases while the share of cropping is relatively depressed. This is because income of the subsistence farmer with few animals usually originates from sale of crops and may be supplemented by sale of chicken and eggs. However, farmers with more livestock supplement crop sales by sale of shoats, culled

Figure 6a. Plot of gross margin from animals and farm size versus livestock holdings.

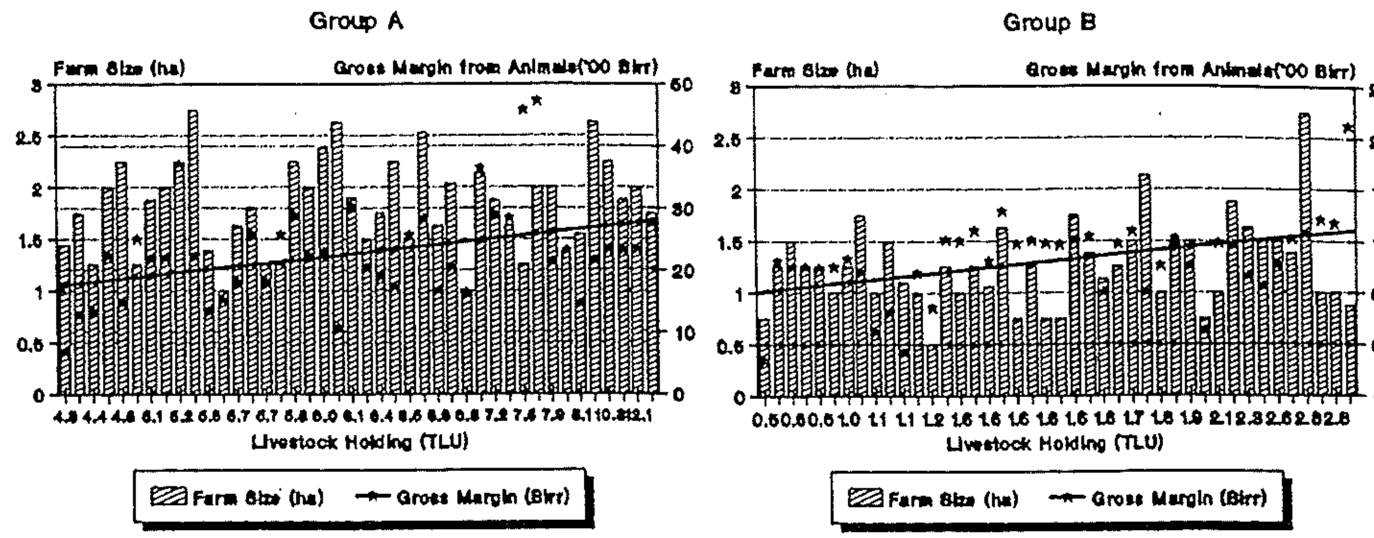
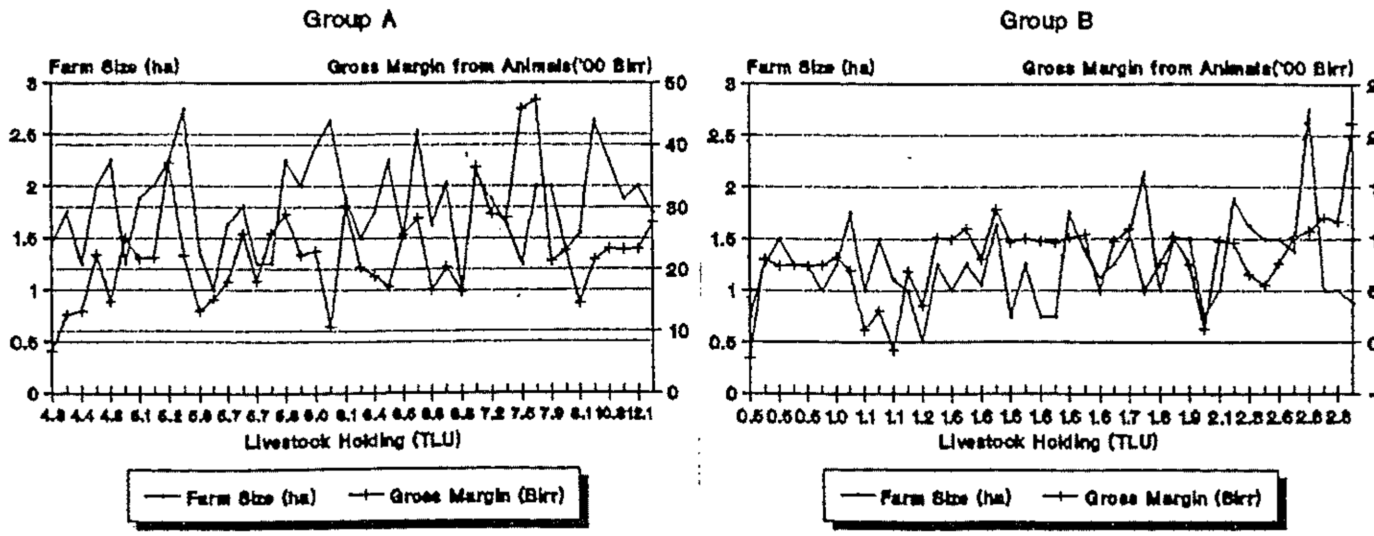


Figure 6b. Changes in gross margin from animals and farm size with livestock holdings.



cattle, byproducts (butter, skin and hides) and income from horse carts (see Table 5.15). Although the share of income from sale of cattle, shoats and equine is larger in Group A than in Group B, the major portion of income from animals originates from sale of byproducts, chicken, eggs and renting horse carts. While sale of butter, skin and hides and renting horse carts were the major sources of income for Group A farmers, sale of chicken and eggs assume increasing importance for Group B farmers.

Table 5.15 Average share (%) of income from animals by origin.

Group	Cattle	Shoats	Equine	Other[a]	Total
A	34.8a	15.4a	9.4a	40.4a	100
B	14.1b	3.0a	3.0a	79.9b	100

NB. Column means followed by similar letters are not significantly different (T-test, $P>0.05$).
[a] Income from 'other' categories includes primarily income from sale of chicken and eggs, skin, hides and butter in both Groups, but also incudes income from horse carts for Group A. No farmer in Group B had income from horse carts.

Therefore, farmers with higher livestock and oxen holdings capable of generating a sizable proportion of their income from animals have the opportunity to reserve crops as a subsistence security for next season against any calamities or until market prices are attractive to empty the stores.

Moreover, Group A farmers with higher livestock and oxen holdings were also found to have significantly ($P<0.001$) higher purchasing powers for agricultural inputs (fertilizers, pesticides, improved seeds, feeds, veterinary, hired labor, etc.) than Group B farmers, which further explains the indispensable integrative roles of livestock in mixed smallholder farming (see Table 5.16).

Table 5.16 Average cash expenses (Birr $year^{-1}$) on agricultural inputs by enterprise.[a]

Group	N	Cropping	%	Fertilizer	%[b]	Livestock	%	Total
A	42	368.16a	75.2	194.9a	53.0	121.38a	24.8	489.54a
B	42	218.70b	79.8	131.6b	60.0	55.22b	20.2	273.92b

NB. Column means followed by dissimilar letters are significantly different (T-test, P<0.05).

[a] Average expenses on agricultural inputs do not include payments made for ox rent and estimated value of farm-produced grain used for seed.
[b] Given as percentage of expenses in cropping.

Fertilizers accounted for more than half of the cash expenses in cropping. Lower share of fertilizers in cropping for Group A is because of higher propensity of farmers in this Group to spend on other inputs like pesticides, hired labor, etc than farmers in Group B. However, because of degeneration of the value of animal manure in cropping as soil improver, all the surveyed farmers of the two Groups were found to depend on purchased mineral fertilizers.

Farm income was found to be significantly (N=84, P<0.001) positively correlated to livestock holdings (77%), oxen holding (74%), cultivated land (70%), total fertilizer use (51%), expenditure on agricultural inputs (54%), and family labor (37%). The best straight line fit of FI on the optimum subset size explained about 70% of the total variation and was significant (P<0.001). This model was:

FI = -398 + 346.97 total livestock (TLU) + 1269.9 area cultivated.

According to this model an increase of livestock holdings by 1 TLU, would be on average expected to raise FI by 346 Birr per year, while an increase of area cultivated by 1 ha would on average lead to an increase of FI by 1269 Birr per year, every other predictor held constant in each case.

iv. Off-farm income (OFI)

There was no appreciable statistical difference ($P>0.05$) between the two Groups in income received out of the regular cropping and livestock husbandry activities of farmers, thus OFI does not make a difference on household income. Yearly incomes were 65.47 ± 183.15 and 71.2 ± 121.01 Birr in Group A and B respectively (large standard deviations reflect considerable variations in off-farm income ranging from none to a few hundreds among farmers). Some sources of OFI in the area were sale of firewood, beekeeping,[12] the local brew of alcohol (*ferso/tela & areke*) as the major engagement of the housewives, handicrafts, seasonal sale of labor, and wages (priests, guards, etc).

Although farmers in Group B have a higher tendency to be engaged in off-farm activities, lack of significant difference between the two Groups reflects limited opportunities for supplementing farm income from sources external to the regular cropping and livestock production activities.

v. House hold income (HHI)

HHI calculated as the sum of FI and OFI, as one would expect, were significantly ($P<0.001$) higher in Group A (4400.4 ± 1657.7) than Group B (1763 ± 563.9) farmers.

Therefore, with increasing degree of integration, as demonstrated by distinctively higher gross margins from crops and animals, and farm income in Group A, farmer welfare has substantially improved.

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[12] Although there exist untapped potential in beekeeping in the area, farmers unable to bring beehives into the new settlements (during villagization) were compeled to sell it or the bees have perished or left the hives in lack of the necessary care at the old sites.

5.2.3.4 Cropping pattern effect

Effects of availability of livestock and particularly traction power on the mix and succession of crops was investigated based on the proportion of cereals (and especially teff) and pulses from the total area cultivated of each household. As such, there was no significant (P>0.05) statistical difference between the two levels of integration in the proportion of cereals as well as pulses from the total area cultivated. Similarly, the PA and PA-Group interaction effects on the proportion of cereals or pulses were not significant (P>0.05).

The average proportion of cereals and pulses in Group A was 84.4% and 15.6%, and in Group B, 86.7% and 13.3% respectively. This is in disagreement to the earlier arguments of ILCA as reported by Gryseels *et al*, (1984) indicating farmers with fewer than a pair of oxen cultivated less of cereals and more of pulses because of the lower labor and traction requirements for the latter crops (see Table 2.5).

As evidenced by the cropping pattern effects reported above, farmers from both Groups give top most priority to production of food crops (cereals). Indeed, farmers with less than a pair of oxen, can not be luxurious enough to allocate about 50% (Gryseels et al, 1984) of the already trivial farm holdings to pulses which are not reliable sources of family subsistence food. They will rather attempt to maximize efforts on securing a sufficient area of food crops as the growing period is short and oxen are worked on alternate days (half of the total available traction hours). The food habit of the farmer also indicates that pulses are not grown as the major food crops. Their major role is maintenance of soil fertility and improvement of yields via residual effects on the succeeding cereal.

Nevertheless, there was a significant (P<0.05) difference between the two levels of integration in the area allocated to teff. The proportion of teff in Group B (72.9%) was significantly (P<0.05) higher than Group A (65.6%). Although the total ratio of cereals was not significantly different, Group B farmers were found to allocate a higher proportion of the total area to a single cereal (teff). While none of the farmers were growing teff alone in Group A, there were six farmers (14.3%) growing only this crop in Group B. While there were only two farmers (4.8%) growing only cereals in Group A, 13 farmers (31%) cultivated only cereals (of which six were only growing teff) in Group B. Moreover, the effects of PA and PA-Group interactions on the proportion of teff were not significant (P>0.05).

Teff is not only the most preferred food cereal, but is also an important cash crop. This is provable from the share of this crop out of the total cash income from crop sale. On average, 92% and 95% of the total crop revenue originated from sale of teff in Group A and Group B respectively and was not significantly (P>0.05) different. Farmers usually grow different varieties of this cereal; the white variety which fetches higher prices in the market is grown primarily for sale while the red and mixed varieties are used for home consumption. Only the difference of 8% and 5% of the total revenue in Group A and Group B respectively originated from non-teff sales. This is also another reason why traction constrained farmers did not go for pulses as it may appear from the outset.

However, the transition of Group B farmers towards a monocrop economy is not a healthy tendency. Apart from the stability and sustainability issues of diverse cropping systems, rotations with both cereals and legumes have remarkably complex bio-physico-chemical advantages over the monomorphism of a single species. Although the yield increasing effect of the legume phase on the succeeding crop is appreciated by farmers, rotations may benefit both the cereal and the legume in the cycle. Rotations of non-leguminous crops may also result in increasing yields of the next crop (see Francis and Clegg, 1990).

According to these same authors, soil aggregation, bulk density, microbial biomass, and water infiltration and extraction are all influenced by rotation. Rotations reduce incidence of pests by breaking the reproductive cycles of the species because most pests are generally host specific. Weed seed populations also can be influenced by the type of crop in the field in a given season. Crop rotation, is thus, considered as the center- piece of integrated pest management along with genetic resistance in crops and limited use of pesticides.

Unless efficient transfer of energy and growth factors among crops in a rotation cycle is achieved to maintain sustainable yields, high but unsustainable levels of productivity can only be attained with high and continuous application of inputs based on fossil fuels, fertilizers and pesticides. Therefore, continuous cultivation of teff in a permanent cropping system (without a fallow period) precludes all the benefits of diversification and rotation with other crops and is ecologically disruptive and unsustainable.

5.2.3.5 Food self-sufficiency effect

Effect of integration on self-sufficiency in food crop production was revealed by looking into the amount of security grain reserve here termed as 'carry over stock' each household is left at the end of the cropping year (1989/90) just before the next harvest in January.

Amount of carry-over stock (GE kg) was significantly ($P<0.001$) higher in Group A (329.96 ± 200.96) than in Group B (96.35 ± 85.0). Carry-over stock per consumer unit was also significantly ($P<0.05$) higher in Group A (55.4 ± 38.53) than in Group B (35.6 ± 45.94). However, there was a significant ($P<0.05$) PA and PA-Group two-way interaction effect on carry-over stocks. Grain reserves in Hidi were significantly ($P<0.05$) higher than all other PAs. Because of the interaction effect, grain reserve in Hora Kilole was significantly ($P<0.05$) lower than all other PAs and was not significantly ($P>0.05$) different between Groups. This is may be because of insignificant ($P>0.05$) differences in the total area cultivated between the two Groups in this PA.

If an estimate of the length of time families could depend for supply of food energy and protein requirements on the grain reserve is made, the food available in each Group will be sufficient for over 2 months and 1 month for Group A and Group B respectively (see Table 5.17).

Table 5.17 Food security from grain reserve in the two levels of integration.

Group	CU[a]	Daily Requirement[b]		Total supply[c]		Sufficiency (days)	
		Energy (Kcal)	Protein (Kg)	Energy (Kcal)	Protein (Kg)	Energy	Protein
A	6.3	14.68	0.251	1130.87	49.46	77	197
B	3.8	8.85	0.152	330.22	14.44	37	95

[a] CU = average consumer unit.
[b] Based on daily per caput energy and protein requirements given by Latham (1979) for Ethiopia as 2330 calories and 39.9 gram respectively.
[c] Based on average composition of all grains (342.73 calories 100^{-1} gram for energy and 14.99 gram 100^{-1} gram for protein) calculated from Agren and Gibsen (1968) for grain reserve of the two Groups.

Amount of carry-over stock was significantly ($N=84$, $P<0.001$) correlated with several parameters like livestock holdings (66%), area cultivated (56%), family size (36%), total 'net yield' of crops (68%), and total 'net yield' of cereals (63%). Thus, all these had significant linear effects on amount of surplus reserved over and above family subsistence requirements.

Figure 7a depicts how farmers increasingly become self-sufficient in food crops with availability of traction power and increasing livestock holdings. Increasing ownership of drought oxen is accompanied by a remarkable decline in food deficits (as shown after TLU 1.1 in Group B). In Group A, as the trend line shows, carry-over stocks were not sufficiently correlated to oxen and livestock holdings possibly due to smaller farm sizes per unit of oxen used. As portrayed in Figure 7b, farm size and grain reserve are sufficiently correlated.

Figure 7a. Plot of carry-over stock and farm size versus livestock holdings.

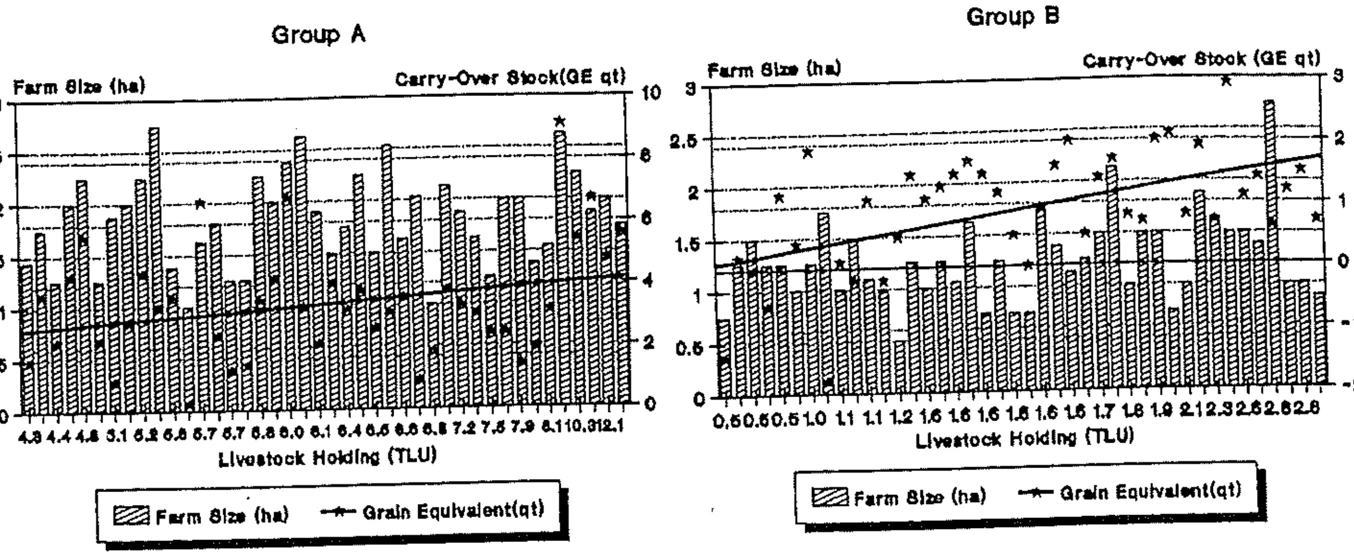
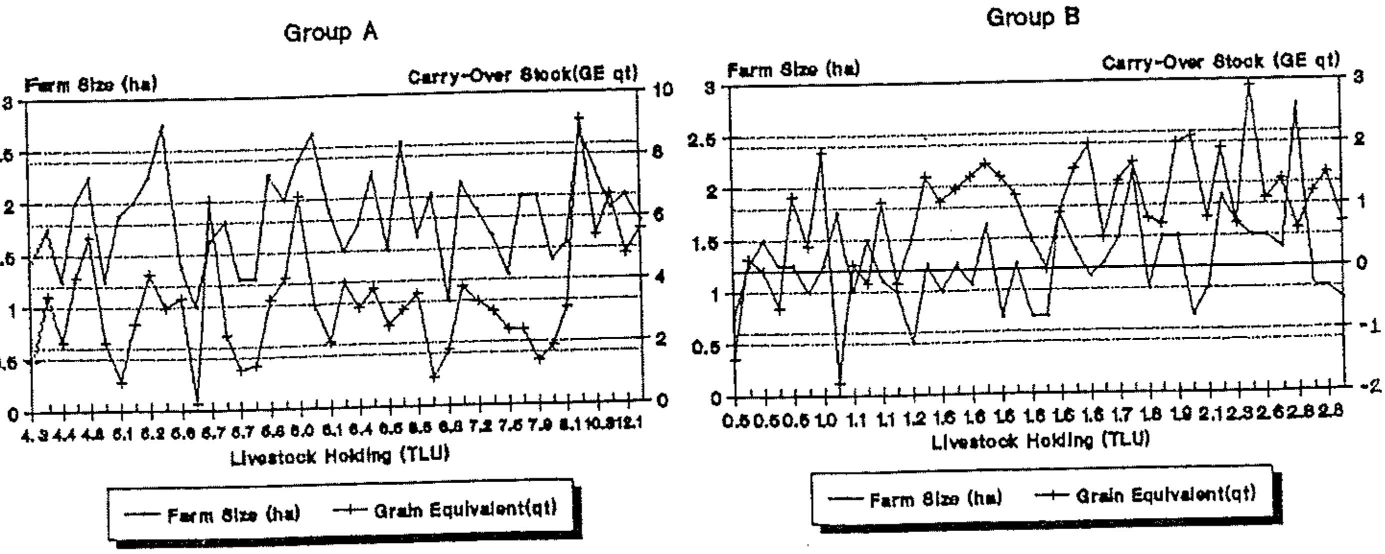


Figure 7b. Changes in carry-over stock and farm size with livestock holdings.



5.2.3.6 Fertilizer use effect

Since manure is used for fuel, chemical fertilizers are the only external subsidies now widely used in Ada district. Fertilizers are often used on highly valued and market-oriented cereals like teff and wheat, but not on pulses. Unlike the general situation at the national level where about 10% of the farmers are using mineral fertilizers, all the surveyed farmers were found to use them in Ada district.

Comparison of average amount of fertilizer used (Kg) indicates that it was significantly ($P<0.001$) higher in Group A (219 $\pm$ 81.6) than in Group B (151 $\pm$ 53.8). This denotes that farmers are following the recommended DAP:Urea ratio of 2:1 on area cultivated for cereals, 1.5 and 1.1 ha in Group A and Group B respectively. On every hectare the MOA recommended rate is 100 Kg DAP (diammonium triphosphate) and 50 Kg urea.

Moreover, fertilizer applied per plot or per hectare was not significantly ($P>0.05$) different between the two Groups. Average levels applied were 154 and 150 kg ha^{-1} in Group A and Group B respectively very similar to the recommended rates. However, PA had a significant ($P<0.01$) effect on total and per hectare use of fertilizers. Hence, total and per hectare fertilizer uses were significantly higher in Hora and Guda PAs than in Hidi PA. A per hectare rate of 130 Kg in Hidi is lower than the recommended rate, while 160 Kg in Hora and Guda is virtually similar to the recommended application rate.

5.2.3.7 Degree of cultivation effect

Several passes with the *maresha* are required for most of the crops before planting. Number of passes required depend on the type of the crop, the soil, and availability of traction power.
The number of passes attained by Group A farmers were significantly ($P<0.001$) higher than Group B farmers for teff, wheat, barley,

chickpeas and horse beans. But was not significant (P>0.05) for all other crops or was inconclusive because of insufficient sample sizes. Relevant cases are summarized in Table 5.18.

Table 5.18 T-test for mean difference in passes attained for each crop.

Crop	Group	N	Mean	Std.Dev	Std. Error	P-value
Teff	A	42	6	0.96	0.15	0.0001
	B	42	4	0.62	0.09	
Wheat	A	41	4.7	1.06	0.17	0.0001
	B	36	3.3	0.44	0.07	
Barley	A	28	4.6	0.74	0.14	<0.0001
	B	30	3.3	0.66	0.12	
Chickpeas	A	29	4.1	0.84	0.16	0.0001
	B	21	2.8	0.54	0.12	
Horse beans	A	33	2.4	0.51	0.09	0.0001
	B	27	2.0	0.00	0.00	

There was a significant (P<0.001) PA effect on number of passes for teff, wheat, barley and chickpeas thus, was higher in Hora Kilole than in all other PAs. But, number of passes were not significantly (P>0.05) different between Hidi and Bore Guda PAs. The two way interaction effect on number of passes was not significant (P>0.05).

Deep ploughing with heavy machinery leading to complete inversion of the soil is repeatedly blamed to be ecologically disruptive exposing the soil to the erosive forces of wind and water and compaction of the soil layer. As a result, 'minimum tillage' and even 'no tillage' (direct drilling) techniques are advocated by many for countering the side-effects of thorough and deep ploughing.

However, minimum and no-tillage require massive use of agro-chemicals to attain a desired level of output, thus are neither economically feasible to the smallholder nor ecologically compatible.

Cultivation in the Ethiopian highlands carried out with the *maresha* does not turn the soil, but loosens it penetrating to the depth of about 15 cm. However, repeated passes with the *maresha* are also blamed for exacerbating sheet erosion. Indeed, this can be a problem during the early periods of the rainy season when the soil is bare and unprotected from erosive rainfall. This problem is aggravated by unwise cultivations up and down the slope on steep hillsides. Complete removal of the stubble plant biomass and crop residues for animal feeding is another factor.

Rediversion of the present use of crop residues to be recycled on cultivated fields presupposes increase in the base grain yield to open up a space for introduction of improved forages. This requires intensification in terms of repeated passes on smaller plots.

When associated with other improved management practices, cultivation leads to more timely planting, lower soil bulk density, and better pre-and post-harvest moisture conservation which lifts average yields and counteracts fluctuations during years of less-than average rainfall (Sandford, 1989). One major reason why absolute yields per hectare (without considering payments made for renting oxen) were significantly higher for white teff, bread wheat and horse beans in Group A could be these differences in the degree of cultivation and preparation of the seed-bed before planting for these same crops.

Cultivation is also advocated for reducing the incidence of weeds either mechanically or by burying, and decomposition of organic matter, and it brings pesticides in to contact with the pest there by increasing their effectiveness (Edwards, 1990).

Therefore, it is here argued that the positive effects of thorough and repeated passes with the local plow will outweigh some of the said negative effects on the ecosystem (ie. the social benefits will more than offset the social environmental costs). In this context, Group A farmers who managed to cultivate repeated number of times for a number of highly valued food crops can be expected to be better off. This is, hence, another invaluable integrative function of livestock which has a net multiplier effect in cropping.

5.2.4 Effects of integration on farming system constraints

5.2.4.1 Constraints of the cropping sub-system

The survey farmers were asked to rank a list of presumed problems (see questionnaire Appendix 9) related to cropping according to their priorities and order of importance (rank 1 as the most pressing and up to rank 3). Ranks beyond Rank 3 were regarded as less important and thus were treated under one category.

i. Cultivable land: A chi-square test for homogeneity of all the different ranks between the two Groups reveals that it was significantly (P<0.001) different. Lack of cultivable land as a problem was more felt in Group A, with the necessary tractive power, than in Group B (see Table 5.19).

Table 5.19 Problem ranking between Groups for shortage of cultivable land.

Group	Total	Rank							
		1	%	2	%	3	%	>3	%
A	42	32	76	4	9.5	4	9.5	2	5
B	42	4	9.5	18.	43	8	19	12	28.5

Shortage of land is a serious issue even to Group B farmers, without a pair of oxen, as indicated by 43% ranking it as the second limiting factor. This fact further strengthens the argument that oxen are worked below their potential capacity and indicates the seriousness of the problem as a subsistence constraint for the very near future.

ii. Lack of draught power: lack of ploughing oxen as a constraint was also significantly ($P<0.001$) different between the two Groups A and B. This problem, as one would imagine, was more serious to Group B farmers than Group A farmers (see Table 5.20).

Table 5.20 Problem ranking between Groups for lack of traction power.

Group	Total	Rank							
		1	%	2	%	3	%	>3	%
A	42	0	0	1	2	0	0	41	98
B	42	36	86	6	14	0	0	0	0

iii. Soil Fertility: The chi-square test for homogeneity of the different ranks between the two Groups was not rejected ie.there was no significant ($P>0.05$) statistical difference in ranking this problem between the two levels of integration. About 62% of the farmers in each Group ranked this problem among the top three constraints of cropping. Thus, deterioration of soil fertility seems to be an equally shared problem between the two Groups regardless of the degree of integration. This is particularly appealing considering the use of animal manure for household fuel which precludes use of this organic fertilizer for maintenance of soil fertility by farmers with large livestock holdings.

iv. Weed infestation: Ranks for this problem between the two Groups were significantly ($P<0.05$) different. While 74% of the surveyed farmers in Group B ranked weeds among the top three constraints, only 42% of Group A farmers fall in this category.

Farmers complain about noxious weeds of cereals like *Amaranthus spp*, *Bidens pilosa*, *Guizotia scabra*, *Plantago lanceolata*, *Scorpirus muricatus*, *Lolium temulantum* and several others also identified as major weed species in Ada district by the Debre Zeit Agricultural Research Centre (1988).

Farmers associate weed infestation to inadequate preparation of the seed-bed before planting and to deterioration of soil fertility. However, a higher rate of weed incidence reported by Group B farmers seems to be a cumulative effect of insufficient cultivation of the soil and the increased degree of monomorphism attained with continuous cultivation of teff without a fallow period or rotation with other crops.

A high incidence of weeds calls for a higher demand for labor and herbicides. In cases where this inputs are costly or unavailable, yields are depressed and vulnerability to crop failures increases. This is especially true under conditions of small land holdings and insufficient traction power which prohibits expansion of area cultivated to compensate for the decline in harvests from weed infestation.

v. Credit: The issue of credit is not appreciated by farmers since they do not know of any formal institutions extending credit services at any sufficient scale. For all financial problems farmers resort to the informal village lenders who provide money at high interest rates. Ranking for this problem was not significantly ($P>0.05$) different between the two Groups. Only 5% and 9% of the farmers in Group A and B perceive lack of credit as a major constraint of cropping respectively.

vi. Fertilizer: Rankings for lack of fertilizer were not also significantly ($P>0.05$) different between the two Groups. About 73% and 55% of the surveyed farmers in Group A and B rank this problem among the top three respectively. Thus, this problem is not particularly important to a certain Group of farmers. But, farmers complain about delays in transport and distribution of fertilizers which often retards date of planting.

Vii. Pests and diseases: As is the case for weeds, ranks for incidence of pests and diseases were also significantly ($P<0.05$) different between the two Groups of farmers. While about 64% of the farmers in Group B rank this problem among the top three, only 33% in Group A fall in this category. This problem is thus, more of a limiting factor to Group B farmers than Group A farmers. Possible explanations are not different from the case of weeds.

Vii. Family labor: Shortage of labor as a constraint to cropping was not ranked differently ($P>0.05$) between the two Groups. About 5% and 9% of the farmers in Group A and B rank this problem among the top three respectively. During periods of peak labor demand (ploughing, planting, weeding, harvesting, etc) farmers utilize the exchange labor and/or buy from the labor market.

5.2.4.2 Constraints of the livestock sub-system

A list of presumed constraints (see questionnaire Appendix 9) to livestock husbandry in the highlands were given to the farmer to be ranked according to his priorities (like the case of constraints in cropping).

i. Feed: The Chi-square test shows that the ranks to this constraint were significantly ($P<0.05$) different between Groups. The problem was very acute to Group A farmers with more livestock holdings than Group B farmers. 100% of the farmers surveyed in Group A ranked shortage of feed as their top limiting factor (Rank1), while 86% of Group B farmers fall in the same category (see Table 5.21).

Table 5.21 Problem ranking between Groups for shortage of animal feed.

Group	Total	Rank					
		1	%	2	%	3	%
A	42	42	100	0	0	0	0
B	42	36	86	4	9.5	2	4.5

However, feed is even a limiting factor to Group B farmers as demonstrated by 100% of farmers in this Group ranking it among the top three priority problems constraining livestock production in the highlands. This is an acute problem of mixed smallholder farming which has now already become a subsistence constraint in several areas in the highlands.

ii. Diseases and parasites: The chi-square test indicates insignificant (P>0.05) difference for this problem between Groups. About 66% and 64% of the farmers in Group A and B ranked this problem among the top three obstacles of livestock production respectively.

Trypanosomiasis is not generally a problem in the highlands, but sporadic outbreaks of a number of infectious diseases like anthrax, pasteurellosis, black leg, and foot-and-mouth disease (FMD) may be serious threats to the livestock sub-system.

If morbidity and mortality are taken in to account, heavy endoparasite burden is responsible for the great production losses in livestock. Liver fluke, lung worm, and intestinal worm infection are serious ailments when livestock are grazing under waterlogged pastures. More than 80% of cattle examined in a field survey at Debre Zeit had signs of liver fluke infection as determined from fecal samples (Mukasa-Mugerwa, 1981).

iii. Credit: Ranks for this problem were significantly (P<0.001) different between the two Groups. Lack of credit seems to have substantial impact on Group B farmers than Group A farmers. While 92% of farmers in Group B ranked it among the top three problems, only 21% of Group A farmers fall in the same category. This is mainly because of distinct differences in farm income between the two Groups. Group B farmers deserve credit particularly for purchase of oxen to be able to work in pairs. Until the cooperativization policy was repealed in 1990, credit for purchase of oxen by the AID Bank was given only to PC-members.

iv. Local breeds: Ranks for poor productivity of locals were not significantly (P>0.05) different between Groups. About 12% and 9% of the farmers in Group A and B rank this problem among the top three respectively. Farmers in both Groups are well aware of difficulties of introducing cross-breds unless the existing acute feed problem is resolved.

v. Labor: There was no significant (P>0.05) difference in ranking this problem between the two Groups. About 21% and 28% of the farmers in Group A and B ranked this problem among the top three respectively.

vi. Other problems: The farmers in Group A considered villagization as a limiting constraint to animal husbandry. About 71% and 12% of the farmers in Group A and B place this problem among the top three. They see raising of small ruminants and even poultry to be difficult in the new crowded settlements. This is critical during the cropping season where animals may cause damages to crops and as a result intense conflicts may arise among several neighbours.

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

Crop and livestock production in the Ethiopian highlands have longstanding notable interactions with remarkably intertwined linkages beneficial to both sub-systems. Among other things, livestock provide economic (output and input) and non-economic (social and security) functions to the rural smallholder mixed farming. Much more important in cropping is the input function, the supply of traction, transport and threshing power and some manure for replenishment of soil nutrients virtually for all cultivated crops in the country, and the farm integrative function which incudes all the beneficial effects of integration for the productivity of resources engaged in agriculture. The cropping sub-system primarily supplies cheap crop byproducts for animal feeding.

Although this study is based on input-output relations in only one cropping year, it is evidenced through the area, yield, income, cropping pattern and other effects of integration that the livelihood of the mixed smallholder has considerably improved with increasing degree of crop-livestock integration. Average area cultivated in Group A (representing a higher degree of integration) was significantly ($P<0.001$) higher than that in Group B (representing a lower degree of integration). However, mean area cultivated per labor unit was not significantly ($P>0.05$) different owing to trivial land holdings of the farmers. Therefore, area cultivated in the farm increases with increasing availability of traction power and livestock holdings, but area effect per family member or per labour unit depends on the existing cultivation and livestock densities.

It appears that the positive area effects of integration overshadow the negative effects (expansion of cropping into grazing grounds) so long as cultivation density and the herd sizes are kept below certain critical levels which minimize the effects of resource competition. Competition for land resources also depends on the base grain yield. Higher base grain yields reduce crop-livestock land use conflicts because less land is to be cropped to maintain a given population density.

Crop yields for the major cereals and pulses net of payments made for renting oxen were significantly higher in Group A than in Group B for white teff ($P<0.01$), mixed teff ($P<0.05$), red teff ($P<0.01$), durum wheat ($P<0.05$), bread wheat ($P<0.01$), chickpeas ($P<0.05$) and horse beans ($P<0.01$). Thus, livestock contribute to sustainability of mixed farming by enhancing the average levels of harvests of the rural poor.

Integration also boosts average levels of farm income in both cropping and livestock production. Gross margins from crops, gross margin from animals and farm income, calculated in a conventional (only for products and services having market values) and non-conventional way (including estimated values of non-market oriented services) were all significantly ($P<0.001$) higher in Group A than in Group B. Livestock contributed 56% and 48% of the farm income in Group A and Group B respectively, while the difference has originated from the cropping sub-system. With increasing farm income, purchasing power of the farmer for agricultural inputs has remarkably improved which further strengthens the symbiotic interactions between the two sub-systems.

At the current level of resource use, level of integration does not seem to have a significant effect on the proportion of the area allotted to cereals or pulses. Nevertheless, traction constrained farmers maintain priority for highly valued food crops (in this case teff). This tendency towards increasing monomorphism prohibits realization of the benefits of crop rotations and jeopardizes the risk averting functions of diversified cropping systems. Thus, transition towards reduced diversity and rotations associated with lack of traction power is risky in the face of environmental stress and may not be sustainable.

Food self-sufficiency and food security increases with a rise in the level of integration. Amount of carry-over stock available per consumer unit was significantly ($P<0.05$) higher in Group A than in Group B.

Availability of crop byproducts and animal manure increases with the level of integration. Amount of crop residue and manure dry matter produced was significantly (P<0.001) higher in Group A than in Group B.

Furthermore, the degree of cultivation for certain highly valued crops with the local plow, *the maresha*, increases with a rise in the level of integration (oxen ownership). Number of passes for teff, wheat, barley, chickpea, and horse bean were significantly (P<0.001) higher in Group A than in Group B. It is argued that the positive effects of repeated and thorough cultivation with the local plow would more than offset the negative effects on the ecosystem. Therefore, livestock once again contribute to sustenance of mixed farming by allowing more frequent and timely cultivation of plots which in turn lifts average yields and counteracts the incidence of pests and diseases.

However, complementary interactions with a net multiplier effect in cropping and livestock production overshadowed competitive interactions so long as increasing subsistence demand and changing agricultural development policies have not created a situation in which land has developed a scarcity value.

Competition for natural and human resources between crop and livestock sub-systems was gradually building up in the highlands as a cumulative consequence of demographic and non-demographic factors. *Under the influence of these self-reinforcing factors, competitive interactions are undermining and even dominating complementary interactions which were historically indispensable for persistence of mixed farming.* Competition for land resources has manifested it self in a continued disappearance of grazing grounds and subsequent expansion of cropping throughout the highlands. Therefore, crop encroachment is a vital factor for the observed tremendous decline in the area of natural pastures.

Undeterred population growth in Ada district for the last decade was significantly (P<0.001) negatively correlated to the decline in grazing areas (95%) and fallow areas (94%), while it was highly positively correlated to expansion of area under crops (95%). Regarding population growth as a proximate compounding factor, however, the influence of other non-demographic factors like low product prices, technological stagnation, forced requisition of grains, urban bias, land entitlement failures, poverty, and ill-conceived development policies which fortify the effects of demographic pressure can not be ruled out. *As a result, crop encroachment into grazing areas should be explained as an outcome of cumulative causation of demographic and institutional factors.*

Increasing conversion of grazing areas into crop lands has resulted in wide divergence between feed supply and demand in the district, and in fact integrated agriculture in the highlands would not have been possible without enormous diversion of crop residues for animal feeding. Even without making allowances for sustainable use of pastures and crop residues at 50% and 70% annual utilization rates respectively, the total annual availability of consumable dry matter is critically in short of the annual requirements. The same is true for digestible protein. As a result, animals are kept at sub-maintenance diets over half of the year except for a few months where there will be sufficient supply of feed at the harvest season from the stubble biomass and crop residues after threshing (when animals will gain weight because of compensatory growth). Thus, energy and protein are among the top nutritional problems of livestock resulting from increasing competition for land resources in mixed farming.

Looked from another vantage point, this is also a worrisome development of crop-livestock interactions for sustainability of mixed farming in the highlands. First, expansion of cropping into grazing areas has further pushed livestock to marginal environments extremely unsuitable for cropping or has resulted in increasing concentration of animals on the remaining small plots with severe effects on the environment.

Second, disappearance of fallow areas coupled with a decline in grazing lands meant that animals now depend on crop residue-based sub-maintenance diets which supply 71% of the total consumable dry matter. Immense diversion of crop residues for animal feeding precludes their use in cropping for replenishment of lost nutrients. Since animal manure is not also returned to the soil, this has led to extensive loss of organic matter out of the system.

Third, maximization of the major livestock functions in the highlands which depends on increasing herd sizes is paradoxical to the increasing divergence between feed supply and demand. Lack of feed will endanger the supply of traction, threshing and transport power and reduces the supply of manure leading to the destruction of the remaining trivial vegetative cover. Lack of animal feed as crucial constraint to crop-livestock integration in the highlands also compromises all other symbiotic interactions (such as investment linkage and the security and buffering functions of livestock in cropping).

Fourth, since specialization does not seem to be the evolutionary tendency of highland farming systems in the foreseeable future, increasing competition for scarce resources (especially land) and the resulting acute shortage of feed would have negative effects on the productivity of both enterprises.

All these developments would indeed jeopardize sustainability of mixed farming. Given the present day circumstances of low development and rehabilitation efforts in the country, shortage of grazing and crop land would become irreversible subsistence constraints within the first decade of the next century (Hurni, 1988). Assuming a cereal grain yield of 800 Kg ha^{-1} and a per capita gross cereal requirement of 300 Kg per year for an average family of five persons, the minimum amount of land cropped per household would be 1.9 ha. If 100% of the area is cropped, the potential human supporting capacity would be 263 persons Km^{-2}. In Ada district, where about 43% of the land area is cultivated, the human supporting capacity is about 113 persons Km^{-2}. With the current rural population growth rate of 2.2% per annum, it can be expected to double every 30 years. The present density of about 82 persons Km^{-2} will thus indicate a severe subsistence constraint with in the coming 15 years.

In the strive for short-term maximum welfare, peasants with limited opportunities would adopt improvident attitudes towards the essence of maintaining the productivity of the resource base. Thus, the environmental costs of massive use of crop residues for animal feeding and animal manure for fuel are externalized to the society. The society at large and the unborn generations would bear this market unaccounted costs. This has also led to a shift in reliance from integrated local agroecological knowledge in maintenance of soil fertility to reliance on fragmented and non-ecological external markets and state extension systems.

Farmers will also remain reluctant to the introduction of cultivated forages so long as the returns from forage production are less than that in alternative crops. Moreover, increased availability of cheap crop byproducts for animal feeding has a 'blinding effect' on forage adoption and pasture management.

6.2 Recommendations

The following recommendations emanate from the argument that mixed farming (integrated crop and livestock production) will remain to be the prominent agricultural systems in the Ethiopian highlands in the foreseeable future. The second transition from mixed farming to specialization would be hindered by several factors like high input/output ratios, poor development of infrastructure, uncertainties in food supply, and propitious environment favouring diversified activities. Specialization in cropping also presupposes tractorization (mechanization with engines) which because of several reasons does not seem to be feasible in the near future. Among all others, small land holdings, low farm income and thus low purchasing power, lack of fossil fuels, steep and rugged terrain of the highlands, high unemployment of the rural labor force which may foster heavy influxes into towns and fear of aggravating ecological disruption would discourage and limit tractorization of smallholder farming in the highlands.

Therefore, the basic strategies for maintenance of close integration of crop-livestock systems and their complementary and symbiotic effects important for sustainability of mixed farming would require:

i. **Improvement of feed quality and quantity:** The crop and livestock sub-sectors are increasingly becoming at loggerheads as a result of acute feed shortage both in quality and quantity. The strategy for feed improvement should encompass:

Forage improvement: Forages can only be adopted in areas where land has no high alternative costs in cropping and where specialized farms (dairy, fattening, etc) would encourage its use. Several grass and legume species considered suitable for different altitudinal zones are identified. Forage seeds may be efficiently distributed to peasants on a contract basis.

Establishment of grass-legume permanent pastures: Introduction of grazing tolerant species in natural pastures would improve feed supply there by reducing the effects of overgrazing and land degradation. The native legumes such as *Trifolium* and *Medicago spp* are considered worthwhile in areas above 2000 m elevation. This, however, presupposes privatization of pasture resources now used as common properties.

Under-sowing cereals with pasture legumes: This seems to be a promising approach since it allows a multiple use of scarce land resources under heavy cropping densities. If successful, it will improve the feeding value of the stubble and assists in maintenance of soil fertility. Where ever the growing period is long, this can be done in the form of a catch crop or in a relay planting technique to utilize the residual moisture for forage production to alleviate the critical shortage of feed in the dry season. This also requires privatization of stubbles and fallows which seems to be impractical under the current open access resource use systems during the dry season. Its success also depends on selection for good combining abilities of the forage and food crop components.

Alley farming: This is an agroforestry technique by which food crops are grown between hedge rows of nitrogen-rich legume shrubs which can be regularly pruned to provide green manure (mulch), additional fodder for animals, firewood and fencing material. *Acacia albida* is already widely used by the farmers of Ada district as a valuable multi-purpose tree. Legumes of other species like *Gliricida, Leucaena, Sesbania, and Calliandra* are reported to be suitable in alley cropping.

Forage production in conservation areas: For rehabilitation of degraded zones, wide areas are set now as stock exclusion sites. These conservation sites may aggravate land use conflicts in densely populated areas. Development of sown forages in this isolation areas would on one hand enable utilization of forages by a cut-and-carry technique and on the other hand facilitates quick revegetation of degraded areas in ways acceptable to the local population.

Use of agro-industrial byproducts: Some agro-industrial byproducts such as cane tops, coffee pulp, molasses, and oilseed meals are currently under-utilized or wasted, thus scope exists for improving their utilization as protein and energy supplements.

ii. Relieve stocking pressure: Another set of efforts to strengthen complementary crop-livestock interactions may include:

Stratification in livestock production: raising of oxen and other animals in the apparently under-utilized rangelands, and their subsequent use in the highlands. Continuous supply of oxen to the highlands from breeder stock kept in areas with low cropping potentials is technically feasible, but lack of efficient marketing infrastructure may preclude its implementation. This may also reduce manure supply in the highlands.

Use of single oxen for traction: In the highlands ILCA has made considerable efforts in developing a technology suitable for use of single oxen unlike the traditional way of using pairs for cultivation. Preliminary results suggest that adequately fed singles with a modified yoke and harness could be used as pairs without a significant loss in efficiency and yield of crops (Gryseels *et al*, 1984). If widely adopted this would resolve not only the stocking pressure, but also the current critical shortage of traction power.

Cow traction: In some parts of the Ethiopian highlands sterile cows are trained for traction. If the current feed shortage is alleviated, cows may be used for dual purposes of milk and work. ILCA's initiatives in this regard are also encouraging. Likewise, horses also now used for traction in some parts may be trained for the dual purpose of transport and traction to ease the stocking pressure.

Rental markets for traction power: Currently there exist various kinds of institutionalized traditional arrangements for hiring oxen. If small scale oxen and/or tractor hiring stations are developed, the present lack of traction power and the stocking pressure would be eased.

iii. Vertisol management: Vertisols accounting about 20% of the HPC zone and about 25% of the highlands are important agricultural soils constrained by poor drainage. It is reported that only a quarter of these inherently fertile agricultural soils is now cultivated. Because of waterlogging during the main rainy season, vertisols are planted late in the cropping season and grow on residual moisture. ILCA has developed a broad-bed maker for improved surface drainage of these soils. If this technology proves successful, the potential of these soils could be realized there by reducing the current incursion of cropping into marginal areas, grazing grounds and eases the excessive pressure on the well-drained upland soils.

iv. Promotion of community forestry programmes: This will reduce the current rampant use of animal manure for fuel. This may open some scope for rediversion of manure for soil restitution. To encourage widespread fuelwood plantation, farmers shall be given absolute ownership rights to their own trees. In the short term, priority should be given to fast growing species like *Eucalyptus*.

v. Redistribution of land: Uneven distribution of land during the period of cooperativization has resulted in excessive pressure on small fragile soils owned by private smallholders. To minimize the ecological effects of land entitlement failures, land should be redistributed according to family sizes in every PA.

vi. Population policy: In the absence of improved agricultural techniques, subsistence farming has depended for a long time in the past in soil mining. These agricultural activities remained within limits of excessive degradation so long as cultivation and stocking densities were kept low. Now, increasing demographic pressure is undoubtedly resulting in land use conflicts in agriculture. Thus, a population policy is urgently needed for the entire country. Efforts in this line should include provision of family planning and sex education and contraceptives at a national level. This can possibly be carried out as part of the curriculum in the schools and through the literacy campaign to the rural population.

vii. Land use policy: The country is currently lacking detailed and comprehensive land use maps. Land capability classification for various uses would be utmost needed to reduce conflicts emerging between various sectors and even among different government departments.

viii. Social economic evaluation of alternative uses of manure and crop residues in cropping: Cost benefit analyses of alternative uses of these resources with the conventional utilitarian approach suggest that these resources will be efficiently employed in their current use (as fuel or animal feed) than for their use in cropping to replenish lost nutrients. Since this approach depends on the 'invisible hand' argument of market prices, the social benefits of stabilizing the ecosystem were not accounted. Therefore, the current ecologically disruptive uses of these resources potentially leading to irreparable damages should be reassessed and scrutinized from the environmental dimension.

Generally, the country's scarce natural resources are disappearing at alarming rates; forests are still being depleted at a rate far in excess of the annual rates of regeneration; soils are being depleted up to six times the annual rates of soil formation, water, wildlife, genetic diversity and all other interrelated elements of nature's economy are being dangerously destroyed. The country is still riding the down ward spiral which led other nations in the past to irreversible crisis. We need to perceive all the catastrophic warnings from nature in the light of the current disruptive land use system. If we recognize the need to cooperate with nature now, it will still be possible to optimize the current resource use system to a state which ensures perpetual productivity of the resource base. Ignorance to do so will not be forgivable by our descendants.

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8. APPENDICES

Appendix 1.

FAO/WHO Coefficients for Converting Family Size into Standardized Household Size.

Age Category (years)	Sex		
	Male	Both	Female
< 1		0.4	
1-3		0.6	
4-6		0.8	
7-9		0.9	
10-12	1.1		1.0
13-15	1.0		0.9
16-19	1.0		0.8
20-39	1.0		0.8
40-49	1.0		0.7
50-59	0.9		0.7
60-69	0.8		0.6
>=70	0.7		0.5

Source: Michael (1985).

Appendix 2.

Coefficients for Converting Household Labor into a Standard Labor Unit.

Sex/Age Category	Condition[a]	Labor Unit
<8 or >75	All	0
Children (8-14)	1	0.5
Children (8-14)	2	0.25
Adult Males (15-65)	1	1.0
Adult Males (15-65)	2	0.5
Old Men (66-75)	1	0.5
Old Men (66-75)	2	0.25
House Wives (15-65)	2	0.5
House Wives (66-75)	2	0.25
Adult Females (15-65)	1	0.7
Adult Females (15-65)	2	0.35
Old Women (66-75)	1	0.35
Old Women (66-75)	2	0.18

[a] Condition refers to the amount of time a family member spends working in the farm. Condition 1 denotes to a family member working more than the average annual labor hours required in the farm here referred to as 'full-time worker'. Condition 2 refers to a family member working less than the annual average working hours required in the farm here termed as 'part-time worker' because of several reasons (students, housewives, farmers with other social or administrative responsibilities, or physically disabled farmers etc.).

Source: Compiled by author based on social division of labor in the family (Appendix 3) and the working condition of the farmer's family as collected from the questionnaires.

Appendix 3.

Social Division of Labor in Ada District for Agricultural Production.[a]

Function	Gender Division of Labor				
	Only Male	Only Female	Both	Mainly Male	Mainly Female
<u>1. Cropping System</u>					
a) Ploughing	x				
b) Planting/seeding				x	
c) Weeding			x		
d) Harvesting				x	
e) Transport of harvest				x	
f) Preparation of threshing ground			x		
g) Threshing				x	
h) Winnowing	x				
i) Transport of produce & storage				x	
j) Bird scaring			x		
<u>2. Livestock System</u>					
a) Milking					x
b) Feeding			x		
c) Herding			x		
d) Collecting manure		x			
e) Barn cleaning		x			
f) Transport of crop residue	x				
g) Milk processing		x			
<u>3. Household Activities</u>					
a) Fuelwood collection					x
b) Fetching water		x			
c) Cooking		x			
d) Washing clothes					x
e) taking care of children					
<u>4. Marketing Activities</u>					
a) Sale of teff			x		
b) Sale of animals	x				
c) Purchase of food stuff					x
d) Purchase of animals				x	
e) Purchase of agricultural inputs	x				

[a] This social division of labor based on gender only works under normal circumstances of the family and particularly when the household is headed by the husband. In all other cases, this division of labor may not be respected since farm activities surpass gender differences and some activities now classed as strictly 'for male' or 'for female' are shared by both sexes.

Source : compiled by author during the survey period.

Appendix 4

Average Market Prices of Crops in Ada District and Conversion Factors for Transformation of Grains into Standard Grain Equivalents.

Crop	Average prices (Birr/100 Kg)[a]			Average of three years	Conversion factor[b]
	1986	1987	1989		
White Teff	104	88	118	103	1.38
Mixed Teff	91	78	94	88	1.18
Red Teff	81	67	86	78	1.04
Durum Wheat	74	57	73	68	0.91
Bread Wheat	63	58	63	61	0.82
Emmer Wheat	70	59	60	63	0.84
Barley	56	54	55	55	0.74
Chick peas	73	53	85	70	0.94
Field peas	86	81	120	96	1.28
Horse beans	52	45	86	61	0.82
Lentils	86	85	105	92	1.23
Rough peas	61	na	63	62	0.83

Source: [a] From Getechew Assamenew (1991).
[b] Compiled by author based on the three year average price of the crops by expressing the respective average prices to the average price of all the crops calculated at Birr 74.75 per 100 Kg. Since ILCA did not carry out regular market surveys in 1988, there was no price data for that year.

Appendix 5.

Average Seed Rates for Different Crops in Ada District.[a]

Crop Type	Seed Rate (Kg ha^{-1})
Teff	40
Wheat	130
Maize	60
Barley	160
Chick peas	100
Field peas	160
Horse beans	120
Lentils	45
Rough peas	40
Harricot beans	40

Source: Average of all the levels used by the survey farmers

Appendix 6.

The 1989 Average Market Prices of Livestock in Ada District.

Animal Type/Species	Price (Birr per unit)[a]
Oxen	528
Cow	390
Heifer	295
Young Bull	278
Calves	129
Ram	62
Ewe	55
Lumb	35
Buck	46
Doe	52
Kid	31
Adult Donkey (male)	230
Adult Donkey (female)	195
Young Donkey	135
Adult Horse	340
Young Horse	160
Adult Mule	800

Source: [a] From ILCA weekly market surveys, weighted average prices for nine condition scores of cattle while conditions were unspecified for shoats. Average prices for different classes of equine are market prices in Ada as indicated by group interviews of survey farmers.

Appendix 7.

Land Use (ha) in Ada District (1979/80-89/90).

YEAR	GRAZING	CULTIVATED	FALLOW	FOREST	OTHER	TOTAL AREA
79/80	20077	42479	452	10212	49080	122300
80/81	18792	43957	395	10212	48944	122300
81/82	18322	44615	365	10212	48786	122300
82/83	16636	46797	337	9499	49031	122300
83/84	16253	47690	315	9499	48543	122300
84/85	15034	49539	250	9499	47978	122300
85/86	14252	50383	210	8910	48545	122300
86/87	13382	51273	158	8320	49167	122300
87/88	12833	52451	104	8320	48592	122300
88/89	12204	53250	87	8320	48439	122300
89/90	11862	54503	67	8320	47548	122300
Mean[a]	12906	52372	130	8438	48458	122300

[a] Average of the latest five years (1985/86-89/90).

Source: Ada Agricultural Development Office, MOA (1990)

Appendix 8.

Livestock Population of Ada District (1979/80-89/90).

YEAR	OXEN	COWS	HEIFER	YBULL	CALVES	SHEEP	GOATS	DONKEYS	HORSES	MULES
79/80	32740	20700	12722	15400	9200	13031	7800	11700	2000	933
80/81	30781	19570	13100	13982	9976	13780	7000	10581	1970	890
81/82	28995	19771	14000	12738	9521	14702	6781	9720	1831	728
82/83	27893	18981	13500	11542	8061	13670	5670	8421	1728	600
83/84	26920	18223	12920	10881	8774	10780	5211	7504	963	650
84/85	25001	17607	12926	10281	8001	10207	6001	9000	957	671
85/86	26551	18060	12003	11000	8621	11780	7000	10032	1000	794
86/87	28056	19312	12300	11470	9880	12217	6000	10000	1025	800
87/88	29079	19210	13720	11921	9032	13000	6710	9811	1200	970
88/89	29000	19100	13002	11527	8983	12600	8031	9011	1301	985
89/90	28780	19000	12040	11021	8731	10023	6700	9032	1125	920
Mean[a]	28293	18936	12613	11387	9049	11924	6888	9577	1130	894

[a] Average of the latest five years (1985/86-89/90).

Source: Ada Agricultural Development Office, MOA (1990).

Appendix 9

Questionnaire used for generation of data on selected comparative parameters

1. Name (head of household)______________________

   Sex_______Group________

   Peasant Association__________________

2. Family size and working conditions in the farm by ages

Name	Age (years)	Condition[a]
Male 1.		
2.		
3.		
4.		
5.		
Female 1.		
2.		
3.		
4.		
5.		
Total		

[a] Condition of work refers to 'Full-time' workers (who work more than the average working hours required in the farm) or 'Part-time' (who work less than the average working hours required in the farm) workers in the farm.

3. Size of land holdings and crop production (for last harvest 1989/90 cropping year)
   a) cultivated land and crop production

Crops	Area *(kert)*	Total Yield (kg)	Ox Rent Payment (kg)
White Teff			
Mixed Teff			
Red Teff			
Durum Wheat			
Bread Wheat			
Other Wheat			
Maize			
Barley			
Chickpeas			
Field peas			
Horse beans			
Lentils			
Rough peas			
Fenu greek			
Niger seed			
Flax			
Total			

Total area of cultivated land with out sequential cropping (kert)____________________

b) cultivable land under fallow (kert)________________

c) grazing land (kert)____________________

d) plantation forest/home garden (kert)____________________

4. Size of Livestock Holding (heads of animals) as of 1981/82 EC

a) cattle————————————

Milking Cows
- local ————
- crossbreds————

Non-milking Cows
- local————
- crossbreds————

Oxen————————
Heifer/Bulls————
Calves————
b) Sheep————
Ewe/Ram————
1-2 years————
Under one year————

c) Goats————
Goat/Buck————
1-2 years————
Under one year————

d) Donkeys————

e) Horses————

f) Mule————

5. Animal Production

I. local Breeds
a) milk yield (lt cow^{-1} day^{-1})————
b) lactation length (months)————

II. Cross-breds
a) milk yield (lt cow^{-1} day^{-1})————
b) lactation length (months)————

6. Expenditure on Agricultural Inputs (Birr $year^{-1}$)
a) fertilizer————
b) veterinary expenses————
c) purchase of oxen————
d) purchase of other animals————
e) purchase of improved seeds————
f) purchase of pesticides————
g) purchase of animal feeds————
h) hired labor in crop production————
i) hired labor in livestock————
j) purchase of tools ————
k) other expenses for improved inputs————

7. Cash Income (Birr $year^{-1}$)

I. Income from animals and byproducts

a) sale of live animals

Animal Sold	No/Type	Unit Price	Total
Cattle 1. Ox			
2. Cows			
3. Heifer/Bull			
4. Calves			
Sheep			
Goats			
Donkeys			
Horses			
Mules			
Chicken			
Eggs			

b) sale of butter――――――――――

c) sale of skin and hides――――――

d) horse carts――――――――――――

e) others――――――――――――――

II. Income from crops and byproducts

Crops	Quantity (100kg)	Unit Price	Total
White Teff			
Mixed Teff			
Red Teff			
Durum Wheat			
Bread Wheat			
Other Wheat			
Barley			
Chick peas			
Field peas			
Horse beans			
Lentils			
Rough peas			
Others			

8. Off-farm Income (Birr $year^{-1}$)

retail trade——————

wage——————

income from sale of labour——————

sale of fire wood——————

sale of local beverages——————

others——————

9. Size of carry-over stock of major food crops just before the next harvest (kg)

a) white teff——————
   mixed teff——————
   red teff——————
b) durum wheat——————
   bread wheat——————
   other wheat——————
c) barley——————

d) horse beans——————
e) field peas——————
f) chick peas——————
g) lentils——————
h) maize——————

10. Number of cultivations (passes with the maresha) up to seeding for selected crops
    a) teff__________
    b) wheat__________
    c) maize__________
    d) barley__________
    e) field peas__________
    f) chick peas__________
    g) horse beans__________
    h) lentils__________
    i) rough peas__________

11. Which of the following are problems of crop production (rank according to their importance 1 as very important)

Problem	Rank
a) Shortage of cultivable land	
b) Lack of ploughing oxen	
c) Deterioration of fertility of land	
d) Drought	
e) Weeds	
f) Lack of credit	
g) Lack of fertilizers	
h) Pests and diseases	
i) Shortage of labour	
j) Others (specify)__________	

12. Which of the following are problems of livestock production (rank as in No 11 above)

Problem	Rank
a) Lack of feeds	
b) Parasites and diseases	
c) Lack of credit	
d) Drought	
e) Lack of labour	
f) Poor productivity of local breeds	
g) Others (specify)________________	

13. Length of the fallow (resting) period of cultivable land (in years)________________________________

14. Fertilizer use (Kg) (1981\82 EC)

Crops	Number of Plots	Area *(Kerts)*	DAP	Urea
			Total	Toal
White Teff				
Mixed Teff				
Red Teff				
Durum Wheat				
Bread Wheat				
Barley				
Maize				
Horse beans				
Field peas				
Chick peas				
Rough peas				
Other Wheat				