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The Economics of Small-Scale Wheat Production Technologies for Kenya

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The views represented in this paper are those of the authors and not to be attributed to their respective organizations.

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Executive Summary

Kenya is a net importer of wheat and is projected to remain so to the end of this century. Wheat is grown in Kenya using mechanized production methods that differ little from what might be observed in many industrialized countries. These methods contrast markedly with wheat-growing methods in many parts of the Third World where more labor-intensive practices are followed.

In Kenya, wheat is not traditionally a smallholder crop, although it is grown on small farms. Maize is the traditional smallholder crop in many parts of Kenya. As a consequence, when wheat land has been settled by smallholders in Kenya cropping patterns have switched from wheat to maize and, to a lesser extent, dairying. Since Kenya is largely self-sufficient in maize production, policymakers and researchers are seeking to promote small-scale, labor-intensive wheat technologies. This decision is based partly on the need to promote employment and income in the rural sector. Given Kenya's high population growth rates and comparatively low wage rates, substituting labor for capital in agriculture has been a central feature of post-Independence land settlement programs.

This study reports on an economic analysis of smallholder wheat technologies. Since smallholder wheat technologies are not used in Kenya, the analysis superimposes technical information from other countries, particularly Pakistan, where smallholder technologies are well established. The analysis involved costing alternative operations of different wheat and maize technologies for different sizes of fields. The time required for operations to be done 1) by machinery of different sizes, 2) by bullocks, and 3) by manual labor with hoes, sickles, or by hand was specified. This provided the basis for costing alternative operations and hence technologies having widely differing degrees of labor intensity for wheat.

In addition to costing technologies with budgetary analysis, the profitability of alternative wheat and maize technologies was analyzed. This was done using 1987 prices of inputs and outputs for the Nakuru district. Besides the analysis of farmer profitability, the national profitability (social profitability) was assessed. National profitability provides a measure of comparative advantage of alternative technologies for wheat and maize in Kenya. Some key parameters were varied to analyze the sensitivity of the results to underlying assumptions.

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Results

Data from previous studies suggested that the area of smallholder wheat in Kenya might be around 15% of total wheat area but that over 70% of the farmers might be growing wheat on that land. However, in considering the potential for smallholder wheat in Kenya current area is probably less important than an assessment of potential area.

A survey of smallholder wheat farmers in May and June 1986 suggested that lack of timeliness in performing certain operations was a key factor affecting wheat yields. Late harvesting was considered to be the main source of yield loss on smallholder wheat farms, although many farmers also attributed sizeable yield losses to late plowing and planting. This information was supported by agronomic studies conducted by wheat researchers in Kenya, Tanzania, and Ethiopia. A wheat yield loss of 20% was estimated to cost some 1,600 Kenyan shillings (Ksh) per hectare (almost US$ 100).

Farm contractors in Kenya generally charge similar rates for their services, irrespective of the size of the field in which plowing, planting, harvesting, or other operations are undertaken. As a consequence, contractors greatly prefer jobs on large farms because they are more profitable and incur less contractor overheads and financial risk per area completed. Jobs on small farms receive low priority and are usually the last, or near to last, to be done in any area. It is for this reason that small-scale wheat farmers have problems completing some operations on time.

The time required to complete the main operations on fields of different sizes was analyzed. The smaller the field, the more extra machinery time is required to finish a given area. Compared to large fields, on small fields more time was lost in turning, headland overlap, setting up machinery in each field, and moving from field to field. The analysis suggested that on very small fields of 0.4 ha, 28% more time was required to plow a given area compared with plowing the same area on very large fields. For combine harvesting, 54% more time was required. In contrast to heavily mechanized operations, labor-intensive operations on small fields require very little, if any, extra time to complete. The dis-economies of size with machinery on small fields suggests that on small holdings labor-intensive wheat technologies might be more economic than the mechanized technologies currently used.

The costs per hectare of alternative operations undertaken on fields of different sizes were analyzed. Apart from using bullocks for certain operations, labor-intensive methods of plowing, cultivating, and planting were generally no cheaper than using a tractor, except for very small fields

(1 ha or less). In contrast, labor-intensive harvesting technologies became cheaper than the full costs of combine harvesting at a field size of just under 4 ha, and was less than half the cost for the smallest field size.

Although using labor-intensive technologies to harvest small fields was cheaper than the estimated full cost of combine harvesting, it was estimated to cost more than contractors' current charges of 500 Ks/ha. Hand cutting and threshing with a large mechanical thresher was estimated to cost about 25% more than the current contractor rate. For this reason, smallholder wheat farmers in Kenya would find labor-intensive wheat technologies attractive only if the technologies sizeably reduced losses caused by harvest delays from having to wait for contractors.

An analysis of the profitability of a range of wheat and maize technologies using 1987 prices suggested that fully mechanized wheat was the most profitable alternative on large fields. On very small fields, however, maize and labor-intensive wheat technology were approximately equal in profitability and superior to fully mechanized wheat. Labor-intensive wheat showed greater profitability than fully mechanized wheat on field sizes less than 4 ha.

Analysis of comparative advantage was undertaken to assess which technologies were most profitable from the national perspective. The analysis involved estimating the "opportunity" prices of all inputs (that is, prices that have been adjusted to be free of all government policy effects and short-term commodity price fluctuations). Generally, using the opportunity prices of inputs led to lower machinery costs than using farmer prices, because the lower costs of repairs and fuel tended to outweigh higher capital costs. Assuming opportunity wage rates equal to current levels, the analysis therefore tended to favor more mechanized technologies.

National profitability was positive for fully mechanized wheat technology on large fields, indicating that in Kenya a comparative advantage exists in producing wheat on large farms with machinery-intensive technologies. On small fields, labor-intensive wheat was more nationally profitable than fully mechanized wheat but producing maize with labor-intensive technology was still slightly more profitable than producing wheat with labor-intensive technology. It was estimated that a 4% price premium would be needed to make labor-intensive wheat more nationally profitable than maize on small fields. This comparatively small difference suggests that the efficiency costs of substituting labor-intensive wheat for maize on small holdings would be low.

Whether or not to devote more resources to small-scale wheat technologies in Kenya is a decision that will be based on a number of considerations, such as profitability, effects on employment, on distribution of income, and on foreign exchange as well as the likely uptake of the research results. Our analysis generally shows that, according to these criteria, smallholder wheat in the Nakuru district offers little or no advantage over maize, since maize grown with labor-intensive technology can offer employment, income for small farmers, and foreign exchange efficiency comparable to smallholder wheat. The economic advantage of maize production depends on the natural advantages that exist in different locations for the two crops on small holdings. Where conditions favor wheat production more than our analysis has assumed, smallholder wheat will offer greater profitability to farmers and to the nation than maize.

The potential for smallholder wheat also depends on two other key factors: 1) the availability of a pool of casual labor to do the cutting, stacking, threshing, and other tasks involved and 2) farmers' preferences for one crop over another. Nevertheless, the low opportunity cost of labor suggests that the potential exists for labor-intensive wheat production, as occurs neighboring Ethiopia.

Implications for Further Research

The results of this study raise several issues for further research. First, more information is needed to assess sources of yield losses on small holdings. Additional data on sources of yield losses could be obtained by a more extensive survey of smallholders who grow wheat. That information might be supplemented by further on-farm analysis of the relationship between planting dates and wheat yields, and between harvest dates and yields. Second, information could be gathered on potential areas for smallholder wheat in Kenya, areas where wheat is currently grown on smallholdings, yields of wheat and competing crops in major production districts, and so on. Finally, analyses similar to this one might be conducted in other districts of Kenya to assess whether the natural advantages of wheat are sufficient to warrant promoting smallholder wheat technology.

If smallholder wheat technology is to be developed further in Kenya, this study suggests that focusing on harvesting technology is probably the most cost-effective strategy. A central element of the strategy with respect to labor-intensive wheat harvesting must be preventing losses by improving the timeliness of operations. If small-scale wheat farmers do not perceive gains in yield (from savings in crop losses) they will be unlikely to switch from their current technologies to others.

The Economics of Small-Scale Wheat Production Technologies for Kenya

Introduction

Population pressure is a key issue facing the Republic of Kenya for the remainder of this century and into the early part of the next. By the year 2000, Kenya's population is projected to be about 35 million (Republic of Kenya 1986). By the turn of the century the number of jobs will have to double to maintain recent rates of employment. In laying out its development strategy to the end of this century, the Government of Kenya strongly emphasized further development of agriculture as the "leading sector in stimulating economic growth and job creation" (Republic of Kenya 1986). This goal implies intensified production of export and food crops.

Population pressure and land settlement have led to considerable change in food crop production in Kenya. Areas where wheat was once grown on large-scale, mechanized farms now produce an array of crops and livestock on the smaller holdings that were part of the land settlement schemes (Jaetzold and Schmidt 1983). Where conditions permit maize to be grown, it is the cereal crop preferred over others on small holdings. In Kenya wheat is not a traditional smallholder crop. However, in most traditional wheat-producing areas many small wheat farms can be found.

In contrast to Kenya, in many other parts of the developing world wheat is a smallholder crop, especially in China, South Asia, parts of West Asia and North Africa, as well as in Kenya's northern neighbor, Ethiopia. In many of these countries but certainly not all, rural wage rates are actually higher than their equivalent in Kenya (CIMMYT 1985), although much more labor-intensive practices are used to grow wheat. In Kenya, smallholder wheat farmers hire machinery contractors to provide tractor and harvesting services.

Kenya is about 60–70% self-sufficient in wheat production. However, projections to the year 2000 suggest that this degree of self-sufficiency will decline if demand grows as rapidly as expected (Republic of Kenya 1986). Kenya has several alternatives for increasing domestic wheat production: expanding into new areas, substituting wheat for other crops, raising levels of inputs applied to wheat, and increasing the productivity of wheat through crop research and extension. Which alternatives to adopt will be influenced by many considerations, including the economic merits of each alternative.

One question facing Kenyan wheat researchers and policymakers is to what extent smallholder wheat production technologies should be researched and promoted. A related question is which of these technologies should receive the bulk of the developmental efforts. To help address these two questions, this study provides an economic analysis of smallholder wheat production technologies in Kenya. Since some smallholder wheat technologies are in the preliminary stages of testing in Kenya, information is taken from other countries, especially Pakistan, to provide a basis for the economic analysis. As well as considering the economics of different technologies using current farmer prices, the study uses methods to adjust prices to analyze the comparative advantage of resources in smallholder wheat production.

The study focuses on one traditional wheat area of Kenya, the Nakuru district, selected because considerable land settlement has occurred in the area and much land has been shifted from large-scale wheat production to smallholder maize production and dairying. Many smallholders in the Nakuru area continue to grow some wheat and presumably would adopt labor-intensive technologies to produce wheat if they were perceived to be beneficial. The economics of labor-intensive technologies would likely be very similar for other regions in Kenya where smallholder wheat production is possible. Another reason for selecting the Nakuru area is that the center of wheat research in Kenya, the National Plant Breeding Station at Njoro, is located there and does research on smallholder wheat technologies.

In summary, the objectives of the study are:

- To analyze the profitability to farmers of smallholder wheat production technologies, specifically for the Nakuru district of Kenya;

- To analyze the comparative advantage of smallholder wheat technologies in the Nakuru district;

- To suggest strategies for research relating to smallholder wheat production; and

- To suggest further economic research relating to production technologies for smallholder wheat in Kenya.

This was a preliminary study, and we hope that the analysis will stimulate further economic research on different technologies and on policies important to Kenyan agriculture. We also hope that the study will encourage similar work in other countries where comparable issues arise.

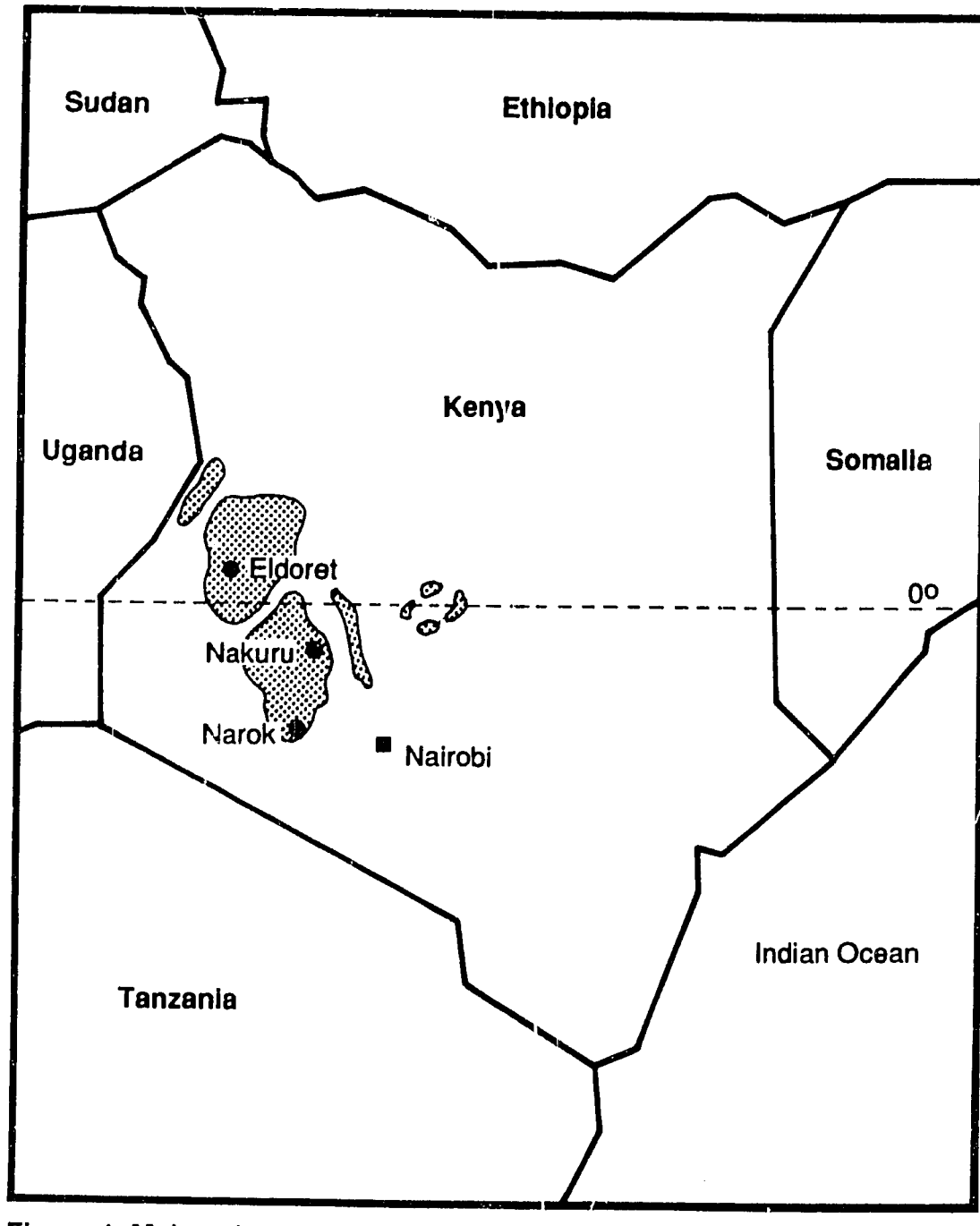

Figure 1. Major wheat-growing regions of Kenya.

Background to the Study

Wheat in Kenya

Wheat is one of seven crops that are "central to achieving the development goals established for agriculture" in Kenya (Republic of Kenya 1986). Some 100,000–120,000 ha of wheat have been harvested annually in Kenya during the 1980s, with average yields ranging from just under 1 t/ha (in the drought year of 1984) to 2.3 t/ha (in 1982). Wheat occupied 2.2% of the total area of crops and pastures for dairying in 1983/84 (Republic of Kenya 1986). Wheat's share of the total value of crops and dairy output of Kenyan agriculture was also just over 2%, although, as a share of marketed output, wheat in recent years has ranged from 2.3–4.9% (Republic of Kenya 1987).

Wheat is mainly grown in the cooler and medium-rainfall regions of Kenya, generally at elevations over 1,800 meters above sea level (Figure 1) and mostly on large farms. The environments for growing wheat are diverse and found throughout Kenya. The main growing regions are:

- Nakuru district and neighboring areas, centered upon Nakuru and areas to the south and west
- Mount Kenya, largely the northern and western slopes
- Uasin Gishu, centered upon Eldoret and comprising areas to the north and east
- Trans Nzoia, centered upon Kitale and the lower slopes of Mt. Elgon
- Narok, on new lands which until recently were Masai pastoral lands

The differences among these growing regions in rainfall and temperature, which are largely determined by altitude and topography, mean that wheat is grown somewhere in Kenya throughout the year. There is a lengthy period between the first dates of planting and harvesting wheat in the "earliest" growing region, lower Narok, and those in the "latest" region, Eldoret. In some parts of Kenya wheat is grown during the short rains, being planted in September and harvested in March. Unlike many other countries, in Kenya the fleet of harvesters and machinery for growing wheat can therefore be occupied for an unusually large number of months of the year. (Of course, this machinery can also be used on other cereal crops.)

With the exception of Narok, the wheat-growing regions listed earlier were part of the large-scale mixed farm areas settled by Europeans. Since 1961, programs have been undertaken to settle more people in these areas, which are generally fertile and amenable to more-intensive cropping. Approximately one-third of the large-scale mixed farm area has been officially subdivided since Independence (World Bank 1982). Many of the new settlers came from areas where maize and other subsistence food crops predominated but little if any wheat was grown. The smallholder settlers naturally engaged in enterprises with which they were familiar and whose products they were accustomed to using: maize, other smallholder crops, and dairying.

Wheat on Small Holdings

There are around two million small holdings in Kenya, averaging about 2 ha. The number, area, approximate average holding size, and employment for different categories of farms are presented in Table 1 using data are from the mid-1970s. Since then the number of small farms has probably increased, and the number of mixed and large farms may have declined somewhat.

Table 1. Distribution by farm size of number of farms, area, and employment in Kenyan agriculture, 1978

	Number of farms	Total area (000 ha)	Approximate average farm size (ha)	Employment (000)	Employment per 100 ha
Small farms	1,704,000	3,500	2	2,236	64
Medium or "gap" farms	40,000	1,000	25	80	8
Mixed farms	1,800	900	500	200 a	6 b
Large farms	2,460	2,500	1,000	–	– c
Commercial ranches	100	650	6,500	–	–
Plantations	475	185	390	129	70

Source: World Bank (1982)

a Includes 144,000 squatters.
b Excluding squatters.
c Not quoted because of uncertainty of data.

Wheat is grown mainly on the medium-sized, mixed, and large farms. Up-to-date information is not available on the extent of wheat area and production on small holdings in Kenya. It was reported that in 1971 wheat production on farms under 20 ha was just over 20,000 t, some 10% of total production. This estimate is higher than in earlier years (World Bank 1982).

Surveys of small farms in some wheat-growing districts all refer to the scarcity and uncertainty of information on numbers of small-scale wheat growers. The best available data are reported by Bartenge (1979) and Mulamula (1983). Estimates of numbers of small-scale wheat farmers in some districts in the late 1970s are presented in Table 2. More current information on wheat on small holdings is unavailable, and a survey of several districts combined with other information from official sources would assist considerably in quantifying the area planted to wheat on small holdings. Data from Mulamula (1983) suggest that, for a sample taken in the Nakuru district, farms smaller than 20 ha occupied no more than 15% of the total wheat area. However, that 15% of wheat area represented well over 70% of the total number of wheat farmers (Table 3, page 7).

Informal discussions with farmers and contractors in Nakuru district and the areas around Eldoret suggest that wheat area, including land devoted to small-scale wheat production, has increased in recent years. The increase has occurred because the price of wheat has been considered more favorable than prices of competing crops. In addition, payments to farmers for maize are often delayed for up to a year whereas payments for wheat are generally more prompt.

Table 2. Number of small-scale wheat farms in selected districts of Kenya

District	Year	Number of small-scale farms
Nakuru	1982	312
Nyandarua	1978	148
Keyo-Marakwet	1978	500
Meru	1978	400
Laikipia		
Ng'Garua Settlement	1978	184
Murmunet Settlement	1978	120

Source: Bartenge (1979) and Mulamula (1983)

Table 3. Farm size distribution in selected areas of Nakuru district, Kenya, 1982

Farm size (ha)	Number	Percentage by number	Estimated total area[a] (ha)	Estimated percentage by area
< 4	88	20	220	1
5–8	112	26	728	4
9–12	60	14	630	4
13–16	21	5	305	2
17–20	31	7	574	3
Total small farms	**312**	**72**	**2,457**	**14**
20–120	96	22	7,200	43
120–400	18	4	4,680	28
> 400	5	1	2,500	15
Total large farms	**119**	**28**	**14,380**	**36**
Total all farms	**431**	**100**	**16,837**	**100**

Source: Mulamula (1983)

a Calculated taking the midpoint of the range of area in each size category.

Important as it may be, the number of small holdings producing wheat is not the central issue for this study. More important is the potential area for smallholder wheat production, which comprises 1) areas where wheat was grown on larger farms and where other crops or pasture are now grown on smallholder settlements; 2) land that might be switched from other crops to wheat if the smallholder technologies were better developed; and 3) potential wheat land on large farms that are being subdivided or might be subdivided in the future. It is likely that the potential area for producing wheat on small holdings considerably exceeds the current area. Whether or not the area of smallholder wheat increases in the future will depend upon the availability of technology for growing wheat on small holdings and the economics of smallholder wheat production compared with alternative crop and livestock enterprises.

Current Wheat Technologies

Farmers' Practices with Large-Scale Technology

Large-scale wheat production in Kenya involves the use of medium to large tractors (75–125 horsepower range) and compatible cultivation, planting, and

spraying equipment and combine harvesters (Harder 1974). Typically, one or two plowings by one-way disc plows are followed by one or two disc harrowings before wheat is planted with a seed drill. If broadleaf or grassy weeds are dense enough to require spraying, a wide, tractor-pulled boom spray is used. Wheat is usually harvested by self-propelled combine harvester and increasingly bulked and transported directly to depots set up to handle bulk wheat. Where transport considerations dictate or bulk grain facilities are distant, wheat is bagged and trucked to depots that receive bagged grain. A numbers of farmers take the wheat straw that is left in windrows by the combine harvester and bale it, sell it, or use it for animal feed or bedding. After the bales and bags are removed, livestock often graze the wheat stubble for up to three months before plowing commences for the next year's crop.

Wheat is commonly grown for three years or more in succession, and then might be rotated with pasture or other crops to break the cycle of diseases and weeds and to improve soil structure. Some progressive farmers employ new conservation tillage practices (stubble mulching and chisel plowing). Some also use "knock down" herbicides such as "Round-Up" and others practice zero tillage before planting. These technologies promise to increase the number of years that the land may be planted to wheat, to sizeably reduce soil erosion, and to improve moisture conservation.

Insufficient moisture remains an important limiting factor for wheat production in most years and districts of Kenya. The recommendations for planting wheat in Kenya place considerable emphasis on performing operations at the appropriate time and on choosing varieties with the optimal maturity for particular locations and elevations (National Plant Breeding Station 1987).

Data reported from trials at the National Plant Breeding Station in Njoro (Toogood 1981) indicate how crucial the time of initial land preparation can be for wheat yields. For example, the highest average yields–3.4 t/ha–were obtained when land was plowed immediately after harvest (1 October), whereas average yields were reduced by 30% when land was plowed six months after harvest (1 April). The time of planting is also an important factor affecting yields. Data reported for Arusha in Tanzania, for example, indicated that when planting was delayed for one month after the optimal date the subsequent yield loss was 27–35% (Lyimo and Button, 1983). Similar findings are reported for locations in Ethiopia (Gebeyehu n.d.), with less consistency, and comparable relationships probably exist for many wheat-growing regions of Kenya.

Harvesting on time is also important to minimize grain losses from weather damage, shattering, bird damage, and so on. Contractors and farmers consulted during this study suggested that a three-week delay in harvesting normally results in losses of 20–30% of grain yield, and even more if weather at harvest is unfavorable.

A number of large-scale farmers use their own machinery to grow and harvest wheat because of the need for timely operations and also because of the size of operation. Large-scale farmers who hire contractors generally obtain their services when they are required because larger areas are usually the most profitable to contractors.

Farmers' Practices on Smallholdings

In contrast with producing wheat on large farms, growing wheat on small farms does not warrant owning machinery for use on one farm alone even if some of it can be used on other crops and enterprises. Thus most smallholders growing wheat hire machinery contractors to undertake many, if not all, of their wheat-growing operations (van Eijnatten 1976, Bartenge 1979).

Farm machinery services can be hired for all operations, although in a few cases a small-scale farmer might elect to buy a tractor and tillage equipment and help pay for the investment by offering contracting services. This practice varies according to the type of operation and the cost of the tillage equipment required. For example, a survey of smallholder wheat farmers in Nakuru district in 1986 (documented in Appendix A) indicated that 24% of farmers grew less than 10 ha of wheat plowed with their own tractors, whereas only 16% planted, and none harvested, with their own machinery.

At present smallholder wheat production technology differs only by degree from that employed on large farms. For example, smallholder farmers reduce the number of tillage operations, often because they lack working capital. This problem can be exacerbated when smallholders rely upon Agricultural Finance Corporation funds to pay for their main farming inputs and for contractors' services, because funds are often delayed in getting to farmers. Tractors and other equipment used on small holdings are somewhat smaller than those used on large farms. Tractors used on small holdings often range between 35–75 horsepower, whereas they typically range upwards of 75 horsepower on large farms.

On small holdings, a number of farmers now use knapsack sprayers in place of larger, tractor-mounted boom sprays. These sprayers appear to be the only labor-intensive technology that smallholder wheat farmers have readily

adopted, although the extent of adoption has not been quantified. At harvest, smallholders largely rely upon contractors' services for combining and for transport. Because smallholders find it difficult to obtain trucks to carry the grain in bulk at the same time as they obtain the harvester, they usually bag the wheat, which serves as a check on the quantity that is marketed.

Most smallholders grow maize and vegetable crops and maintain a small dairy herd. Generally, the area planted to maize is determined by each household's subsistence need for maize. Most smallholders consulted for this study reported that they planted from 0.8 to 1 ha of maize. When asked why they did not plant more, they generally said that this area was sufficient in most years to meet household needs and that on larger areas farmers faced a labor constraint, particularly with weeding maize by hand after planting. Smallholders generally reported that they preferred to grow wheat rather than maize beyond the levels set by their household food needs and by the labor constraint. Wheat was reported to be an easier cash crop to manage than maize and was also more profitable if the farmer depended upon hired labor.

Dairying sometimes complements crops on smallholdings. Labor requirements for dairying are more evenly distributed throughout the year because farmers rotate land from crops to pastures and because dairy cattle can consume crop residues, roadside pasture, and other readily available feed that might otherwise be underused. However, dairying can also substitute for wheat production. A few farmers reported that they were increasing their dairy output by putting more land under pasture and reducing the area of wheat.

Constraints of Smallholder Wheat Production

All wheat researchers, farmers, and contractors contacted for this study reported that smallholders who grow wheat have serious problems performing crop operations on time. To explore this issue, a short survey of smallholder wheat farmers was undertaken in 1986 in two wheat-growing regions of Kenya, the districts of Nakuru and Eldoret. The aim of the survey was to assess how much the main wheat-growing operations were delayed on small farms and to obtain farmers' assessments of how much yields were reduced because of the delays.

Of the 45 farmers surveyed who grew no more than 4 ha of wheat in 1986, the average farm size was 8 ha, and the average area planted to wheat 2.6 ha. Average reported wheat yields for this sample of smallholder farmers

were 2.6 t/ha (or 11.6 bags per acre) in 1985. The average reported yield for the Nakuru district in the same year was 3.2 t/ha (14 bags per acre). Some 76% of farmers assessed that they suffered yield losses because operations were not done on time; the remainder either believed that lack of timeliness did not lower yields or did not respond to the question. Among the farmers who asserted that lack of timeliness reduced yields in 1985, the average assessed loss was 22%, or some 580 kg/ha wheat. This represents a loss at current wheat prices of some Ks 1,700/ha, more than US$ 100/ha at the official exchange rate. Such losses correspond closely with assessed costs of harvest delay in a risky wheat-growing environment in Australia (Whan and Hammer 1985).

Interestingly, 55% of farmers estimated that harvesting delays caused the greatest yield loss, 30% that delays at planting caused the greatest yield loss, and only 8% felt that delays in plowing caused the greatest yield loss.

It should be noted that farmers with more than 4 ha of wheat reported similar estimates of yield loss in total. No strong correlation could be found between assessed yield loss and farm size, suggesting that yield losses of the magnitude described above are not confined to very small wheat farmers. Only 39% of the farmers with more than 4 ha of wheat reported that harvesting delays caused the greatest yield loss, and a similar number thought late planting was the source of greatest loss. Just over 20% said that late plowing was the greatest cause of the yield loss. These data suggest that lack of timeliness might not simply be a problem for very small wheat farmers but may indeed be a more general problem, faced by medium-sized farmers in Kenya as well.

Certain operations may not be performed at the optimal date for valid economic reasons. For example, small farmers may value the feed obtained from stubble sufficiently to delay plowing. Lack of cash may also prevent operations from being performed at the date that is best for maximizing yields. Farmers may also be somewhat cautious in deciding upon the date of planting, aiming to ensure that plenty of moisture is available for seed to germinate. Despite such considerations, the general opinion voiced in many meetings with farmers, contractors, and wheat researchers was that smallholders producing wheat face serious constraints with regard to timeliness of operations.

Table 4. Profitability of maize and wheat (Ksh/ha) calculated using different contractor charges and four levels of yield loss, 1987

	Maize tractor plow and cultivate (Ksh/ha)	Wheat by contract 0 loss (Ksh/ha)	Wheat by contract 10% loss (Ksh/ha)	Wheat by contract 20% loss (Ksh/ha)	Wheat by contract 30% loss (Ksh/ha)
Returns					
Grain	6,557	8,587	7,728	6,869	6,001
Straw/stover	2,480	1,740	1,740	1,740	1,740
Total	9,037	10,327	9,468	8,609	7,751
Costs					
Plowing	500	500	500	500	500
Harrowing	600	600	600	600	600
Planting	188	250	250	250	250
Hand weeding	900	0	0	0	0
Spraying	0	250	250	250	250
Hand cut/pick	300	0	0	0	0
Machine reap	0	0	0	0	0
Thresh/shell	225	0	0	0	0
Harvest	0	500	500	500	500
Seed	281	613	613	613	613
Fertilizer	1,095	1,095	1,095	1,095	1,095
Herbicide	0	329	329	329	329
Insecticide	90	0	0	0	0
Gunnies	426	681	681	681	681
Interest	246	257	231	206	180
Miscellaneous	242	254	252	251	250
Variable costs	5,093	5,329	5,301	5,275	5,248
Gross margin	3,945	4,998	4,167	3,334	2,503
Land rent	1,000	1,000	1,000	1,000	1,000
Profit	2,944	3,998	3,167	2,334	1,503

Some indication of how reduced yields can influence profitability is provided in Table 4. In this analysis, 1987 contractors' charges for each machinery operation were used (along with prices and technical information documented in Appendices C and D). Budgets were prepared assuming yields of 2.8 t/ha for wheat (12.5 bags per acre) and 3.5 t/ha for maize (15.5 bags per acre). Budgets for wheat assuming additional yield losses of 10%, 20%, and 30% were also prepared. At wheat yields of 2.8 t/ha, the profitability of wheat is just over Ks 1,000 higher than that of maize. However, with a 20% loss in wheat yield, maize becomes the more profitable crop. A 20% loss of yield in

wheat production implies a loss of profitability of over Ks 1,500/ha. These budgets indicate the magnitude of the losses that some smallholder wheat producers may incur when operations are not performed on time.

Constraints of Farm Machinery Contracting

The rates charged by farm machinery contractors are established in a basically free market for their services. Government tractor hiring services exist in some locations but provide a miniscule share of the total contractor service for wheat and other cereals in Kenya. The government also encourages the continued development of the private farm machinery contractor market (Republic of Kenya 1986).

Although there are exceptions to the rule, rates for hiring machinery services are set according to general rates established by the contractors' associations. The general rates might be adjusted according to the distance the contractor must travel and according to working conditions, which are influenced by soil type, slope, amount of crop residue, and so on. However, the rates generally do not vary widely between farms of differing sizes. This lack of variation is the main reason that smallholder farmers have difficulty obtaining contractors and often have to wait for their services, for up to a month in extreme cases.

Economies associated with operating machinery on larger fields are a major reason for the delays faced by smallholders. Generally speaking, the smaller the field, the greater will be the amount of time lost by machinery contractors in providing a particular service. Greater loss of time per hectare implies higher costs per hectare of providing services. Thus contractors aim to provide services to larger farms first, because they are the most profitable.

In order to assess how contractors' real costs of providing services for different field sizes might vary, we calculated the amount of time lost from the following in a normal working day:

- Overlapping with turning and headlands;
- Moving from field to field;
- Setting the machinery in each new field; and
- Servicing machinery daily.

Details of the calculations are presented in Appendix B. The approach followed was based upon Brown and Schoney (1985). It should be noted that no attempt was made to factor in additional losses of time that might be incurred because there are more obstacles on small fields, because machinery breaks down, and because weather is uncertain.

To derive the assumptions underlying the calculations, considerable time was spent with farm machinery contractors, asking them about average work speeds and work widths for different operations, about the time usually needed to move from field to field, about the typical shape of fields, and about average daily service time and work hours.

Estimates of the amount of machinery time lost for five main farming operations for different field sizes are presented in Figure 2 (page 15). The estimates have three key features. First, as field size declines, each of the operations displays increasing amounts of time lost per working day. Second, wider equipment loses a greater amount of time per day for a given field size and shows much higher rates of inefficiency than narrower equipment. Third, for each operation there appears to be a minimum field size above which reductions in lost time diminish.

These results are indicative of the increasing time needed to perform particular machinery operations as field size declines. Although detailed surveys of time taken for farm machinery contractors to complete different fields could be undertaken, this exercise could be very costly and might be subject to measurement errors and uncertainties deliberately excluded from the analysis.

Alternative Small-Scale Wheat Production Technologies

Alternative Crop Growing Technologies

A wide array of equipment and methods could be employed in Kenya as small-scale wheat production technologies, although the costs of some might render them less economic than contractors' services. For more details on these technologies, some very useful references include Gardezi et al. (1979), Morris (1981), the International Center for Research in the Semi-Arid Tropics (1983), Tanner and Ransom (1985), and Smale (1987).

For plowing, alternative technologies range from digging land by hand, which is done in most maize-producing areas of Kenya, to plowing with bullocks, and to using small, motorized two-wheeled or four-wheeled tractors with a plow attachment. Each of these operations is likely to be less effective

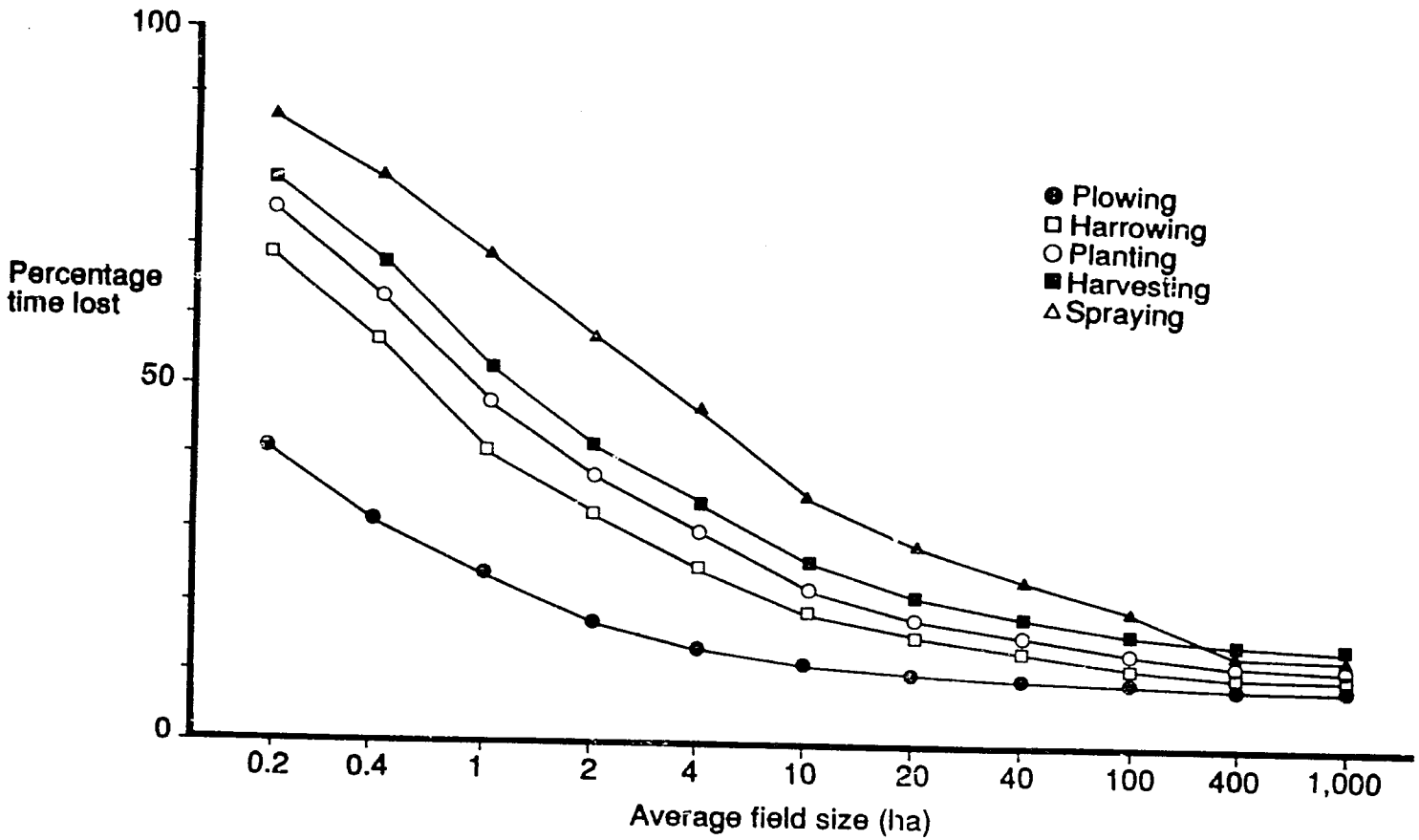

Figure 2. Amount of machinery time lost per day related to average field size.
Note: Bottom scale is not continuous.

than the larger tractor-pulled plow in providing evenness of plow penetration and weed kill, especially if the operation is spread over a much longer period. However, labor-intensive methods of plowing are used widely in other countries (Copland 1985, Binswanger 1986) and in other parts of Kenya with different cropping systems (Ministry of Agriculture and Livestock Development 1986, Ockwell 1987).

For cultivating, potential alternatives to disc harrowing with a medium-sized tractor include digging by hand, using bullocks to cultivate, or using small two-wheeled or four-wheeled tractors with cultivators attached. To plant wheat, the common method used by smallholders in other countries is to broadcast seed and fertilizer by hand and then to harrow the land. The harrowing may be done manually or with bullocks or with small two-wheeled or four-wheeled tractors, depending upon field size, labor availability, and the slope of the land. Small planters drawn by bullocks or small tractors could also be employed, although it is unlikely that small farmers could afford to buy that equipment unless they could hire it out extensively on other small holdings. Much development of animal traction has been undertaken in Africa and Asia, with the International Livestock Centre for Africa (ILCA) and ICRISAT playing important roles (Westley and Johnston 1975, Munzinger 1982, ICRISAT 1983, Aked 1984, Copland 1985). Far less work has been undertaken on small-motorized cultivation equipment in Africa than in Asia (see for example the machine specifications for different small-motorized equipment provided by the Agricultural Machinery Development Program, International Rice Research Institute).

To control weeds on small holdings, a tractor-drawn boom spray could readily be displaced by knapsack sprayers or by hand weeding where labor is sufficient. Scarcity of water is a major constraint to spraying, and most contractors deliver water as well. Since newer herbicides are applied at more concentrated rates using much less water per hectare, the water constraint will probably decline over time. Knapsack sprayers are easily available in Kenya and have been established as a feasible, economical tool for applying herbicides on small holdings.

Agronomic considerations associated with each of the wheat technologies are important. For example, if broadcasting seed were to replace line planting on small holdings (the current technology), heavier seed and fertilizer rates would be needed to achieve the same plant density and ensure that the nutrients applied would be just as effective. Rudd and Barrow (1973) found that the effectiveness of fertilizer is more than halved when seed is broadcast instead of line drilled, although other studies suggest that the reduction of effectiveness is not so great (Tanner and Ransom 1985). The tradeoff of

earlier planting by broadcasting against later planting by line drilling must then be made. Clearly, agronomic research must be combined with economic and other research before such technologies are extended to farmers.

So far, we have reviewed alternative methods of plowing, harrowing, planting, and controlling weeds, all involving widely differing degrees of labor and machinery use. Other alternative technologies involving minimal tillage practices save on labor and machinery (Tanner and Ransom 1985, National Plant Breeding Station 1985). For this study we have not evaluated the economics of these technologies, since it is clear that if the cost of "knock down" herbicides and their application is lower than the costs of cultivation, then the profitability of minimal tillage will be very much determined by the yields achieved. Agronomic research on minimal tillage is underway in Kenya and some wheat farmers use minimal tillage technologies quite successfully For some economic analysis of these technologies, see the National Plant Breeding Station (1985).

Alternative Harvesting and Threshing Technologies

A wide array of harvesting and threshing technologies for wheat is available (Hanson, Borlaug, and Anderson 1982). Within one region of Pakistan, for example, some very interesting changes in the use of harvesting technology are occurring (Smale 1987). Farmers appear to be choosing between more mechanized and more labor-intensive methods according to economic criteria, farm size, comparative costs, availability of labor, time to complete harvest, and so on. Smale (1987) found that larger farmers are adopting combine harvesting services more rapidly in Pakistan while small farmers continue to use more labor-intensive methods.

The most labor-intensive harvesting and threshing methods involve cutting, stooking, and later threshing and winnowing the wheat by hand. A sickle is normally used to cut the wheat, which is tied into bundles bound with straw and then stooked or stacked, sometimes under cover if there is a risk of weather damage. Threshing involves flailing the wheat on the ground and winnowing it by tossing grain and chaff in the air when there is enough wind to separate the chaff from the grain. Sometimes bullocks are used to flail the grain by trampling, or wheat is flailed by hitting the heads against a log. Small sieves can be used to clean the wheat as well.

An important advantage of cutting before threshing is that wheat can be harvested at a much higher moisture content than wheat that is combine harvested. Cutting can begin when wheat has a grain moisture content well above 20%, provided that wheat can be stored where natural drying can occur without risk of weather damage or rotting. Normally wheat in Kenya is not

harvested above 14- 15% moisture content unless the grain is dried. Earlier cutting helps reduce the risk of loss from bad weather and also minimizes shattering of grain during cutting. In Pakistan, a common charge for manually cutting and stooking wheat is 10% of the harvested grain.

In place of manual cutting, mechanical cutting with small attachments to small two-wheeled or four-wheeled tractors is possible. Larger reapers are also used in India and Pakistan to eliminate the tedious task of cutting by hand and to lower cutting costs. The cut wheat is then bundled and stooked or stacked before threshing.

Mechanical threshing and winnowing have largely replaced manual methods in the Indian Punjab and Pakistan (Gupta and Singh 1986). Specialist thresher operators provide this service in the main wheat areas of these countries. While small motorized threshers are available, most mechanized threshers are large, typically driven by a 65 horsepower tractor (normal throughput of a large thresher is
1 t/hr). A charge of 10% of threshed grain is the usual cost for the service, and most farmers will also assist the thresher operator with feeding and bagging.

One useful by-product of mechanical threshing is that the wheat straw is chopped and blown from the thresher into a stack. Farmers find that the chopping adds value to the straw as a livestock feed and straw continues to provide valuable income to farmers in Pakistan (Longmire, Ahmad, and Hussain 1989). Combinations of reaper binders, tractor-pulled harvesters, and small, self-propelled combine harvesters are also used to varying degrees.

Budgetary Analysis of Alternative Technologies

Costing Alternative Operations

To better identify those technologies likely to be most profitable or least costly to farmers, each operation was costed separately for different field sizes. Initially, costing involved estimating for each operation the machinery time lost per hectare and the machinery time required to complete one hectare. Then costs per hour of operation were calculated for each machine or pair of oxen. After adding the costs of manual labor required in the operation, the cost per hectare of each operation was estimated.

A limited number of operations were included to keep the analysis manageable. The operations were:

1) Plowing
   a) Plowing with a 3-disc plow pulled by a 75 horsepower tractor
   b) Plowing with a 7 horsepower two-wheeled tractor with a single-furrow moldboard plow attached
   c) Plowing with a pair of oxen pulling a single-furrow moldboard plow
   d) Digging by hand with a heavy hoe

2) Harrowing or cultivating
   a) Harrowing with offset disc harrows pulled by a 75 horsepower tractor
   b) Cultivating with a small spring-tined cultivator pulled by a 7 horsepower two-wheeled tractor
   c) Cultivating with a small spring-tined cultivator trailed behind two oxen
   d) Cultivating by hand with a hoe

3) Planting
   a) Planting with a seed drill, incorporating seed and fertilizer in rows spaced 18 cm apart
   b) Broadcasting both seed and fertilizer by hand, followed by a harrowing with a spiked-tooth harrow pulled by a 7 horsepower two-wheeled tractor to incorporate the seed and fertilizer
   c) Broadcasting both seed and fertilizer by hand, followed by a harrowing with a spiked-tooth harrow pulled by a pair of oxen to incorporate the seed and fertilizer
   d) Broadcasting both seed and fertilizer by hand, followed by a manual harrowing, either with an improvised rake or light harrows pulled by hand

4) Weed control
   a) Spraying with a wide boom spray pulled by a 75 horsepower tractor
   b) Spraying with a knapsack sprayer
   c) Hand weeding

5) Harvesting
   a) Harvesting with a self-propelled combine harvester and conveying grain to a bagging unit in the field where workers fill bags and stitch them

b) Cutting with a reaper attached to a 75 horsepower tractor and stacking
c) Cutting with a small reaper attached to a 7 horsepower motorized two-wheeled tractor and stacking
d) Cutting by hand with a sickle and stacking
e) Threshing with a large mechanical thresher
f) Threshing with a small motorized thresher
g) Threshing and winnowing by hand

Appendix B shows the assumptions used to estimate the time required to undertake different operations with machinery and oxen and the sources of the assumptions. Estimates of the time required to do particular operations with machinery and oxen in fields of different sizes are presented in Table 5 (page 21). As would be expected, more time is required to complete a hectare with the more labor-intensive operations than the mechanized ones, the difference being greatest with the largest fields.

The time required to perform certain operations by hand was also obtained. Data were drawn from the following sources: Smale (1987), Longmire, Ahmad, and Hussain (1989), Byerlee and Longmire (1986), Byerlee (1985), and information in farm management bulletins in Zimbabwe and Kenya. Farmers, researchers, and extension officers also provided information on time required to do particular tasks with wheat and maize in the Nakuru district. The manual labor inputs for alternative operations are presented in Table 6 (page 22). Sizeable differences in the amount of labor required to perform particular operations can readily be observed. In practice, labor requirements will vary considerably according to many factors, including worker incentive, weather, soil type, topography, and so on. The data in Table 6 thus are best estimates of the average time needed to do the various operations.

Estimates of costs per hectare of different operations for 1987 are presented in Table 7 (page 23). Plowing with oxen is comparatively cheap, although soil penetration and weed kill might be less effective. Plowing with a large tractor is the next cheapest operation for all sizes of field, with the margin favoring this method as field size increases.

For harrowing, using oxen is also the cheapest option, although using large tractors also costs less than the other more labor-intensive operations, except for very small fields (1 ha and less). A similar pattern emerges for planting, with hand broadcasting and oxen harrowing costing the least. Other methods of planting do not appear to be any cheaper than using a large tractor and drill, except (again) for very small fields.

Table 5. Time required for different machinery operations to complete one hectare

	Average field size							
	.2 ha	.4 ha	1 ha	2 ha	4 ha	10 ha	20 ha	40 ha
	(h/ha)	(h/ha)	(h/ha)	(h/ha)	(h/ha)	(h/ha)	(h/ha)	(h/ha)
3-disc plow	3.84	3.24	2.84	2.69	2.60	2.53	2.51	2.49
3-m harrows	2.28	1.64	1.21	1.04	0.94	0.86	0.83	0.81
4-m drill	2.10	1.45	1.02	0.85	0.75	0.67	0.64	0.62
10-m sprayer	1.85	1.15	0.69	0.51	0.41	0.33	0.30	0.27
4-m harvester	1.95	1.31	0.89	0.72	0.63	0.56	0.53	0.51
2.2-m reaper	1.72	1.36	1.11	1.01	0.95	0.90	0.88	0.87
2-wheel tractor and plow	11.91	11.45	11.11	10.96	10.87	10.79	10.75	10.73
2-wheel tractor and cultivator	3.92	3.46	3.12	2.96	2.87	2.79	2.75	2.73
2-wheel tractor and harrow	3.48	3.02	2.67	2.52	2.42	2.34	2.31	2.28
2-wheel tractor and reaper	3.92	3.46	3.12	2.96	2.87	2.79	2.75	2.73
2 oxen and plow	14.33	13.81	13.41	13.23	13.11	13.01	12.97	12.93
2 oxen and cultivator	4.06	3.52	3.13	2.94	2.83	2.73	2.68	2.65
2 oxen and harrow	3.63	3.10	2.70	2.52	2.40	2.30	2.25	2.22
Hand sprayer	4.48	3.74	3.21	2.99	2.85	2.74	2.68	2.65

Table 6. Labor requirement of alternative operations, in addition to machinery or oxen labor

Operation	Labor (days/ha)
Plowing	
75 HP tractor and 3-disc plow	0
2-wheel tractor and plow	0
Pair of oxen and plow	2.5
Hand digging	72
Harrowing/cultivating	
75 HP tractor and disc harrows	0
2-wheel tractor and cultivator	0
Pair of oxen and cultivator	2.5
Hand cultivation	40
Planting	
75 HP tractor and seed drill	0.125
Broadcast seed, harrow, 7 HP tractor	2.5
Broadcast seed, harrow, pair of oxen	2.5
Broadcast seed, harrow, manual	12.5
Spraying	
Boom sprayer and tractor	0.025
Hand sprayer	0
Hand weeding	10
Harvesting	
Combine harvester	0.375
Reaper attached to tractor	2.5
Large mechanical thresher	2.5
Reaper attached to 7 HP tractor	3.8
Small motorized thresher	4.2
Hand cutting	12.5
Hand threshing and winnowing	30

With regard to weed control, spraying by hand is a very low-cost method. But when chemical costs are added to the cost of spraying, hand weeding becomes more attractive for small farmers. Obviously the economics of hand weeding depend very much upon weed density. If weeds are sparse, hand weeding may be the cheapest alternative. However, greater weed density could readily make the outlay for chemicals and spraying very cost-effective if the weed kill is timely. For small farmers, knapsack spraying is a very economical method of applying herbicides.

Table 7. Costs per hectare of different operations for different field sizes

	Average field size							
	.2 ha (Ksh/ha)	.4 ha (Ksh/ha)	1 ha (Ksh/ha)	2 ha (Ksh/ha)	4 ha (Ksh/ha)	10 ha (Ksh/ha)	20 ha (Ksh/ha)	40 ha (Ksh/ha)
Plowing								
75 HP tractor and 3-disc plow	762	643	564	534	517	504	498	496
2-wheel tractor and plow	1,083	1,041	1,010	997	988	981	977	975
Pair of oxen and plow	244	236	230	228	226	225	224	224
Hand digging	1,080	1,080	1,080	1,080	1,080	1,080	1,080	1,080
Harrowing/cultivating								
75 HP tractor and disc harrows	581	417	307	264	239	220	212	206
2-wheel tractor and cultivator	357	315	283	270	261	254	250	248
Pair of oxen and cultivator	224	236	230	228	226	225	224	224
Hand cultivation	600	600	600	600	600	600	600	600
Planting								
75 HP tractor and seed drill	567	392	275	229	203	182	174	168
Broadcast seed, harrow, 7 HP tractor	392	349	318	304	295	288	285	282
Broadcast seed, harrow, pair of oxen	277	270	264	261	259	258	257	257
Broadcast seed, harrow, manual	188	188	188	188	188	188	188	188
Spraying								
Boom sprayer and tractor	446	279	167	124	99	80	72	67
Hand sprayer	34	29	24	23	22	21	20	20
Hand weeding	150	150	150	150	150	150	150	150
Harvesting								
Combine harvester	1,663	1,120	761	623	543	485	460	444
Reaper attached to tractor	371	302	253	234	222	213	209	206
Large mechnical thresher	435	435	435	435	435	435	435	435
Reaper attached to 7 HP tractor	413	371	339	326	317	310	306	304
Small motorized thresher	539	592	592	592	592	592	592	592
Hand cutting	188	188	188	188	188	188	188	188
Hand threshing and winnowing	450	450	450	450	450	450	450	450

On small fields, combine harvesting is a very high-cost method. Only for fields of around 10 ha or more do the costs for combine harvesting decline below contractors' actual charges in 1987 of approximately Ks 500/ha. The costs of combining in fields averaging under 1 ha are more than double this amount. However, costs of a large reaper (and tractor) and large thresher are also quite high, ranging from Ks 630 to Ks 800/ha. Hand cutting combined with using a large thresher is cheaper than using the large reaper, and much cheaper than the underlying costs of combine harvesting in fields smaller than 2 ha. Small motorized cutting and threshing, as well as hand threshing, appear to offer no cost advantage over other methods, although they might offer some additional flexibility for smallholder wheat farmers.

Generally, the results in Table 7 suggest that the cost savings of more labor-intensive cultivation methods are not that significant. The use of bullocks appears to offer sizeable savings, but they could readily be offset by the poorer land preparation and weed kill that result from using light bullock-drawn equipment instead of tractor-drawn equipment. The analysis indicates that smallholder farmers would have to perceive significant positive yield effects from more labor-intensive technologies (for example, from more timely cultivation) before they would be likely to adopt them.

Clear cost savings are estimated from the use of knapsack spraying and *effective* hand weeding. It is for this reason that knapsack spraying is already widely employed on small fields in the district. This analysis suggests that on large fields knapsack spraying is also cheaper than using the tractor-drawn boom sprayer, provided that enough labor is available to do the job on time.

The analysis also suggests that contractors considerably undercharge for the full costs of combine harvesting in small fields by charging a flat rate for all sizes of fields. It is for this reason that contractors give low priority to small fields during harvest and tend to leave them to the very last. The high underlying costs of combine harvesting on small fields suggest that small farmers could readily benefit from the introduction of smallholder harvesting technologies, not so much because of the immediate cost savings (since farmers pay the average contractor charge of Ks 500/ha for harvesting), but because harvesting would be more timely.

Profitability of Maize and Wheat under a Range of Technologies

Using the costs estimated for different operations, we constructed per-hectare budgets comparing the profitability to farmers of different maize and wheat technologies for several field sizes. Many technologies could be derived by combining operations in various ways, as well as by varying the scale of the

operations (as demonstrated in India by Gupta and Singh, 1986). For this study, five different wheat technologies were singled out for analysis:

1) **Fully mechanized**
A combination of operations 1(a), 2(a), 3(a), 4(a), and 5(a) outlined on pages 18–20.

2) **Big reaper and thresher**
A combination of 1(a), 2(a), broadcasting and disc harrowing with a large tractor to incorporate the seed, 4(b), 5(b), and 5(e).

3) **South Asian**
A combination of 1(a), 2(a), broadcasting and disc harrowing with a large tractor to incorporate the seed, 4(b), 5(d), and 5(e).

4) **Small motorized**
A combination of 1(b), 2(b), 3(b), 4(b), 5(c), and 5(f).

5) **Oxen and labor intensive**
A combination of operations 1(c), 2(c), 3(c), 4(c), 5(d), and 5(g).

Three maize technologies were analyzed. Digging and cultivating by hand was the most labor-intensive technology, for it involved manual digging, planting, weeding, and harvesting. A second technology, using bullocks for plowing and cultivation, was analyzed. The third technology analyzed involved the use of a large tractor for plowing and cultivating.

The main operations and input levels employed in the budgets for different technologies are presented in Table 8 (page 26). Operations and input levels were based upon information provided by farmers, extension officers, and others who had previously prepared budgets for the Nakuru district. The yield levels assumed were 2.8 t/ha (12.5 bags per acre) for wheat and 3.5 t/ha (15.5 bags per acre) for maize. By-product yields were taken from information provided by farmers and contractors on the amount of straw and grazing typically derived from wheat and maize. For wheat, the estimated by-product yield was 50 bales of wheat straw and the equivalent of 6 months of grazing for dairy cattle; for maize, it was the equivalent of 12 months grazing. The analysis shows that the yields of maize and wheat by-products form quite an important component of total returns, and further analysis could be conducted to evaluate farmers' perceptions and strategies with respect to use of crop residues.

Table 8. Operations and inputs for wheat and maize under a range of technologies on a per-hectare basis, Nakuru district, Kenya

Operation	Type of technology						
	Maize, hand dig and hand cultivate	Maize, ox plow and cultivate	Maize, tractor plow and cultivate	Wheat, ox plow and labor intensive	Wheat, ox plow and labor intensive	Wheat, small motorized	Wheat, South Asian
Plowing (no.)	1	1	1	1	1	1	1
Harrowing (no.)	1	1	2	1	1	1	2
Planting (no.)	1	1	1	1	1	1	1
Hand weeding (no.)	2	2	2	2	2	0	0
Spray weeds (no.)	0	0	0	0	0	1	1
Hand cut (no.)	1	1	1	1	1	0	1
Machine reap (no.)	0	0	0	0	0	1	0
Thresh/shell (no.)	1	1	1	1	1	1	1
Combine/harvest (no.)	0	0	0	0	0	0	0
Inputs							
Seed (kg/ha)	25	25	25	125	125	125	125
Fertilizer (DAP) (kg/ha)	125	125	125	150	150	150	150
Fertilizer (CAN) (kg/ha)	125	125	150	150	150	150	150
Herbicide (Buctril) (L/ha)	0	0	0	0	0	2.5	2.5
Gunnies (no./ha)	39	39	39	28	28	31	31

Table 9. Profitability of maize and wheat per hectare under a range of technologies

Assuming a field size of 4 ha	Type of technology							
	Maize			Wheat				
	Hand dig and hand cultivate	Ox plow and cultivate	Tractor plow and cultivate	Ox plow and labor intensive	Small motorized	South Asian	Big reaper thresher	Fully mechanized
	(Ksh/ha)	(Ksh/ha)	(Ksh/ha)	(Ksh/ha)	(Ksh/ha)	(Ksh/ha)	(Ksh/ha)	(Ksh/ha)
Returns								
Grain	6,557	6,557	6,557	7,728	8,587	8,587	8,587	8,587
Straw/stover	2,480	2,480	2,480	1,740	1,740	1,740	1,740	1,740
Total	9,037	9,037	9,037	9,468	10,327	10,327	10,327	10,327
Costs								
Plowing	1,080	226	517	226	988	517	517	517
Harrowing	600	226	478	226	261	478	478	478
Planting	188	188	188	259	295	426	426	203
Hand weeding	900	900	900	0	0	0	0	09
Spraying	0	0	0	0	22	22	22	99
Hand cut/pick	300	300	300	188	0	118	0	0
Machine reap	0	0	0	0	317	0	222	0
Thresh/shell	225	225	225	450	592	435	0	0
Harvest	0	0	0	0	0	0	0	543
Seed	281	281	281	767	767	767	767	613
Fertilizer	1,095	1,095	1,095	1,313	1,313	1,313	1,313	1,095
Herbicide	0	0	0	0	329	329	329	329
Insecticide	90	90	90	0	0	0	0	0
Gunnies	426	426	426	613	681	681	681	681
Interest	276	211	240	216	297	275	277	243
Miscellaneous	273	208	237	213	293	272	273	240
Variable costs	5,734	4,376	4,977	4,4,71	6,155	5,703	5,740	5,041
Gross margin	3,303	4,661	4,060	4,997	4,172	4,624	4,587	5,286
Land rent	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Profit	2,303	3,661	3,060	3,997	3,172	3,624	3,587	4,286

A sample budget with measures of the profitability per hectare of alternative technologies for wheat and maize is presented in Table 9 (on the previous page). The budgets in Table 9 were calculated assuming an average field size of 4 ha. A 10% wheat yield loss was assumed because soil penetration and weed kill are poorer when oxen are used to prepare land. Fully mechanized wheat is the most profitable wheat technology, with the oxen and labor-intensive wheat technology ranking second. Using oxen is the most profitable of the maize technologies. Wheat grown using current (fully mechanized) technology is considerably more profitable--almost 2,000 Ksh/ha more profitable--than maize grown with labor-intensive methods.

The main results of the budgetary analysis for different average field sizes are presented below in Table 10. Estimates of the profitability per hectare of alternative technologies for five different field sizes are presented: 0.4 ha, 1 ha, 4 ha, 10 ha,and 40 ha. A key result apparent from the table is the difference in profitability among the alternative wheat technologies. On the smallest fields fully mechanized wheat production is the least profitable technology, whereas the most labor-intensive technology is the most profitable. In contrast, on the largest fields the fully mechanized technology is clearly the most profitable. Compared with maize, wheat is more profitable on large fields. However, for very small fields the profitability of smallholder wheat is similar to that of maize, suggesting that, under local growing conditions, farmers' preferences and the availability of seasonal labor might be farmers' main considerations when choosing between the two crops (assuming that labor-intensive technologies for wheat are available and farmers know about them).

Table 10. Profitability of alternative wheat and maize technologies for five field sizes, 1987

Type of technology	Average field size (ha)				
	0.4 (Ksh/ha)	1 (Ksh/ha)	4 (Ksh/ha)	10 (Ksh/ha)	40 (Ksh/ha)
Maize					
Hand dig and cultivate	2,303	2,303	2,303	2,303	2,303
Ox plow and cultivate	3,639	3,652	3,661	3,664	3,667
Tractor plow and cultivate	2,527	2,858	3,062	3,118	3,158
Wheat					
Ox plow and labor intensive	3,632	3,880	3,997	4,002	4,006
Small motorized	2,926	3,148	3,171	3,204	3,230
South Asian	2,885	3,332	3,625	3,703	3,758
Big reaper and thresher	2,759	3,260	3,586	3,674	3,738
Fully mechanized	2,705	3,672	4,286	4,450	4,566

To summarize, the above costing and budgets suggest that labor-intensive wheat technologies show superiority over fully mechanized wheat technology on small fields under 4 ha. The superiority of labor-intensive technologies stems largely from the higher costs of fully mechanized harvesting. Among the alternative operations that could be developed for more labor-intensive wheat production in Kenya, hand harvesting appears to offer the greatest potential saving to farmers and contractors. (Currently, contractors bear the high costs of harvesting small fields, since they charge a flat rate, approximately, for all harvesting operations irrespective of field size. The cost to farmers with very small wheat fields is the lengthy delay in harvesting, the yield losses associated with the delay, and the high cost of searching for contractors.)

From the farmer perspective, however, using more labor-intensive technologies to produce wheat appears to be no more profitable than growing maize on small holdings. Nevertheless, since smallholder wheat, compared to maize, would involve different dates of planting and of performing other key operations in the crop cycle, a balance of smallholder wheat and maize cropping would spread resources more evenly and be less risky for farmers than specializing in one crop.

National Profitability of Smallholder Wheat Technology

Measuring National Profitability

The analysis using actual prices faced by farmers in 1987 indicates the incentives that exist for farmers to adopt smallholder wheat technology in Kenya. Another issue that research managers should consider is the national profitability of smallholder wheat technology. Measuring national profitability is equivalent to assessing the comparative advantage that might exist in smallholder wheat production technologies in Kenya. Given that Kenya's projected population growth suggests that wages will remain comparatively low in rural areas, it is quite possible that in growing wheat on smallholdings an efficient use of resources will involve more labor-intensive technology.

Methods of assessing national profitability involve valuing all inputs and outputs in wheat and maize production at their real or opportunity prices to Kenya. These include prices that reflect longer-term international market prices for grains and tradable inputs (such as fertilizers), adjusted to their

farm-gate equivalent. The opportunity prices of domestic resources are also estimated using procedures similar to those outlined in Scandizzo and Bruce (1980), Byerlee (1985), Byerlee and Longmire (1986), and Pearson and Monke (1987). Essentially, each input and output employed in the costings above is valued at its opportunity price, which is the price obtained after eliminating the effects of all government subsidies, taxes, and exchange rate interventions.

The procedures employed to calculate the opportunity prices of all inputs and outputs for 1987, except the opportunity price of land, are documented in Appendix C. The opportunity price of land was set as the net national returns to land in its second most nationally profitable use. It is important to note that the shadow or opportunity wage rate was set equal to current wages. The opportunity price of capital (or social rate of interest, in real terms) was set at 10% per annum, 2% higher than the real interest rate on commercial borrowings in Kenya in 1987.

The percentage differences between actual farmer prices and the farm-level opportunity prices are also presented in Appendix C (Table C.1). They indicate how 1987 prices compare with longer term opportunity prices estimated for Kenya. Grain prices in 1987 are assessed to be some 12–16% higher than their longer term opportunity price. This is because longer term World Bank projections of international prices were used rather than prices based on current trend levels (World Bank 1986). It turns out that internal wheat and maize prices in Kenya are within a few percentage points of current trend levels in international prices, adjusted to the farm level. In the case of maize, the average between import parity and export parity prices at the farm level was taken as an approximation of the longer term opportunity price, since it is likely that Kenya will fluctuate between net exporting and net importing of maize.

Fertilizer prices in Kenya, in contrast to those of grain, are currently below their opportunity price because of a projected increase in world fertilizer prices by the World Bank. Farmer prices of agrochemicals and jute bags in 1987 are assessed to be higher than their opportunity price. In the case of farm machinery, however, 1987 farmer prices are below their opportunity levels, the latter being inflated by an assumed differential of 10% between the shadow exchange rate and the official rate (Appendix C).

Results of National Profitability Analysis

First we calculated costs of different operations for different field sizes using opportunity prices (Table 11). Generally operations involving machinery were estimated to cost slightly less when opportunity prices were used. The estimated reductions in costs of fuel and repairs more than outweighed the higher capital costs associated with the higher purchase price of the machinery (10% devaluation) and the higher social interest rate. Note that this result was based on the assumption that the opportunity cost of labor would not change. Table 12 (page 32) shows how costs of different operations calculated using opportunity prices differed from those using actual prices.

Table 11. Breakdown of costs of tractor and combine harvester operations calculated using opportunity prices and actual farmer prices, 1987

	Cost per hour of:			
	Tractor		Harvester	
	Actual prices	Opportunity prices	Actual prices	Opportunity prices
Purchase price (000 Ksh)	343	377	1,223	1,345
Depreciation (Ksh/h)	23.0	25.3	163.9	180.2
Capital cost (Ksh/h)	18.3	25.1	65.1	89.4
Fuel and oils (Ksh/h)	48.7	42.8	67.0	58.8
Repairs and maintenance (Ksh/h)	44.6	33.9	464.7	268.9
Operator labor (Ksh/h)	2.5	2.5	2.8	2.8
Contractor overheads (Ksh/h)	13.7	13.0	76.4	60.0
Total cost per hour (Ksh/h)	154	146	852	674

The analysis of comparative advantage was undertaken for two different situations. First, the national profitability of alternative wheat technologies was compared ignoring competition with maize. The results of this comparison are presented in Table 13 (page 32). A positive estimate of national profitability implies that a comparative advantage exists in a particular technology. A negative national profitability implies that the technology has no comparative advantage. For small fields, national profitability is highest for labor-intensive wheat technology. However, for fields above 4 ha, fully mechanized wheat technology has the highest national profitability. These results suggest that mechanized wheat technology is an efficient method of growing wheat on all but small holdings.

Table 12. Comparison of costs of different operations calculated using opportunity prices and actual farmer prices, 1987

Operation	Cost per hectare using: Actual prices (Ksh/ha)	Opportunity prices (Ksh/ha)	Percentage difference
Plowing			
75 HP tractor and disc	517	489	5.7
2-wheeled tractor	988	817	20.9
Oxen and plow	226	210	7.1
Hand digging	1,080	1,080	0
Planting			
75 HP tractor and drill	203	181	12.2
Broadcast seeding and 2-wheeled tractor	295	257	14.8
Broadcast seeding and oxen harrow	259	257	0.8
Broadcast seeding and manual harrowing	188	188	0
Spraying			
Tractor and boom sprayer	99	90	10.0
Hand sprayer	22	19	15.8
Hand weeding	150	150	0
Harvesting			
Combine harvester	543	431	26.0
Tractor and reaper	222	209	6.2
Large mechanical thresher	435	419	3.8
2-wheeled tractor and reaper	317	272	16.5
Small motorized thresher	592	559	5.9
Hand cutting	183	188	0
Hand threshing and winnowing	450	450	0

Note: Costs per hectare are based upon an average field size of 4 ha.

Table 13. National profitability of alternative wheat technologies by field size, excluding competition for domestic resources from maize, 1987

Wheat technology	National profitability per ha — Average field size: 0.5 ha (Ksh/h)	1 ha (Ksh/h)	4 ha (Ksh/h)	10 ha (Ksh/h)	40 ha (Ksh/h)
Ox plow and labor intensive	355	39	–544	–683	–781
Small motorized	–355	–568	–1,059	–1,175	–1,255
South Asian	–632	–622	–854	–924	–974
Large reaper and large thresher	–739	–678	–878	–939	–981
Fully mechanized	–473	–39	544	683	781

Table 14. National profitability of alternative wheat and maize technologies by field size, including competition for domestic resources from maize, 1987

Wheat and maize technology	National profitability per ha				
	Average field size				
	0.5 ha (Ksh/h)	1 ha (Ksh/h)	4 ha (Ksh/h)	10 ha (Ksh/h)	40 ha (Ksh/h)
Wheat, labor intensive	–301	39	–544	–683	–781
Wheat, South Asian	–933	–622	–854	–924	–974
Wheat, fully mechanized	–774	–39	544	683	781
Maize	301	–114	589	–730	–829

Second, analysis of comparative advantage was undertaken assuming that wheat and maize are competing for domestic resources. In this case the technology with the highest national profitability on small fields is maize, although labor-intensive wheat ranks a close second (Table 14). On fields of 4 ha and above, fully mechanized wheat has the highest national profitability, which tends to confirm the finding that mechanized wheat technology is an efficient use of resources on larger farms.

Sensitivity Analysis

Discussions with research managers and the existence of a program of research on small-scale wheat technologies in Kenya indicated that policymakers and research managers place great emphasis on developing labor-intensive wh at technology in Kenya. One question analyzed in this study was the size of premium above the opportunity price of wheat that would be needed to make small-scale wheat technology competitive with maize. Say, for example, that policymakers were to suggest that a premium of 10% be paid on the price of wheat to promote domestic wheat production. Adding this premium to the price of wheat in the national profitability analysis led to a clear margin of profitability in favor of labor-intensive wheat technology over maize.

Other sensitivity analysis suggested that only a 4% opportunity price premium for wheat would be sufficient to make smallholder wheat technology more nationally profitable than maize on small fields. This result suggests that if policymakers' preferences strongly favor smallholder wheat over maize, the efficiency cost of pursuing such a strategy would be comparatively

small, to the point of being far outweighed by other uncertainties in the analysis--future directions for prices, wages, interest rates, and so on. Of importance also would be the potential adoption of smallholder wheat technology in the country.

Note that the measures of national profitability are an indicator of the foreign exchange earning efficiency of alternative technologies. The 4% premium suggests that on small holdings more labor-intensive wheat and maize technologies would be almost indistinguishable in their foreign exchange earning efficiency. On large farms suited to wheat, mechanized wheat technology generates foreign exchange most efficiently (the savings of foreign currency that occurs when domestic wheat displaces imports more than outweighs the foreign exchange costs of machinery, fuel, fertilizer, and agrochemicals).

An important consideration for policymakers in establishing their preferences is the employment-generating effects of alternative technologies. The total labor input for different wheat technologies varies widely. Fully mechanized technology involves less than two days of direct labor per hectare, mainly the labor of the machinery operator. In contrast, the most labor-intensive wheat technology involved almost 180 days of labor per hectare, mainly associated with manual digging, weeding, and harvesting. Intermediate technologies using bullocks or machinery for cultivation were estimated to require a total of 20–30 days of labor, about 15 of which are for harvesting. Every hectare of wheat land harvested by hand therefore would generate about 15 days of direct employment in Kenya, concentrated during the harvest. It should be remembered that current maize technologies are even more labor-intensive than potential wheat technologies. Therefore, although labor-intensive wheat technologies displacing mechanized technologies would generate jobs on farms, there would be a net loss of jobs if labor-intensive wheat were to displace maize. Overall employment effects might be quite different from the direct farm employment effects, as well.

One major uncertainty faced by policymakers and research managers in making longer term decisions for Kenya is the future direction of real wages. In this analysis, the opportunity wage rate for rural labor was assumed to equal current wages. Longer term projections for economies in sub-Saharan Africa indicate little prospect that real wages in agriculture will increase, mainly because of the pressure of population growth.

Sensitivity analysis was undertaken by varying the opportunity wage rate to assess the impact of differences in wages on the national profitability of alternative maize and wheat technologies. The main results are presented in

Table 15. A key feature of these results is that the national profitability of maize relative to labor-intensive wheat is even higher with wage rates 50% below those used in the original analysis. As expected, the competitiveness of fully mechanized wheat is lower. On the other hand, higher wages lead fully mechanized wheat to dominate in national profitability for all sizes of field analyzed.

Table 15. Effect of different wage rates on national profitability of competing wheat and maize technologies, 1987

	National profitability per ha		
	Opportunity wage rate		
Wheat and maize technology	**50% below 1987 level (Ksh/h)**	**1987 level (Ksh/h)**	**50% above 1987 level (Ksh/h)**
Average field size 0.4 ha			
Wheat, labor intensive	–549	–301	–235
Wheat, South Asian	–1,555	–933	–492
Wheat, fully mechanized	–1,730	–774	178
Maize	523	301	–182
Average field size 40 ha			
Wheat, labor intensive	–369	–781	–1,325
Wheat, South Asian	–772	–974	–1,309
Wheat, fully mechanized	–133	781	1,234
Maize	133	–829	–1,791

Analysis was also conducted to assess whether the results are sensitive to the cost of capital (the social interest rate). Generally, the rankings of national profitability remained very stable across a wide range of real interest rates. This reflects the fact that capital costs for machinery tend to be low in relation to total costs of operation (Table 11, page 31).

Concluding Comments

The analysis summarized above was done to provide an indication of the likely profitability and comparative advantage of smallholder wheat technology in Kenya. Other economic analyses might be conducted to address the issue of smallholder wheat technology for Kenya and to explore many similar questions for other African countries: What incentives should be

provided for mechanization? Should research be done on more labor-intensive technologies or on more machinery-intensive ones? Which technologies should be promoted? Do labor-intensive technologies always save foreign exchange?

The analysis in this study is restricted to only one region of Kenya, the Nakuru district. It is possible that other districts might display different relationships between the economics of wheat and maize, as indeed should be the case across agroenvironments within Nakuru district. The dramatic diversity of Kenyan agriculture within relatively short distances suggests that in some areas stronger natural advantages might favor one crop or one technology over another. Information on the structure of agriculture in areas potentially suited to smallholder wheat technology is available from secondary sources and could be drawn together to better assess the potential for labor-intensive wheat in Kenya.

On smallholdings currently growing wheat, one of the major advantages of switching to more labor-intensive methods would be better timeliness of operations, especially harvesting. However, it remains unclear just how much lack of timeliness costs smallholders. Farmer surveys and agronomic trials could provide more precise information on this question. One point from Smale (1987) that is relevant is that losses from harvesting by hand can be quite significant. Further work in Kenya could be undertaken to assess the likely extent of these losses in relation to current losses on smallholder wheat farms.

An important consideration in deciding about a strategy for smallholder wheat technology is the availability of labor to perform the labor-intensive operations. Discussions with farmers in the course of this study suggested that a surprisingly high number were aware of labor-intensive methods for harvesting wheat. Some old farmers had seen such technologies in the 1940s. Others were aware of the methods used to harvest rice with sickles. Whether sufficient manual labor could be obtained to undertake the rather menial task of cutting the smallholder wheat crop by hand is an open question but one that should be seriously addressed before promoting such technologies in Kenya. Preliminary studies of labor groups to assess whether they would be likely to accept hand cutting and stacking wheat would help answer this question (see Smale 1987, for example).

A second important consideration is the crop production preferences of smallholder farmers. Currently, maize is the highest priority subsistence food crop for smallholders in Kenya because it is important in rural diets. It is debatable whether smallholder farmers could be convinced to grow wheat in

place of maize and sell the wheat to buy maize for home consumption. If smallholder farmers could not be given the incentive to do so, the potential area of smallholder wheat in Kenya would be considerably diminished. Certainly the economic analysis above suggests that farmers presently have little incentive to substitute smallholder wheat for maize except where natural advantages favor wheat more than assumed in this study.

Ultimately, the technologies that farmers choose will be determined by how they perceive the alternatives in terms of profitability, the ease of understanding and using new methods, the reduction of risk, and compatibility with farmers' preferences. This preliminary analysis suggests that the smallholder wheat technologies that justify most attention relate to improved timeliness, especially of harvesting. Unless smallholder farmers see sizeable gains from more timely wheat operations with alternative technologies, they are unlikely to switch from current methods.

References

Adelhelm, R., and K. Steck. 1974. *Agricultural Mechanisation Costs and Profitability*. Kitale, Kenya: Agricultural Extension Services and West German Federal Agency for Economic Cooperation.

Aked, L.G. 1984. Every tractor in its place. *African Farming* 33–35.

Bartenge, J.K. 1979. *Major Small Scale Wheat Producing Areas and Farmers' Farming Circumstances: Report 1979*. Njoro, Kenya: National Plant Breeding Station.

Brown, W.J., and R.A. Schoney. 1985. Calculating least-cost machinery size for grain farms using electronic spreadsheets and microcomputers. *Canadian Journal of Agricultural Economics* 33:47–65.

Binswanger, H. 1986. Agricultural mechanization: A comparative historical perspective. *Research Observer* 1(1): 27–54.

Byerlee, D. 1985. *Comparative Advantage and Policy Incentives for Wheat Production in Ecuador*. CIMMYT Economics Program Working Paper No. 01/85. Mexico, D.F.: CIMMYT.

Byerlee, D., and J. Longmire. 1986. *Comparative Advantage and Policy Incentives for Wheat Production in Rainfed and Irrigated Areas of Mexico*. CIMMYT Economics Program Working Paper No. 01/86. Mexico, D.F.: CIMMYT.

CIMMYT. 1985. *CIMMYT World Wheat Facts and Trends. Report Three: A Discussion of Selected Wheat Marketing and Pricing Issues in Developing Countries*. Mexico, D.F.: CIMMYT.

Cleaver, K., and M. Westlake. 1987. Pricing, marketing, and agricultural development in Kenya. MADIA Study, second draft. Nairobi, Kenya: World Bank and Ministry of Agriculture.

Copland, J.W. (ed.) 1985. *Draught Animal Power for Production*. ACIAR Proceedings Series No. 10. Canberra, Australia: Australian Centre for International Agricultural Research.

Gardezi, J., A. Rauf, M. Munir, K. Altaf, Q. Mohd-ud-Din, and B. Lockwood. 1979. *A Study of Mechanical and Traditional Wheat Threshing in Multan District, Punjab, Pakistan: Some Preliminary Results*. Working Paper No. 3, The Consequences of Small Rice Farm Mechanization Project. Faisalabad, Pakistan: Faculty of Agricultural Economics and Rural Sociology, University of Agriculture.

Gebeheyu, G. (n.d.) *Effect of seeding date on grain yield of bread wheat grown at different altitudes*. Addis Ababa: Holetta Research Center.

Gupta, M.L., and G. Singh. 1986. Mathematical model for selecting wheat threshing systems for farms in North India. *Agricultural Mechanization in Asia, Africa, and Latin America* 17(2):61–67.

Hanson, H., N.E. Borlaug, and R.G. Anderson. 1982. *Wheat in the Third World*. Boulder, CO: Westview Press.

Harder, D.E. 1974. *Growing Wheat in Kenya*. Njoro, Kenya: National Plant Breeding Station.

ICRISAT. 1983. *The Animal-Drawn Wheeled Tool Carrier*. Information Bulletin No. 8. Patancheru, A.P., India: International Crops Research Institute for the Semi-Arid Tropics.

Jaetzold, R., and H. Schmidt. 1983. *Natural Conditions and Farm Management Information*. Vol. 2 of *Farm Management Handbook of Kenya*. Nairobi, Kenya: Ministry of Agriculture, Kenya, in cooperation with the German Agricultural Team of the German Agency for Technical Cooperation.

Longmire, J., M. Ahmad, and S. Hussain. 1989. *Farmer Profitability of Alternative Cropping Patterns in the Mardan District, North West Frontier Province, Pakistan*. Islamabad, Pakistan: Pakistan Agricultural Research Council/CIMMYT.

Lyimo, S.D., and R. Button. 1983. Review of crop management research in Tanzania. In *Proceedings of Regional Wheat Workshop for Eastern, Central, and Southern Africa*. Arusha, Tanzania: Tanzania Agricultural Research Organization, CIMMYT, and Canadian International Development Agency.

Ministry of Agriculture and Livestock Development (Kenya). 1986. *Agricultural Costs and Prices*. Vol. 3b of *Farm Management Handbook of Kenya*. Nairobi, Kenya: MALD, Farm Management Branch.

Mulamula, H.H.A. 1983. Wheat in Kenya: Current status. In *Proceedings of the Regional Wheat Workshop for Eastern, Central, and Southern Africa*. Arusha, Tanzania: Tanzania Agricultural Research Organization, CIMMYT, and Canadian International Development Agency.

Munir, M. 1981. *An Evaluation of the Farmers' Decision-Making for Investment in Farm Machinery*. Working Paper No. 26, The Consequences of Small Rice Farm Mechanization Project. Islamabad, Pakistan: Agricultural Development Council and International Rice Research Institute.

Munzinger, P. 1982. *Animal Traction in Africa*. Eschborn, West Germany: German Agency for Technical Cooperation.

National Plant Breeding Station (Kenya). 1985. Alternative Agricultural Technology for Small and Large Scale Farming Communities in Districts for Higher Yields and Quality. Farmers' Field Day. Njoro, Kenya. Friday 11th October. Mimeo.

National Plant Breeding Station (Kenya). 1987. *1987 Recommendations on Wheat, Triticale, Barley, Oats, and Oil Crops*. Njoro, Kenya: National Plant Breeding Station, Ministry of Agriculture, Republic of Kenya.

Ockwell, A. 1987. Personal communication concerning information on bullock power from recent surveys of dryland farming systems in Machakos and Kitui Districts. Nairobi, Kenya: ACIAR.

Pearson, S.R., and E.A. Monke. 1987. *The Policy Analysis Matrix: A Manual for Practitioners*. Falls Church: Pragma.

Republic of Kenya. 1985. *Import Licensing Schedules*. Nairobi, Kenya: Government Printer.

Republic of Kenya. 1986. *Economic Management for Renewed Growth.* Sessional Paper No. 1. Nairobi, Kenya: Government Printer.

Republic of Kenya. 1987. *Economic Survey 1987.* Nairobi: Central Bureau of Statistics, Ministry of Planning and National Development.

Rudd, C.L., and N.J. Barrow. 1973. The effectiveness of several methods of applying superphosphate on yield response by wheat. *Australian Journal of Experimental Agriculture and Animal Husbandry* 13:430–33.

Scandizzo, P.L., and C. Bruce. 1980. *Methodologies for Measuring Agricultural Price Intervention Effects.* Staff Working Paper No. 394. Washington, D.C.: The World Bank.

Sharpley, J. 1985. *Net Foreign Exchange Earnings of Kenya's Agricultural Sector.* Report for the Government of Kenya funded from IDA Credit 1045–KE for Export Promotion Technical Assistance. London: Institute of Development Studies, University of Sussex.

Smale, M. 1987. *Wheat Harvest Technology in Punjab's Rice-Wheat Zone: Combines, Laborers, and the Costs of Harvest Delay.* Islamabad, Pakistan: Pakistan Agricultural Research Council/CIMMYT Collaborative Program.

Tanner, D.G., and J.K. Ransom. 1985. Potential research priorities for the small scale wheat farmer. In *Proceedings of the Regional Wheat Workshop, Eastern, Central and Southern Africa and Indian Ocean.* Njoro, Kenya: National Plant Breeding Station and CIMMYT. Pp. 183–227.

Toogood, J.A., ed. 1981. *Proceedings of Wheat Workshop, South, Central, and East Africa.* Chilango, Zambia: Mount Makulu Research Station.

van Eijnatten, C.L.M. 1976. *A Study of the Production of Wheat in the Naro-Moru and Waraza Settlement Schemes in Kieni East, Central Province, Kenya.* Technical Communication No. 17. Nairobi, Kenya: Department of Crop Science, Faculty of Agriculture, University of Nairobi.

Westlake, M. 1987. The measurement of agricultural price distortion in developing countries. *The Journal of Development Studies* 2: 367–81.

Westley, S.B., and B.F. Johnston, eds. 1975. *Proceedings of a Workshop on Farm Equipment Innovations for Agricultural Development and Rural Industrialisation.* Occasional Paper No. 16. Nairobi, Kenya: Institute for Development Studies, University of Nairobi.

Whan, I.F., and G.L. Hammer. 1985. The cost of delay in harvesting wheat. *Review of Marketing and Agricultural Economics* 53(1): 14–24.

World Bank. 1982. *Growth and Structural Change in Kenya: A Basic Economic Report.* Report No. 3350–KE. Main Report and Four Annexes. Washington, D.C.: The World Bank.

Appendices

Appendix A
Survey of Timeliness of Operations on Small Wheat Holdings in the Nakuru and Eldoret Districts

In May and June 1986, farm management students of Egerton University College, under the supervision of Egerton faculty and with support from CIMMYT, conducted a survey of timeliness of operations on small wheat farms in Nakuru and Eldoret. A total of 73 farmers was surveyed; 45 of them grew no more than 4 ha of wheat.

A copy of the survey questionnaire follows.

Egerton College and CIMMYT Project
Survey of Timeliness of Operations on Small Wheat Farms in Nakuru District

Farmer _____

Location _____

1. Nature of farm ownership _____

2. Size of farm _____Acres

3. Area planted to wheat (1985) _____Acres

4. Average yield of wheat (1985) _____Acres

(continued)

5. For each of the operations listed in each column, evaluate the various variables:

Variables	1985 Spray	1985 Harvest	1986 Plow	1986 Harrow 1st	1986 Harrow 2nd	1986 Harrow 3rd	1986 Plant
a. Week/month done:							
b. Own machinery used: Yes/No							
c. Hired machinery used: Yes/No							
d. If c above, was contractor available when needed? Yes/No							
e. If not, how many days were you delayed?							
f. What was the main cause of the delay? 1) Weather 2) Finance 3) Inputs 4) Contractor							
g. How did you pay the contractor? 1) Cash 2) Invoice 3) AFC 4) Other							
h Nature of request for contractor's services? 1) Ad hoc 2) Advance arrangement							
i. Which delay caused the greatest loss?							

6. Does the farmer ever assess his wheat yield in relation to untimeliness of any of the above operations? Yes/No

7. If yes, how much yield loss on average does he experience? _____% of yield

8. Were you able to purchase inputs on time? Yes/No

9. If no, which input was not purchased on time?

   1) Fertilizer _____

   2) Seed _____

   3) Chemical _____

10. Why? _____

_____

11. Did you use agricultural credit? Yes/No

12. If yes, when was seasonal credit applied for? Month of _____

13. When was seasonal credit approved? Month of _____

Name of enumerator: _____

Date conducted: _____

Thank the farmer for his or her assistance with this survey.

Appendix B
Estimating Machinery Lost Time and Time Required to Complete a Hectare for Different Machinery Operations and Different Field Sizes

Farm machinery contractors reported that the costs of operating machinery are generally higher on a per-hectare basis on smaller fields than on larger ones. Higher costs on smaller fields result from the increasing amount of time lost, as average field size declines, through headland overlap, turning, moving from field to field, and "setting up" the machinery in each new field before starting the job. In addition, each day contractors lose machinery working time because they have to service their machines and move them from their base to the fields where they work.

Some evidence from machinery contractors emphasizes the extra time required for working small fields. It was reported that on smaller fields (generally less than 4 ha), standard-sized combine harvesters might cut 10 ha in an average working day. However, in the best large fields up to 16 ha could be harvested. This difference implies a 37.5% efficiency loss for the combine harvester in small fields. Similarly, it was reported that on small holdings contractors expected to plow 0.3 hectares ha/h (0.75 acres/h), whereas with larger fields above 4 ha they expected to plow 0.4 ha/h (1 acre/h).

The time required to complete one hectare for particular operations and the amount of machinery time lost per day for different average field sizes were calculated using spreadsheet analysis and assumptions obtained from machinery contractors. The calculations were made using average working speed, average working width, average road speed, average time to set up in each new field, average time per day for servicing machinery, and average daily work hours. After discussions with farmers and contractors, it was also assumed that the typical shape of a field in the district is a 2 x 1 rectangle and that the average distance from one field to the next is 10 times the length of the field.

The calculations were made for field sizes ranging from 0.2 ha (0.5 acre) to 1,000 ha (as the extreme case). The calculations were as follows:

1) **Field width**

$w = (10000.a/r)^{0.5}$

where: w = width of field (m)
a = area of field (ha)
r = ratio of length of field to width

2) **Field length**

$x = r.w$

where: x = length of field (m)

3) **Number of 180° turns per field**

$t = (w/m)+4$

where: t = number of 180° turns per field
m = machine width (m)

4) **Area of headland overlap per field**

$o = (t.(3.14151.m^2/2))+(4.m.w)$

where: o = area of headland overlap (ha)

5) **Time taken to finish one field and shift to next**

$f = (s/60)+((a+o)/(1000.v.w/10000)) + (d.x/1000.u)$

where: f = time to complete field and shift (h)
s = average setup time in each field (min)
v = average work speed (kph)
d = ratio of distance between fields to length of field

6) Area completed per day

$$b = a.(h-(g/60))/f$$

where: b = area completed per day (ha)
h = daily working time (h)
g = average time for daily service (min)

7) Percentage time lost per day

$$p = 100.(1-(b/(1000.v.m.h/10000))$$

where: p = time lost per day (%)

An example of these calculations is presented in Table B.1 for plowing with a 3-disc plow at 6 km/h, the plow having a working width of 1 m. Note that the time required to plow one hectare and the percentage of time lost per day both decline as field size increases. For very large fields, the calculations imply a plowing rate of around 2.5 h/ha (1 acre/h), very similar to the estimates provided by contractors. For a small field, say 0.4 ha (1 acre), the time required increases to around 3.2 h/ha (0.78 acres/h).

Using the above method, the estimated time lost per day and the time required to complete one hectare were computed for 14 operations with machinery and oxen. Assumptions concerning other machinery and oxen operations are presented in Table B.2. The estimated time lost per day for these operations and the time required to complete one hectare are reported in Tables B.3 and B.4.

Table B.1. An example of calculating both time lost by machinery and time required to complete one hectare, plowing with a 75 horsepower tractor

Key assumptions: Plowing with a 75 HP tractor and 3-disc plow

Average work speed . . . . . 4.5 km/h
Average work width . . . . . 1 m

Average road speed . . . . . 15 km/h
Average setup time . . . . . 10 min

Average daily service . . . . . 45 min
Average work hours . . . . . 8 h

Avg. size of each field (ha)	Field width (m)	Field length (m)	Number of 180° turns per field	Area of headland overlap per field (ha)	Time taken to finish a field and shift (h)	Area completed per day (ha)	Amount of downtime (%)	Avg. time need to complete 1 ha (h/ha)
0.2	32	63	40	0.02	0.7	2.1	42.1	3.84
0.4	45	89	53	0.03	1.2	2.5	31.3	3.24
1	71	141	79	0.04	2.6	2.8	21.7	2.84
2	100	200	108	0.06	4.9	3.0	17.3	2.69
4	141	283	149	0.08	9.4	3.1	14.5	2.60
10	224	447	232	0.13	23.0	3.2	12.3	2.53
20	316	632	324	0.18	45.4	3.2	11.3	2.51
40	447	894	455	0.25	90.2	3.2	10.7	2.49
100	707	1,414	715	0.40	224.2	3.2	10.2	2.47
400	1,414	2,828	1,422	0.79	892.7	3.2	9.8	2.46
1,000	2,236	4,472	2,244	1.25	2,228.1	3.3	9.6	2.46

Table B.2. Key assumptions employed in calculating the time required to complete one hectare with different machinery operations

Operation	Avg. working speed (km/h)	Avg. working width (m)	Avg. road speed (km/h)	Avg. time to set up in each field (min)
75 HP tractor	4.5	1.0	15	10
With 3-disc plow	4.5	1.0	15	10
With 2-way disc harrows	4.8	3.0	10	10
With seed drill	4.8	4.0	10	10
With boom spray	4.8	10.0	10	10
Combine harvester	6	4.0	12	10
Reaper with 75 HP tractor	6	2.2	15	5
7 HP 2-wheeled tractor	4	0.25	6	5
With plow	4	0.25	6	5
With cultivator	4	1.0	6	5
With tined harrows	4	1.2	6	5
With reaper attachment	4	1.0	6	5
2-oxen team				
With plow	4	0.2	4	5
With cultivator	4	1.0	4	5
With tined harrows	4	1.2	4	5
Knapsack spraying	4	1.0	4	10

Source: Farm machinery contractors, Nakuru and Eldoret districts; Munzinger (1982); and Westley and Johnston (1975).

Note: Average daily service time is 45 minutes for tractor, 60 minutes for the combine harvester, 30 minutes for the two-wheeled tractor, and 10 minutes for oxen gear. An eight-hour day is assumed for all mechanized operations and a six-hour day for bullock operations.

Table B.3. Estimated time lost as a percentage of daily working hours, by operation, for different field sizes

	Average field size (ha)					
	0.4 (%)	1 (%)	4 (%)	10 (%)	40 (%)	400 (%)
75 HP tractor						
With 3-disc plow	31	22	15	12	11	10
With 2-way disc harrows	58	42	26	20	14	11
With seed drill	64	49	30	23	16	11
With boom spray	82	70	49	37	24	14
Combine harvester	68	53	34	26	19	14
Reaper with 75 HP tractor	44	32	20	16	13	10
7 HP 2-wheeled tractor						
With plow	13	10	8	7	7	6
With cultivator	28	20	13	10	8	7
With tined harrows	31	22	14	11	9	7
With reaper attachment	28	20	13	10	8	7
2-oxen team						
With plow	9	7	5	4	3	3
With cultivator	29	20	12	8	6	4
With tined harrows	33	23	13	9	6	4
Knapsack spraying	33	22	12	9	6	4

Table B.4. Estimated time required to complete one hectare for different machinery operations, by average field size

	Average field size (ha)					
	0.4 (h/ha)	1 (h/ha)	4 (h/ha)	10 (h/ha)	40 (h/ha)	400 (h/ha)
75 HP tractor						
With 3-disc plow	3.2	2.8	2.6	2.5	2.5	2.5
With 2-way disc harrows	1.6	1.2	0.9	0.9	0.8	0.8
With seed drill	1.5	1.0	0.7	0.7	0.6	0.6
With boom spray	1.2	0.7	0.4	0.3	0.3	0.2
Combine harvester	1.3	0.9	0.6	0.6	0.5	0.5
Reaper with 75 HP tractor	1.4	1.1	0.9	0.9	0.9	0.8
7 HP 2-wheeled tractor						
With plow	1.4	1.1	0.9	0.9	0.9	0.8
With cultivator	11.5	11.1	10.9	10.8	10.7	10.7
With tined harrows	3.5	3.1	2.9	2.8	2.7	2.7
With reaper attachment	3.0	2.7	2.4	2.3	2.3	2.2
2-oxen team						
With plow	13.8	13.4	13.1	13.0	12.9	12.9
With cultivator	3.5	3.1	2.8	2.7	2.6	2.6
With tined harrows	3.1	2.7	2.4	2.3	2.2	2.2
Knapsack spraying	3.7	3.2	2.8	2.7	2.6	2.6

Appendix C
Farm-Level Prices Employed in Costing Alternative Technologies and in Analyzing Farmer and National Profitability

Current Farmer Prices

Initially, costs of machinery and budgets were prepared using actual farmer prices for 1987. These prices were based on reported prices for inputs and outputs, adjusted to the farm level in the Nakuru district. When transport costs warranted an adjustment from the farm-level price to the Nakuru town price, these adjustments were also made. Thus, prices of grain and fertilizer were adjusted for transport costs while all other inputs and outputs were priced out of Nakuru.

The method of calculating the farm-level prices of wheat and maize is presented in the first four lines of Table C.1 (page 56). The farm prices were calculated as the price at depot of a standard grade, less the transport cost from farm to depot and the interest cost to the farmer resulting from delayed payment on maize. The interest cost was calculated for a six-month delay using the market rate of interest (adjusted for inflation and to a six-monthly basis) times the value of maize at the farm. Gunnies were not included in the pricing, since they are listed as an input in the crop budgets.

Farm prices of forage (maize stover and wheat stubble) were based upon their value in grazing dairy cattle. Thus if the stubble or stover provided the equivalent of one year's grazing by one dairy cow, the stubble or stover was valued at the gross margin of a grazing dairy cow (Ministry of Agriculture and Livestock Development 1986). The local net price (after baling costs) of baled wheat straw was used to price this by-product.

Prices of other farm inputs were obtained from other sources, including Kenyan Grain Growers Cooperative Union and other agents' retail outlets in Nakuru. Previous prices were documented in an unpublished Kenya National Farmers' Union Memorandum on farm prices in Kenya, which contained a series of farm input and output prices at Nakuru from 1981 to 1986, priced at store midyear. Other prices were taken from National Plant Breeding Station (1987) and Ministry of Agriculture and Livestock Development (1986).

Prices of threshers were based on prices in Pakistan, where this type of equipment is manufactured locally. In Kenya wheat threshers are not locally manufactured, although local manufacture of maize shellers is common. The price of the large thresher was estimated from information gathered in Pakistan where the local price of a thresher converted to US dollars was

Table C.1. Farm-level prices employed in costing alternative technologies in the profitability analysis, 1987

Item	Actual farmer prices 1987	Opportunity prices 1987	Percentage difference 1987
Wheat (Ksh/90 kg)	276	238	16
Maize (Ksh/90 kg)	169	150	12
Baled straw (Ksh/bale)	10	10	0
GM dairy cow (Ksh/cow)	2,480	2,480	0
Gunnies (Ksh/unit)	21.9	13.4	64
Wheat seed (Ksh/kg)	6.1	5.3	16
Maize seed (Ksh/kg)	11.2	10.0	12
Fertilizer (DAP) (Ksh/50 kg)	234	312	–25
Fertilizer (CAN) (Ksh/50 kg)	215	288	–26
Buctril (Ksh/L)	132	102	29
Roundup (Ksh/L)	390	300	30
Dipterex 5% (Ksh/kg)	15	12	26
Malathion (Ksh/kg)	80	62	29
Interest (%/yr)	16	18	–11
Inflation (%/yr)	8	8	–
Plowing (Ksh/ha)	500	–	–
Harrowing (Ksh/ha)	300	–	–
Planting (Ksh/ha)	250	–	–
Spraying (Ksh/ha)	250	–	–
Harvesting (Ksh/ha)	500	–	–
Land rent (Ksh/ha/yr)	1,000	–	–
Diesel (Ksh/L)	5.80	5.09	14
Wage rate (Ksh/day)	15	15	0
Insure machinery (% value new)	1	1	0
Tractor (75 HP) (Ksh/unit)	343,000	377,000	–9
3-disc plow (Ksh/unit)	32,000	35,000	–9
10-ft harrow (Ksh/unit)	66,000	72,000	–9
12-ft drill (Ksh/unit)	95,000	104,000	–9
36-ft sprayer (Ksh/unit)	35,660	39,000	–9
16-ft harvester (Ksh/unit)	1,233,000	1,345,000	–9
7-ft reaper (Ksh/unit)	33,000	36,000	–9
Large thresher (Ksh/unit)	45,500	50,000	–9
2-wheel tractor and attachment (Ksh/unit)	31,500	35,000	–9
Thresher (7 HP) (Ksh/unit)	25,200	27,700	–9
2 oxen and attachment (Ksh/unit)	5,000	5,000	0
Hand sprayer	2,210	2,400	–9

Table C.2. Pricing wheat and maize at the farm level, Nakuru district, Kenya, 1986 and 1987

	Wheat		Maize	
	1986	1987	1986	1987
Price at depot in bags				
Standard grade, Nakuru (Ksh/bag)	286	286	188	188
Transport cost				
Farm to Nakuru (Ksh/bag)	10	10	10	10
Interest cost for delayed payment (Ksh/bag)	0	0	9	9
Farm price in bags (Ksh/bag)	276	276	169	169
Longer term world price, FOB US Gulf (US$/t)	120	120	95	95
Freight rate, US Gulf to East Africa (US$/t)	40	40	40	40
CIF East Africa (US$/t)	160	160	160	160
Add white maize premium (US$/t)	–	–	145	145
Long-term exchange rate (Ksh:US$)	18	18	18	18
CIF East Africa (Ksh/t)	2,904	2,904	2,450	2,450
Port charges and rail freight, Mombasa-Nairobi (Ksh/t)	452	452	452	452
CIF Nairobi (Ksh/t)	3,356	3,356	2,902	2,902
Rail freight, Nakuru-Nairobi (Ksh/t)	210	210	210	210
On rail price, Nakuru (Ksh/bag)	283	283	242	242
Marketing and handling (Ksh/bag)	35	35	35	35
On-farm opportunity price (Kenya importing maize) (Ksh/bag)	238	238	197	197
Ratio producer price to opportunity price (Kenya importing maize) (%)	116	116	85	85
Opportunity export price, maize, FOB Mombasa (Ksh/t)	–	–	2,178	2,178
Opportunity farm price, maize, Nakuru district (Kenya exporting maize) (Ksh/bag)	–	–	103	103
Ratio producer price to opportunity price (Kenya importing maize) (%)	–	–	163	163

Note: Rail freight as follows: Nakuru–Nairobi, 210 Ksh/t; Nairobi–Mombasa, 320 Ksh/t; and Nakuru–Mombasa, 400 Ksh/t. When Kenya is assumed to export maize, it is to Red Sea ports. Freight rate to Red Sea ports is assumed to be US$ 35/t, and from Mombasa to Red Sea ports, US$ 20/t, including a port loading fee of US$ 8/t.

approximately $US 1,380 in mid-1985. Converting this price to Kenyan shillings, and assuming higher costs of local manufacture in Kenya, the 1987 price of the thresher in Kenya was estimated at Ksh 45,500. (Costs were assumed to be 100% higher: there is a 20% import duty on steel in Kenya, a 65% duty on imported tires, and 25–35% duty on parts for machine tools and other equipment likely to be needed by machinery manufacturers if they were to produce threshers in Kenya. The price of a maize sheller capable of processing 50 bags/h in Kenya in late 1985 was approximately $US 1,850, compared with about $US 940 for a sheller of comparable capacity in Pakistan.)

Similar procedures were used to estimate the price of a reaper attachment to a tractor. Such attachments were selling for just over $US 1,000 in Pakistan in early 1987. Prices of the small motorized thresher were taken from tentative quotations made on this equipment from outside Kenya and were set to be 20% below the price of a two-wheeled tractor plus attachment. The price of the two-wheeled tractor plus attachments was taken from Ministry of Agriculture and Livestock Development (1986), a 1986 price. To obtain the 1987 price, the 1986 one was indexed according to annual changes in prices of tractors in Nakuru from 1986 to 1987.

Prices of a pair of oxen and equipment were taken from an economic survey conducted in the Machakos and Kitui districts (Ockwell 1987). Oxen use is common in these areas and the price of a working bullock was quoted at Ksh 1,800–2,500. A plow was an additional Ksh 760.

Opportunity Prices

In analyzing the real resource cost or profitability to the nation of alternative technologies, the farmer prices were adjusted to remove the effects of short-term fluctuations in international commodity levels and effects of taxes, subsidies, and exchange rate policies. Procedures in Byerlee (1985), Byerlee and Longmire (1986), Cleaver and Westlake (1987), and Pearson and Monke (1987) were followed. All prices employed in the analysis were adjusted for transport and other costs to the farm level in the Nakuru district.

The opportunity prices of wheat, maize, and compound fertilizer were drawn from World Bank projections of prices for these commodities to the year 2000 in real 1985 US dollars. These prices were considered to be more reliable than current prices in guiding the longer term decisions to be made concerning allocation of research resources (Pearson and Monke 1987). Following assumptions outlined in Tables C.2 and C.3, international prices were then adjusted to their farm-level equivalent following Westlake (1987).

Table C.3. Pricing compound fertilizer at the farm level, Nakuru district, Kenya

	Di-ammonium phosphate	Calcium ammonium nitrate
Longer term world price, FOB US Gulf (US$/t)	205	–
CAN price differential (%)	–	–10
Freight rate, US Gulf to East Africa (US$/t)	40	40
CIF East Africa (US$/t)	245	244.5
Long-term exchange rate (Ksh:US$)	18.15	18.15
CIF East Africa (Ksh/t)	4,447	4,075
Port charges and rail freight, Mombasa–Nakuru (Ksh/t)	452	452
On rail price, Nakuru (Ksh/bag)	245	226
Retailing margin, including packaging (%)	25	25
Opportunity retail price, Nakuru (Ksh/bag)	306	283
On-farm opportunity price (Ksh/bag)	234	215
Actual price paid on farm (Ksh/bag)	234	215
Ratio producer price to opportunity price (%)	0.75	0.74

For wheat, the consumption point for pricing was Nairobi, assuming that Kenya will remain a net importer of wheat for the foreseeable future (Republic of Kenya 1986, Cleaver and Westlake 1987). For maize, pricing was based on both net importing and net exporting situations, since projections suggest that Kenya will remain nearly self-sufficient in maize. The high cost of transport means that the opportunity price of maize in most years will fall somewhere between that for the net importing situation and that for the net exporting situation. Compound fertilizer was priced on the assumption that Kenya will remain a net importer of fertilizer.

Ratios of current farmer prices to opportunity prices were calculated and are reported in Table C.1. The opportunity prices of hay, stover, and stubble grazing were set at their current market prices. While there is support to dairying through import duties on dairy products in Kenya, it was unclear how much these duties add to the value of hay, stubble, and stover.

The calculations of the opportunity prices of tradeable farm inputs are documented in Table C.4. Assumptions of domestic value-added through local assembly, processing, or manufacture were drawn from discussions with farm machinery agents and others, transport agents, and Sharpley (1985). Adjusting for transport costs and quoted import duties (Republic of Kenya 1985), the import price of tradeables was estimated. The opportunity price at the farm level was calculated by applying an exchange rate adjustment of

Table C.4. Estimating the opportunity price of tradeable farm inputs at the farm level, Nakuru district, Kenya, 1987

	Average farm-level price	Domestic value added (%)	Weight per unit (kg)	Freight, Mombasa to farm (Ksh/t)	Import duty (%)	Estimated import price (Ksh/unit)	Opportunity price at farm level (Ksh/unit)	Exchange rate adjustment factor
Gunnies (Ksh/unit)	21.9	30	0.25	1,025	45	5.3	13.4	1.1
Buctril (Ksh/L)	131.8	30	1	1,025	30	63.8	101.8	1.1
Roundup (Ksh/L)	389.7	30	1	1,025	30	190.2	300.4	1.1
Dipterex 5% (Ksh/kg)	15.0	30	1	1,025	30	6.6	11.9	1.1
Malathion (Ksh/kg)	79.6	30	1	1,025	30	38.3	61.6	1.1
Diesel (Ksh/L)	5.8	50	0.85	1,025	25	1.5	5.1	1.1
Tractor, 75 HP (Ksh/unit)	343,000	40	2,500	1,025	0	203,238	376,873	1.1
3-disc plow (Ksh/unit)	32,000	60	800	1,025	0	11,980	34,995	1.1
10-ft harrow (Ksh/unit)	66,000	60	1,000	1,025	0	25,375	72,344	1.1
12-ft drill (Ksh/unit)	95,000	40	1,000	1,025	0	55,975	104,329	1.1
36-ft sprayer (Ksh/unit)	35,660	40	500	1,025	0	20,834	39,141	1.1
16-ft harvester (Ksh/unit)	1,223,000	40	4,000	1,025	0	729,700	1,344,617	1.1
7-ft reaper (Ksh/unit)	33,000	60	400	1,025	0	12,790	36,198	1.1
Large thresher (Ksh/unit)	45,500	60	1,000	1,025	0	17,175	49,794	1.1
2-wheel tractor and attachment (Ksh/unit)	31,500	30	100	1,025	0	21,948	34,635	1.1
Thresher, 7 HP (Ksh/unit)	25,200	40	100	1,025	0	15,018	27,703	1.1
Hand sprayer (Ksh/unit)	2,210	30	2	1,025	0	1,545	2,431	1.1

10% to the estimated import price and adding transport and the value-added percentage on to that figure.

For machinery, opportunity prices were higher than actual prices because of duty-free entry and the exchange rate adjustment factor. Only diesel, jute sacks, and agrochemicals displayed sizeably higher farm prices than their equivalent world prices. Spare parts are also considerably higher than world prices and were generally reduced by a factor of 40–50% to reflect opportunity prices.

Opportunity prices of nontradeable farm inputs involved some simplifying assumptions. Wage levels were assumed to remain unchanged, and real interest rates were set at 10%/yr.

Finally, since maize and wheat seed are tradeable inputs, prices were fixed as a ratio of the opportunity prices of grain.

Exchange Rate Adjustment Factor

To estimate the underlying or real value of tradeable inputs and outputs to a country, the shadow exchange rate or the exchange rate conversion factor needs to be estimated (Pearson and Monke 1987). The shadow exchange rate is the exchange rate at which equilibrium is estimated to occur in the foreign currency market, namely, that level at which demand for foreign currency in Kenya would equal supply of foreign currency without any rationing or controlled rates of exchange.

One indicator of the shadow exchange rate is the illicit market rate for foreign currency. In August 1987, the author was informed that in the illicit market there was a premium for foreign currency of 5–10% over the official rate, which is maintained by rationing currency.

Another method of assessing the shadow price of foreign currency is to calculate the trade-weighted real exchange rate for the country over a number of years. If a suitable base year can be chosen in which the market for foreign currency was in equilibrium, any deviation from the base year of the index will represent movement away from purchasing power parity and might be used as a guide to setting the shadow exchange rate.

For this study the trade-weighted real exchange rate was calculated for Kenya using International Monetary Fund (IMF) and United Nations trade data. Exchange rates for all of Kenya's major trading partners were taken

from IMF data and converted to real bilateral exchange rates against Kenyan currency. Thus:

$$REX_k = EX_k/(CPI_k/CPI_a)$$

where: REX_k = real bilateral exchange rate between Kenya and trading partner country "a" (real Kenyan shillings per unit of foreign currency)

EX_k = nominal exchange rate between Kenya and trading partner country "a" (actual Kenyan shillings per unit of foreign currency)

CPI_k and CPI_a = indexes of inflation in Kenya and trading partner country "a", respectively.

The trade-weighted real exchange rate was then calculated by summing the trade-weighted individual country real exchange rate indices. These indices were calculated using 1980 as the base year. The trade weights were calculated as the average value of imports and exports in 1982-83 for each country expressed as a percentage of the overall average value of imports and exports of all countries for which data were reported. The year 1982-83 was used because data were not readily available for more recent years.

The overall trade-weighted real exchange rate index is presented in Figure C.1. In recent years Kenyan currency has grown stronger in real terms. In simple terms this strengthening occurs when the local currency does not depreciate as rapidly as comparative rates of inflation between Kenya and its major trading partners would suggest. The strengthening in real terms of the Kenyan shilling suggests that the exchange rate adjustment factor for 1987 should be positive. For the years 1981–1986, the real exchange rate index has averaged about 112 points. If a base of 100 is acceptable (the 1970 index was at this level and the real exchange rate returned to near this level in the late 1970s), this suggests that the exchange rate adjustment factor for recent years should be around 10%.

The final method of estimating the exchange rate adjustment factor involved estimating the net protection coefficient for all tradeable commodities in Kenya. This was calculated roughly as follows:

- Average duty rate on imports 16%
- Average duty rate on main exports 0
- Average subsidy on non-traditional exports 20%

- Value weights of imports: main exports: nontraditional exports 50:40:10

- Overall net protection coefficient 10%

It was suggested by financial analysts in Kenya that a portion of sales taxes levied might also be seen as a protection for local industry. If these were to be included, the exchange rate adjustment factor could readily double. However, for this study, there was no apparent reason to include the sales tax component to arrive at the exchange rate coefficient.

Given the above results, an exchange rate adjustment factor of 10% was employed in opportunity pricing tradeble commodities.

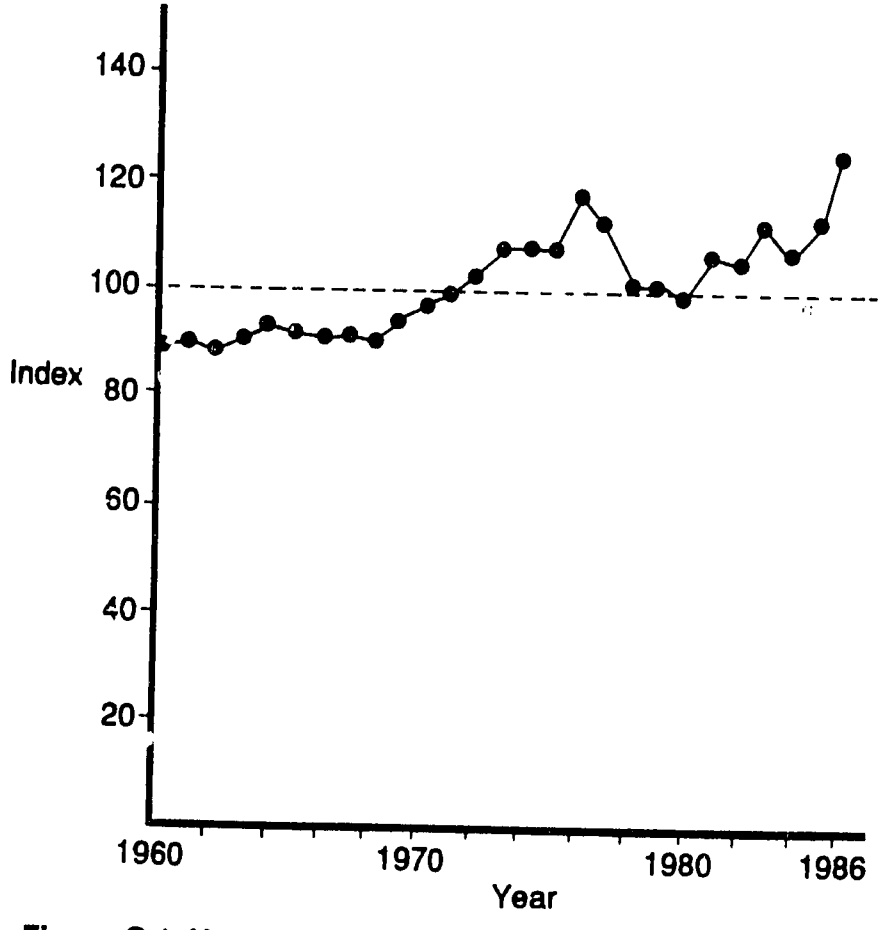

Figure C.1. Kenya's trade-weighted real exchange rate, 1960-86.

Note: Increases in the real exchange rate imply a real appreciation of Kenyan currency.

Appendix D
Calculation of Costs of Alternative Machinery and Bullock Operations

To assess the underlying costs of alternative operations, both mechanized and more labor-intensive ones, full costs of machinery operation were calculated on a per-hour basis. These costs were then combined with estimates of time required to complete a particular operation and of the amount of manual labor required for that operation (that is, manual labor additional to operator labor) to calculate the machinery and labor costs of alternative operations for different field sizes. Manual labor costs were calculated using the wage rate in Table C.1, and costs of machinery operation also were based upon the price assumptions outlined in Appendix C.

The formulas for costing machinery are based on Byerlee (1985, Appendix D) and Byerlee and Longmire (1986, Appendix B). Very similar methods are detailed in Adelhelm and Steck (1974) for the Kenyan context. Six cost components for machinery were singled out: depreciation, capital (financing the investment), fuel and oils, repairs and maintenance, operator labour, contractors' overheads, and housing and insurance. The main methods for costing were as follows:

Depreciation

Costed using a straight-line rate of depreciation. The hourly depreciation is calculated by taking the difference between the new purchase price and the current secondhand value (assumed to be 33% of new value), and dividing this by the total working hours of the machine (hours per year multiplied by number of years of work).

Capital

Costed taking an average of the new purchase price and the secondhand value, multiplying this by the commercial interest rate (less the rate of inflation) and dividing by total hours worked per year by the machine.

Fuel and oils

Costed using the assumption of a fuel consumption rate of 125 g/h/HP, where 1 kg diesel = 1.18 L (Ministry of Agriculture and Livestock Development 1986). Oil, grease, and other lubricants were costed as an extra 5% of the total diesel fuel cost.

Repairs and maintenance

Costed using the ratio of expected repairs and maintenance costs to new price, as documented in Ministry of Agriculture (1986). These ratios included a 40% loading for tax, most of which is for import duty (Republic of Kenya 1985). These ratios are probably considerably inflated by the long lead time farm machinery dealers have in importing spare parts and by the limited competition in supplying spare parts. Dealers informed us that they had to order spare parts from overseas and obtain foreign currency allocations well ahead of receiving the parts. For example, the equivalent ratios for Mexico were estimated to be between 80–90% of new value, compared with 170–440% in Kenya (*op. cit.* and Byerlee and Longmire 1986, Appendix B).

Operator wages

Costed at the wage levels contractors pay skilled and reliable operators. The relative operator wage factor shown in Table D.1 is the ratio of machinery operator hourly wage to the hourly wage for rural workers.

Contractors' overheads

Costed at 10% of total machinery costs per hour. An additional loading on costs at 1% of new value is for housing and insurance (Ministry of Agriculture and Livestock Development 1986).

The parameters employed in costing alternative machinery operations are presented in Table D.1. As well as inlcuding machinery in common use in Kenya, the analysis included the use of oxen and alternative types of smaller scale machinery.

The calculations of machinery costs per hour are reported in Table D.2. The new prices of the machinery are also presented in this table. The sources of these figures are documented in Appendix C.

Table D.1. Parameters for costing machinery per hour

Type of machinery	Relative value (as % new price)	Years of life	Hours per year	Fuel use per (L)	Repairs and maintenance factor	Operator wage
Tractor, 75 HP	33	10	1,000	8	130	1.33
3-disc plow	33	12	350	0	390	0
3-m harrow	33	12	350	0	440	0
4-m drill	33	8	350	0	190	0
10-m sprayer	33	8	200	0	240	0
4-m harvester	33	5	1,000	11	190	1.5
2.2-m reaper	33	8	400	0	240	0
Large thresher	33	8	400	0	240	0
2-wheeled tractor plus attachment	33	4	350	1	240	1
Thresher, 7 HP	33	6	350	1	240	1
2 oxen and attachment	33	5	400	–	150	1
Hand sprayer	33	6	200	0	170	1

Table D.2. Calculating machinery costs per hour (including operator labor)

	Purchase price (Ksh)	Depreciation (Ksh/h)	Capital cost (Ksh/h)	Fuel and oils (Ksh/h)	Repairs and maintenance (Ksh/h)	Operator labor (Ksh/h)	Contractor overheads (Ksh/h)	Total cost per hour (Ksh/h)
Tractor, 75 HP	343,000	22.98	18.25	48.72	44.59	2.49	13.70	154.17
3-disc plow	32,000	5.10	4.86	0.00	29.71	0.00	3.97	44.57
3-m harrow	66,000	10.53	10.03	0.00	69.14	0.00	8.97	44.57
4-m drill	95,000	22.73	14.44	0.00	64.46	0.00	10.16	114.51
10-m sprayer	35,660	14.93	9.49	0.00	53.49	0.00	7.79	87.48
4-m harvester	1,223,000	163.88	65.06	66.99	464.74	2.81	76.35	852.07
2.2-m reaper	33,000	6.91	4.39	0.00	24.75	0.00	3.60	40.48
Large thresher	45,500	9.53	6.05	0.00	34.13	0.00	4.97	55.81
2-wheel tractor and attachment	31,500	15.08	4.79	6.09	54.00	1.88	8.18	90.91
Thresher, 7 HP	25,200	8.04	3.83	6.09	28.80	1.88	4.86	54.22
2 oxen and attachment	5,760	1.68	0.67	5.00	3.75	1.88	1.30	14.39
Hand sprayer	2,210	1.23	0.59	0.00	3.13	1.88	0.68	7.62

Note: For oxen, fuel cost is the assessed annual cost of feed, divided by work hours per year.