Is bullock traction a sustainable technology ? A longitudinal case study in northern Ghana

by

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Is bullock traction a sustainable technology ?
A longitudinal case study in northern Ghana

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by

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List of abbreviations and symbols

#	Number
%	Percent
¢	Cedi (Ghanaian currency, 1 US $= 1065 Cedis in 1994)
BO	Bullock traction owning households
BT	Bullock traction technology (refers to the use of bullock traction at the field level or generally to the bullock traction technology)
cf.	(confer, lat.) see
CV	Coefficient of Variation
Δ	Difference (in...)
e.g.	(exempli gratia, lat.) for instance
etc.	(et cetera, lat.) and so on
f.	following (page)
ff.	following (pages)
GE	greater or equal than
GTZ	Deutsche Gesellschaft für technische Zusammenarbeit, Eschborn, Germany
i.e.	(id est, lat.) that is to say
LE	lower or equal than
MoA	Ministry of Food and Agriculture
NAES	Nyankpala Agricultural Experiment Station (now SARI)
NBO	Not bullock traction owning households (consist of rented bullock traction and hoe households)
NBT	Non-bullock traction technology (refers to fields where BT is not used for soil preparation)
p.	Page(s)
Sig.	Significance level (after statistical test)
SARI	Savanna Agricultural Research Institute, Nyankpala (formerly NAES)
T¢	Thousand Ghanaian Cedis

1 Statement of the problem and objectives of the study

The technology of bullock traction (BT) was introduced in northern Ghana in the early 1930's. By that time, the benefit of BT was not considered to be saving labor for tillage (this benefit of BT was recognized much later, as we will see below) but rather to be an important part of mixed farming as opposed to the prevailing separate production of livestock and crops. Mixed farming was thought to help increase soil fertility through integrating livestock husbandry and crop production:

> "But whilst to increase soil fertility by the use of manure is a big step forward, not to improve methods of cultivation at the same time would be to lose much of the potential value of that fertility: manuring and cultivation must go hand in hand. Animal cultivation provides the solution." (Lynn 1937:53)

This realization led to the promotion of BT in northern Ghana through school farms, demonstration fields and agricultural research stations and extension work which concentrated in the Dagomba and the Mamprusi areas. The methods of introduction and teaching of the Department of Agriculture were harsh: If a farmer wished to use animals to pull a plow or cultivator, he was helped to obtain implements only after his manure making was considered satisfactory.[1] This shows that the real intention of promoting BT was to advocate mixed farming through the combination of manuring, composting and livestock use.

Yet, by 1957, the Department of Agriculture could only count 715 farmers that practiced mixed cultivation. This apparent failure was due to a number of factors including the lack of need to change farming practices in relatively low populated areas with no food shortage and sufficient soil fertility, lacking capital to purchase bullocks, shortage of plows and implements, and a lack of veterinary services that could ensure animal health. From the methodological point of view one aspect was certainly important: the 'top down' approach and little participation of farmers which has been identified as an impediment to successful technology development.[2]

After Ghana became independent, the political priorities for agricultural development were the modernization of agriculture by introducing modern farming methods such as the use of tractors, combine harvesters, mineral fertilizers, irrigation schemes etc. A substantial breakthrough of these modern farming methods was never observed. After Ghana's economy almost collapsed in the early 1980's and economic recovery programs were implemented, the focus of agricultural development shifted towards farming practices that were less dependent on government sub-

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[1] Der (1986)

[2] See Chambers (1992), Chambers et al. (1989), Scoones & Thompson (1994), Pretty (1994); See also Hesse (1996) for the potentials of mixed farming in northern Ghana

sidies and their profitability less dependent on relatively cheap import prices caused by an overvalued currency such as tractors, harvesters, etc. Recognizing BT as labor saving technical progress that did not require costly imports as was the case with tractors and combine harvesters etc., the interest in bullock traction emerged again.[3]

In northern Ghana, the advantages of BT compared with hoe tillage were subject of a detailed investigation by Panin (1988).[4] In other West-African countries numerous authors analyzed the economic advantages of animal traction, particularly bullock traction.[5] A network of several research institutions was formed and workshops held within the region whereby research on the economics of animal traction was presented (Starkey & Ndiame 1988, Starkey & Faye 1990).

All the existing studies on animal traction are based on a similar methodological approach: the identification of the difference between animal traction and hand hoe plowing is analyzed using cross sectional data. At a certain point of time, data were collected comparing the two technologies. These studies did usually not include aspects of the sustainability of animal traction, i.e. the development of animal traction features over time. In particular, the long terms effects of animal traction on land use, labor allocation, productivity, and returns to factors of production at the field level and the long terms effects on farm-households that adopt animal traction in terms of their resource endowment, crop production management, and household income could not be looked at in cross-sectional studies.

It is therefore the main objective of the present study to contribute to further research on the long-term development of bullock traction tillage-systems over time. This follow up study to Panin (1988) investigates the developments of bullock trac-

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[3] Ghana was not the only country in sub-Sahara Africa that adopted after independence from former colonial powers policies that were designed to leapfrog the animal traction stage by providing tractors and tractor -hire services at subsidized rates. Most of these attempts to tractorization failed and several countries reverted to the encouragement of animal traction. Among those countries were Tanzania, Zambia, Guinea and Ivory Coast (Pingali et al. 1987:89). See also Kirk (1984a) for the case of Togo and Kirk (1984b) for the case of Cameroon.

[4] See also Panin (1987), Panin (1989), Panin (1990), and Panin & de Haen (1989).

[5] “Animal traction” as opposed to “bullock traction” may include (beside the use of bullocks for plowing which is the main focus of the present study) the use of donkeys and cows for plowing and for pulling carts for transportation. The authors reporting on the advantages of animal traction include: Adesina (1992), Barret et al. (1982), Brüntrup (1995), Blench (1988, 1995), Birch-Thomsen (1995), Delgado (1989), Jaeger (1986), Jaeger & Matlon (1990), Jansen (1993), Jolly & Gadbois (1996), Kirk (1984a), Kirk (1984b), Kjaerby (1983), Lassiter (1981), Pohl (1981), Pingali et al. (1987), Sargent et al. (1981), Savadogo (1994), Strubenhoff (1988), Singh (1988), Starkey (1991), Toulmin (1992), and Weil (1970).

tion within identical households that took part in the 1982/83 study in the villages of Nakpanduri, Sakogu and Gbinbalanchet in northern Ghana.

The present study is divided into the following sections:

Chapter one introduces to the problems and objectives of the present study.

Chapter two describes the theoretical background and concentrates on the question of what changes in the bullock traction tillage systems would be expected to have taken place.

Chapter three describes the methodologies applied for conducting field work and data analysis.

Chapter four presents a description of changes in socio-economic conditions in the study area with special attention to the changes in the economic-political framework such as the impact of Ghana's structural adjustment program on smallholder farmers in the study area.

Chapter five presents an analysis of the changes in the effects of bullock traction that have taken place on the field level during the past 12 years. Special emphasis is given to changes in land use, labor allocation, physical productivity and returns to factors of production between 1982 and 1994, and the importance of rented bullock traction fields in 1994.

Chapter six presents the changes in effects of bullock traction on the household level. This chapter addresses in particular the changes between bullock traction owning versus not owning households in terms of the demographic characteristics, resource endowment, crop production, household income, and the profitability of bullock traction investment.

Chapter seven addresses aspects of changes in pattern of adoption of bullock traction in the study area. A brief overview of the state of bullock traction adoption in the study area is followed by the investigation of what factors characterize households that adopt bullock traction.

Chapter eight evaluates whether the theoretical expectations elaborated in chapter two are in line with the empirical observations of chapters five to seven and presents the conclusions that can be drawn from the present study.

Chapter nine provides a summary of the present study which is followed by the list of references and the appendix.

2 Theoretical background of bullock traction as a sustainable technology

2.1 Concept of sustainability of a technology

The report “Our common future” (WCED 1987)[6] initiated modern interest of scientists and politicians with the issue of sustainability and since then the principle of sustainable development has gained general acceptance.[7] In the Brundtland report, sustainable development was defined as meeting the requirements of present generations without undermining the natural resource base which would compromise the ability of future generations to use these resources. Subsequently many authors have analyzed, criticized, and reviewed the importance of the concept of sustainability.[8]

There are, however, as many definitions of sustainability as authors who write about it. As the present study is primarily concerned with the sustainability of bullock traction within farming systems[9] of northern Ghana, a number of definitions can immediately be excluded, e.g. those that deal with sustainable development in general and those defining sustainability of projects. Turning to the sustainability of farming systems, there are three main aspects of sustainability that the great number of definitions of sustainability have in common (Hailu & Runge-Metzger 1993):

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[6] The report “Our common future” (WCED 1987) is commonly known as the “Brundtland report”

[7] The concept of sustainability has been an accepted principle of forest management for the last 300 years (Evelyn 1664: *Silva, or a discourse on forest trees*, Colbert 1669: *French Forest Ordinance*, cit. in Wiersum 1995). In 1804, a German forestry lecturer described sustainability as follows: “Every wise forest director has to evaluate the forest stands without losing time, to utilize them to the greatest possible extent, but still in a way that future generations will have at least as much benefit as the living generation” (cit. in Schmutzenhofer 1992)

[8] See for instance Batie (1989), Christen (1996), Harwood (1990), Hailu & Runge-Metzger (1993), Keeney (1990), Norgaard (1991), Markandya & Pearce (1991), Pearce et al. (1990).

[9] The term “farming systems” in this study refers to the household as a whole with all its activities. The farming system can be seen as a set of sub-systems, e.g. crop production, animal production, off farm activities etc. Among the several definitions for “farming systems” (see Manig 1993), the definition of Dillon & Hardaker (1993) seems to be most suitable for the present study: “The system of production used by a farmer as specified by the technology used, resources available, preferences held and goals pursued within a given agro-ecological and socio-economic environment”. Within this framework, the present study focuses primarily on the agricultural production of farm-household systems.

Sustainable agricultural systems

a) secure and improve the quality of the environment

b) are economical viable and also consider the demands of future generations

c) secure and improve the quality of life of the population.

Given the complexity of these key elements the present study focuses on a defined subset of these aspects of sustainability that are directly related to the technology of bullock traction. The question, therefore is not only whether or not and how bullock traction was maintained over time in the study area but also, whether it contributed to the sustainability of the existing farming systems, i.e. from an environmental, economic, and social perspective over time.

As the main focus of this study is the change in bullock traction tillage systems over time, it is important to determine the reference situation, i.e. the original situation that changes are compared with, and hence the period of time considered. In this respect there is a strong relationship between the methodology applied and those aspects of the farming systems that can be considered for the analysis of change. In this study, the reference situation is determined by the results of the dissertation of Panin (1988).[10] Therefore, only those aspects that were included in the analysis of the bullock traction tillage systems a decade ago by Panin (1988) can be analyzed for changes over time within the farming systems of northern Ghana.

These information about changes in farming systems over time include aspects that are in line with the common components of sustainability definitions, as mentioned above. Whether or not the quality of the environment is secured or improved over time can be assessed with the physical productivity, i.e. crop yields. Because yields are subject to substantial variation between years (Runge-Metzger 1993), possible differences between the years of 1982 and 1994 have to be interpreted carefully.

Whether or not bullock traction tillage systems are economically viable depends to some great extent on the question of whether the profitability of the technology BT has changed over time. Related to this is the productivity and the returns to the resources engaged in agricultural production, especially land and labor, which are directly affected by the use of BT. The effects of BT on the productivity and the returns to land and labor in addition to other household income sources also affect household income as a whole. The effect of BT on household income might serve as

[10] The study of Panin (1988) included a comparison of bullock traction versus hoe tillage. Bullock traction is therefore the one special case of animal traction that is of special interest for the present study and the term “animal traction” and “bullock traction” might be used interchangeably.

an indicator for the question of whether or not the quality of life of the people in the study area could be secured and improved over time.

Changes in the bullock traction tillage systems are, in fact, changes related to the "technology" of bullock traction. What needs to be clarified here is the meaning of bullock traction as a "technology".

According to Rogers (1995:35):

> "A technology is a design for instrumental action that reduces the uncertainty in the cause-effect relationships involved in achieving a desired outcome. Most technologies have two components: (1) *hardware*, consisting of the tool that embodies the technology as a material or physical object, and (2) *software*, consisting of the knowledge base for the tool."

In agricultural development, particularly in developing countries, changes related to "technology" are often of particular interest because a new technology is seen to be advantageous as compared to an old (mostly traditional) technology by scientists and politicians who would like farmers to adopt the new technology. The changes related to bullock traction technology, therefore, include aspects of technology choice which are discussed in the following section.

2.2 Determinants for the adoption of the bullock traction technology

2.3 Theoretical aspects of technology choice

The study of technology choice, that is the investigation of why a person adopts or rejects a certain technology, has a substantial history of academic interest. One early and important study concerning the diffusion of hybrid maize seed in Iowa of the United States was conducted by Ryan & Gross (1943) in the discipline of rural sociology. Their focus was the question of what variables were related to innovativeness and what factors explain the rate of adoption. The pattern of diffusion that they observed followed the now classic sigmoid, or "S-shaped" adoption curve. They interpreted the slope of the adoption curve as being primarily a consequence of interpersonal research networks of information exchanges.

During the mid 1980's, the disciplines of economics and, more precisely, agricultural economics, became increasingly interested in the study of adoption and diffusion of technologies.[11] The research of economists that emerged can be catego-

[11] In sociology, technology was increasingly seen as a problem rather than a solution. Modernity was increasingly seen as destruction of tradition rather than emancipation from tradition and academic interest in the study of adoption and diffusion of technologies declined (Ruttan 1996).

rized into two broad classes: (a) the conventional micro-economic equilibrium models, and (b) the newer set of evolutionary models (Ruttan 1996).

In equilibrium models, diffusion is not so much interpreted as a *learning* process, but rather as a result of a *transition* between *equilibrium levels* which are defined by certain economic conditions (costs, prices, market structures, etc.). One important aspect of research within the equilibrium tradition has been the conceptualization of the process of technological change as a *substitution* rather than a *diffusion* phenomenon. A new technology will be adopted as a substitute for an older one when it is superior (e.g. more cost efficient). Important research using equilibrium models include the development of unified invention-diffusion models (Binswanger & Ruttan 1978, Thirtle & Ruttan 1987, Ruttan 1988) and the international diffusion of technology (Hayami & Ruttan 1985, Ruttan 1995).

Evolutionary models of diffusion research focused more on detailed characteristics of each technology, degrees and forms of diversity between adopting agents, and the endogenous evolution of incentives, constraints and selection mechanisms including the evolution of relative advantageousness of different technologies (see e.g. Dosi et al. 1984). One major insight of evolutionary models is the dynamic interaction between macro and micro levels in a system that leads to the emergence of spatial and temporal patterns which are *driven*, rather than *dissipated* by micro-level diversity (Ruttan 1996).

In the case of the present study the question of technology adoption and diffusion is narrowed to the question of why farmers adopt bullock traction, why they possibly don't adopt bullock traction any more, or why they never did adopt it and, more specifically, what determines their decision. *Ex ante*, it cannot be excluded that farmers who once adopted bullock traction, remain bullock traction adopters over time. Evidence provided by Blench (1988, 1995) has shown that it might be possible that one time adopters might not maintain bullock traction adoption over time. Micro-economic theories seem more capable of explaining the reverse of the adoption as compared with evolutionary theories. Evolutionary theories concentrate mainly on future adoption *strategies* (Ruttan 1996) whereas the driving forces that explain adoption behavior in micro-economic theories (e.g. price changes causing a substitution of technology) can equally explain the reverse of technology.

The subsequent sections will therefore use micro-economic theories to explain major aspects of bullock traction benefits that might explain bullock traction adoption, non-adoption, or giving up adoption and, additionally, aspects will be discussed that might have an impact on these benefits over time. First, however, the following paragraphs briefly discuss important attributes of technology choice, as presented in the argument of Rogers (1995).

Generally, technology choice might be affected by the following attributes of a technology (Rogers 1995:36):

a) triability,

b) observability,

c) compatibility,

d) complexity, and

e) comparative advantage.

These attributes are especially important in the evaluation of the likelihood of adoption, i.e. the diffusion of new technologies. Because new technologies bear some degree of uncertainty, the *triability* and *observability* are attributes that are heavily influenced by communication systems. To reduce the uncertainty the person has to obtain information. The better information a person gets about the new technology, the better will the judgment be about the choice of the available alternative technologies. For this study, an important question is whether these communication channels that provide information to reduce uncertainty about the technology of bullock traction have changed over time.

For agricultural innovations[12], the most important sources of information about the innovation are the agricultural extension service and other farmers such as neighbors, relatives or friends. It is unlikely that the communication with other farmers will have changed over time but particular attention must be paid to the role of the agricultural extension service. The role of agricultural extension services for the adoption of bullock traction has been discussed in an interesting study by Blench (1988, 1995). Blench traveled across Nigeria to study the question of why bullock traction had not spread further south although, paradoxically, the conditions for such a spread seemed suitable, e.g. abundant land, available cattle, good road networks that allowed good market access, and low trypanosomiasis challenge (Zebu cattle were frequently found in the area). In his study, Blench (1988, 1995) interviewed farmers who had never used bullock traction, farmers who currently use bullock traction and farmers who had once used bullock traction but no longer did so. His general conclusions are:

a) the southern limit of bullock traction does not correspond to the ecological border line between the semi-arid and semi-humid zones,

b) soil characteristics (soil hardness) were not a constraint,

c) trypanosomiasis was not a general problem,

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[12] The term “innovation” refers to an idea, a practice or an object that is perceived to be new by an individual or other unit of adoption (Rogers 1995:35).

d) the cultivation of Yam which requires mounding that cannot be done by bullock traction was quite localized, but

e) "Lack of knowledge is a major cause of the failure of bullock traction to spread further south." (Blench 1995:27)

Similarly, Hailu (1990:138) found a positive association between the frequency of farmers visits to the extension service office and the adoption of bullock traction. On the one hand, these findings of Blench (1988, 1995) and Hailu (1990) suggest that awareness of bullock plowing and in particular knowledge about using the plow, controlling animal diseases, managing herds etc. is one important determinant explaining the pattern of bullock traction adoption.[13] On the other hand, examples from Ethiopia and Madagascar where animal traction has a long history suggest that agricultural extension services and external development efforts have done little or nothing to affect its progress (McIntire et al. 1992:47). Similarly, Tiffen et al. (1994) report that use of bullock plows spread in the Machakos district of Kenya early and with little government promotion. In other areas of the semi-arid tropics animal traction spread even though development programs failed or only partially succeeded (Starkey 1988).

In light of these mixed results, the present study will address the question of whether the communication channels between farmers and the agricultural extension service have changed in the study area over time and whether this has had any effects on the adoption, non-adoption or the maintenance of bullock traction adoption in the study area in the empirical part of the study.

Because the present study deals with bullock traction in an area that was already subject to an earlier detailed investigation by Panin (1988), it has to be assumed that the *compatibility* of the technology bullock traction with existing farming systems is not an issue per se. Panin (1988) conducted a cross sectional study where he compared bullock traction adopters with non-adopters, thus the technology must have been compatible with the existing farming systems of the adopters, i.e. the technology is *potentially compatible* with farming systems in the study area. Whether or not the adoption of the technology of bullock traction was compatible with the farming systems of those households that did not adopt bullock traction (including non-adopters and rejecters) seems to depend mainly on the remaining two attributes of technology choice: *complexity* and *comparative advantage*.

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[13] In the Blench (1988, 1996) study, those farmers that had previously adopted bullock traction but used it no longer included those that give up bullock traction purposely, i.e. they actively rejected it, and those that did not give up bullock traction voluntarily, e.g. after their animals got stolen or died and could not be replaced due to financial constraints. The Hailu (1990) study did not separate these lapsed adopters but only considered adopters and non-adopters.

The following sections describe the current state of knowledge about the complexity and comparative advantage of bullock traction compared to the previously used technology which is primarily the use of the hand hoe. The aim is to identify possible factors are identified that might have affected the advantages of bullock traction over time, in particular since 1982/83.

2.4 Direct benefits of bullock traction: current state of knowledge

In most studies, the advantages of animal traction, including bullock traction, have been identified as the reduction of labor requirements, the enlargement of the cultivated area, greater yields and changing cropping patterns (Pingali et al. 1987, McIntire et al. 1992). The current state of knowledge about the effect of bullock traction with regard to these factors will be summarized in the following sections in order to identify areas where changes in the effect of bullock traction on farming systems in northern Ghana are likely to have taken place.

2.4.1 Labor requirements

The effects of bullock traction on the labor requirements are theoretically well known and have been discussed elsewhere (see e.g. Ruthenberg 1985:60ff., Hayami & Ruttan 1985:90, Ellis 1993:223ff.). Instead of repeating the existing knowledge in great detail, the present study will, therefore, only highlight some of the important relationships between bullock traction and labor requirements and will, additionally, summarize recent empirical findings on this issue.

The transition from hoe plowing to animal traction plowing is a classic example of a labor saving technical change.[14] The idea that technological change is induced by changes in relative factor prices was first proposed by Hicks ([1932] 1963:124-125) in the context of labor saving inventions:

> "The real reason for the predominance of labor saving inventions is surely that which was hinted at in our discussion of substitution. A change in the relative prices of the factors of production is itself a spur to innovation and inventions of a particular kind -directed at economizing the use of a factor which has become relatively expensive."

As the cost of a factor of production rises, cheaper factors are substituted for the now more expensive one. Hicks ([1932] 1963) extended the argument to hypothesize that firms would respond to the trends in relative factor prices by focusing their search for new technologies on new methods that would permit them to substi-

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[14] *Technical change* is defined as a shift from an old to a new production method (Ellis 1993:224).

tute the increasingly cheap factors for the increasingly expensive ones. There is abundant evidence linking changes in relative factor prices to factor saving technological change (see e.g. Binswanger 1974, Binswanger & Ruttan 1978, Hayami & Ruttan 1985, Ruttan 1995).

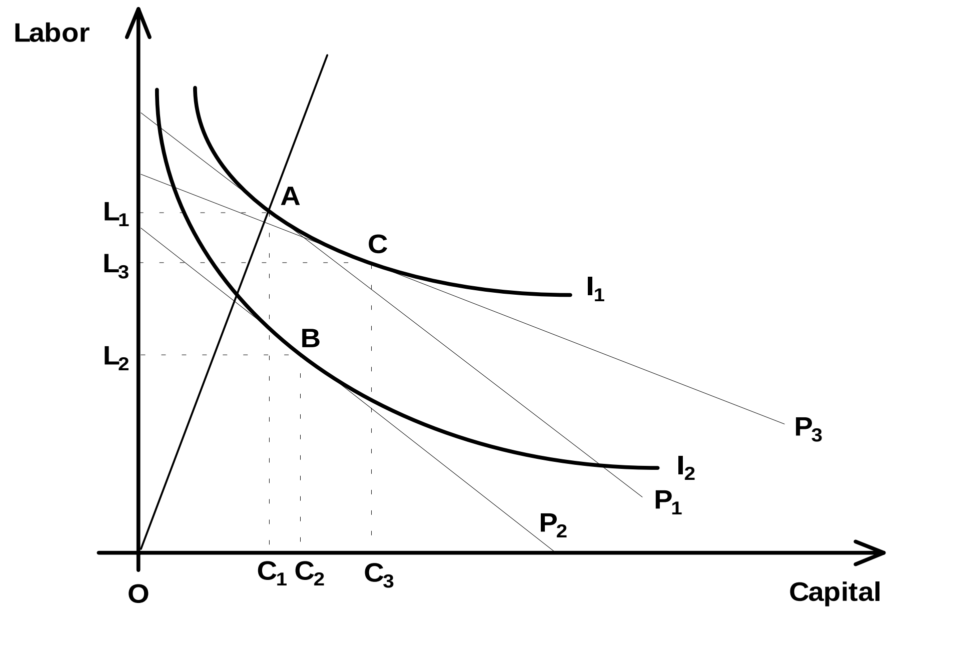
Figure 2-1 shows the implications of labor saving technical change more clearly. A shift from hand plowing to bullock traction plowing can be interpreted as a shift from the equilibrium point A to point B in the Figure 2-1. Point A represents the hand hoe situation where a certain amount of labor input (L_1) is combined with a certain amount of capital input (C_1) resulting in a given amount of output, represented by the isoquant I_1. At point A, the isoquant I_1 intersects the isocost line P_1 which slope is determined by the factor price ratio of capital to labor. Point B lies on the new isoquant I_2 which is, in fact, an inward shift of isoquant I_1, and represents all efficient combinations of labor and capital producing the same level of output with the new technology. Assuming that the factor price ratios remain constant, point B is the tangential point of I_2 and $P_{2,}$ which has the same slope as the isocost line P_1 but is shifted downwards parallel to P_1.

The new cost minimizing equilibrium point B represents the efficient combination of capital and labor with C_2 units of capital and L_2 units of labor. Compared to point A, the new technology has increased the capital input from C_1 to C_2 and reduced the labor input from L_1 to L_2. Such a change from point A to B would be a typical shift of technology such as from hand hoe tillage to animal traction plowing.

Technical change is *biased* when the factor proportions, i.e. the ratio of labor to capital, do not remain constant. A feature of labor saving technical change, such as the shift from point A to B, is that the share of labor in the total value of output falls relative to the share of capital, even when the relative prices between the two factors stay the same. In Figure 2-1, all points along the line O-A-D have constant factor proportions (see also Ellis 1993:227-30 for an extensive discussion of labor saving technical change in the tradition of Hicks ([1932] 1963)).

A different type of change occurs if the new technology is not associated with a reduction in total production cost, i.e. the isoquant I_1 remains unchanged and the same level of output is produced with a different combination of labor and capital, as is indicated by a shift from point A to point C in Figure 2-1. At point C, the labor input decreased from L_1 to L_3 and the capital input increased from C_1 to C_3 but the output level (isoquant I_1) remains the same. This substitution of one factor with another can only occur as a response to changes in the factor price ratio because it is assumed that the cost minimizing equilibrium is achieved when marginal costs equal marginal productivity, or in other words, where the marginal rate of substitution (slope of isoquant) equals the reverse ratio of factor prices (slope of isocost line).

A shift from point A to C, i.e. a substitution of labor with capital, would be the effect of a replacement of one technology with another if the new technology fails to increase total output for a given total resource cost, but results in significant displacement of labor by machines.



Source: amended from Ellis (1992:178)

Figure 2-1 Factor substitution versus labor saving technical change

Because the collection of detailed data on the allocation of labor to certain farming operations is a time and cost-intensive undertaking, only few empirical studies analyze the effect of bullock traction on the labor input. However, empirical results of the seventeen studies reviewed by Pingali et al. (1987) show that there is general agreement that the transition from hoe cultivation to bullock traction plowing reduces the amount of the total labor that is required during the time of land preparation (see also Ruthenberg 1980). These findings are in line with Pingali & Binswanger (1984) who analyzed the effect of bullock traction on labor requirements of fifty-two locations worldwide in addition to an extensive literature review.[15] They showed by employing a log linear regression analysis that the use of

[15] The literature reviewed by Pingali et al. (1987) included: Mettrick (1978), Whitney (1981), Barret et al. (1982), McIntire (1981), Oluoch (1983), Jaeger (1986), Starkey (1981) and unpublished data from the Institut National de la Statistique et des Etudes Economiques (INSEE), France; Bureau pour le Développement de la Production Agricole (BDPA), France; Compagnie Française pour le Développement des Fibres Textiles (CFDT), France; Overseas Development Ministry, United Kingdom (ODM), Institut des Savanes (IDESSA), Ivory Coast, International Crops Research Institut for the

animal traction (dummy) significantly affects the overall labor use but not the yield per hectare.

Although the relationship between bullock traction and household labor input is clear, it is less clear whether the total labor input *per hectare* declines when the plow is used instead of the hoe. This question is complicated by the fact that the use of the plow is associated with other factors that might affect labor input. For instance, it was discussed above that higher yields are often observed when animal traction is associated with the use of fertilizer. In this case, it is expected that due to higher yields the time required for weeding and harvesting will increase compared to hoe tillage, which is not associated with fertilizer use and produces therefore lower yields requiring less time for weeding and harvesting. All in all, and in most locations, the overall labor input rose when the plow replaced the hoe (Pingali et al. 1987:106ff.).

For northern Ghana, Panin (1988:68ff.) found that not only the overall labor input but also the labor input per hectare was lower for BT adopters than non-adopters. It is important to note that BT adoption in this case is limited to the transition from hoe cultivation to bullock plowing. Other features of animal traction such as weeding or transportation were not included. With regard to farming operations, bullock traction required more labor for clearing, weeding and harvesting while the labor input of ridging and planting was reduced. The use of bullock traction, however, did not affect the seasonality of labor. Bullock households used more of their own household labor (as opposed to hired labor) than non-bullock households. Panin (1988) also concluded that the burden of farm labor for woman was reduced when bullock traction was adopted.

Contrary to Panin (1988), Runge-Metzger (1991:104ff.) found no significant relationship between the use of bullock traction and the overall labor input. A dummy variable for the use of bullocks had to be excluded from a regression model with the total labor input being the dependent variable because it did not produce conclusive results. With the dependent variable representing only the labor input for June till August, the number of bullock traction working days significantly affected total labor input per household which means that the effect of bullock traction on the labor requirements was observed for the planting operations but not for farming operations in general. On a per hectare basis, Runge-Metzger (1991) found there was a lower input of labor per hectare of bullock traction adopters compared with non-adopters. This result, however, was only true for a village with lower population

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density and not for his second study village with higher population density which was characterized by a higher proportion of irrigated land.

In summary, the positive effect on labor requirements of the transition from hoe plowing to bullock traction plowing is, at least theoretically, a well established fact. Bullock traction is a classic example of what neoclassical economics refers to as *labor saving technical change*. Empirical studies have shown that the labor input for the land preparations was reduced by bullock traction compared with hoe tillage on a *per household* basis (Pingali et al. 1987, Panin 1987, Runge-Metzger 1991). There is less consistency in the empirical studies about the effect of bullock traction on the labor input *per hectare*. In some studies reviewed by Pingali et al. (1987) the labor input per hectare was not reduced by bullock traction and in other studies such as Panin (1988) and partly Runge-Metzger (1991, only one of two study villages depending on the population density) the labor input per hectare was lower for bullock traction adopters compared with non-adopters.

2.4.2 Cultivated areas

Assuming that one advantage of bullock traction adoption is the reduction of the labor requirements, as discussed in the previous section, the question is how this saved time might be utilized. Theoretically, it is possible that bullock traction adopters utilize the time that is set free by the bullock traction adoption for cultivating a larger area than their hoe farming counterparts provided that additional land is available and additional labor input satisfies the farmers preferences (labor-leisure trade-off). A larger cultivated area would directly increase the crop production income and, thus the household income (see section 2.4.5). But one problem associated with empirical cross sectional studies is that it cannot easily be determined whether larger farm sizes are the cause or the effect of bullock traction adoption.

In their review of seventeen studies about animal traction in sub-Sahara Africa, Pingali et al. (1987:98ff.) found that bullock traction households usually cultivated larger areas of land than hoe households. The fact that bullock traction households were larger in terms of the cultivated area was irrespective whether or not the locality was favorable (in terms of rainfall) or not. Bullock traction households not only cultivated larger *total* areas but also up to 25% larger areas *per person* irrespective of the ecological zone. The review of Pingali et al. (1987) therefore suggests that bullock traction leads to an increase in the cultivated area in total and per person and hence an increase in agricultural production. This conclusion is also supported in a later study by Jolly & Gadbois (1996) for Mali. The reviewed studies did not include information on the source of the additionally cultivated area, which might have been either reduced fallow or newly cleared bush land (McIntire et al. 1992:68).

In line with these findings, Panin (1988:45) found that bullock owning households had significantly larger farm sizes than non-bullock owning households in northern Ghana. The cultivated area per person of bullock traction owning households was larger than non-bullock traction owning households but not statistically significant (Panin 1988:55). By contrast, Runge-Metzger (1991:166) reported significantly larger cultivated areas per person for bullock traction owning households compared to non-bullock traction owning households in two villages of the Upper East Region of northern Ghana.

One important shortcoming of the studies reviewed so far is related to the nature of cross sectional studies. A cross sectional approach attributes differences between household types to bullock traction whereas some of the differences between the household types might be caused by factors associated with bullock traction. For instance, bullock owning households were found to be larger in terms of number of persons (i.e. consumers and producers) and wealthier. In some cases bullock traction adopters also had better access to credit markets. These differences affect both the decision to adopt bullock traction and decisions to use other advanced farming techniques such as fertilizer use, the use of better seed varieties, etc. which in turn affect crop production performance, household income, etc.

In conclusion, recent studies in West Africa in general and in northern Ghana in particular show that bullock traction adopters are cultivating larger areas on a *per household* and a *per person* basis. But it has also been shown that bullock traction adopting households are usually larger and wealthier. They, therefore, have a larger labor force or have more financial resources to hire more labor than households of non-bullock traction adopters. From the literature review it is not clear whether larger cultivated areas are a consequence of the adoption of bullock traction, or whether bullock traction is the effect of larger cultivated areas or whether other factors that cannot be attributed to bullock traction could have caused the observed differences.

2.4.3 Yields

Before the issue of the effect of bullock traction adoption on crop yields is discussed in detail, one must ask why yields of bullock traction tillage should be different from non-bullock traction tillage? Whether or not a yield difference is associated with the switch from one tillage technology to another is first of all a question of what technologies are compared (zero tillage with hoe tillage or hoe tillage with bullock traction tillage?) and, second, a question of what underlying mechanism actually causes the difference.

According to Pingali et al. (1987:102), crop yields of one tillage technology compared with another might be higher when the “quality of tillage” is improved. The “quality of tillage” might be improved in the following situations:

a) zero tillage is replaced by tillage, in which case the type of tillage technology (hand or plow) is irrelevant,

b) shallow plowing is replaced by deep plowing,

c) a change in plows takes place, e.g. from a scratch plow to a moldboard plow,

d) using the plow compared with the hoe allows a more timely completion of land preparation and subsequently planting and weeding.

In addition, Starkey (1991) provides examples from Ethiopia where yields were more reliable in years with lower rainfall due to an improved seed bed preparation, called “broad bed” ridge formation which was a consequence of a switch from one tillage technique to another. Other factors that might explain differences in yield response to tillage include (Pingali et al. 1987: 102ff):

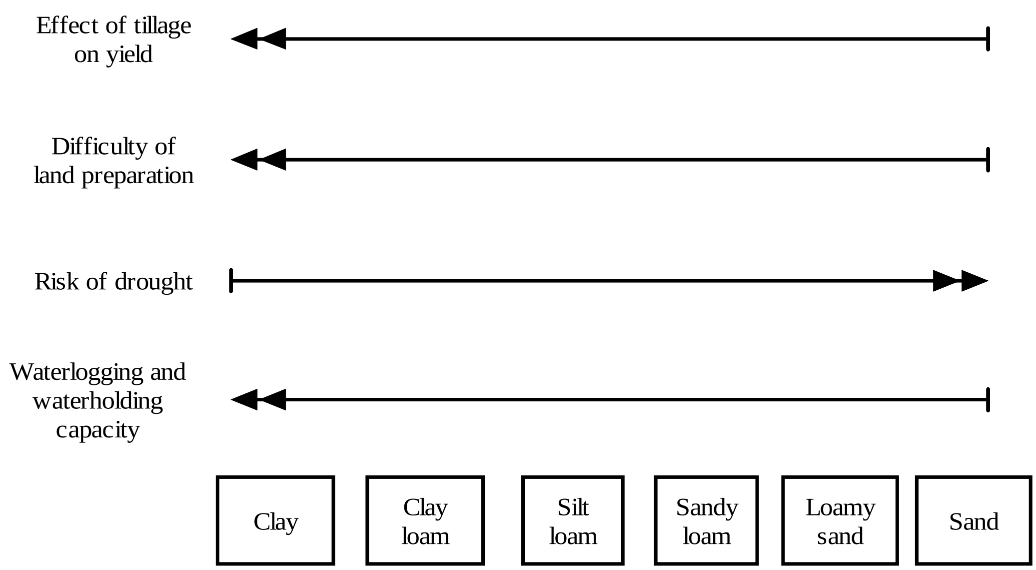
a) the soil type,

b) the toposequence in relation to soil types, and

c) crop specific responses to tillage.

With regard to the soil type, tillage is most responsive on clay soils and least effective on sandy soils, as shown in Figure 2-2. The reason for this is that tillage improves the physical condition of the clay soil by increasing the porosity and changing the poresize distribution. This in turn improves the aeration, root penetration and water infiltration and reduces evaporation (Nicou & Charreau 1980:373). Additionally, weed control may be carried out more easily.

With regard to the toposequence, Pingali et al. (1987) found that animal traction usually started in bottomlands before it spread to mid and upper slopes. There are bound to be soil differences between the floor of the valley and the summit of a hill. They argue that farmers will start using cultivating the bottomlands and then gradually move upwards, in the course of time, because the best quality soils are to be found in the valleys. This argument, however, is related to the effects of population growth which will be discussed below (see section 2.5.1). In the study area, the landscape does not vary in altitude such that a cultivation shift from valleys to highlands would be possible. Thus, the issue of toposequence and soil types in relation to animal traction is not relevant for the study area.



Source: amended from Pingali et al. (1987:60)

Figure 2-2: Soil characteristics and benefits of plowing

Crop specific responses to tillage were investigated in field trials between 1952 and 1969 by the Institut de Recherches Agronomiques Tropicales (IRAT). According to Charreau (1974:237 cit. in Pingali et al. 1987:62) the lowest yield response to tillage was observed for groundnuts and highest for rainfed rice. The order of crops according to relative yield increases through tillage was: rainfed rice (36%), sorghum (29%), maize (27%) and cotton (27%), pearl millet (21%) and groundnuts (19%).

However, differences in yield response according to the soil type, the toposequence, and the specific crops grown as described so far were derived solely from observations comparing tilled areas with untilled areas. This means that the improvements primarily come from plowing the soil compared with not plowing the soil at all. For the purpose of the present study it is more relevant to focus on the shift from the hand hoe plowing to bullock plowing, because this was the initial focus of Panin (1988) although the practice of zero tillage cannot be excluded beforehand. For the present study, therefore, it is important to note that the question of whether yield differences are associated with a shift from the hand hoe to the plow is thus the question of whether the switch from the hand hoe to the plow is associated with a better quality of tillage. Because it is technically feasible to achieve a given quality of tillage by using either a plow or a manual technique, it might be difficult to observe yield differences between hoe and animal plowing that are directly caused by the tillage technology, as will be seen below in the review of the existing literature.

Theoretically, the positive *ceteris paribus* effect of bullock traction on yields directly increases the crop production income and thus the farm-household income (see section 2.4.5). In the terminology of neoclassical economics, the positive effect of bullock traction on crop yields can be described as an upwards shift of the production function that represents the relationship between yields and an input, say labor. Two different shifts of the production function are possible, and can be distinguished in Figure 2-3, which shows a shift from the curve O-N1-G1 to O-N2-G2 and alternatively a shift from the curve O-N1-G1 to the curve O-N3-G1. The first shift represents the improvement of the quality of tillage by, for instance, replacing zero tillage with tillage (irrespective whether bullock traction or hoe), replacing shallow plowing with deep plowing. This upward shift (O-N2-G2) allows to achieve a higher maximum yield as compared with the default situation (O-N1-G1). Note, that from a certain amount of labor input, A1, the production function becomes horizontal because it is unrealistic to assume further increases in yields by increasing the labor input beyond a certain level.

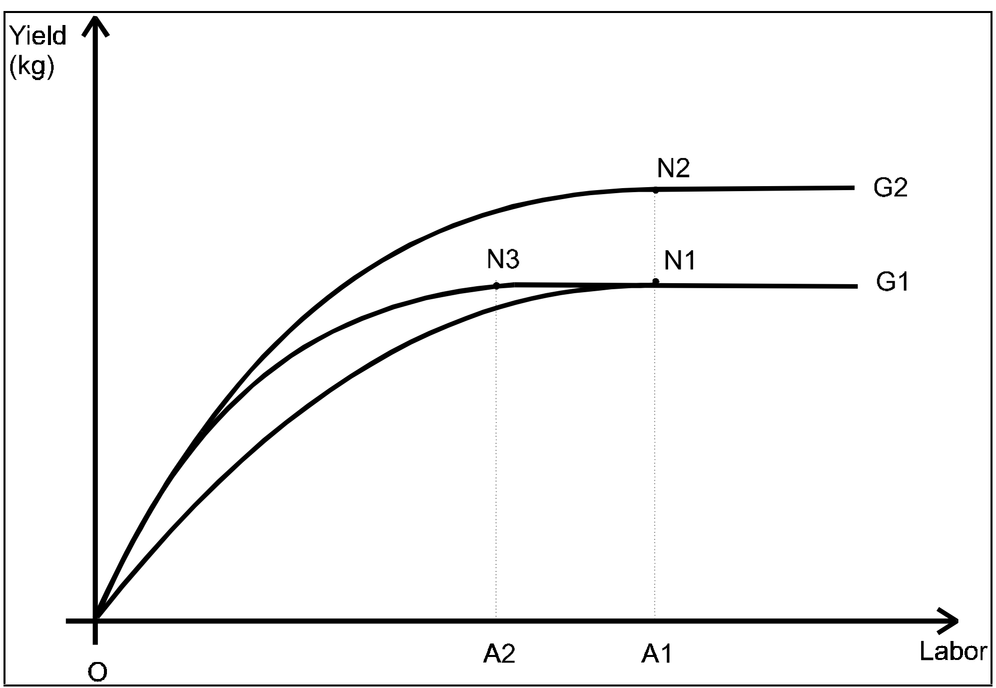


Figure 2-3: Theoretical effect of bullock traction on the production function

This shift assumes that the input of labor A1, that marks the maximum amount of labor causing further increments of yields, remains unchanged when *ceteris paribus* the quality of tillage is improved. An alternative assumption is that the "quality of tillage" is less related to soil physical characteristics, but *ceteris paribus* to the improved timeliness of plowing, planting, and weeding that is the effect of replacing hoe tillage with bullock traction. Then it is more realistic to assume a shift from the original curve O-N1-G1 to the new curve O-N3-G1. In this case, the maximum yield that could be achieved by using the new technology that characterizes the curve O-N3-G3 is not higher than that of the default curve O-N1-G1. But here the point is that bullock traction plowing produces the same yield for less labor than hoe plowing. Thus the maximum amount of labor that allows further yield increments shifts from A1 to A2.

The overall effect of replacing the hand hoe by bullock traction on crop yields might be of the type O-N2-G2, i.e. improving the quality of tillage by improving soil physical characteristics, or of the O-N3-G1 type, i.e. improving the timeliness of tillage, planting, and weeding, or a combination of both. How these effects of the replacement of hoe tillage with bullock traction interact is not easy to investigate in empirical studies because the pure effects of bullock traction on crop yields are difficult to isolate form other yield affecting factors, as demonstrated in the following review of empirical work that focuses on the effect of bullock traction on crop yields.

In the seventeen studies reviewed by Pingali et al. (1987), some show a positive, some a negative and some no relation between the use of animal traction and yields. In those cases that showed a positive relation between animal traction and yields, it was clear that animal traction was *associated* with higher yields but it was not clear whether animal traction had *caused* higher yields. One confounding fact is that the use of animal traction was in most cases associated with a higher use of other yield affecting factors such as mineral fertilizer or improved seed varieties. Where animal traction was associated with the use of fertilizers the higher yields attributed to animal traction may in fact be attributable to the use of fertilizers.[16]

The seventeen studies reviewed by Pingali et al. (1987) did not always specify whether the comparison was between animal traction and hoe plowing (major effect: timeliness), animal traction and zero tillage (major effect: soil physical characteristics), or a combination of both. Advantages of animal traction adopters compared with non-adopters in terms of yields might have been over estimated in cases where,

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[16] For the association of animal traction with fertilizer use see also Barret et al. (1982), Lassiter (1981), Jaeger (1986), Kirk (1984), and Hailu (1990). Jolly & Gadbois (1996) report higher yields for bullock traction adopters in Mali but do not provide further insights regarding the mechanisms that produce higher yields.

for example, fields that were not plowed at all were included with fields that were plowed by hoe. In this case, the comparison of adopters with non-adopters includes both the comparison of tillage with non-tillage and the comparison of animal traction tillage with hoe tillage. The field trials reviewed by Jaeger (1986:6) show that when tillage is compared with zero tillage, the tilled fields have significantly higher yields.

Jaeger (1986) stressed that the effect of animal traction on yields can best be measured at the field level instead of at the farm-household level. This is because the different effects of improving the quality of plowing, timeliness of plowing, planting and weeding, and the association of animal traction with other yield affecting factors might confound the analysis at the farm-household level where several different tillage technologies (animal traction plowing, hoe plowing, no plowing) are combined at the farm-household level. Therefore, it is problematic to measure the effect of bullock traction on crop yields by cross-sectional comparisons of group means with bullock traction yields being one group non-bullock traction yields being the other group. The most appropriate analytical tool to assess the effect of bullock traction on yields is therefore the production function analysis at the field level because this procedure allows one to isolate the effect of bullock traction from other yield influencing factors.

Jaeger (1986) employed the production function approach to measure the effect of animal traction on crop yields in Burkina Faso. He found that animal traction was a significant variable explaining yield variation only in the case of maize and groundnuts fields and not for other crops. His analysis, however, was a comparison of fields that were plowed with animal traction (bullock and donkeys) with fields that were not plowed at all. He concluded that the difference in soil types and rainfall between the sampled fields caused high variation in yields between the fields, and thus animal traction was not a significant variable for explaining crop yield variations for all crops.

In northern Ghana, Panin (1988:61) showed a positive effect for bullock traction on yields at the field level using the production function approach. Runge-Metzger (1991:115) found a positive association of bullock traction with yields in only one out of his two study villages. The village where the positive yield effects of bullock traction were found was characterized by less land shortage compared with the village where no relation between bullock traction and the physical productivity was observed. More timely tillage was not observed by Runge-Metzger (1991:118). However, the association between the adoption of bullock traction and fertilizer applications is not discussed by Panin (1988) or Runge-Metzger (1991) whereas Hailu (1990:138) found a significant relationship between bullock traction adoption and fertilizer use in northern Ghana. It is also unclear in the Panin (1988) and the Runge-

Metzger (1991) studies to what extent zero tillage fields were included in the comparison. It appears from their studies that the default situation is hoe plowing which is compared with bullock traction plowing but a careful look at Table 12 in Panin (1988:61) reveals that the non-bullock traction fields included fields that were either tilled by hoe or not tilled at all. This means that Panin (1988) provides evidence that in northern Ghana at least some fields might not be plowed at all which might bias the results of the comparison of yields of bullock traction versus non-bullock traction fields.

In summary, higher yields theoretically increase household income by increasing the crop production income. The major means by which bullock traction might affect crop yields are the improvement of the soil physical characteristics (replacing not plowing with plowing or replacing shallow plowing with deeper plowing) and the timeliness of plowing, planting, and weeding (replacing hoe tillage with animal traction). The effect of bullock traction on crop yields can theoretically be described as an upward shift of the production function. Pingali et al. (1987) concluded from a review of seventeen empirical studies that the positive effect of animal traction on crop yields has been often caused by factors that were associated with animal traction, such as fertilizer use, rather than animal traction itself (this relationship has also been observed for northern Ghana by Hailu, 1990). The best analytical tool to measure the effect of bullock traction on crop yields is, therefore, the production function analysis (instead of cross-section comparison) at the field level instead of at the farm-household level (Jaeger 1986). For northern Ghana, Panin (1988) found there were higher yields for bullock traction fields than non-bullock traction fields by using the production function analysis. In the study of Runge-Metzger (1991) in northern Ghana, the effect of bullock traction on crop yields depended on the study village location. A positive association of bullock traction with yields was found in a village with less land scarcity compared with the other study location. Both these studies may confound zero tillage and hoe tillage.