the time-consuming process of turning the teams at the end of the field (figure D 20).

The greater the investment in the training of the draft animals and the more experience the animals possess, the higher is their value. In addition, close ties often exist between the owner and the draft animals. This furthers a longest possible working life of the animal, which can end with the death of the animals from old age.

Generally, in the determination of the working life of the animals the following factors play a role (according to Bonnet, et al., 1988):

– the availability of younger animals suited for harnessing,

– the increasing resistance to disease with increasing age of the animals,

Fig. D 20: Faster turning of the team with a second person during weed control in South Brazil (Photo: Schmitz)

– the investment for training the animals and/or the demands of the owner on the degree of training of the animal,

– the demand for meat of the respective animal type in the region.

While the returns for draft animals such as donkeys, whose meat is not eaten, increase progressively with their working life, a high demand for beef can cause the duration of utilization for draft cattle to be reduced.

In contrast to herded cattle in the Sine-Saloum region in Senegal, draft animals receive more intensive feeding and better veterinary services. Thereby, they achieve a better weight development and heavier carcasses for slaughter. (Reh, 1982) Animals are scarce due to the high demand for meat. Young animals already begin training from the age of two years for draft power. This leads to a better exploitation of fodder resources; however, if the animals are only utilized for approximately three years until slaughter, the draft oxen have not reached their full draft power potential. (Lhoste, 1986) This aspect hardly plays a role however, since no heavy plowing is done in this region because of the short vegetation period and the light soils.

In summary, the high investment for training the draft animals must be weighed against an intensive use of meat and the connected short duration of utilization of the draft cattle. In addition, the increased demand for meat near the consumer centres simultaneously increases the risk of theft; whereby, more docile trained animals are easier to steal than untrained (Bonnet, Guibert et al., 1988). For poorly trained animals and a brief annual duration of their utilization, on the other hand, a sufficient availability of labour is necessary for managing work operations.

E. Aspects of implement use

1. Labour productivity and distribution

1.1 Productivity

Animal traction serves especially the purpose of reducing work peaks by means of mechanizable work operations, expanding the cropping area, making the work easier or facilitating the cultivation of heavy soils (e. g. river valley bottoms). According to Pingali et al. (1987) mechanization initially occurs with energy-intensive and – for the farmer – toilsome work operations. Thus, the draft animals are generally first employed for seedbed preparation (transition from hand hoe to the plow) and for transportation. In the first years following their introduction the draft animals are only used for a few work operations, so that the labour productivity (yield per labourer) does not increase, in comparison to the farms without animal traction. The labour-saving effect is at first often cancelled out by more thorough land clearing (destumping) and animal husbandry.

Also the area productivity (yield per hectare) generally does not increase alone by means of mechanization. In comparison to soil tillage with the hoe the yield due to plowing does not expand (Pingali et al., 1987; Strubenhoff, 1988; see section C 4.1). The area productivity can actually decline due to a reduction of mixed cropping. Planting can follow a certain time plan more accurately, however this advantage is temporarily eliminated during the period of expansion of the area under crops. On the other hand, more rapid and frequent weeding with draft animals can increase the yield considerably, although one can generally accomplish more thorough work with the hand hoe.

Increasing intensity of draft-animal use, also for all work operations, considerably increases the benefits of draft-animal technology. In drier regions the increase of area performance for cultivation and seeding at the start of the rainy season to reduce the risk is particularly important. Pre-conditions are however that

- the cropping area is not expanded,
- the danger of animal loss is low,
- the implements are reliable and do not represent an additional risk by down-time due to poor spare part and material supplies.

If the vegetation period is too short, the implements cannot be fully exploited and their purchase is not worthwhile. Animal traction can then only be introduced under certain conditions, such as for light soils and low potential of weed invasion (e. g. in Senegal), via direct seeding with an animal-drawn seeder (see section F 3, case study: Senegal).

In part, profitability is first achieved with additional hiring out of the animals and the implements (Kirk, 1987; Strubenhoff, 1988). This can include assistance to relatives or neighbours as well as wage labour or labour exchange, for example plowing against hoe-

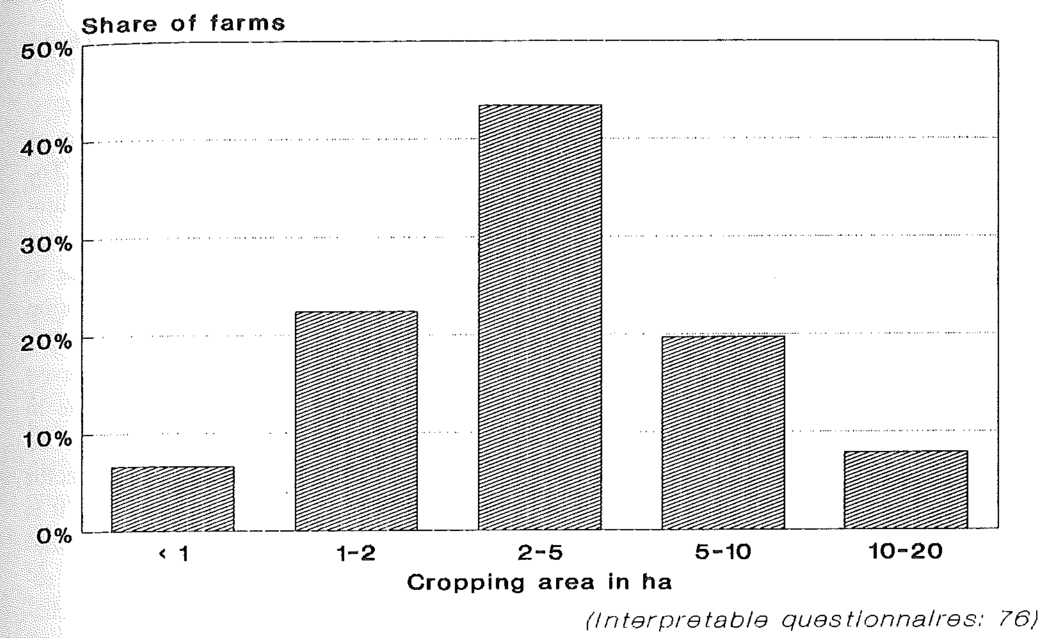
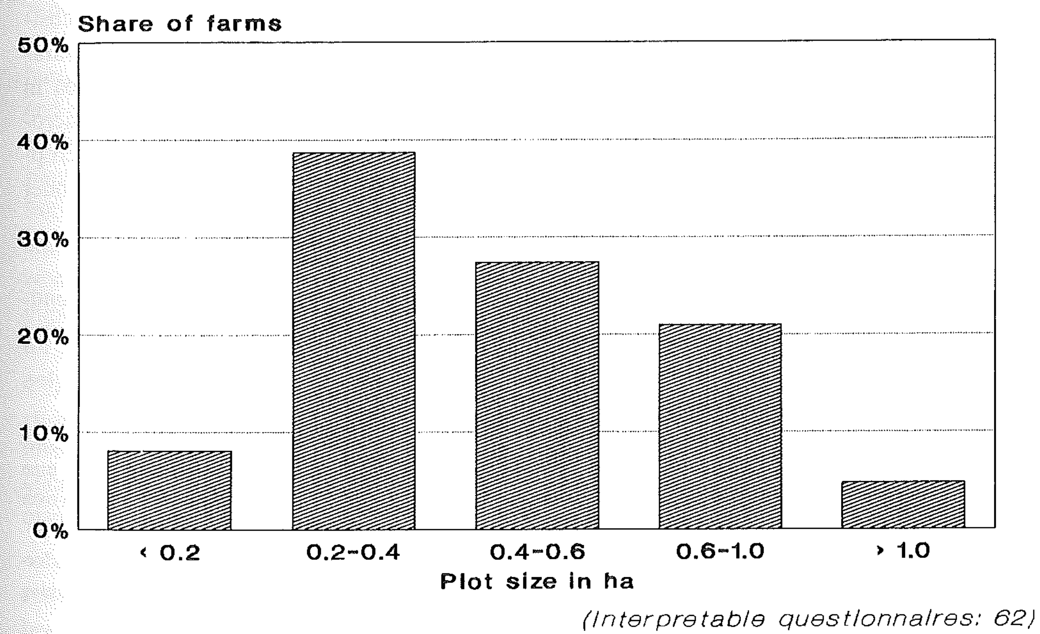


Fig. E 1: Survey results for cropping area in the draft-animal regions

Fig. E 2: Survey results for plot size in the draft-animal regions



ing weeds. This possibility only exists as long as a larger proportion of farmers do not own draft animals. The danger exists that the social position of a few draft-animal farmers will be improved at the cost of the hand-hoe farms, as has been reported from Zambia (Kurbjuweit, 1989). In the survey it was found that hiring out occurs in approximately half the cases.

The farm areas in the draft-animal regions predominantly have a size of between 1 and 10 ha (86%), close to three-quarters are smaller than 5 ha (figure E 1). The plot sizes usually are between 0.2 and 1.0 ha (figure E 2).

In 73% of the cases the draft-animal farms are being expanded. If animal-traction measures are in the introductory phase of a development project and are still limited to the farmers under the supervision of the project, then an expansion is occurring in all the cases according to the survey. In regions having permanent cropping and better developed mechanization the expansion is found to a lesser extent. These areas are characterized more frequently by high land-use intensity, distribution and tradition of animal traction, greater mechanization of work operations such as weeding and seeding as well as the employment of tractors. Particularly in the initial phase of draft-animal use, it must be reckoned that cropping areas will expand, whereby either new areas are cropped, the fallow is reduced or a redistribution of land to the advantage of draft-animal farms takes place.

The maximum area that can be cultivated by draft animals depends, among other things, on the duration of the vegetation period and the daily working time of the team. In North Cameroon the limit is 3.2 ha per season for plowing and 4.4 ha for ridging (Kirk, 1987). Here the teams are used daily for 5 hours. Strubenhoff (1988) assumes a maximum of draft-animal labour to be 400 hours in Togo[1]. On the basis of pure calculations this limit would be achieved with the cropping area of 10 ha (plow) and 15 ha (ridger). Due to the time limitation for seedbed preparation because of the short growth period the capacity limit should already have been achieved with 8 ha. In humid areas, for example in South Brazil, a greater cropping area can be cultivated. There a transition to the tractor takes place above 15 ha cropping area. It is interesting that the profitability of motor mechanization in rainfed cropping in this region is only achieved with 35 ha of mechanizable cropping area (double-axle tractor, no vegetable cropping) (Klingensteiner, 1987). Between the maximum area of 10 – 15 ha, which can be cultivated with a span, and the mentioned 35 ha there exists a large gap that, considering low wages and world market prices for agricultural products, can only be closed by hiring out, if state subsidies are not included. The economic minimum is set at about 5 ha cropping area in Togo, which also applies for North Cameroon (climate: semihumid/semiarid). The cropping area of most farms however lies under this figure according to the survey.

Because of the greater power force expended during the work peaks to date a displacement of work to other periods of the year occurs for animal traction. Thereby, regionally varying modified work peaks could be created for non-mechanized work operations.

1 Assumption for the Savanes region: working time with teams 6 h/d, 6 d/week, equals 120 h/month over a period of 3 -4 months; proportion of seedbed preparation in draft-animal labour 50%; area performance 20 h/ha for plowing and 15 h/ha for ridging (Strubenhoff, 1988).

1.2 Labour distribution

Depending upon the structure of a farm-household system the available labour force, the investment capacity and the incentive to mechanize can vary substantially. Mechanization can reduce the load or increase the burden of men, women and children to a varying extent. Since in general only a certain number of working hours can be achieved by the farms, changes in the time investment for the different work operations can have a direct impact on the remaining work. According to Kirk (1987) in North Cameroon the work peaks can shift from seedbed preparation to harvest by the exploitation of all possibilities of mechanization with animal traction. One part of this work can be accomplished by increasing the burden on the family members (e. g. women and children for weeding) or transfer to seasonal labourers, depending upon the kind of distribution of labour in the family. Family labour forces should be used to the maximum. (Persoons, 1988) It is only worthwhile to do other work with draft animals and to invest in new implements in addition. This applies especially for seeding, which generally is a work peak only in areas having short vegetation periods. At the same time, however, it requires a high investment for equipment and places demands upon the technical level in terms of utilization, maintenance and repair.

As long as some work operations have not been mechanized the expansion of cropped areas will continue to lead to an increased mobilization of hired labour from outside the farm. Animal traction increases the overall demand for labour forces, especially seasonally (Kirk, 1987). Rural exodus and land distribution are the primary factors which influence the supply of labour forces. In South America a class of landless rural farm workers is being created due to the extreme concentration of land ownership and releasing of labour forces in the course of motor mechanization; this differs from the situation in Africa.

In Africa animal traction is particularly being introduced by larger families who can afford the investment and additional expenditure arising from the expansion of cropped areas or animal husbandry. The increasing importance attached to formal education leads however to the phenomenon that child labour, e. g. for tending the animals, competes with school attendance.

The division of labour based on gender is highly influenced by ethnic and religious backgrounds. Some ethnic groups do not allow the women to participate in agriculture. Generally, the women in Islamic regions, for example, the Toucouleur, Fulbe and Haussa south of the Sahara are seldom seen working in agriculture, which leads to an increased demand for labour forces from outside and favours the advancement of mechanization. (Valentin and Spittler, 1976; Kirk, 1987)

In general, draft-animal work is carried out by the men. Women and children do manual work such as weeding. The problem exists that animal traction can be an advantage to the men, in that by the undertaking of tasks such as transport or expansion of cropped areas at the cost of women's fields they attain a better economic position. Credits for teams and equipment are mostly directed to the men.

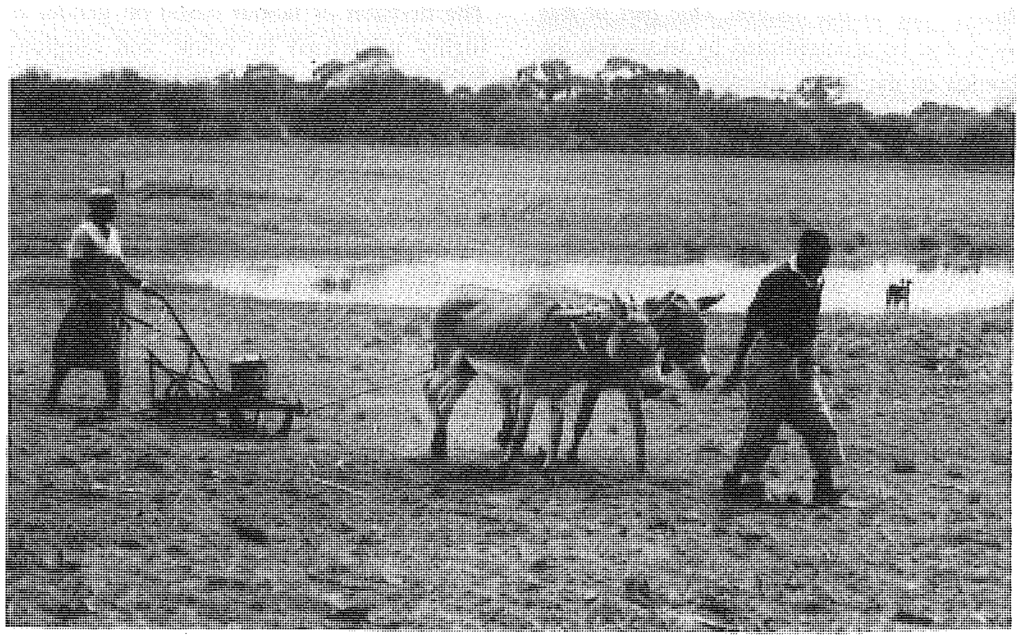
In many regions, particularly in Africa, the women have their own fields and the profits do not always flow into the family budget. In a project in the Northwest province of Cameroon it was attempted by the introduction of animal traction to make the work on the women's fields easier and to integrate the men into cropping of fields, since the importance of their traditional activities (hunting, harvesting tree crops) was receding. The project was exclusively directed to the men, who became owners of oxen with their own fields by way of a loan contract. The position of women was adversely affected since

– their workload increased due to non-mechanized tasks with the expansion of cropped areas,

– the traditional women's fields were reduced, leading to a decline in the income of the women and their diminishing social standing.

Following the outbreak of protest from the women, who saw themselves being reduced to mere farmhands, the programme was extended also to include the women. Nevertheless, the additional workload and the minimal amount of animal use remains a problem on the women's fields which are difficult to mechanize (mound cropping). (Bruchhaus, 1984; Zweier, 1986)
Many farms are run solely by women, especially in the areas bordering South Africa. In Botswana and Lesotho this applies to 40 – 50% of the farms. Tasks done with draft animals are conducted by the women (figure E 3); only plowing remains a matter for the men.

Fig. E 3: Draft-animal work on farms managed by women in Botswana (Photo: Nüsing)



In South Brazil the distribution of tasks is influenced by the European immigrants:

- The men work with implements on the fields. Storage, transportation and marketing are also their domain.
- Women on the whole work more. They take care of the household, the garden and the animals. Weeding with the hoe and harvesting are also among their main tasks.
- Seldom does a woman operate draft-animal implements or the tractor.
- On the other hand, men are more often observed to be daily wage earners in weeding and harvesting, especially in coffee and cotton growing regions.

Mechanization can therefore have an impact on the intra-family division of labour, create a demand for labour forces outside the family and lead to a supply of services for draft animals.

1.3 Crops

Only certain crops are suited for mechanization, which merely plays a subordinate role for permanent cropping. Only weeding is carried out with draft animals in some permanent crops, e. g. coffee in Brazil. Some tuberous plants such as yam are difficult to mechanize. A balanced working calender for the Centrale region (figure E 4), additionally favoured by the tropical rainy climate, renders the use of implements superfluous, while the working calender in the drier Savanes region (figure E 5) shows up defined work peaks (see section F 2, case study on Togo).

Most annual crops, on the other hand, are easy to mechanize. Crops which are broadcasted such as wheat or barley only require the draft animals for plowing and in some cases for harrowing. Draft-animal implements facilitate especially seeding and weeding of crops such as maize, sorghum, beans, cotton or groundnuts, where row cropping is combined with the demand of a wide spacing. Weeding is especially important for plants that possess the trait of a slow initial development. Crops which are traditionally connected with ridging can easily be mechanized. The ridger is also partially used for both soil preparation and weed control.

Since the introduction of animal traction is today frequently done in conjunction with growing certain cash crops, e. g. labour-intensive cotton, a considerable surplus investment can occur with harvesting. As a consequence of modified work peaks due to the expansion of areas under cash crops there is less time available for work operations for other crops under some circumstances. The cropping schedule therefore changes because of mechanization. Thereby, typical crops can become prevalent according to the respective level of mechanization. For example, in South Brazil beans which are predominantly harvested by hand are primarily grown on smallholdings that work with animal traction, whereas it is more advantageous to produce wheat and soybeans on larger motor mechanized farms due to the possibility of mechanizing the harvest.

Mechanization with draft animals has an impact on mixed cropping systems. In these systems there is an interaction between the different plant types, for a minimum of two crops, at least during a part of the vegetation period. They build up a system similar to the natural vegetation forms, as opposed to pure stands with only one plant type. Particularly in traditional cropping systems aimed at sus-

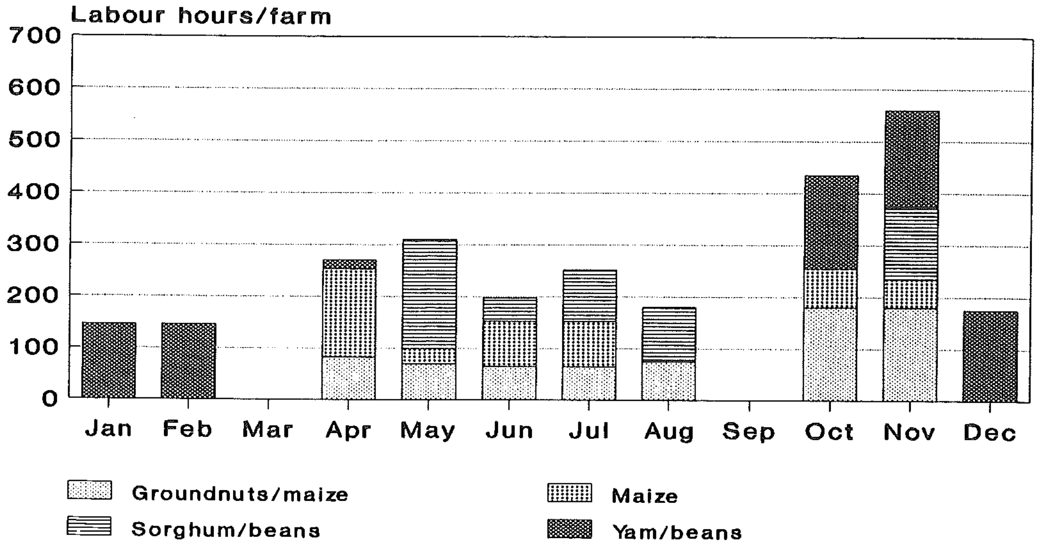
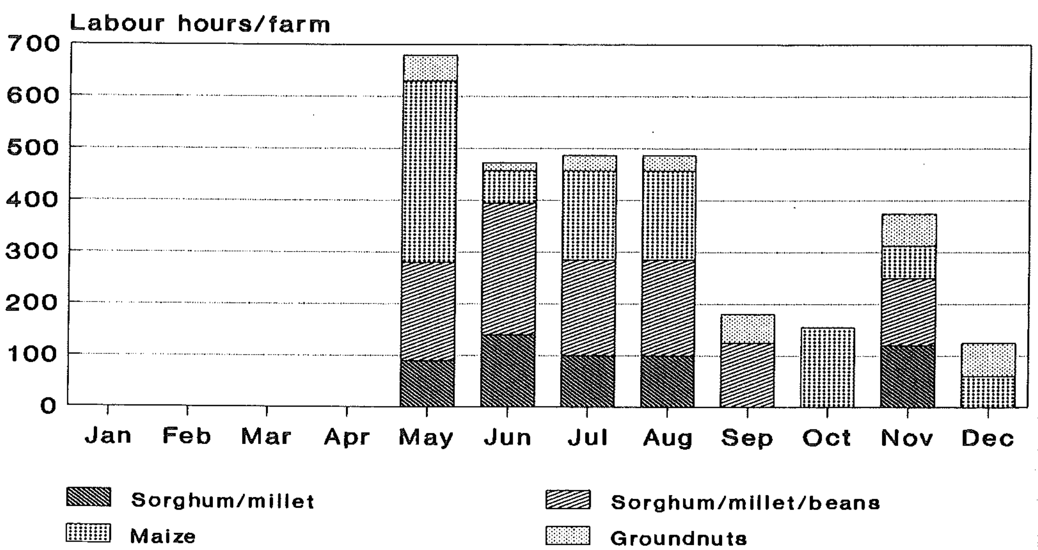


Fig. E 4: Working calender for the Centrale region. Source: Strubenhoff (1988)

tainability, numerous stable, very complex mixed cropping systems have evolved. In contrast to pure stands they have the advantage with otherwise identical conditions that they yield a larger and more certain harvest on the same area, exploit the soil more efficiently and provide a more complete soil cover (erosion control, low weed invasion, low evaporation). (Müller-Sämann, 1986; Steiner, 1984; Vieira, 1985)

Fig. E 5: Working calender for the Savanes region. Source: Strubenhoff (1988)



Sanchez (in: Andrews and Kassam, 1977; modified), distinguishes, aside from crop rotation systems, between the following mixed cropping methods:

- mixed intercropping: mixed crops without any regular arrangement, mechanization can only occur for soil preparation
- row intercropping: two crops simultaneous or sown in rows in very close succession (e.g. maize and beans either in separate rows or alternately in the same row); well suited for mechanization with soil preparation, seeding with animal-drawn implements can be rendered more difficult due to protracted seeding dates, closer spacing causes problems for weeding
- strip intercropping: two crops in narrow plots beside each other; no problems for mechanization
- relay intercropping: staggered planting within one vegetation period with overlapping of partner crops; soil preparation and seeding of second crop is difficult
- multi-storey cropping: association of small annuals and higher perennials; unproblematic with sufficient vertical and horizontal spacing.

Mechanization by means of animal traction requires in part a modification of these cropping systems, since the plots can no longer be uniformly cultivated and tilled. As long as only the seedbed preparation is mechanized mixed intercropping systems can be maintained without any regular arrangement if the seeding times of the included crops are not too far apart. In Botswana with mixed cropping of maize, sorghum, cowpea and other plants broadcasting is practiced and the seed is subsequently plowed in with draft animals (Nüsing, 1989). On the other hand, mound cropping, as with the women's fields in Northwest Cameroon, cannot be easily mechanized. The introduction of animal traction is connected with a reduction of such cropping systems and, in general, a transition to row cropping occurring in parallel. The simultaneous planting of two different crops could be done with seeders by initially sowing every second row. In Brazil, an animal-drawn implement has been designed to sow beans and maize together (Mantovani, 1986). It is more difficult to seed if, for example, maize is sown two weeks after beans, or if beans are sown in a nearly mature maize stand. In order to avoid damage to the neighbouring crop seeding is usually done manually. A very efficient hand-operated seeder is being used in Brazil (see section G 2: case study Paraná). Weeding becomes difficult if the row spacing is too small and one plant type has already developed further. In this case a single-blade cultivator is employed, which however often causes damage to the roots of the crops, or weeding is done by hand hoe. (compare Erbach and Lovely, 1977)

In part, the share of mixed cropping is being reduced in order to achieve better work with the cultivator. Also, chemical fertilizer and herbicides are increasingly being applied, although it is very difficult to proportion the dressing in concert with the needs of the adjacent plant. This constraint ultimately triggers the gradual disappearance of mixed cropping systems.

1.4 Work operations

In the survey the proportion of work done with draft animals in the individual work operations – clearing, seedbed preparation, seeding, weeding and transportation – on the farms was investigated (see questionnaire in annex I). The percentages total to 100%, so that changes in the emphasis on singular operations have direct consequences for the share of other work operations. Since no draft animals are normally used for harvesting in the regions examined (only for transporting the crop), a shifting of labour investment for the individual work operations, e. g. with greater cropping area, cannot completely be determined in the survey.

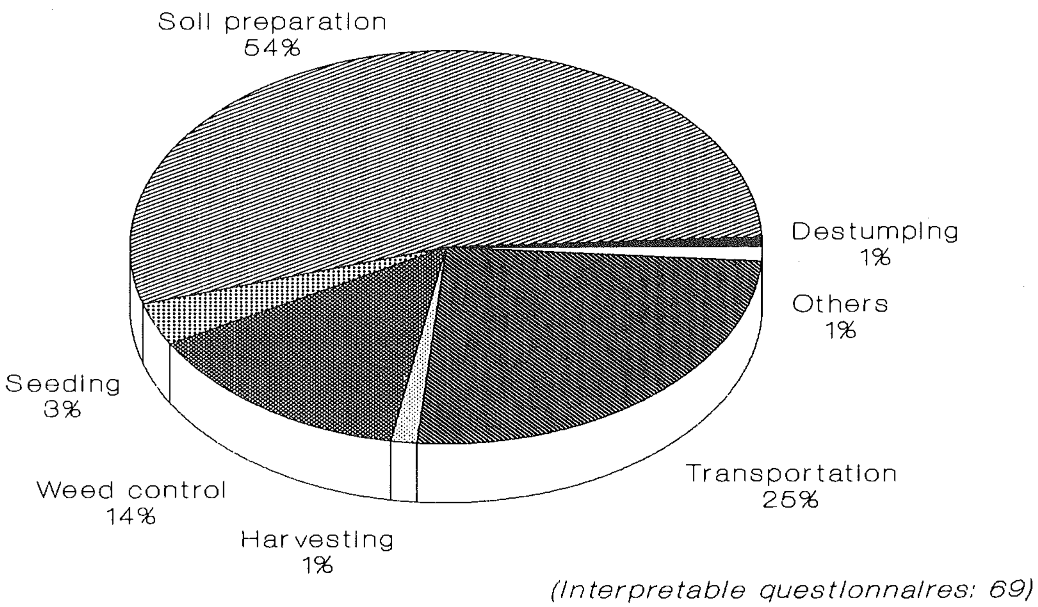
On the average, soil preparation with draft animals takes up the largest share, followed by transportation, weed control and seeding (figure E 6). Clearing and harvesting as well as other work operations (such as threshing) are not significant for animal traction according to the survey. The figures must be attributed in part to soil preparation or transportation.

Soil preparation (plowing, cultivating, ridging) is without exception in all cases a component part of draft-animal work. The regions where direct seeding is practised and no soil preparation takes place are very limited.

If the investment for soil preparation decreases due to the introduction of draft animals and the cropping area is expanded, then work bottlenecks arise with weeding and harvesting. Persoons (1988) reported on Mali that a farmer can plant 2.5 ha of cotton, but can only weed 1.5 ha and harvest 0.8 ha. To date the harvest (except for groundnuts) has been left out of draft-animal mechanization. The mechanized work operations in Europe and North America such as clearing of tubers or mowing of grain are only mechanized on the motorized level in highly technicized regions such as South Brazil. Work bottlenecks during harvest operations are all the greater

- the further advanced the mechanization of other work operations on the farm are
- the more the biological-technical modernization on the farms is applied
- the more the harvest is tied to deadlines (Kirk, 1987).

Fig. E 6: Proportion of animal traction for the individual work operations



With full exploitation of animal traction for the work operations the harvest in North Cameroon, for example, requires 56% of the labour investment occurring during the vegetation period (Kirk, 1987). Often the previous work operations are not mechanized because of bottlenecks arising during harvesting.

According to the survey only in one-third of the regions is seeding conducted by draft-animal seeders. Animal-drawn seeders are used to a greater extent in areas where agriculture is characterized by

- permanent cropping (table E 1)
- tradition and greater distribution of draft-animal husbandry.

Partially an already high proportion of motor mechanization is achieved. This, however, does not apply for the West African countries.

The soil is worked thoroughly; the mouldboard plow and often the harrow are used, however in no case the ard plow.

Seeding with animal traction plays a role in the survey wherever the number of humid months is above 4.5 (table E 2). In tropical wet climates with more than 9.5 humid months the work operation is again exclusively carried out manually.

Brazil is an exception here (e. g. the state of São Paulo, for which no questionnaires were distributed). Exactly in this climatic zone draft animals are intensively used for all work operations. The high land-use intensity, the tradition of animal traction by Euro-

Table E 1: Relationship between land-use intensity (R value), the degree of mechanization and the utilization of draft animals for seeding and weed control

R value	Proportion of draft-animal work (in %)		Proportion of cases without use of draft-animal work (in %)	
	Seeding	Weeding	Seeding	Weeding
< 80	1.7	13.8	78.8	27.3
≥ 80	6.8	16.5	56.0	24.0

Table E 2: Relationship between climate and the utilization of draft animals for seeding and weed control

	Tropical climates				Subtropical climates
	Rainy climates	Humid-summer climates	Wet and dry climates	Dry climates	Permanently humid hot summer climates
	%	%	%	%	%
Seeding	0	1.5	2.0	0	14.57
Weeding	20.0	8.9	13.6	19.5	20.57
Interpretable questionnaires	5	15	36	4	7

pean immigrants and the industrialization play a particular role here. Also, in the immediate neighbouring state of Paraná, which has a constant wet and hot summer subtropical climate, there is a high proportion of work achieved by animal-drawn seeders.

According to our experience seeders are utilized in practice on the farms where animal traction is intensive and
- the technical level has reached an overall high niveau, such as in Brazil,
- money flows into the farms from wages earned elsewhere and labour forces are scarce, such as in Lesotho, where 50% of the men work in South Africa,
- the vegetation period is very short and the crops must be sown as quickly as possible, such as in Senegal and Mali.

More than half the cases in the survey in which seeders are utilized are located in Brazil. In the Andes and most African countries seeding is not conducted with animal-drawn implements. The use of seeders represents, in the technical and economic view, the highest level of development of animal traction in Africa and South America.

Although the responses originated essentially from regions with animal traction, weeding, however, is done exclusively manually in more than 30% of the instances. Thus, the relatively low proportion, where weeding with draft animals is found, also in regions having a tradition of draft animals, is surprising, although the labour productivity can be considerably increased thereby. With greater land-use intensity the effort for weeding increases over-proportionally and leads to a steep reduction of labour productivity in the hand-hoe system, up to a point of limitation of the total production of a farm. Simultaneously, where the R value is high this work operation can be more easily mechanized with draft animals. In his analysis of animal traction in Cameroon, Kirk (1987) has determined that weeding is only gradually being mechanized. This work operation is precisely the area in which the highest labour savings can be achieved.

In the regions where no weed control occurs with draft animals, where soil preparation and transportation are the primary draft-animal tasks, the work is carried out over-proportionally at the manual level (up to 78%). One of the reasons can be sufficient available labour forces on the farm. Further reasons for not mechanizing weed control could be that
- investments and repairs (abrasion) could present a risk where the infrastructure (procurement of spare parts) is poorly developed
- seeding would have to be done in exact rows,
- work operations would be less tied to schedules,
- in many cases the work would not have to be carried out by the farm manager.

Considering the high labour investment for weed control the decision remains for the farmers, when a scarcity of labour forces exists, either to limit the cropping area and to conduct intensive weeding or to take the risk of poor weeding on larger areas. The latter choice would be connected with greater investment for soil preparation and additional costs for seed.

Weed control with animal-drawn implements occupies a significant proportion of the work operations in all climatic zones (table E 2). Due to the risk of weed invasion great importance is attached to it in the trop-

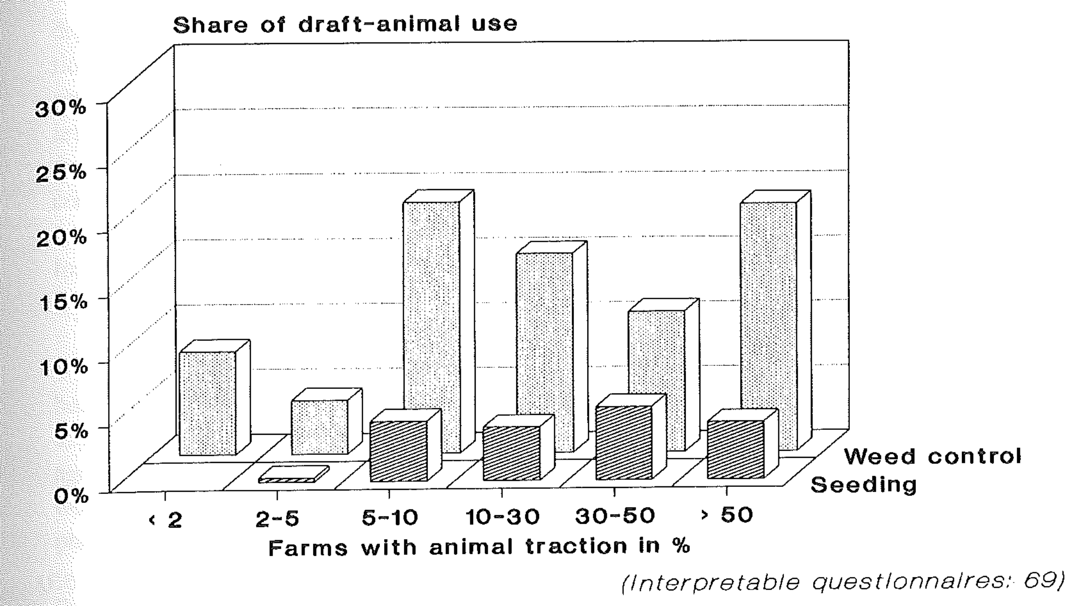


Fig. E 7: Relationship between proportion of farms with animal traction and the use of draft animals for seeding and weeding

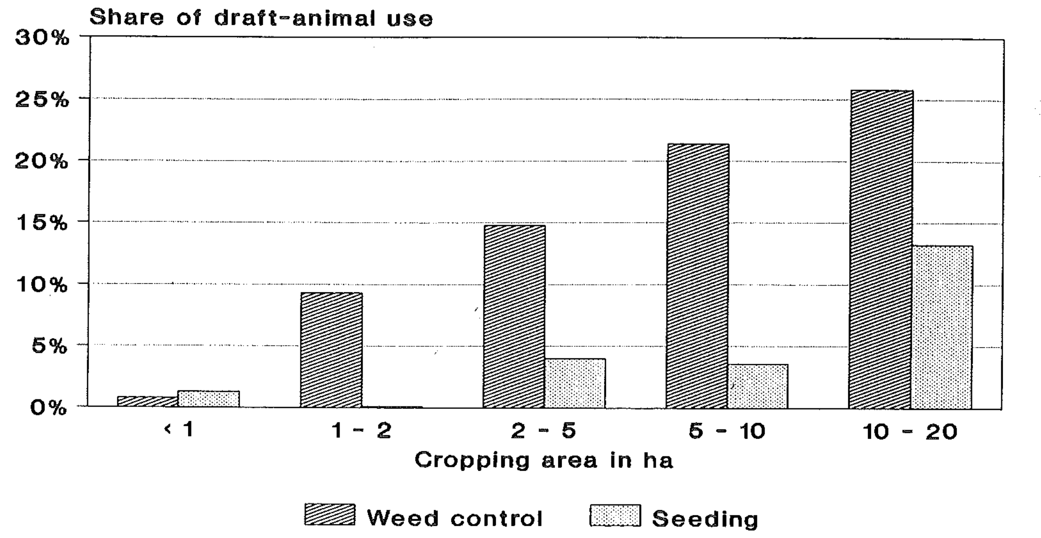
ical wet climates. On the other hand, in tropical dry climates where weed invasion is not severe it can be easily accomplished.

Where the ard plow is commonly employed, weed control is done with this implement when animals are engaged for the task.

Sowing with seeders only takes place where weeding is carried out with draft animals. However, it was mentioned only half as many times by the respondents in the survey. Sowing with seeders also increases directly proportional to the increasing share of weed contol in the work operations conducted with draft animals. Both work operations gain importance with increasing distribution rates of animal traction within all draft-animal activities (figure E 7).

With a distribution of animal traction in less than 5% of the farms, the seeder is practically not represented, while weed control already shows a mentionable share of the draft-animal tasks. Seeding with animal-drawn implements first plays a role with a greater distribution.

With an expanding cropping area the share of seeding increases only slightly (figure E 8). The high figure for farm size of 10 – 20 ha is attributed to the South Brazilian cases, where motor mechanization is prevalent and the draft animals are still only employed to a minimal extent for soil preparation. The importance of weed control is continuously receiving more attention; this means that for larger cropping areas it will become a bottleneck.
For all plot sizes the share of seeding remains under 2%; only in the 0.6 - 1 ha range does it increase to 7.5% (figure E 9). Weeding operations increase with the size of the plots.

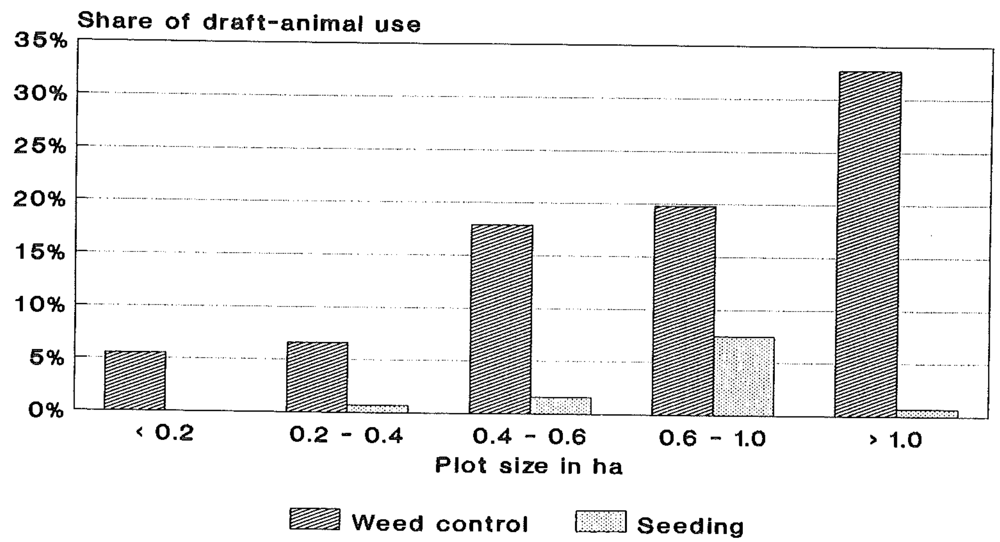


(Interpretable questionnaires: 63)

Fig. E 8: Relationship between cropping area and employment of draft animals for seeding and weeding

The possibility of transportation with on-farm draft animals is minimal in one-quarter of the cases or not exploited at all (17 cases under 10%). This applies particularly for the Andes countries and Ethiopia, where the ard plow is used but usually no other animal-

Fig. E 9: Relationship between plot size and employment of draft animals for seeding and weeding



(Interpretable questionnaires: 59)

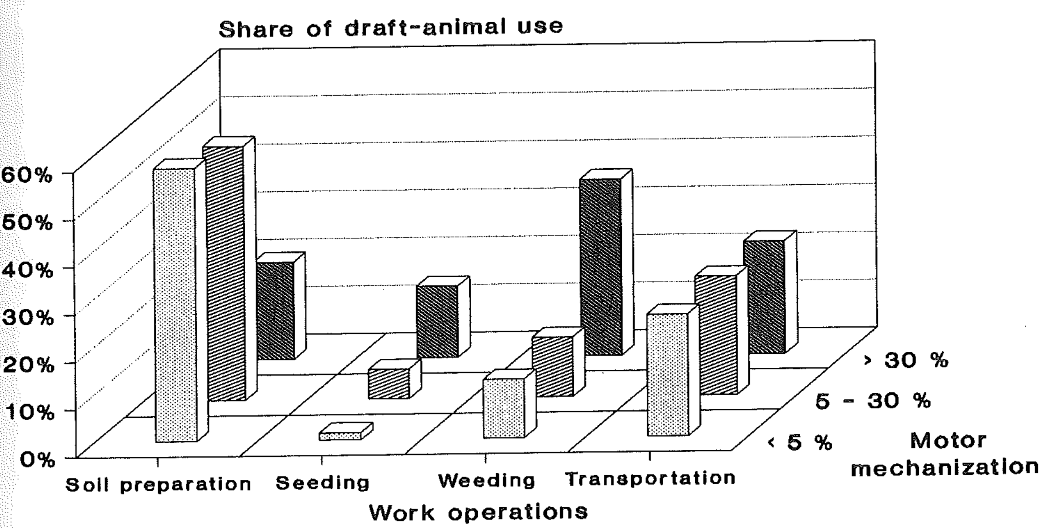
drawn implements. In all cases animal traction has a tradition and is widespread. Here, animal traction appears to remain on the level of own implement fabrication by the farmers themselves. It must be taken into consideration though, that the ard plow can be employed as a multipurpose implement, for breaking furrows during seeding and weed control.

With less land-use intensity transportation becomes the most important work operation. Thereby, animal traction has a below average distribution (16.3% share of the total work) and is partially still in the initial phases.

Regarding the heavier work operations, as in plowing, the use of the tractor is gaining popularity, also on draft-animal farms. In this case the harvest residues simply are worked in, the soil is better prepared and is easier to work in subsequent operations with other implements. The tractor can, however, only function under suitable conditions (deep soils, slight slopes, few obstacles). Its use considerably increases the risk of erosion. With the transition to motor mechanization the emphasis of the individual work operations employing animal traction is being shifted (figure E 10).

With an increasing use of tractors the soil preparation with draft animals decreases by more than half. The farms that do not immediately switch over to motor mechanization hire the tractors for soil preparation, while the following work operations are conducted by draft animals (mixed mechanization). Especially seeding gains importance, whereby the better technological environment and the greater land-use intensity play a significant role. Most of the reported cases are in South Brazil (5 out of 6). Experience in Africa confirms this tendency (table E 4). Transportation with draft animals retains its

Fig. E 10: Relationship between motor mechanization and animal traction for individual work operations



Interpretable questionnaires motor mechanization: < 5 % = 49, 5 - 30 % = 15, > 30 % = 5 importance, also where a higher proportion of motor mechanization is found.

In the draft-animal regions motor mechanization is initially employed for soil preparation in all the cases. Also, transportation has a prominent standing. The subsequent work operations are only represented to a slight extent, whereby seeding is mentioned most frequently. This data correlates with the experience reported, where seeding follows soil preparation in mixed mechanization with a tractor.

The interaction between the individual work operations, the mechanization level, the cropping system and natural endowment can be well illustrated with the case of Lesotho. The great majority of farms own an animal-drawn plow (table E 3).

Due to the use of the tractor the share of draft-animal plows is lower in the lowlands and foothills (table E 4). Animal-drawn seeders and cultivators are primarily employed here, as row crops such as maize, sorghum and beans take up the greatest part of the cropping area. In the mountains, on the other hand, wheat and barley are mainly broadcasted. Tractors cannot be used here because of an unsuitable topography.

The substantial number of seeders is attributed to the limited time span for soil preparation and seeding due to the early frost, the savings from wages earned in South Africa and the scarcity of labour forces. The marketed share is therefore very low; only 19% of the farms have any surplus produce to sell. (Großmann, 1986)

Table E 3: Ownership of draft-animal implements in Lesotho. Source: according to Großmann (1986)

Region	Ownership of draft-animal implements in % of the farms						Number of farms
	Plow	Harrow	Seeder	Cultivator	Cart	Sled	
Lowlands, foothills	67,9	21,4	50,0	46,4	25,0	35,7	28
Mountains	100,0	65,0	10,0	7,5	0,0	0,0	20

Table E 4: Proportion of farms using various energy sources in work operations in the lowlands and foothills, and the mountains. Source: according to Großmann (1986)

Region	Soil preparation			Seeding			Weed control		
	Manual %	Animal %	Tractor %	Manual %	Animal %	Tractor %	Manual %	Animal %	Tractor %
Lowlands, foothills	0,0	42,9	57,1	0,0	96,4	3,6	100,0	71,4	0,0
Mountains	0,0	100,0	0,0	100,0	0,0	0,0	100,0	65,0	0,0
48 interviews; the hand hoe is also always used for weed control									

2. General features of the implements

2.1 Overview of implements

The descriptions of the implements are subdivided according to the following categories: soil preparation, sowing and application of fertilizer, weed control and harvesting. A distinction is made between soil preparation and seedbed preparation only when necessary. Mechanical weed control, also representing a kind of soil preparation, is treated separately, although the same implements are partially used for soil preparation and weed control, such as the ard, ridger and chisel plow or cultivator.

For further classification of soil-preparation implements two approaches are possible: according to design or to manner of operation.

For this treatise it appears appropriate to index the implements used for soil preparation according to manner of operation, since they are directly connected to the requirements of the respective location. Design is employed as a further criterion, but it is subordinate to the manner of operation.

One can thus distinguish between
- implements that operate symmetrically to the line of draft power, such as the ard,
- implements that work assymmetrically, such as the mouldboard plow,
- rotating implements such as the disk plow or disk harrow.

Implements that work symmetrically to the line of draft power and rotating implements mainly loosen and mix the soil, while the mouldboard plow primarily turns it.

In the group of symmetrically working implements most belong to the category for soil preparation. These are:
- ard,
- ridger,
- chisel plow and cultivator,
- shovel-type implements such as the fuçador.

Implements for both soil preparation and weed control are collectively considered under the term chisel plow. In the narrower sense the term chisel plow is used for deeper soil preparation with tines and superficial tilling with duckfoot, sweep shares, etc. (e. g. bico de pato; section G 2.4.4). If the implements are employed for weed control, then the term cultivator is used. The fuçador is treated in section G 2.4.2.

Implements for harvesting are hardly used in rainfed cropping in the regions investigated. Merely the groundnut lifter plays a greater role (section F 3.4.5). The use of mowing implements for grain harvesting are conceivable. However, the introduction of such implements, which has been attempted in Senegal and Brazil, has to date been unsuccessful. Under the conditions in South Brazil, with a high technological level and the promotion of wheat cropping, this implement might be worthwhile for the farmers. It could increase labour productivity by a factor of 20. However, it is questionable whether the expected number of sales could be an incentive for the farm machinery manufacturers. Only then could they be purchased for an appropriate price. (Fabry, 1990)

Multipurpose toolbars are used in numerous quantities in West Africa, especially as chisel plows and cultivators. The larger equipment such as the Ariana (figure F 20) or the similarly designed Policultor 600 in Brazil have been distributed under the auspices of special development programmes or in training centres; there are only a limited number of them, however. The sales of the wheeled tool carrier (Polyculteur in West Africa or Policultor 1500 in Brazil) have been less encouraging (for the reasons see section F 3.4.7 and Starkey, 1988a). The policultors were manufactured by CEEMAG, but production has been discontinued. At present they are fabricated by APAC.

Harvesting implements and multipurpose toolbars are not treated in great detail here, but receive attention in the case studies.

2.2 Design and maintenance problems

Under tropical or subtropcial conditions as, for example, in South Brazil the implements must often work on fields having large quantities of organic matter (growth of fallow, weeds or harvest residues). The most frequent constraints in these regions are working in this mass and the resulting clogging.

A low weight of the implements is of importance where the plots are far apart or are located on slopes (e. g. at various altitude lev-

Fig. E 11: Transport of an ard to the field (Pakistan) (Photo: Küpper)

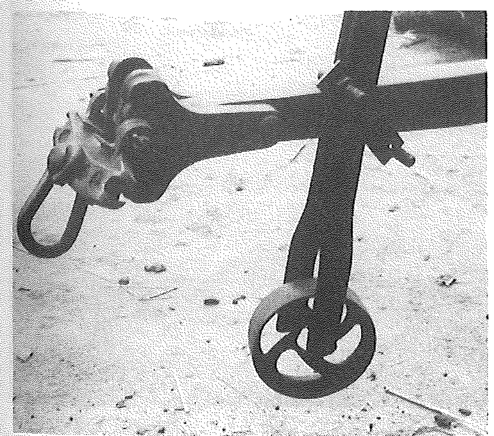
els because of the distribution of risk) and the associated transport of the plow to the fields.

The transport of implements to the fields can be done in different ways:
- the farmer carries the implement (figure E 11),
- it can be loaded on the animal, the cart or a sled (also forked branch),
- it can be dragged.

Dragging frequently causes damage to the implement, also the handle can become bent. This leads to an imbalanced burden on the farmer during the work. Sometimes, the implement remains on the field, which can lead to rapid deterioration and theft of the parts.

The handles generally cannot be adjusted to the tallness of the farmer. This often leads to an unbalanced bodily load. In one region differences of the height of the seeder handles were found to be between 89 and 114 cm and the widths between 51 and 76 cm (Casão et al., 1987).

Fig. E 12: Worn out bearing of plow wheel (Photo: Nelles)



A key problem of the technical functioning of the implements is the bearings for rotating parts. Abrasion of the wheel bearing on mouldboard plows is frequently reported (figure E 12).

A one-sided wheel mounting, as with the implements in Togo, brings negative results. Simple repairs done by farmers, e. g. replacing the axle with water pipes or wooden bars (figure E 13), become very difficult. A fork-type mounting is then recommended. Occasionally, the wheel has too small a diameter for the soil characteristics or the existing plant growth. Solid wheels and too small wheels clog easily in wet and heavy soils. Large-dimensioned spoke wheels would be more appropriate in this case. The publications often suggest the use of a supporting skid as an alternative, but in practice they are seldom encountered.

Fig. E 13: Axle replaced by wooden bar (Photo: Schmitz)

Connections with bolts are also a risk factor regarding potential damage. Prior to the introduction of mouldboard plows the work was done manually or with traditional animal-drawn implements; now a new unknown technology has been introduced whose principles of functioning are not simply understood. Moreover, suitable tools are lacking (spanners etc.) and often the incorrect sizes or the wrong parts are delivered (Togo, Tanzania, Zimbabwe, Niger). Worn out parts then cannot be exchanged, rendering the work difficult. Therefore, the adjustment of seed covering scrapers, tines of cultivators or the regulation of fertilizer applicators should be designed to be altered without the use of spanners. In order to avoid a loss of bolts some joints should preferably be welded. The reason given by Kenyan farmers for the disappearance of bolts was "screw-eating dogs", which was one of the grounds for the failure of multipurpose implements (Neunhäuser, 1984). The loss of a clamp bolt leads to the fixing of the working width of a cultivator with wooden wedges, as shown in figure E 14.

Seeders place the highest demands on manufacturing and maintenance in the regions investigated, because of the required precision for the many rotating parts.

Most of the implements are treated in the following sections, although some are discussed exclusively or in greater detail in conjunction with case studies because of their regional importance.

Fig. E 14: Emergency repair of an adjustment in South Brazil (Photo: Schmitz)

3. Field preparation

3.1 Requirements

A central problem for the utilization of implements, especially in the humid climatic zones, is the huge amount of organic material lying on the fields at the start of the cropping cycle. Fallow, both short and winter fallow that has a high weed infestation, or undecomposed harvest residues are the cause of this condition. This frequently leads to the practice of burning. Thereby not only nutrients but especially the organic matter content is reduced, which the cation exchange capacity and the stability of the aggregate maintains. To prepare the fields for subsequent soil preparation and further work operations the following processes are necessary, depending upon the climate and land-use intensity:

- clearing and removal of tree stumps and roots,
- chopping of vegetation from short fallow,
- management of harvest residues,
- working in or mulching of green manure.

In order to reduce the workload[1] and to prevent burning animal-drawn implements are partially utilized. However, to date very few techniques exist at the level of animal traction to clear the fields.

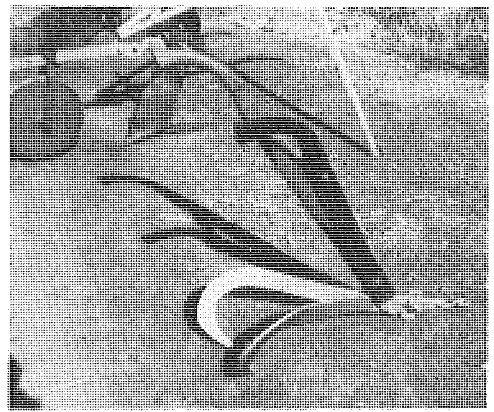
1 For fallow of several years the average requirement for field preparation is approx. 100 labour hours/ha (Casão, 1987).

3.2 Implements

Simple implements have been developed for the removal of tree stumps (figure E 15).

For mulching weed material or green manure crops, especially in humid areas, only mowing bars, which to date have not been accepted in the regions investigated, and knife rollers exist, which are also suitable for processing harvest residues. The disc harrow (section E 5.3) can also be used for working in harvest residues. In South Brazil the knife roller is commonly found, both on motor-mechanized farms which practice no-tillage as well as on smallholdings with draft animals. Further experience has been made in Northeast Brazil, Tanzania and Cameroon, where they are however not widespread.

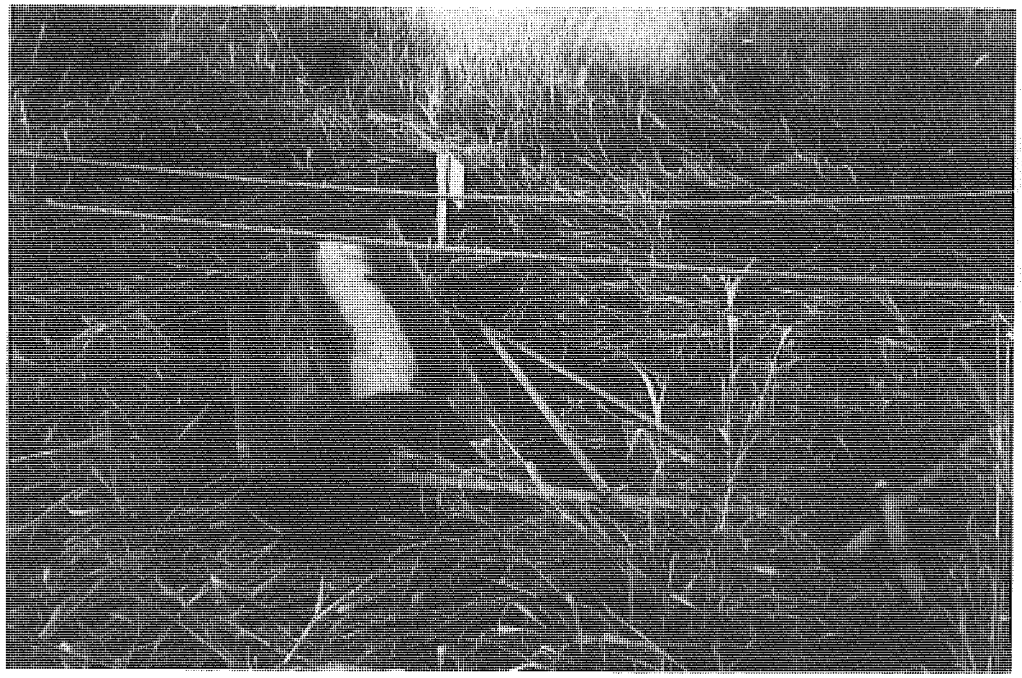
Fig. E 15: Destumper at IAPAR (Photo: Schmitz)



Knife roller

The knife roller (figure E 16) consists of a roller made of wood or metal, upon which flat metal knives are mounted on the circumference. The principle of operation is that the knives of the roller bend over or chop off the stems of plants as it passes over them. The expended pressure depends upon the number of knives and their spacing, which in turn is determined by the circumference. If the number of knives is increased with the same circumference, then the pressure is reduced and the risk of clogging in the space between the knives increases. Further factors determining the efficiency of the roller are: working weight, construction material for the knives and mounting angle of the knives. The quality of the work is determined by the fiber and moisture content of the plants.

Fig. E 16: Knife roller (Photo: Schmitz)



In South Brazil to date the knife roller has primarily been used to chop residues of fallow. In the meantime, it is also recommended for the mulching of green manure and chopping of harvest residues (maize stalks). However, it cannot process all types of green manure, for example black oats. On slopes of over 20% and on stony ground the knife roller can hardly by utilized. David (1988) states that the speed of oxen is too slow. This implement is manufactured by the farmers or by local artisans.

Trials have been made at IAPAR to improve the knife roller. The roller material (tree trunks, oil drums), working weight, method of applying weights, number of knives, circumference and cutting angle of the knives were tested. In the TIRDEP project in Tanzania the knife roller has also been tested for weed control, especially after fallow and in terrain having many roots. The roller proved to be essentially well suited for work in grass up to 3 m high following fallow and for weed control in permanent crops. Usually two working runs were sufficient. For weed control after seeding, which would be feasible with a smaller implement in principle, the implement was less appropriate. With weed control in maize the spacing between the knives remained too high, also at a maximum number of knives, so that the weeds could not be destroyed at an early stage of growth. Furthermore, during this season the wet soil clogged the knives. For draft-animal use one model made of wood with assymetric application of draft power has proven to be suitable; it is arranged so that the animals need not walk directly through high plant growth. For the protection of the animals, especially on slopes, either the roller is covered or the attachment of a drawbar is necessary. The advantages with the drawbar are improved maneuverability, smaller headland (6 m instead of 10 m with chain) and easier reversing in the case of obstacles (Becker, 1987). A knife roller developed in Northeast Brazil that weighed 70 kg proved to be too light. The recommended weight should be between 250 and 400 kg, depending upon the draft animals and the existing vegetation. It is advantageous to be able to adjust the weight. However, no moveable fill material should be used, e. g. water. This would reduce the quality of the work, leave tracks and cause an extra load on the animals. As an optimal solution Becker (1987) investigated an implement in Tanzania of 1 m diameter with 80 cm-long knives and 8 – 10 knives made of tempered and sharpened steel – used leaf springs can be applied for this purpose – with a spacing of 25 cm at a mounting angle of 0 degrees. A sub-divided or flexible knife roller would be a more useful implement, but this would raise the cost considerably. (Figueiredo, 1988; Becker, 1987; compare Bertol and Wagner, 1987)

The labour saved with a 3-year growth of grass (organic mass = 10 t/ha) as opposed to manual work is substantial: with the knife roller 6 days/ha vs. 70 days/ha by hand. (Becker, 1987).

4. Soil preparation

4.1 Soil fertility

All cropping measures must be directed to the conservation of soil fertility. Soil fertility is defined as the natural and sustainable potential of the soil with respect to the production of crops (Klapp, 1967). The fertility of the soil is decisively influenced by the soil-preparation methods undertaken. The following physical, chemical and biological components determine the soil fertility.

The texture, i.e. the relative proportion of fine and coarse particles present, provides information on and leads to conclusions regarding the pore distribution, structure stability and nutrient supply. Soils with a high silt content can store the most amount of moisture available to the plants. Sandy soils usually hold little moisture for the plants, as they cannot counteract the forces of gravity. They do not generally possess a stable structure, since the surface forces of the sand grains are minimal. Thus, the organic components of water-storage capacity and the structure of the soil are decisive. Loamy and clayey soils indicate generally stable structures, since the greater inner surface area leads to stronger attractive forces between the soil particles. As also clay minerals are the carriers of cation exchange capacity, the natural fertility of these soils is better than sandy soils. (Dehn, 1981)

The soil structure is the conglomeration of various soil particles in aggregates as well as their shape and arrangement. It determines the distribution of coarse, medium and fine pores that affect moisture availability and drainage. This is extremely important for precipitation conditions in the tropics. There, the soil structure, namely the building up of aggregates, is created by swelling and shrinking, root growth, activity of larger soil fauna and soil tillage. The soil structure depends, among other things, upon the proportion of iron and aluminium oxides and the types of clay minerals. Severely weathered soils have a high percentage of iron oxides and kaolinite, which has the property that it does not swell with exposure to moisture and subsequent drying. Less weathered soils are characterized by a high share of minerals that are able to swell.

The proportion of coarse pores is significant for infiltration and the exchange of gases. In tropical rainforest infiltration rates of several hundred mm/h are reached due to the high proportion of pore volume, so that even with intensive rainfall there is no surface runoff (Sanchez, 1976). The coarse pores also determine the space in which roots can potentially grow.

The bulk density is determined by the share of pore volume as well as the relationship of mineral to organic matter. For optimal root growth the soil should be loose. Bulk densities of between 1.0 and 1.2 g/cm^3 are reasonable. The compaction of a loose soil by 0.15 g/cm^3 can already reduce root growth to about half (Trouse, 1979: in Dehn, 1981). Thus, the achievable moisture potential is reduced for the plant, which is crucial in zones having high rainfall fluctuations. Particularly critical for plant growth are abrupt density changes (such as clay concentration horizons, plow sole), which also can lead to a parched water table.

Plants often react more sensitively towards soil than air temperature. When the soil is protected from direct sunlight the soil temperature corresponds essentially to the air temperature in the humid tropics. Without cover this can rise to more than 15ºC higher. Soil temperatures of over 35ºC approach the upper limitation for plant growth.

Building up a high stable content of humus by supplementing the soil with organic material and hindering a too rapid decomposition must be the priorities of a sustainable agriculture. Humus and organic matter can decisively improve the properties of the soil. Nevertheless, the practice of removing organic matter and residues, for example by burning or the pasturing animals, is common. Measures for supplying organic material, such as green manure and application of animal dung, are not being exploited in most of the regions investigated.

4.2 Soils

In most cases the regions in the survey do not possess similar types of topsoils, rather soil associations are encountered that are influenced by a host of factors; here the landscape relief plays a prominent role. The properties of the components of the associations are important for soil preparation. Moisture and clay content of a soil determine the soil stability and thus the tillability. The optimal range for tillage is very narrow for clayey soils. The more clay a soil contains and the drier it is, the harder is its condition. The space for roots, one of the most important aspects for plant growth, is limited in shallow soils. Furthermore, the moisture supply for the plants in the thin soil layer is not always assured due to low moisture storage capacity. This factor is especially important where short dry periods also occur during the vegetation period. The risk of erosion is critical, since the thin arable layer can rapidly be removed in contrast to soils having a greater depth. Shallow, stony soils are difficult to till.

Oxisols (USST), the most severely weathered of all soil formations, are predominantly found on relatively flat, old land surfaces. They are very deep and usually have a stable structure, and are very suited for mechanized cropping. Despite the high clay content (up to 80%) they often occur as loam or loamy sand because of the building up of stable micro-aggregates in the fields. The bulk density is very low, so that in part with compaction (e. g. in tractor tracks) higher yields are achieved due to a better moisture supply. Two days after a heavy rainfall the soil can be tilled. Most possess few nutrients except for those originating from volcanic primary rock.

On slopes, from which weathering products are constantly being removed by means of water erosion and soil flow, Ultisols and Alfisols (USST) occur as recent formations. They have a somewhat higher natural soil fertility, but are structurally less stable. In part they are characterized by greater texture differences between the A and B horizon[1], so that there is a severe risk of erosion. Moreover, gravel deposits or stone layers can limit the tillability near the soil surface on the upper slopes. During dry seasons the Alfisols become very hard, rendering soil preparation impossible. These so-called "millet soils" in West Africa tend to form crusts and to possess a higher bulk density, which makes root growth difficult (Klaij and Serafini, 1988).

Inceptisols, a classification of newer soil formation, occur where the soil removal process has reached hardpan. Relatively fertile soils can be created on freshly weathered hardpan and in the sedimentation basin of rivers, if the sediment did not originate from Oxisols from the older highlands. Vertisols (USST) are nutrient-rich lower lying soils having a high clay content, which have originated from basalt or are created on a stowage level in depressions beside older soils (reformation of clay minerals), where however nutrient deficits can occur, e.g. phosphorous and potassium. A pre-condition for the creation of Vertisols is a changing wet climate, in which they are subject to high moisture fluctuations and regular drying out. Vertisols represent an extreme case here, due to their high clay content and the high proportion of swelling clay minerals. The most suitable range for tillability between too wet and too dry conditions is very narrow (minute soils). They can therefore not be optimally tilled.

Sandy and silty soils having a low structural stability tend to form a sealed surface, crust immediately and therefore undergo risk of erosion. The breaking up of crust formations can increase infiltration and thus reduce the surface water runoff, the trigger for water erosion; the impact of this measure for weakly structured soils is rapidly reduced, especially with rainfall. Sand achieves a high bulk density of 1.5 g/cm^3, and under heaviest compaction upto 1.7 g/cm^3. The compactions are solid, and thus no roots can penetrate them. This is most evident with fine sand, which has the densest compactions. Drier sand can be tilled; the measure may be useless however since it does not retain its structure produced by the tillage operation. (Roth, 1989)

Aside from stones in the narrow sense, laterite concretions can render the soil preparation difficult. In a semihumid/semiarid climate iron-rich amorphic mass (Plinthite layer) can occur deeper in the soil at the break-off point on edges of slopes, which can arrive on the surface by tillage and dry out irreversibly (Sol Ferralitique Remanié – FS). In soils which have often been tilled pea-size concretions are found, which can take up to 50% of the soil profile, e. g. in the humid tropics of West Africa.

4.3 Toposequence and soil types

The soils change along a slope with regard to depth and clay content. These changes can occur within a few hundred meters, depending upon the topography (figure E 17).

In the humid tropics steep slopes are seldom found. Wavy, hilly landscape without rugged edges (half-oranges) occur or flat land, such as found in the Congo and Amazon basins. Stones are rare. On slopes there are soil

1 The various soil layers originating from primary rock are designated as horizons, the A horizon being the top layer.

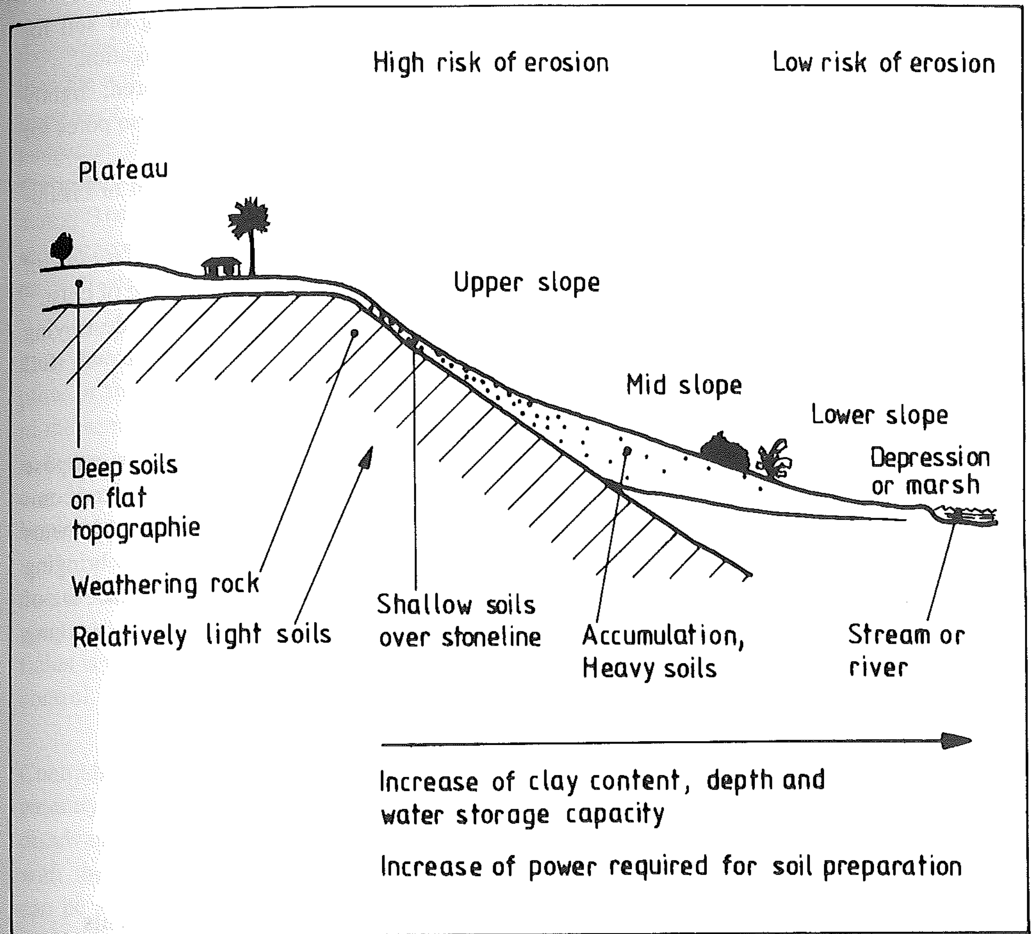


Fig. E 17: Toposequence (according to Dehn, 1981; Pingali et al., 1987)

sequences, e.g Oxisol, Ultisol, Inceptisol (USST). In the wet and dry climates of the humid tropics (e. g. South Brazil) their are more jagged slopes. In savanna climates the sequence can consist of Alfisol, Ultisol and Vertisol (USST) ("le rouge, le gris et le noir"). (Roth, 1989)

On the upper part of the slope the soil can be flat and stony. The risk of erosion is high due to the inclination and the shallow soils allow no margin for soil loss. The clay content, the depth and the water storage capacity increase at lower levels. The soils on the upper slopes are correspondingly easier to till, also manually. Alluvial soils, heavy black soils having a substantial quantity of organic matter, are found in valley bottoms. Because of the soil moisture they can be used year round as pasture (e.g. Vertisols in the valley bottom with a changing wet climate, such as in Zambia, Malawi, Tanzania or Ethiopia). They require high investment of energy; in part, they can only be cultivated after considerable expenditures for water management and drainage. On the other hand, the risk of drought is greatest on the upper slopes. The farmer must weigh the lower power input requirement against the greater risk of drought. This risk decreases with increasing humidity. (Pingali et al., 1987)

The zone preferred for cropping depends upon the climate and the population density. In arid areas the lower slopes or valley bottoms receive preference. In semiarid areas cropping begins on middle slopes and replaces the pastures on the lower slopes and valley bottoms with increasing population pressure. In humid regions the upper slopes are also cultivated. Labour-intensive water management measures are only worthwhile in lowlands when sufficient labour resources are available on the basis of the population development.

The intensification of soil preparation on the medium slopes leads to severe erosion problems for many tropical soils. Due to the heavy soils in the valleys the transition from the hand hoe to the plow takes place here first, according to Pingali et al. (1987). This does however not apply generally, as the example of Casamance (Senegal) shows, where animal traction is utilized more on the plateau. Also in south Paraná the plow becomes more widespread on the upper slopes.

4.4 Objectives

Various aims are pursued with soil-preparation measures:

- weed control, especially prior to sowing,
- creation of certain surface structures (e.g. ridges); seedbed preparation for smooth operation of seeders; crumbling of soil for special crops; preparation for irrigation,
- loosening of poorly structured, tightly compacted soils; creation of coarse pores for better root penetration,
- working in of organic material or chemical fertilizers,
- increasing the infiltration by means of loosening soil, especially breaking of crust,
- reduction of evaporation by destroying capillary structure or hindering growth (full fallow).

In general, loosening only serves a purpose when the soils have previously become compacted, e. g. by heavy tractors, implements or animals. Further aims such as bringing leached soil components to the surface are of lesser importance with the shallow working depth of draft-animal implements.

4.5 Various aspects of soil preparation

4.5.1 Impact of utilizing implements

The mechanization of soil preparation alone does not produce a quality gain in comparison to the hand hoe, and thus does not improve the area performance (yield per ha) (Pingali et al., 1987). Weed control with the hand hoe, also a soil-preparation measure, is considerably more effective. With draft-animal use beside the increase of labour productivity only the possibility of cultivating unused heavier soils is given.

The mouldboard plow has become widely distributed in the tropics and subtropics at the level of animal traction, in contrast to motor mechanization where disk implements dominate. Its decisive advantage is an effective weed control. It leaves a finer seedbed than the ard or chisel plow. Frequently, the implement, which is adapted to cropping in temperate climates, has been introduced by European settlers in new agro-ecological zones. The implements used for the subsequent work operations are designed for work on well prepared fields following plowing.

Less intensive preparation with the chisel plow or the ard are particularly widespread in the semihumid/semiarid regions. The soil is loosened without turning. In some soils, e. g. Vertisols in Ethiopia, the ard is the only implement used for soil preparation. Further work operations can hardly be carried out due to an unsuitable soil structure or clogging. Access to the wet, poorly drained fields is very difficult, for example for weed control.

Contradictory investigations have been apparently conducted on the advantages and disadvantages of soil preparation, especially with the plow. These deviating statements can be attributed to the considerably differing basic conditions of soil type and climate, however. Yield increases after plowing (Charreau, 1974: in Pingali et al., 1987) and a reduction of erosion have been determined (Charreau, 1972 in: Sanchez, 1976) in semihumid/semiarid regions having soils that tend to become compacted, while in humid regions less significant yield growth (Vincente-Chandler, 1966 in: Sanchez, 1976) and an increase of erosion has been measured (Marquez and Bertoni, 1961 in: Sanchez, 1976). Plowing causes a temporary reduction of soil bulk density. The enlargement of pore volume however does not apply to all pore size classifications. Plowing creates essentially large pores favouring root growth, especially important on soils having a higher bulk density and non-swelling clay minerals (kaolinite). Thereby an increase of the infiltration rate is achieved, at least for a certain period of time. The medium and fine pores determining the moisture content capacity can only be created biologically or physically (swelling and shrinking), and can be destroyed by working the soil.

A disadvantage is that by intensive soil preparation, especially with the mouldboard plow, the soil is more intensively aerated and warmed, the decomposition of organic matter is accelerated and moisture loss causes higher evaporation. Plowing means, in addition, an over-loosening: the loosened structure is not initially suited for cropping and it takes time for restabilization of the soil. Mechanical loosening by means of soil preparation possesses only limited stability. After a short time the bulk density can already be greater than for no-tillage and in the long term it can be higher than the latter (Armon and Lal, 1979 in: Dehn, 1981). The looser the soil is after tillage, the more sensitive it is to compaction. This applies especially for a sandy soil having little organic matter. After some recompaction higher moisture capacity will be achieved.

Many soils become depleted with prolonged cultivation. Due to compaction of the topsoil when uncovered or the creation of compaction horizons (e. g. plow sole) they become less permeable and more susceptible to surface water runoff and soil loss. Intensive soil preparation, especially the establishment of a fine-crumbed structure, contributes to a reduction of infiltration due to a decline of aggregate stability and surface sealing. Water drainage can take place unhindered if the surface is uncovered. No resistance is provided against wind erosion. A coarse seedbed

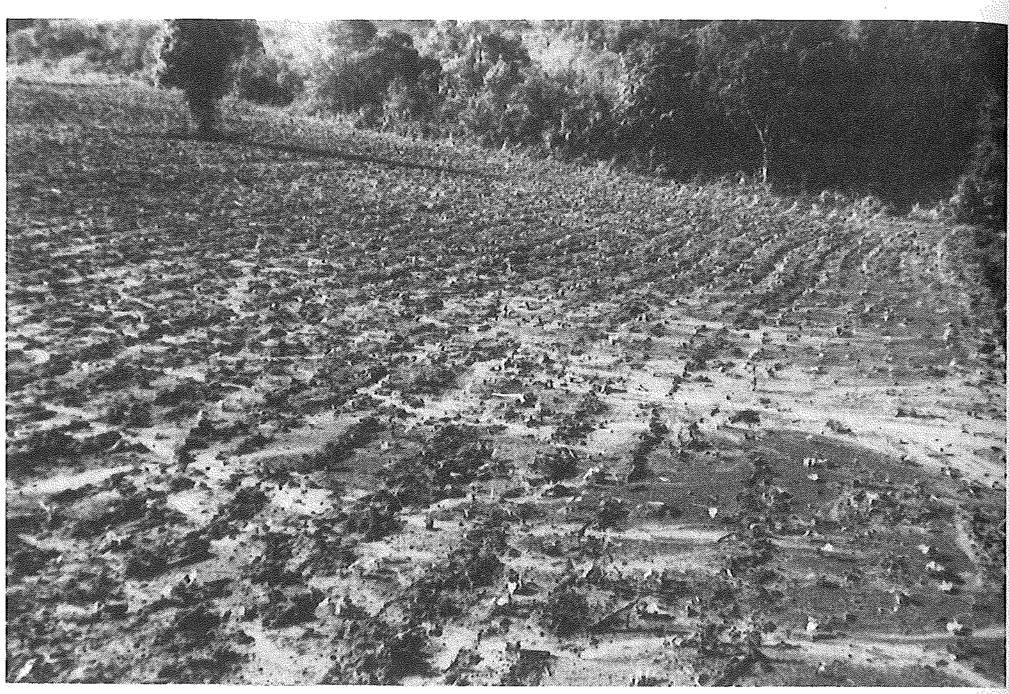


Fig. E 18: Erosion after rain at the end of a dry season in South Brazil (Photo: Schmitz)

preparation, as for example with the ard, therefore brings with it a reduction of risk against erosion.

Smallholder agriculture also contributes to damage caused by erosion, particularly due to the penetration of hilly terrain (fig. E 18).

The individual crops have a varying impact on the amount of soil loss; the following rankings have been determined for humid regions (table E 5).

In the various cropping regions the sequence is adjusted to concur with the seeding date,

Table E 5: Soil loss of crops in comparison to maize-beans-mixed cropping (Bertoni et al., 1972: in Vieira, 1987)

Crop	Soil loss %	Crop	Soil loss %
Maize-beans-mixed crop	100	Soybean	199
Beans	377	Potato	182
Cassava	336	Sugar cane	123
Groundnut	264	Maize	119
Rice	249	Sweet potato	65
Cotton	246		

since the impact of erosion tends to vary in the course of the year.

Soil preparation is minimized or totally omitted for no-tillage under mulch cover. The soil is covered with organic material. The no-tillage method[1] is referred to when no soil preparation has been carried out over several vegetation periods. Minimum tillage or the no-till approach are less suited for soils that tend to become crusted or compacted, are poorly drained or undergo little biological activity (Hartmans and Kuile, 1983). Weed control remains a constraint for no-tillage under wetter tropical conditions.

4.5.2 Soil preparation in semihumid/semiarid climates

Tillage at the beginning of the cropping period in the wet season

In dry regions (dry savanna, semi-desert) agriculture is at risk due to a scarcity of water. Here, a humus-conserving, water-saving soil preparation is critical. Turning the soil leads to a loss of moisture. Therefore, minimum soil tillage with the chisel plow or no-till methods are applied, followed by a breaking of the soil capillarity during weed control. Traditionally, ards are often used for this purpose. The use of the plow is not recommendable in these zones due to the risk of erosion (wind, water) and the low area performance. The organic matter required for mulching is difficult to produce here, since the cropping of green manures, for example, is not possible because of the scarcity of moisture. Harvest residues are usually no longer available to cover the soils, as they are necessary for animal fodder.

1 No-tillage means that less than 30% of the soil is moved (Phillips and Phillips, 1984).

Fieldwork is generally begun after the first rains. In Morocco, for example, the ard is utilized for surface tillage. Due to the short duration of the growth period in many regions in West Africa and Northeast Brazil soil preparation is only carried out on the surface and directly after sowing or no-till operations. Sowing must take place as rapidly as possible after the first rains, otherwise the yield declines drastically. No-tillage is favoured by the occurrence of sandy soils and low risk of weeds in the Sudan zone of Africa. Working in of organic matter at this point becomes superfluous (figure C 7). In order to perform plowing in the wet season the first rains must moisturize the soil to a sufficient depth. Subsequently, 4 to 5 days of work (25 hours) are necessary to plow one hectare with a team of oxen (Bordet et al., 1988).

Where soils tend towards compaction, as in most of Senegal, soil preparation could be more favourable than soil-conserving no-tillage to achieve a better root penetration and thus a higher yield. Simultaneously, the infiltration could be improved. Studies in dry regions showed an increase in yield by means of soil preparation; rice improved the most while groundnuts the least: sequence – rice, sorghum, maize, cotton, millet, groundnut. (Charreau, 1974: in Pingali et al., 1987) Other trials in sandy Alfisols in Senegal have proved the positive effect of superficial soil preparation with the hand hoe as well as deep plowing, in comparison to no-tillage (Nicou, 1972 in: Sanchez, 1976). In this case there was no difference in yields between the fields cultivated manually and those with the tractor. Considering an economic assessment the result would be an increase of profits in West Africa, particularly for cotton, rice, groundnut and maize (in this order). (Pingali et al., 1987)

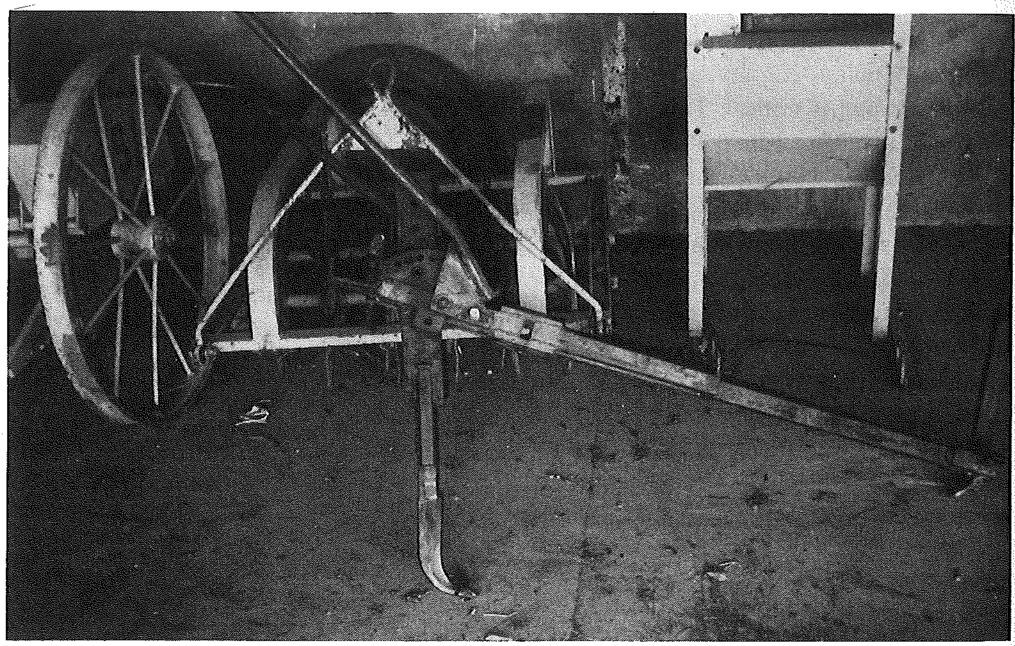
Although various studies (e.g. Chopart, 1981) have proved the positive effect of plowing on the yield and these findings have become priority areas for the extension services, plowing is not accepted in some regions, e. g. in Senegal. Plowing with animal traction is only beneficial in rainfed cropping in the Sudano-Sahel zone when precipitation is above 900 mm per annum. This statement must be modified corresponding to the type of soil and practices accompanying plowing: The heavier the soils and the higher the moisture uptake or retention capacity, the more recommendable is plowing. (Bordet et al., 1988)

In order to overcome the limitation of tillage because of the short vegetation period, the time of soil preparation could then also be selected at the end of the vegetation period or during the dry season. Both of the two methods would be suitable for increasing the water uptake during the first rains of the rainy season. The procedures are discussed further below.

Tillage at the end of the cycle or during the dry season

Soil preparation at the end of the cycle, e. g. with the chisel plow and rigid tines, would loosen the soil and thus increase the infiltration during the first rainfalls. At the same time, harvest residues could be worked in. This method, as recommended by research, has proved to be impracticable. The following reasons speak against this approach:

Fig. E 19: Chisel plow for tillage in the dry season, at the ISRA experimental station in Kaymor, Senegal (Photo: Schmitz)



- It requires a repetition of soil preparation for seedbed preparation at the beginning of the rainy season with the above described negative effects, and thus means an extra work operation.
- It competes with the harvesting operations and requires the removal of harvest residues grazed throughout the dry season.
- The agronomic effect is disputed, since the effect is possibly no longer evident by the time the rainy season begins (Bordet et al., 1988).

A further useful method is soil preparation during the dry season with the chisel plow. Various tines have been developed in the Sahel zone for soil preparation where precipitation is under 900 mm (figure E 19). (Bordet et al., 1988; Sene, 1988)

The work in dry seasons is only possible on very sandy soils. But even for numerous light soils in Senegal this is not possible because of the required high draft power due to compaction. The first operations showed that the necessary draft power overloaded the oxen teams. A further developed tine, which was pulled by 2 oxen of 400 kg in good condition, required a draft power of ca. 90 kp in light soil (clay content of 12-15%). The working depth was 9 cm; the infiltration profile was deeper than without tillage (Le Thiec and Bordet, 1988). However, the operations did not go beyond the bounds of the experimental station.

4.5.3 Soil preparation in transitional zones

Cropping on ridges is widespread in transitional regions of the semihumid/semiarid climate, e. g. in Casamance in south Senegal (1000 – 1300 mm rainfall) and in the Savanes region of Togo (1000 – 1100 mm rainfall). This is practised primarily in Africa (88% of the cases) according to our survey; in South America it is often used for some crops (potatoes, tobacco). To a great extent the ridger is used exclusively for preparing these fields. Ridged cropping offers, aside from its application in irrigation systems, particular advantages in the regulation of the moisture supply:

- With suddenly occurring high quantities of rainfall in this generally drier region plants stand above water and ridged soil drains well.
- Ridged cropping reduces the surface runoff and increases infiltration. Therefore, storage of water in the deeper layers is greater than cropping on flat soil.
- The soil is only partially tilled, and narrow unworked strips remain under the ridges.
- The ridged soil is loose, favouring the growth and harvesting of tubers and groundnut.
- In cold mountainous climates the ridges offer protection against light frost due to their influence on the microclimate.

The increase of water storage is particularly important for many of the semihumid/semiarid-occurring Alfisols and Ultisols, whose storage capacity is low. Ridged cropping has advantages if the dry season sets in at a later part of the growth period and the roots have penetrated to a deeper level. The crops are protected against waterlogging caused by heavy rainfall. During dry periods in later growth phases the plants can protect larger water reserves in lower layers. By shifting the ridges for the subsequent crop an efficient weed control is achieved. (Dehn, 1981) To control evaporation a compacted, smooth or a loose surface of the ridges is desirable, depending upon the climate and the soils.

Cropping on ridges promotes a more rapid mineralization. Frequently the harvest residues are placed into the furrows, the ridges are flattened, covering the residues. In Senegal (south of Sine-Saloum) methods are used to rebuild ridges by cutting perpendicularly to the old ones. This facilitates soil preparation when low amounts of precipitation occur at the beginning of the rainy season.

Ridged structures provide protection against erosion, as long as the rainfall is not so great that it causes the ridges to burst on hilly terrain. A system of tied ridging (figure E 20) has been developed to reduce soil losses, which can be substantially greater than on flat seedbeds. Wind erosion also is reduced by cropping on ridges (Fryrear, 1984: in Klaij and Sarafini, 1988).

Fig. E 20: Tied ridging in Malawi (Photo: Roth)

According to Bouchet, director of SEMA in Boulel, Senegal (cited by Gaudefroy-Demonbynes, 1957: in Bordet et al., 1988) cropping on ridges increases yields by up to 20% where high precipitation occurs (more than 1000 mm per annum). In these wet areas more time is available for soil preparation and weed control presents more serious problems. According to our survey ridged cropping however is also frequently practised where low average precipitation occurs (between 500 and 1000 mm).

4.5.4 Soil preparation in humid climates

In the wetter regions usually only the migrants from the savanna zones practise cropping on ridges, e.g. in the Centrale region of Togo (1200 – 1300 mm rainfall). This leads to the conclusion that the ridges originated from the transition from semihumid to subhumid climate, where due to the high humidity already a greater importance is attached to weed control than in the dry savanna. On the other hand, cropping on mounds is widespread in humid climates, especially where the land is used less intensively. The topsoil is accumulated in mounds and thus nutrients are collected. The cropping area on mounds is small. Weed control plays a lesser role in this system and tree stumps are not an obstacle.

Covering the soil represents an essential measure for conserving soil fertility in the tropics and subtropics. According to Rockwood and Lal (1974) the main advantage of mulching, in combination with minimal soil tillage or no tillage, lies in the assured and cheap reduction of erosion. The effect of the mulch consists in protection from the impact of raindrops, which causes surface sealing. This advantage has an effect especially in regions as e.g. in South Brazil where 60 mm per hour or 250 mm per day at seeding time are not unusual. Here, an effective erosion control is only assured by means of a permanent soil covering (Derpsch et al., 1988).

Soil fertility is influenced positively by means of no-tillage under mulch cover whereby soil temperature fluctuations are reduced and higher temperatures are avoided. A slower mineralization occurs due to the low cultivation intensity (Lal, 1975). A higher moisture availability is achieved by a reduction of evaporation and higher infiltration rates in no-tillage under mulch cover. The biological soil activity is increased with prolonged application of mulching under the no-till method.

Despite the positive impact of no-tillage under mulch cover reported by many authors (e. g. for South Brazil: Monegat, 1985; Derpsch et al., 1988) this method in the humid regions is not widespread in practice in terms of animal traction, especially in Africa. The no-till technique places high demands on the management and the cropping of green manure for the production of necessary mulch means an extra investment. Significant problems such as weed control without extra inputs such as herbicides, as well as nutrient dynamics remain unsolved. Appropriate draft-animal implements for sowing on unprepared soil is not yet ready to be put into practice.

In contrast to the semihumid/semiarid regions weed control and the working in of organic matter represent the main constraints in humid areas. More time is available for soil preparation due to the longer vegetation period. Therefore, soil preparation with the plow predominates here on the level of animal traction.