A Comparative Assessment of Combine Harvesting Vis-à-vis Conventional Harvesting and Threshing in **Arsi Region, Ethiopia**

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INTERNATIONAL MAIZE AND WHEAT IMPROVEMENT CENTER

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* Mohammed Hassena and Regassa Ensermu are agricultural economists at Kulumsa Research Center, Asella, Ethiopia. Wilfred Mwangi is a principal economist with the International Maize and Wheat Improvement Center (CIMMYT) and also Director of Agriculture, Ministry of Agriculture, Kenya. At the time this paper was drafted, Hugo Verkuijl was an associate scientist at CIMMYT, Addis Ababa, Ethiopia. The views expressed in this paper are the authors' and do not necessarily reflect policies of their respective institutions.

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Abstract: This study describes wheat harvesting and threshing technologies in Arsi Region, southeastern Ethiopia, and assesses their profitability compared to that of alternative wheat harvesting technologies. Data were collected from a random sample of 160 farmers from two purposively selected districts, Asasa and Etheya, where harvesting and threshing operations are becoming increasingly mechanized. Logit analysis showed that proximity to a hiring station, topography (accessibility), education level, and wheat area significantly affected farmers' decisions to adopt combine harvesting. Promoting the use of combine harvesters will widen yield and income gaps between farmers living in accessible and inaccessible areas, which has negative implications for overall economic development. Policies need to be directed towards the introduction of intermediate technologies for wheat threshing in less accessible areas. Educated farmers were better aware of the yield loss and consequent economic loss of using traditional harvesting and threshing methods. All farmers, particularly those without an education, need to be informed of the benefits of combine harvesting to increase adoption and reduce yield differences between literate and illiterate farmers. The profitability analysis determined that combine harvesting reduced yield losses, costs, and processing time and increased profitability. At the national level, the costs of combine harvesting are much lower than those incurred at the farmer level. Financial and economic profitability analyses indicate that combine harvesting is more profitable for the nation than manual harvesting and threshing.

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EXECUTIVE SUMMARY

Agricultural mechanization is not new to farmers in Arsi region, Ethiopia. It was introduced in the study area at the inception of the Chilalo Agricultural Development Unit (CADU) in 1969, but during the Dergue regime was limited to producer cooperatives and state farms. Since the change in government in 1991, small farmers have had access to mechanized technology such as the combine harvester.

The objectives of this study were to describe the current wheat harvesting and threshing technologies in the Arsi region and to assess and compare the profitability of alternative wheat harvesting technologies. Primary data were obtained from 160 farmers, who were selected using probability proportional to size at peasant association (PA) level and simple random sampling at farmer level. Farmers were sampled from two purposively selected districts in Arsi, Asasa and Etheya, where harvesting and threshing operations are becoming increasingly mechanized. Once the farmer survey was complete, descriptive statistics, logistic regression, and partial budget analysis were used to describe the current wheat harvesting and threshing technologies and to analyze the profitability of alternative technologies.

The study area is located in Arsi, southeastern Ethiopia. Most of the area is flat and therefore conducive to mechanized agriculture. The farming system is mixed crop-livestock, which is dominated by small cereals, particularly wheat. Wheat is produced both for home consumption and for generating cash.

Farmers in the study area used two types of harvesting and threshing methods: manual harvesting (MH) and combine harvesting (CH). MH farmers had smaller families (7 persons) than CH farmers (7.5 persons). MH farmers were older and had more farming experience; however, CH farmers had larger farms and were more educated. The average land holding managed by a household was 3.4 ha, of which 2.47 ha was formally donated by a PA.

Most farmers in both areas used oxen for land preparation. Only a few farmers used tractors. The wheat varieties most commonly grown by both groups were Pavon-76, Batu, and Dashen. All sample farmers used about 88 kg/ha of fertilizer. Most farmers hand weeded once or twice. The average time spent weeding was 20.7 man days/ha and 22.1 man days/ha for MH and CH farmers, respectively.

During the survey, only 17% and 60% of farmers in Asasa and Etheya, respectively, harvested at least one of their fields manually. The total labor and animal power requirement varied greatly due to climatic conditions and type of livestock used. On average, 25 and 36 man days and 33 and 51 animal days were required for traditional harvesting and threshing in Asasa and Etheya, respectively.

The harvesting and threshing method used by most farmers in the study area was combine harvesting. In Asasa and Etheya, 78% and 59% of farmers, respectively, used a combine on at least one of their fields. Most combines were privately rented (61%) or accessed through government agricultural mechanization services (31%). Recently, the number of combine harvesters in the study area has increased and the service and quality of harvesting has improved. Farmers mainly used tractor-trailers to transport their harvest.

A third method, used only in a few cases, was manual harvesting and motorized threshing using a stationary thresher. This method was limited to a small number of farmers in the Etheya area, particularly where combine harvesting had no comparative advantage due to unfavorable topography.

The logit analysis showed that proximity to a hiring station, topography (accessibility), education level, and wheat area were factors that significantly affected a farmer's decision to adopt the combine harvester. The odds in favor of using a combine increased by a factor of 1.6 when wheat area increased by 1 hectare. The likelihood of using a combine significantly increased by a factor of 3.8 for farmers who had better access to the technology due to favorable topography. Consequently, promoting the use of combine harvesters will result in a widening gap in both yield and income between farmers living in accessible and inaccessible areas, which has a negative implication on overall economic development. Thus, policies need to be geared towards the introduction of intermediate technologies for wheat threshing in inaccessible areas.

Educated farmers were more likely to use a combine harvester. An elementary and secondary education increased the likelihood of adoption by a factor of 3.3 and 6.7, respectively, compared to no education. Educated farmers were better aware of the yield loss and consequent economic loss of using traditional harvesting and threshing methods. Therefore, all farmers, particularly those without an education, need to be informed of the benefits of combine harvesting in order to increase adoption and reduce yield differences between literate and illiterate farmers.

As in most developing countries, population pressure in Ethiopia is high and agricultural labor is abundant. Consequently, agriculture is expected to be labor intensive, particularly in areas where farms are small due to severe land shortage. The use of alternative technologies has been necessary, however, due to substantial yield losses observed during traditional harvesting and threshing relative to combine harvesting. Combine harvesting was found to reduce yield losses, costs and processing time, and increase profitability. As a result, many farmers in the study area adopted this technology.

Though the average cost of combine harvesting was 11.30 Birr/qt (1 Birr = US$7), the total cost per quintal differed markedly over the study area. As a result of low yields and high weed pressure, combine harvesting costs were much higher in Asasa (19.53 Birr) than Etheya (15.44 Birr). Also there was a cost increase per quintal of 21% in Asasa and 23% in Etheya for manual harvesting relative to combine harvesting. Besides a reduction in costs, the incremental net benefit of combine harvesting over manual harvesting and threshing was 38% and 16% in Asasa and Etheya, respectively.

On a national scale, the costs of combine harvesting are much lower than those incurred at the farmer level. Financial and economic profitability analyses have provided evidence that combine harvesting is more profitable for the nation than manual harvesting and threshing.

A Comparative Assessment of Combine Harvesting Vis-à-vis Conventional Harvesting and Threshing in Arsi Region, Ethiopia

Mohammed Hassena, Regassa Ensermu, Wilfred Mwangi, and Hugo Verkuijl

1.0 INTRODUCTION

1.1. Background

Farming in Arsi, like elsewhere in Ethiopia, is generally labor intensive. However, in some localities of Arsi (Asasa, Etheya, Lole, and Dhera) there has been a shift towards the use of agricultural machinery, especially for wheat production. Since the inception of the Chilalo Agricultural Development Unit (CADU) in 1969, farmers in the aforementioned areas have been interested in mechanical threshing due to the initial promotion of agricultural machinery (Jonsson 1972).

CADU's research section evaluated the performance of local farm implements against new farm machines (CADU 1969, 1970, 1971). Various models of harvesting and threshing machines were evaluated, and a substantial output loss resulting from traditional harvesting and threshing techniques was found. Technical feasibility and economic viability of the new methods were confirmed (Jonsson 1972). The main consequences of introducing mechanical technologies during the 1970s were the eviction of tenants, increased unemployment, and soil erosion (Kifle 1972; Holmberg 1972). For these reasons, CADU decided to stop promoting the technologies.

From 1974 to 1991, producer cooperatives and state farms were the main users of farm machinery, while individual small-scale farmers did not have the opportunity. Since the political and economic reform of 1991, the producer cooperatives have been dismantled and individual small-scale farmers have started to benefit from hiring agricultural machinery. These services are provided by government-owned agricultural machinery hiring stations and private owners. State farms and the Ethiopian Seed Enterprise (ESE) also provide services to surrounding farmers. The reason behind the provision of services by both the ESE and large state farms is to establish good relationships with the surrounding farmers.

Since the transitional government came to power, there has been a relative improvement in the policy environment that allows investment in agricultural machinery, and, consequently, the number of private suppliers of agricultural machinery services has increased. This has encouraged some individuals (e.g., civil servants, traders) in towns and well-to-do farmers to embark on farming ventures through renting land from surrounding farmers for a specified period and using hired machinery for all farm operations.

1.2 Objectives of the Study

The induced innovation theory (Hayami and Ruttan 1985) identifies two paths of technological development in agriculture, depending on whether they are labor saving (mechanical innovation) or land augmenting (biological innovation). It was thought that innovation in peasant agriculture should be oriented towards biological rather than mechanical innovation because the latter deviates most from considerations of social efficiency, employment creation, and more equal income distribution. Two lines of argument prevail among researchers and development practitioners in Ethiopia regarding the mechanization of harvesting and threshing operations. One group considers mechanization to be a substitute for animal power and labor, and argues that there is little or no reduction in the overall cost of producing a given output, and no net efficiency gains in terms of higher output. Higher yields, if observed, are offset by higher production costs, especially if resources are valued at social, rather than private, efficiency prices. The other group claims that net productivity increases as a result of the mechanization of harvesting and threshing technologies. The two lines of argument correspond to the substitution view and net contribution view, respectively, in agricultural mechanization literature (Binswanger 1978).

This study was therefore designed to assess the benefits of combine harvesting vis-à-vis conventional harvesting and threshing. The specific objectives of the study were to:

- Describe current wheat harvesting and threshing technologies used by farmers.
- Assess and compare the profitability of alternative wheat harvesting and threshing technologies.
- Draw policy implications.

1.3 The Study Area

The study area, encompassing Asasa and Etheya districts, is located in the Arsi zone of Oromiya regional state, southeastern Ethiopia (Figures 1 and 2). These and the surrounding districts are the major bread wheat producing areas in Ethiopia and form part of the country’s wheat belt.

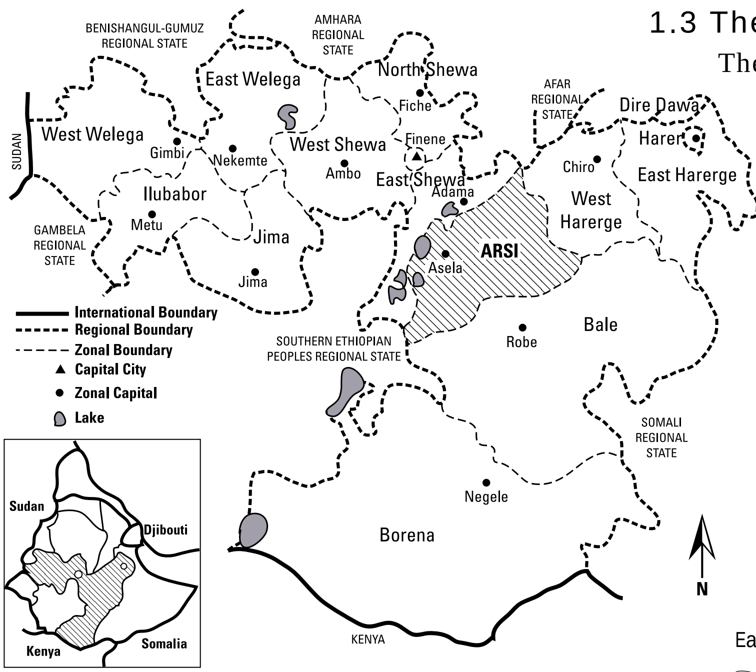

Figure 1. Arsi, Oromiya National State.

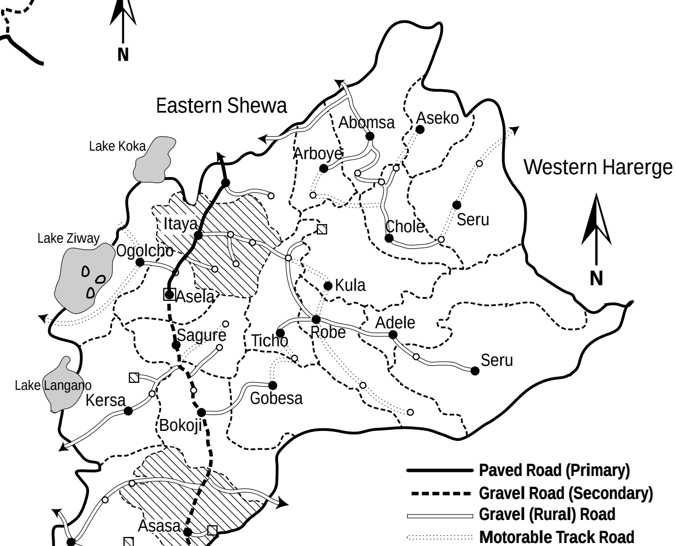

Figure 2. The study area in Arsi Administrative Region.

The elevation of the study area ranges from 2000 meters above sea level (masl) to 2500 masl. Most of the area is flat, although sloping areas unsuitable for mechanized agriculture are located adjacent to Mount Chilalo in Etheya and Mount Kaka in Asasa. Soil pH is about neutral (6.5) in Asasa and slightly lower in Etheya. Annual average precipitation is 824mm (29 year average) at Kulumsa and 667 mm (26 year average) at Asasa. Most precipitation falls during the growing season in June-October (Figure 3).

Prior to the 1960s, livestock production was the dominant farming system. At that time, crop production was characterized by different rotation systems followed by long fallow periods. The main crops grown were barley and wheat, and to a lesser extent peas, beans, and linseed. The same field was sometimes cultivated consecutively for 4-5 years before being left fallow for 10-15 years (Lexander 1968; CADU 1966).

Since the 1960s, the farming system has changed considerably. Farmers have shifted to a crop-livestock system, and farm sizes have become considerably smaller as population has increased and crop land has been divided among more people. Small cereals dominate the system. Wheat is commonly grown in the mid-altitude areas, where it is a subsistence crop as well as a major source of cash for farmers. Since the 1960s wheat area and yields have increased. In the higher altitude areas, barley is the most important crop.

About 75% of Ethiopia's total bread wheat area is located in Arsi, where temperature, rainfall, soils, and elevation are especially amenable to wheat cultivation (Hailu Gebremariam 1992). Farmers' wheat management practices in Arsi are advanced relative to other wheat-growing areas of the country, chiefly because the area has benefited from more than two decades of sustained effort to disseminate improved agricultural technologies. Moreover, the area is serviced by good roads that provide access to markets.

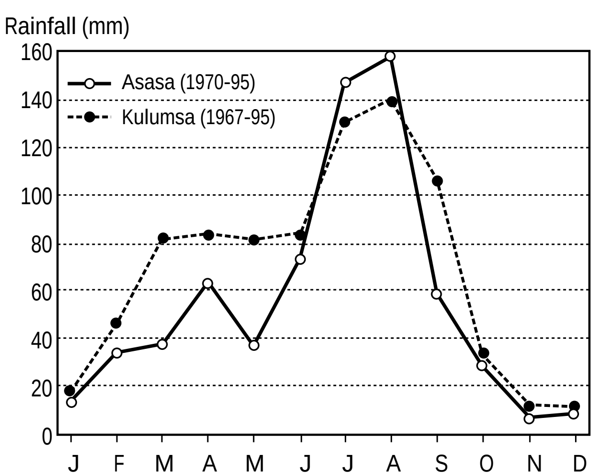

Figure 3. Average monthly rainfall at Asasa and Kulumsa Research Centers, Ethiopia.

There are a number of large state-owned mechanized farms in Asasa and Etheya. In Asasa, two state farms (Tamela and Garadela) produce mainly wheat for market. The other state-owned farm is part of the Ardayeta multipurpose training center. These farms account for 13% of the total land in Asasa. In Etheya, one state farm multiplies basic seed. All of these farms use, and have made farmers aware of, agricultural machinery.

2.0 METHODOLOGY

2.1 Sampling Procedure

A formal survey was undertaken to collect the data for this study, although secondary information was also used. Asasa and Etheya were purposively selected because harvesting and threshing operations are becoming increasingly mechanized in these areas. Multistage sampling was employed to sample peasant associations (PAs) at the first stage and farmers at the second stage. Twenty PAs were randomly sampled (ten from each of the two survey areas) using probability proportional to size sampling technique (Poate and Daplyn 1990). At the second stage, eight farmers were sampled from each PA using simple random sampling. The total sample size was 160 farmers, and they were interviewed between January and April 1996, using single-visit formal surveys.

2.2 Analytical Model

The logit model was used to analyze factors influencing the decision to use combine or other harvesting and threshing techniques. Feder *et al.* (1985) showed that many models used in adoption studies fail to meet the statistical assumptions necessary to validate the conclusions based on the hypothesis tested. They suggested the use of qualitative response models. The two most common models used in adoption studies are the logit and probit. The advantage of these models is that the probabilities are bounded between 0 and 1. Moreover, they compel the disturbance terms to be homoscedastic because the forms of probability functions depend on the distribution of the difference between the error terms associated with one particular choice and another. Usually a choice has to be made between logit and probit, but, as Amemiya (1981) has observed, the statistical similarities between the logit and probit models make such a choice difficult. The choice of model may be evaluated *a posteriori* on statistical grounds, although even here, in practice, there will usually not be strong reasons to choose one model over the other. We selected the logit model, because the dependent variable is dichotomous and the model is computationally easier to estimate.

Following Gujarati (1988), the model is specified as:

$$\ln\{P(X)/(1-(P(X))\} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots. + \beta_7 X_7 + \varepsilon_i,$$

where:

X_1 = Access to technology (0 = not accessible; 1 = accessible);
X_2 = Age of the household head (yr);
X_3 = Education (0 = illiterate; 1 = primary education);
X_4 = Education (0 = illiterate; 1 = secondary education);
X_5 = Gender (0 = female; 1 = male);
X_6 = Family size (no. of adults);
X_7 = Farm size (ha); and
ε_i = error term.

Farmer's access to the technology (X_1): The accessibility of combine hiring services is measured in terms of a farmer's nearness to towns and topography of the area, and is grouped as accessible and non-accessible. It is hypothesized that the use of combine harvesting services will increase with nearness to combine hiring stations and with terrain that is conducive to combine harvesting.

Farmer's age (X_2): It is hypothesized that with increasing age a farmer will be less likely to use a combine harvester. Younger farmers may have greater access to information because they have had greater access to education, and thus they will be more aware of new harvesting technologies. Older farmers might not have access to this information.

Farmer's education level (X_3 and X_4): Formal schooling enhances a farmer's ability to perceive, interpret, and respond to new events in the context of risk. Hence, education is hypothesized to increase the probability that farmers will use a combine harvester. Education level is a categorical variable. The categories are illiterate, elementary school (grade 1-6), and secondary school (grade 7-12).

Gender of the household head (X_5): It is hypothesized that households headed by males have more access to information on mechanized harvesting and therefore will be more likely to adopt the combine harvester.

Family size (X_6): Larger households have sufficient labor required to manually harvest wheat. Thus, a larger family size would be expected to decrease the probability that a farmer will use a combine harvester.

Farm size (X_7): It is hypothesized that as a farmer's wheat area increases, he/she is more likely to hire a combine harvester to ensure that harvesting operations are completed on time.

A partial budget analysis was carried out to determine the financial and economic profitability of different harvesting and threshing methods. The conversion factor approach was used to determine the economic profitability of harvesting and threshing technologies. This approach converts the market value of an item into its economic value. The conversion factors used are all given in MEDAC (1998).

The shadow price of an item is given by:

$$SP = CF_i * MP_i$$

where:
SP = shadow price;
CF = conversion factor; and
MP = market price of the item.

3.0 DEMOGRAPHIC AND SOCIOECONOMIC CHARACTERISTICS

Demographic and socioeconomic characteristics of sampled households are shown in Table 1. Women headed about 8% of households in the study area. Widowhood/absent husbands and the practice of polygamy were the main reasons that women in the study area were heads of households. Of these females, 83% were widowed and the remaining 17% were divorced or married to soldiers who lived away from the farm.

Farmers that used manual harvesting (MH) had slightly smaller families (7 persons) than those that used combine harvesting (CH) (7.5 persons). The MH farmers (45 years) were older than CH farmers (42 years) and also had more farming experience (26.5 and 23.4 years, respectively). About 2% of MH farmers had off-farm income compared to 7% of CH farmers. Differences between households were not significant.

About 75% of MH farmers were illiterate compared to 47% of CH farmers (Table 2). The CH farmers were significantly better educated than the MH farmers ($\chi^2 = 11.7$; $p<0.01$).

Table 3 shows land ownership by method of harvesting in the study area. The average area formally given by the local PA was significantly larger for CH farmers (2.6 ha) than MH farmers (2.3 ha) ($t=2.2$; $p<0.05$). Likewise, total farm size (area under crops) was significantly larger for CH farmers (2.5 ha) than MH farmers (2.0 ha) ($t=3.1$; $p<0.01$). Also, CH farmers left significantly more land under fallow than MH farmers. The CH farmers rented significantly more land for livestock and crops, and leased out significantly more land for sharecropping compared to MH farmers. This process effected the transferal of land from farmers who were not using combine harvesters to those who were. There were no significant differences between the amount of land rented for sharecropping or leased out for cash. The CH farmers managed more land that was owned by their parents or wife than MH farmers.

Table 1. Demographic and socioeconomic characteristics of farmers by harvesting method, Arsi, Ethiopia

	MH farmers		CH farmers		
Variables	Mean	Standard deviation	Mean	Standard deviation	t-test
Total family size	6.9	3.9	7.5	4.1	0.9 (NS)
Adults (>17 yr)	3.0	1.8	3.4	1.9	1.3 (NS)
Children (14-17 yr)	1.5	1.0	1.9	0.8	1.7 (NS)
Children (<14 yr)	3.6	2.5	3.5	2.5	0.8 (NS)
Age of household head (yr)	45.2	15.0	42.0	14.4	1.4 (NS)
Experience of household head (yr)	26.5	15.0	23.4	13.2	1.3 (NS)

Note: MH = manual harvesting; CH = combine harvesting; NS = not significant.

Table 2. Education level of farmers by method of harvesting, Arsi, Ethiopia

	Manual harvesting		Combine harvesting		
Educational level	Number of farmers	Percent of farmers	Number of farmers	Percent of farmers	χ^2
					11.7***
Illiterate	44	74.6	46	46.9	
Elementary school	12	20.3	38	38.8	
Secondary school	3	5.1	14	14.3	

Note: *** = significant at p<0.01.

Table 3. Land ownership by method of harvesting, Arsi, Ethiopia

Land ownership details	Manual harvesting		Combine harvesting		t-test
	Average area (ha)	Standard deviation	Average area (ha)	Standard deviation	
Farmer's land given by PA	2.3	0.8	2.6	1.0	2.2**
Farmer's grazing land	0.5	0.5	0.6	0.4	0.3 (NS)
Farmer's fallow land	0.7	0.6	1.2	0.8	2.1**
Parents' land	1.5[a]	–	2.0	1.2	–
Wife's land	1.5[b]	0.7	1.3	1.0	–
Rented for livestock	0.6	0.5	1.3	0.6	3.0***
Rented for crops	0.6	0.4	1.2	0.8	2.3**
Rented for sharecropping	0.9	0.3	0.9	0.2	0.4 (NS)
Leased out for cash	0.8	0.3	1.1	0.8	0.9 (NS)
Leased out for sharecropping	0.5	0.0	1.6	0.8	3.3**
Total farm size	2.0	0.8	2.5	1.3	3.1***

Note: NS = not significant; ** = significant at p<0.05; *** = significant at p<0.01.
[a] One farmer.
[b] Two farmers.

4.0 PRE-HARVEST WHEAT PRODUCTION TECHNOLOGIES

4.1 Land Preparation

Land preparation for crop production starts during February in Asasa, and most fields (50%) are plowed for the first time in March. In Etheya, most fields (62%) are not plowed until April. Frequency of land preparation varies over the study area, mainly due to differences in soil texture. Soils in Asasa are relatively sandy compared to those of Etheya and, as a result, the frequency of plowing is low.

Oxen are traditionally used for land preparation, but a few farmers also used a tractor at least once during the study. Ninety percent of plots that had been plowed by tractor at least once were harvested using a combine. Similarly, 58% of plots that had been plowed using only oxen were harvested using a combine. Thus, a higher proportion of tractor-plowed and oxen-plowed fields were harvested using a combine. It was also noticed that farmers who used a tractor at least once tended to use a combine rather than harvest manually. The χ^2 test confirmed this trend. Only 9% of plots had been plowed at least once by tractor, however, which indicated that the contribution of the tractor to land preparation for wheat production is minimal in the study area.

4.2 Wheat Varieties

Table 4 shows the wheat varieties currently grown by farmers in the study area. During the study, the most commonly grown varieties were Pavon-76 (38.3%), Batu (25.11%), and Dashen (23%). These are semidwarf varieties released in the early 1980s. Although these were the most popular varieties throughout the study area, there were differences in the proportion of these varieties planted between MH and CH farmers. The MH farmers grew Pavon-76, Dashen, and Batu in almost equal proportions, whereas the CH farmers grew mainly Pavon-76 (43.4%), and to a lesser extent Dashen (19%) and Batu (22%).

4.3 Fertilizer Use

All sample farmers used fertilizer for wheat production. Over the study area, the average fertilizer rate was around 88 kg/ha; however, it was higher (95 kg) for Etheya and lower (81 kg) for Asasa. Although the average fertilizer rate for MH and CH plots was almost equal over the study area, there were small insignificant differences at the district level. In Asasa, MH farmers used 71 kg and CH farmers used 82 kg of fertilizer, whereas in Etheya, MH farmers used 92 kg and CH farmers used 98 kg of fertilizer.

Table 4. Wheat varieties grown by farmers in the study area

	Manual harvesting		Combine harvesting	
Varieties	Number of farmers	Percent of farmers	Number of farmers	Percent of farmers
Pavon-76	24	28.9	66	43.4
Dashen	25	30.1	29	19.1
Batu	26	31.3	33	21.7
K6295-4A	3	3.6	20	13.1
Enkoy	1	1.2	2	1.3
Mitike	0	0.0	1	0.7
Wabe	0	0.0	1	0.7
Israel	3	3.6	0	0.0
Kubsa	1	1.2	0	0.0
χ^2 (df = 4)[a]			14.38	

[a] Enkoy, Mitike, Wabe, Israel, and Kubsa were considered in a single category as “others” for the chi-square analysis.

4.4 Weed Management

The two main methods of weed control used in the study area were hand weeding and herbicides. Hand weeding, the traditional method, was used in 87% of plots. On average, farmers used about 21 man-days to weed 1 ha of wheat. Some farmers weeded only once, while others weeded twice. Some farmers combined hand weeding with an application of herbicide (hand weeding usually occurred after herbicide was applied, though some farmers weeded before and after applying herbicide). Labor used for hand weeding did not vary significantly between MH and CH farmers.

Herbicide was applied to about 50% of plots in the study area at an average rate of 0.62 l/ha 2,4-D. The two study areas differed markedly with regard to the proportion of plots that received herbicide and the application rate. Herbicide was applied to only 34% of wheat plots in Asasa compared to 66% in Etheya. The average application rate in Asasa was about 1.0 l/ha and only 0.45 l/ha in Etheya. Average application rates did not significantly differ between CH and MH plots in both locations.

5.0 CURRENT WHEAT HARVESTING AND THRESHING TECHNOLOGIES

Two methods of wheat harvesting and threshing were commonly used in Asasa and Etheya. The traditional method is manual harvesting and oxen threshing. Combine harvesting was introduced in the early 1970s by the CADU project, but was disrupted during the Dergue regime. During the study, about 68% of farmers (78% in Asasa and 59% in Etheya) used a combine harvester (Figure 4).

5.1 Manual Sickling and Oxen Threshing (Traditional Harvesting)

Manual harvesting and threshing is labor intensive. About 27% of farmers in Asasa and 41% of farmers in Etheya manually harvested all of their wheat fields. About 5% of farmers in Asasa and 14% of farmers Etheya manually harvested some of their wheat fields and harvested the remainder using a combine.

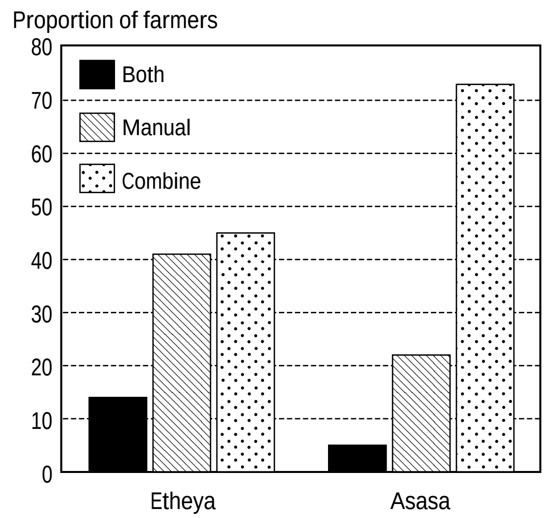

Figure 4. Wheat harvesting methods in Arsi, 1995.

During manual harvesting, wheat is usually stacked on the field until the farmer has finished harvesting his/her other fields. After a certain period the wheat is transported to the threshing plot, traditionally in a wooden cart pulled by a pair of oxen. Recently, however, a shortage of draft power has forced farmers to use pack animals, particularly donkeys, as the major means of transportation. If the farmer lacks oxen or donkeys or if the field is close to the threshing ground, human labor may be used to transport the wheat. Once at the threshing plot, the wheat is threshed immediately or heaped for a certain period depending on the weather, availability of oxen, or household grain requirement. Prior to threshing, the plot is cleared of grass. A group of livestock, mainly oxen and bulls, are used to trample the wheat bundles. The straw and grain are then winnowed, measured, and transported to storage.

Table 5 shows the timing of harvesting and threshing and the method of transporting wheat in Asasa and Etheya. Only 17% of wheat fields in Asasa and 60% in Etheya were harvested manually. Harvesting begins at the end of September in Asasa and at the end of October in Etheya; however, in both cases, November is the peak manual harvesting time, when about 60% and 79%, respectively, of wheat fields are harvested. The average number of man days per hectare required to complete harvesting in Asasa (6.7) was significantly lower than in Etheya (16.6) ($t=3.12$, $p<0.01$). Studies by Gavian and Gemechu (1996) found that it took 17 man-days/ha to complete harvesting in Tiyo woreda, which neighbors Etheya. This suggests that the data from Asasa underestimate the labor requirement for harvesting. Moreover, informal discussions with farmers in the area indicated that it took 12-20 man-days/ha, depending on crop density. For this reason, the value of 16 man-days/ha was used in the profitability analysis for Asasa.

Ninety-six percent of farmers in the study area left their wheat heaped in the field after harvesting until they had finished harvesting other crops. Then they transported the crop to the threshing plot where it was heaped again. In Asasa, the first heaping (0.35 man-days/ha) took less time than in Etheya (1.17 man-days/ha). Also, farmers in Asasa needed less time (0.3 man-days/ha) to heap their wheat at the threshing plot compared to those in Etheya (0.75 days/ha). Most farmers in Asasa (85%) used oxen to transport wheat from the field to the threshing plot, while most farmers in Etheya used pack animals (96.6%). Other means of transport used were humans and vehicles.

Table 5. Timing of manual harvesting and threshing, and method of transporting wheat in Asasa and Etheya

	Asasa		Etheya	
	Number of fields	Percent of fields	Number of fields	Percent of fields
Time of harvesting				
September	1	5	0	0.0
October	4	20	5	8.2
November	12	60	48	78.7
December	3	15	8	13.1
Method of transport				
Pack animal	0	0	58	96.6
Oxen	17	85	0	0.0
Human labor	3	15	1	1.7
Vehicle	0	0	1	1.7
Commencement of threshing				
November	7	37	6	9.8
December	11	58	44	72.1
January	1	5	11	18.1
Method of harvesting and threshing				
Combine harvester	97	83	61	40.1
Oxen	20	17	91	59.9

In Asasa, about 2.6 man-days/ha were required to transport the wheat bundles to the threshing plot, whereas about 13.5 man-days/ha were required in Etheya (Table 6). The animal labor used was 2.1 oxen-pair days/ha in Asasa and 10.8 donkey-days/ha in Etheya. Three main factors affected the amount of labor required to transport the wheat bundles: distance from the field to the threshing plot, utilization of wheat straw, and mode of transport. In Etheya, farmers used the wheat straw for animal feed and thus threshed near the homestead; however, most farmers in Asasa did not use the straw for animal feed and hence threshed near the wheat field. The method of transportation used in the two study areas also influenced the amount of labor required. Farmers in Etheya used donkeys, while farmers in Asasa used oxen to transport wheat bundles. An oxen pair is usually able to transport more wheat at a time than a donkey.

Although some farmers started threshing in November, the majority of farmers in both localities threshed in December. About 5.65 and 7.96 man-days/ha were used for threshing in Asasa and Etheya, respectively, while the average number of animal days used was about 30.4 days/ha and 42.5 days/ha in Asasa and Etheya, respectively. Once the grain was trampled and separated from the straw, it was winnowed to clean the seed. This process took about 4.03 man-days/ha and 1.54 man-days/ha in Etheya and Asasa, respectively.

Table 6. Labor (days/ha) required for wheat operations in Asasa and Etheya

Wheat operation	Type of labor	Asasa	Etheya	t-test
Harvesting	Human	6.70[a] (20)[b]	16.60[a] (59)[b]	3.12***
Heaping in the field	Human	0.35 (18)	1.17 (58)	4.57***
Heaping at threshing plot	Human	0.30 (9)	0.75 (54)	2.14**
Transportation	Human	2.64 (19)	13.48 (61)	7.13***
Transportation	Oxen/donkey	2.11 (19)	10.79 (61)	7.13**
Threshing	Human	5.65 (20)	7.96 (44)	1.76 (NS)
Threshing	Oxen	30.40 (20)	42.50 (61)	1.68 (NS)
Winnowing	Human	1.54 (4)	4.03 (26)	1.37 (NS)

Note: NS = not significant; ** = significant at p<0.05; *** = significant at p<0.01.

[a] Average working time per day is 5 h for livestock and 8 h for humans.

[b] Number of farmers.

5.2 Combine Harvesting

In Arsi, the combine harvester has substantially reduced the labor requirement for wheat production. About 78% of farmers in Asasa used the combine on at least one of their wheat fields compared to 59% of farmers in Etheya. A combine was used to harvest about 83% and 40% of wheat fields in Asasa and Etheya, respectively. It may be misleading to extrapolate these figures to represent Arsi in general, however, since the topography, infrastructure, and proximity to repair and maintenance services in the study area are more suited to combine harvesting than most other regions in Arsi.

More farmers in Etheya (68.5%) rented a combine harvester from a private owner than farmers in Asasa (52%), while 32.6% of farmers in Asasa rented from the government-owned Agricultural Mechanization Service Stations (AMSS) compared to 28% of farmers in Etheya (Table 7). About 11% of farmers in Asasa rented a combine harvester from Ardayeta Training Center and state farms, while about 4% of farmers in Etheya rented from the ESE. Most farmers in Asasa (57.8%) and Etheya (61.1%) used a combine harvester during November (Table 7).

Farmers had difficulties in gaining access to a combine harvester. To acquire the service of a machine, they had to form groups with adjacent farmers to collect enough money to cover the required service. In 1995, 91% of farmers formed a group to rent a combine, while only 9% accessed a machine directly or through an individual contract. About 90% of farmers in Asasa and 89% of farmers in Etheya formed groups to rent a combine harvester. This was mainly due to economies of scale, since a large and continuous field is required to achieve maximum combining efficiency, and also partly due to a shortage of machines. After the survey (during the harvest of 1996), the number of combines in the area increased and the latter explanation became less important.

One problem associated with combine harvesting is yield estimation. About 88% of farmers in Asasa and 92% in Etheya had to clean and re-measure their yields after harvesting. This process used about 0.7 days/ha and 0.9 days/ha in Asasa and Etheya, respectively. The operator's estimation of yield (used to charge the farmer) was about 38% higher than the farmer's estimation, although part of this difference was attributed to different measurement methods. Farmers weighed their grain in bags of 115-130 kg, while the combine operators used quintals (100 kg). About 73% of farmers in Asasa and 94% of farmers in Etheya used tractor-trailers to transport wheat to their homestead, while 15% and 2%, respectively, used pack animals. Other farmers used human labor.

Table 7. Source of combine harvester and timing of harvesting for farmers in Asasa and Etheya

	Asasa		Etheya	
	Number of farmers	Percent of farmers	Number of farmers	Percent of farmers
Source of combine harvester				
Private owner	52	56.5	37	68.5
Government station	30	32.6	15	27.8
State farm	10	10.9	-	-
ESE	-	0.0	2	3.7
Timing of harvesting				
October	4	4.5	0	0.0
November	48	57.8	33	61.1
December	25	30.1	20	37.0
January	6	7.2	1	1.9

Tractors were hired per hour or according to weight of goods transported. All tractor users in Etheya and 30% of tractor users in Asasa paid on the basis of weight. The average cost of transporting wheat, based on weight, was higher in Asasa (2.4 Birr/100 kg) than Etheya (2 Birr/ 100 kg) (1 Birr = US$7). Due to lower yields in

Asasa, tractors operated at less than capacity, which private owners compensated for by charging by the hour. The average cost of transporting wheat per hour was 2.1 Birr/100 kg. Winnowing was required after harvesting and threshing, because the grain was not cleaned sufficiently during combining and took about 15 minutes per quintal.

5.3 Manual Sickling and Motorized Stationary Threshing

A third harvesting method used in the study area, though on a very small scale, was manual sickling and motorized stationary threshing. This method requires the wheat bundles to be fed manually into the machine, and the grain, though semicleaned, needs further cleaning once threshing has been completed. No farmers in the study area used this method. This technology is currently limited to demonstrations by the Asella Rural Technology Promotion Center. According to the center, the technology needs further refining before it is marketable.

6.0 FACTORS INFLUENCING THE ADOPTION OF THE COMBINE HARVESTER

The amount of wheat area owned by a farmer significantly affected the method of wheat harvesting used. The average area owned by CH farmers was 1.57 ha, compared to 0.86 ha owned by MH farmers. About 75% of the wheat area in the study region was harvested using a combine harvester. The fact that the area harvested by combine harvester (75%) is greater than the proportion of farmers who used a combine (68%) confirms that a higher proportion of farmers having a larger area of wheat used a combine harvester than farmers with smaller area of wheat. When we differentiate this fact based on location, the wheat area harvested by combine is 86% and 60% in Asasa and Etheya, respectively. This partly confirms the general view that the introduction of the combine harvester has contributed to expanding the area under wheat.

Another factor that greatly influenced the farmer's choice of method for harvesting wheat was the level of education (χ^2 is significant at 0.01). As shown in Table 8, a greater proportion of literate farmers used a combine harvester than illiterate farmers. Eighty-eight percent of farmers with a secondary education used a combine, compared to only 53% of illiterate farmers.

Besides wheat area and education, other factors (accessibility of the technology, farmer's age, sex, and family size) were expected to influence a farmer's decision to use a combine. Thus it was hypothesized that a farmer's decision to adopt the combine harvester was influenced by the combined effect of a number of factors. A logit model was fitted and the results are presented in Table 9.

Table 9 indicates that 78% of the total variation in the sample was explained. Figures for correctly predicted adopters and non-adopters of the combine harvester were 89% and 56%, respectively. The chi-square figure in Table 9 indicates that the parameters included in the model are significantly different from zero at the 1%

Table 8. The effect of farmers' literacy level on their decision to use a combine harvester

Level of education	Number of farmers	Percent of combine users
Illiterate	53	53
Basic literacy	37	62
Elementary	50	82
Secondary	17	88

level. All variables except family size had the expected sign in the model. Though not significant, younger farmers tended to use a combine more than older farmers. As expected, male-headed households were more likely to use a combine than female-headed households. This suggests that female-headed households do not have easy access to combine owners (to make hiring arrangements) due to sociocultural reasons. The model result was therefore in line with the sociocultural circumstances prevailing in the study area. Accessibility, education level, and total wheat area all positively and significantly affected the adoption of the combine harvester.

The proximity of the farm to a hiring station and topographic conditions (accessibility) were important factors that affected the adoption of the combine harvester. The odds in favor of using a combine were positively and significantly influenced by a factor of 3.8 for farmers who had better access to the technology. This indicates that there is a natural limit to the expansion of the combine hiring business. Observations, mostly made after the survey, showed that this limit has nearly been reached in the study area. In this case, the problem of unfavorable topography can be overcome by the introduction of the stationary thresher. Education level also had a statistically significant impact on the use of the combine harvester. Farmers with an elementary education were more likely (by a factor of 3.3) to use a combine than illiterate farmers. Moreover, the odds in favor of using a combine were higher (by a factor of 6.7) for farmers with a secondary education compared to illiterate farmers. With each increase in wheat area of one hectare, the likelihood of using a combine increased by a factor of 1.6. The average area owned by CH farmers (1.57 ha) was significantly higher than MH farmers (0.86 ha).

Table 9. Parameter estimates of a logistic model for factors affecting farmers' adoption of combine harvesters, Asasa and Etheya

	Parameter estimates for combine harvesters		
Explanatory variable	**β**	**Wald-statistic**	**Exp (β)**
Intercept	-3.228**	5.5	
Accessibility	1.333***	7.5	3.8
Household head age (yr)	0.005	0.1	1.0
Education level			
Elementary	1.196**	4.5	3.3
Secondary	1.908**	4.3	6.7
Gender of farmer (male)	0.951	1.4	2.6
Family size (no.)	0.041	0.4	1.0
Total wheat area (ha)	0.450***	13.7	1.6
Model chi-square	54.23***		
Overall cases correctly predicted	78.34%		
Sample size (N)	157		

Note: ** = significant at $p<0.05$; *** = significant at $p<0.01$.

7.0 YIELD COMPARISON BY HARVESTING METHOD

As described previously, wheat management practices (excluding land preparation and variety selection) are not significantly linked to method of harvesting. With regards to land preparation, the proportion of fields plowed by tractor was insignificant, hence its effect on overall yield may not be statistically significant. Moreover, Pavon-76, which was mostly used by CH farmers, did not produce significantly different yields to other semi-dwarf varieties Dashen and Batu, except where there was a location effect. Thus, the difference in yield shown in Table 10 was mainly attributed to harvesting method.

As shown in Table 10, wheat yield differs between the two harvesting and threshing methods. In addition there is a remarkable difference between the two locations, particularly for manual harvesting and threshing.

Table 10. Average wheat yield estimates (qt/ha) in Etheya and Asasa

	Yield		
	Manually	Combine harvested	
Location	harvested	Estimated[a]	Measured[b]
Etheya	17.2	26.8	19.3
Asasa	9.2	21.1	12.2

[a] Yield estimated by combine operators.
[b] Yield estimated after winnowing and weighing.

The yield difference between combine harvesting (as measured by the combine operator) and manual harvesting in Etheya was 35.4%, whereas the corresponding figure in Asasa was much higher at 57.1%. This was mainly due to a high level of weeds in the harvested grain. According to Jonsson (1972), yield loss due to manual harvesting and threshing relative to combining was 35%, which is in agreement with the results from Etheya. Jonsson further estimated a yield loss of 15% due to oxen threshing in the highlands of Ethiopia. The yield difference between the harvesting and threshing methods is due to a number of factors, with the most important being:

- Yield loss which occurs during manual sickling, collecting, transporting, threshing (e.g., animals feeding whilst trampling over wheat bundles), and untimely harvesting and threshing. The major economic incentive for adopting the combine harvester is to avoid these losses.
- Differences in the unit of measurement used by the combine operator and the farmer. Combine operators assume that 1 qt = 100 kg, while farmers use sacks with weights usually ranging from 115 to 130 kg. This accounts for a 15-30% difference in yield estimation between manual and combine harvesting.
- Purity of the harvest, particularly in Asasa where the weed population is high. Combine operators will not adjust the cleaner to effectively separate weeds from grain. The high proportion of farmers that winnow after combine harvesting confirms this. Yield (qt) is estimated by volume-to-weight ratio. A given volume will have a standard weight labeled on the container. Where there is a high level of weed seeds, the container is filled before the correct weight of grain is achieved, thus resulting in substantial discrepancies.

To avoid yield bias due to varying purity levels and exaggerated estimates made by combine operators, the yield measured by the farmer (see column 4 in Table 10) was used in the profitability analysis. Moreover, to eliminate the effect of measurement bias on the profitability comparison, both yields (columns 2 and 4 of Table 10) were adjusted upwards by 30%.

8.0 FINANCIAL PROFITABILITY ANALYSIS

Partial budgeting was used to compare the profitability of manual and combine harvesting and threshing of wheat in the study area. The partial budget is a way of analyzing the profitability of two or more competing enterprises or technologies by considering the costs and benefits that vary between/ among the technologies (Table 10). The benefits were calculated by multiplying yield and price. The yield from CH plots in Etheya (25.1 qt/ha) was significantly higher than from CH plots in Asasa (15.9 qt/ha) ($t=3.9$; $p<0.01$). Similarly, yields from MH plots in Etheya (17.2 qt/ha) differed significantly from CH yields in Asasa (9.2 qt/ha) ($t=5.1$; $p<0.01$).

The labor requirements for manual harvesting (Table 6) were found to differ between Asasa and Etheya. Different agroclimatic conditions and operational procedures between the two areas could explain these differences. Costing of both human and animal labor for manual harvesting and threshing was determined according to Gavian and Gemechu (1996).

The material requirements for manual harvesting are shown in Appendix 1. These materials can be either purchased or made at home but all have a market value. Material costs were determined by first using the price per unit and then calculating the cost in Birr/ha. It was expected that, on average, the materials would serve two hectares per season and have different service lives, as indicated in the appendix.

The costs of combine harvesting include the service charge, which is based on weight or volume of produce and the cost of transportation to the homestead. The harvesting cost is based on quintal of grain harvested. In the study area, the average charge was 11.4 Birr/qt, however this varied with the source of the combine - the ESE charged 10 Birr/qt, while private owners charged 11.8 Birr/qt. Other public suppliers, such as the AADE and government mechanization stations, also charged around 10 Birr/qt. About 3% of farmers were charged per hectare, which worked out at about 230 Birr/ha on average. Most farmers were charged per quintal and this was used in the analysis. The operators of combine harvesters usually calculated the cost of transporting grain to the homestead on the basis of weight or time.

Most CH farmers (58%) were charged 2 Birr/qt to transport their grain using a trailer. The transport cost was calculated using the operator’s estimation of the number of quintals of grain multiplied by the charge per quintal. The operator’s estimation was, on average, 21.1 qt of wheat in Asasa and 26.8 qt of wheat in Etheya.

Another cost associated with harvesting was the tip for the operators who helped to more accurately estimate yield. Farmers in Asasa paid significantly higher tips (16.0 Birr) than farmers in Etheya (10.85 Birr) ($t=2.1$; $p<0.05$).

Labor costs incurred by the farmer were grain cleaning and yield measurement. The operators of combine harvesters usually estimated higher yields when charging for the harvesting operation. Farmers in Asasa and Etheya worked for about 0.7 days/ha to clean and measure their harvest.

Results of the partial budget analysis are shown in Table 11. The cost per hectare of manual harvesting and threshing was lower in Asasa (294.03 Birr/ha) than Etheya (447.05 Birr/ha). Similarly, the cost of combine harvesting was lower in Asasa (310.54 Birr/ha) than Etheya (387.47 Birr/ha). In Asasa, the cost per quintal of manual harvesting and threshing (24.5 Birr/qt) was 21% higher than the cost of combine harvesting (19.53 Birr/qt). In Etheya, the cost per quintal of manual harvesting and threshing (19.96 Birr/qt) was 23% higher than for combine harvesting (15.44 Birr/qt). Thus, the adoption of the combine harvester significantly reduced operation costs per quintal. The cost per quintal of manual harvesting was about 23% higher in Asasa than Etheya. This was due to cleaner yields in Etheya and a lack of grain cleaning in Asasa. The cost per quintal of combine harvesting was about 26% higher in Asasa, mostly due to the significantly higher yield per hectare in Etheya. In Asasa, the net benefit of combine harvesting was about 38% higher compared to manual harvesting and threshing, while in Etheya it was about 16% higher.

Table 11. Financial profitability (Birr/ha) of wheat harvesting and threshing technologies in Asasa and Etheya

	Asasa		Etheya	
	Manual harvesting	Combine harvesting	Manual harvesting	Combine harvesting
Yield (qt/ha)[a]	12.0	15.9	22.4	25.1
Gross return[b]	1692	2242	3584	4016
Costs of manual harvesting				
Labor[c]	–	–	–	–
Harvesting[d]	72.00	–	74.7	–
Heaping[d]	2.92	–	8.64	–
Transportation[d]	11.88	–	60.66	–
Threshing[e]	31.08	–	43.78	–
Winnowing[e]	8.47	–	22.16	–
Animal labor[f]	138.48	–	213.16	–
Storage[g]	6.00	–	11.20	–
Material cost	23.20	–	12.75	–
Cost of combine harvesting				
Hire of combine harvester	–	240.54	–	305.52
Transport with trailer	–	42.20	–	53.6
Storage	–	7.95	–	12.55
Labor (cleaning and weighing)	–	3.85	–	4.95
Tip for operator	–	16.00	–	10.85
Total costs that vary	294.03	310.54	447.05	387.47
Net income	1397.97	1931.46	3136.95	3628.53

[a] Yield = 130% of the yield from Table 5.
[b] Price of wheat in Asasa = 141 Birr/qt; Etheya = 160 Birr/qt (average April '97–July '98).
[c] Labor for manual harvesting is taken from Table 6, and material cost is calculated in Appendix 1.
[d] Labor cost for harvesting, heaping, and transportation = 4.5 Birr/day (Gavian and Gemechu 1996).
[e] Labor cost for threshing and winnowing = 5.5 Birr/day (Gavian and Gemechu 1996).
[f] Animal cost for threshing and transportation = 4.0 Birr/day (Gavian and Gemechu 1996).
[g] Storage cost = 0.5 Birr/qt.

9.0 ECONOMIC PROFITABILITY ANALYSIS

The economic profitability analysis was concerned with the impact of the project on the national economy. It can be distinguished from financial analysis in that attention is not confined to the costs and benefits affecting an individual or single unit in the economy but instead focuses on the economy as a whole. The second major aspect of economic analysis is based on the possibility that some of the prices used in the analysis may not adequately reflect the economic value of the item concerned due to market imperfection, external effect, and government control (MEDAC 1998). These are common phenomena in developing countries. In such instances, the assessment of projects, enterprises or technologies using market prices may not give a very accurate indication of the costs and benefits to the national economy.

For the financial price to reflect the economic price, there is a need to disaggregate the cost items, particularly that of machinery costs, into tradable and non-tradable components and to make corrections for the different price distortions on each component. There are three successive steps in adjusting prices: adjustment for direct transfer payments, adjustment for price distortion in traded items, and adjustment for price distortions in non-traded items.

During harvesting and threshing operations, farmers make use of tradable and non-tradable goods, which are priced differently due to national trade policy. People may pay a premium on tradable goods over non-tradable goods. To adjust the financial prices of these goods to economic prices (efficiency prices), the Foreign Exchange Premium (FEP) needs to determined. Therefore, the premium that people are willing to pay for tradable goods represents the amount that, on average, tradable goods are mispriced in relation to non-tradable items when the official exchange rate is used to convert the foreign exchange price into domestic values.

There are two ways of incorporating the premium of foreign exchange into our economic analysis. The first is the Shadow Exchange Rate (SER) approach, which multiplies the value of traded items, using the official exchange rate, by the FEP. This makes the traded items relatively more expensive in terms of domestic prices. Another method is the conversion factor approach, which is used in this study. This method reduces the domestic price of non-traded items by an amount that reflects the FEP (Gittinger 1982). The conversion factor (CF) for item i is defined as:

$$CF_i = \frac{SP_i}{MP_i} \text{ or } Sp_i = CF_i * MP_i$$

where:
SP_i = shadow price for item *i*;
MP_i = market price for item *i*; and
CF_i = conversion factor for item *i*.

The Ministry of Economic Development and Cooperation provided the conversion factors for non-tradable items (MEDAC 1998).

Ethiopia imports combine harvesters and trailers. Tractors are assembled at Nazareth. However, most of the tractor parts are imported. For the costing of combine harvesters, tractors, and trailers, import parity prices were used. In the current government's agricultural policy, imports of agricultural machinery are not taxed, and investors are exempted from certain taxes for certain periods, depending on the nature and location of the investment. Furthermore, there is no subsidy on the import of agricultural machinery. Although subsidies and taxes do not distort the price of agricultural machinery, a 12% sales tax and 30% duty tax on spare parts increases the cost of spare parts by 45.6%. These taxes were reduced in calculating the efficiency cost of machinery.

Calculation of machinery costs for combine harvesters, tractors, and trailers are shown in Appendix 2. The cost components of combine harvesting are labor and machinery costs. The machinery costs include depreciation, capital, repair and maintenance, fuel and oil, and the operator's labor (Byerlee 1985). To calculate efficiency price, these costs are separated into tradable and non-tradable components. The tradable components are depreciation (100%), repair and maintenance (75%), and fuel and oil (73%) (MEDAC 1998).

The total number of working hours and the harvesting capacity of combine harvesters were estimated for machines hired from private enterprises. Operators worked about 15 hours a day during peak harvesting time. They harvested for about three months (60 effective days), moving from Dhera, Asasa, to Sinana in Bale Highlands.

The efficiency of a combine harvester depends on field size and plot yield. In large seed multiplication fields at the Kulumsa Research Center (KRC), about 84 qt can be harvested per hour where plot yields are high. In Kenya, in smaller fields (<4 ha), a standard sized combine can harvest 10 ha in an average working day; however, up to 16 ha can be harvested in larger fields. This indicates a 38% loss in harvesting efficiency for combine harvesting small fields (Longmire and Lugogo 1989).

Machine operators estimate that for a plot yield of about 40 qt/ha, a combine can harvest at a rate of 60-70 qt/hr, and, in plots with a yield of about 20 qt/ha, 30-35 qt/hr can be harvested. Using the operator's yield estimations from Table 5 (21 qt/ha in Asasa and 27 qt/ha in Etheya), it was calculated that a combine can harvest 36 qt/hr in Asasa and 40 qt/hr in Etheya. However, since the fields are small and not always in close proximity, losses of 30% in harvesting time can occur. A more realistic harvesting estimate is only 25-28 qt/hr. In 60 working days of 15 hours, it was calculated that a combine harvests up to 22,500 qt of wheat in Asasa and 25,200 qt in Etheya.

A third calculation was required to estimate the cost of transporting the harvest to storage (Appendix 2). A tractor and trailer are used for this operation and work alongside the combine harvester for 15 hours. Loading and unloading takes 15 minutes per hour and transportation takes 45 minutes. About 28 qt is transported per trip, resulting in 420 qt per day, or 25,200 qt per harvesting season. An important assumption made when breaking down the tractor costs was that the tractor and the trailer are only used for transporting wheat. Also, the service life of a tractor was increased from 12 to 18 years because it worked for only 60 days per year.

The cost components of manual harvesting and threshing are human and animal labor and local materials - all of which are non-tradable. Although cattle are exported, they are still considered non-tradable because cattle export is very small and has been decreasing in recent years. In converting financial price into economic price, the values of all tradable components were used without change, while the values of all non-tradables were multiplied by their conversion factor. For unskilled rural labor, the conversion factor for Oromiya (0.731) was used instead of the national average (0.598), because the value was higher for Oromiya than for other regions. Using the national average would underestimate the value of labor in the study area (MEDAC 1998). All component costs were then summed to determine the cost to the nation of harvesting and threshing wheat in the study area using the different methods.

Ethiopia is a net importer of wheat, thus import parity price was used to determine the price of wheat in the study area (Appendix 3). The different components of wheat price were cost-insurance-freight (CIF) price at Assab port, port cost, transport from port to study area, labor, and services. To calculate the economic price, the cost components of wheat were divided into tradable and non-tradable. The price of wheat at the port and the port cost were valued at the official exchange rate. The transport cost of wheat was 26 Birr/qt to Asasa and 36 Birr/qt to Etheya. About 86% of the transport cost was tradable (MEDAC 1998). Labor and services are non-tradable and were multiplied by their conversion factor.

Partial budgeting was used to analyze the economic profitability of wheat harvesting and threshing in Etheya and Asasa (Table 12). The private cost of manual wheat harvesting and threshing in Asasa and Etheya was 34% and 43% higher, respectively, than the national cost. The private cost of combine harvesting was more than double (109%) in Asasa and 86% higher in Etheya, compared to the national cost. These calculations suggest that the adoption of the combine harvester will reduce the per capita unit cost of harvesting to the nation more than it will to the individual farmer. This cost reduction should persuade the government to facilitate the importation of more combine harvesters. Since there is no import tax in Ethiopia, as well as tax exemptions in certain years for private investors, the difference between what the farmer and the nation pays lies mainly in the hands of the enterprises that provide the service. The effect of this benefit to the nation depends on the investors' marginal propensity to invest, which in turn is influenced by government investment policy and related factors.

Combine harvesting in both localities was more profitable to the nation compared to manual harvesting. The net return from combine harvesting was 64% higher in Asasa and 18% higher in Etheya compared to manual harvesting. Thus, the economic analysis showed that combine harvesting has a higher net income and lower costs compared to manual harvesting and threshing.

In the early 1970s, the social effect of mechanization was documented in the study area. It resulted in disguised unemployment and eviction of farmers, mainly due to the land tenure system in place at that time. Although a rigorous analysis was not undertaken, some of the current social effects of combine harvesting are discussed below.

The combine harvester frees about 25-36 man days of unskilled labor per hectare (Table 6), which is supplied predominantly by the farming family and partly by hired labor. This reduction in labor is more than compensated for, however, due to:

1) increases in wheat area and yield that create a demand for labor for weeding, cleaning, loading, unloading, storing, and other tasks;
2) an increase in the number of combines and tractors, which create jobs for mechanics, operators and managers; and
3) an increase in the number of workers in the villages, which causes some individuals, particularly women, to set up retail businesses.

Similarly, the use of the combine harvester frees about 33-51 animal-days/ha. Farmers in the study area maintain a large population of oxen, mainly for draft purposes and transportation, which compete with dairy cows for limited feed resources. Therefore, the replacement of oxen with combines may mean an increase in dairy production, which has important nutritional implications for the farming population.

Table 12. Economic profitability analysis of wheat harvesting and threshing in Asasa and Etheya (Birr/ha)

	Asasa		Etheya	
	Manual harvesting	Combine harvesting	Manual harvesting	Combine harvesting
Yield (qt/ha)[a]	12.0	15.9	22.4	25.1
Gross return[b]	1591.44	2108.66	2750.50	3082.03
Costs of manual harvesting				
Labor[c]	–	–	–	–
Harvesting	52.63	–	54.61	–
Heaping	2.13	–	6.31	–
Transportation	8.68	–	44.34	–
Threshing	22.72	–	32.00	–
Winnowing	6.19	–	16.20	–
Storage[d]	4.39	–	8.19	–
Animal labor[c]	101.23	–	155.82	–
Material cost	21.00	–	11.54	–
Costs of combine harvesting				
Labor (cleaning and measuring)[c]	–	2.81	–	3.62
Material cost (combine harvester)	–	102.90	–	149.10
Material cost (tractor and trailer)	–	25.80	–	39.10
Storage[d]	–	5.45	–	8.60
Tip for operators	–	11.70	–	7.93
Total costs that vary	218.96	148.66	312.81	208.35
Net income	1372.48	2257.32	2437.69	2873.68

[a] Yields are taken from Table 10.
[b] Farm gate price of wheat is taken from Appendix 3.
[c] Labor and animal costs are similar to Table 10, but are multiplied by conversion factor 0.731.
[d] Storage cost is multiplied by conversion factor 0.685 for services (Appendix 3).

10.0 CONCLUSIONS AND POLICY IMPLICATIONS

The Ethiopian wheat research program has made recommendations to farmers, which mainly include high yielding varieties, optimum fertilizer rates, and weed management. Due to concerted efforts by the extension service in recent years, farmers have mostly adopted these recommendations. However, the current extension packages do not include harvesting, threshing, and post-harvest technologies. To maximize the benefits of pre-harvest technologies, yield loss during and after harvest must be minimized.

The average family size of MH farmers (7 persons) was slightly smaller than that of CH farmers (7.5 persons). The MH farmers were older and had more farming experience, while CH farmers had larger farms and were more educated. Most farmers used oxen for land preparation and few used tractors. The most commonly grown wheat varieties for both farmer groups were Pavon-76, Batu, and Dashen. All sample farmers used about 88 kg/ha of fertilizer and there were no significant differences between CH and MH farmers. Most farmers hand weeded once or twice. The average number of weeding days was 20.7 and 22.1 man-days/ha for MH and CH farmers, respectively.

With 75% of the wheat area in the study region harvested using combines, the study clearly shows that farmers are interested in mechanical harvesting and threshing technologies. The main reasons for using the combine were economic benefits (for both farmers and the nation), a shortage of oxen, and a reduction in labor. The use of mechanical technology enabled farmers to increase their wheat production primarily by reducing yield loss (35%) during harvesting and threshing and secondly by indirectly increasing wheat area. Thus, the use of the combine harvester contributes to increased food self-sufficiency for farmers and the nation.

The logit model showed that proximity to hiring stations, topography of the area (accessibility), education level of the farmer, and wheat area were factors that significantly affected the adoption of the combine. The odds in favor of using a combine increased by a factor of 1.6 with every increase in wheat area of one hectare. The odds in favor of using a combine were positively and significantly influenced by a factor of 3.8 for farmers who had better access to the technology due to favorable topography. Therefore, the promotion of the combine harvester will result in a widening gap in both yield and income between farmers living in accessible and inaccessible areas. This has a negative implication on overall economic development and, therefore, policies need to be geared towards introducing intermediate technologies for wheat threshing in inaccessible areas.

Farmers who had an elementary level of education were more likely (by a factor of 3.3) to use a combine harvester compared to illiterate farmers. Moreover, a secondary education increased the likelihood of adoption by a factor of 6.7. Educated farmers were better aware of yield loss and consequent economic loss resulting from traditional harvesting and threshing methods. Therefore, all farmers, particularly those without an education, need to be informed of the benefits of combine harvesting to increase adoption and hence reduce the yield difference between literate and illiterate farmers.

As in most developing countries, population pressure is high in Ethiopia and agricultural labor is plentiful. With such an abundant labor force, agriculture is expected to be labor intensive, particularly for small holders where land shortage is critical. However, the substantial yield loss observed due to traditional harvesting and threshing of wheat relative to combine harvesting has necessitated the use of alternative technologies. The study showed combine harvesting, as an alternative technology, to be effective in terms of reducing yield loss, timing of operations, cost reduction, and profitability. As a result, many farmers in the study area have adopted this technology.

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Appendices

Appendix 1.

Material costs of manual harvesting

Items	No.	No. of seasons	Price/unit	Cost (Birr/ha) Asasa	Etheya
Harvesting					
Sickle	1	2	20	5	5
Transport					
Yoke	1	5	12	1.2	–
Miran	1	3	7	1.17	–
Necklet	4	1	0.75	1.5	–
Beam	1	6	10	0.83	–
Trailer	1	2	23	5.75	–
Rope	20	2	1	5	5
Threshing					
Fork	1	10	20	1.0	1.0
Handle	1	2	2	0.5	0.5
Layida	1	4	10	1.25	1.25
Total material cost				23.2	12.75

Note: All materials are assumed to work 2 ha per season.

Appendix 2. Calculation of machinery costs

Parameters used to calculate machinery costs

	Combine harvester	Tractor	Trailer
Horse power (HP)	105	75	–
Residual value (s)	0.2	0.2	0.2
Service life (n)	10	20	18
Quintal/yr (qt)	25200 (22500)[a]	25200 (22500)	25200 (22500)
Coefficient of maintenance (m)	0.8	0.8	0
Interest rate (i)	0.105	0.105	0.105
Wage rate per hour (w)	2.67	1.11	–
Price of machinery (Birr)			
Asasa	612,784.9	165,678.9	25.381.04
Etheya	611,634.9	164,878.9	24,881.04

[a] Value in parentheses is for Asasa.

1. Depreciation cost per quintal (D)

$$D = \frac{((1 - s)p)}{nQ}$$

where:

p = price of the machine; other variables are as defined in the table above.

2. Capital cost per quintal (I)

$$I = i\left[\frac{(1 - s)p/2}{Q}\right]$$

where:
all variables are as defined above.

3. Fuel cost per quintal (F)

$$F = [0.17(HP)(P_f)]/q$$

where :
P_f = price of fuel per liter;
q = quintal worked per hour.

4. Oil cost per quintal (O)

$$O = 0.15F$$

5. Repair and maintenance per quintal (M)

$$M = mp/Q$$

6. Operator's labor per quintal (L)

$$L = w/q$$

where:
w = wage rate per hour.

7. Total cost per quintal = $D_i + I_i + F_i + O_i + M_i + L_I$

where:
$_i$ = machine type (combine, tractor and trailer).

Appendix 3.

Calculation of wheat price (Birr/qt) at the farm gate

	Asasa	Etheya		Asasa	Etheya
		Tradable			
CIF wheat price	72.14	72.14		72.14	72.14
Port cost	22.59	22.59		22.59	22.59
Transport (86.3%)	31.07	22.44		31.07	22.44
		Non-tradable	**Conversion factor**		
Transport (13.7%)	3.56	4.93	0.876	3.12	4.32
Labor	2.03	2.03	0.731	1.48	1.48
Services	1.49	1.49	0.685	1.02	1.02
Farm gate wheat price (Birr/qt)				132.62	122.79

Note: CIF = cost-insurance-freight.