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Economic Evaluation of On-station Operational Scale (OPSCAR) Trials Conducted at Sadore, Niger

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INTRODUCTION

Operational scale trials (OPSCAR) aimed at comparative evaluation of technology packages were conducted at the Sahelian center of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) from 1986 to 1988. The rationale for embarking on OPSCAR is to experiment with technologies on plots that approximate farm sizes of smallholders in order to assess their relative economic performance. The objective was to identify a package whose components contributed significantly to higher and sustainable yields (Renard et al., 1988). The objective of this paper is to present an economic evaluation of the results obtained from these trials.

Description and justification of trials

The packages in the operational scale trials comprised of combinations of:

1. Animal traction for ridging and weeding;
2. application of phosphorus fertilizer at the rate of 13 kg ha^{-1};
3. improved millet (ITMV 8001) and cowpea (TVX 3236) cultivars; and
4. millet/cowpea rotations.

The usefulness and beneficial effects of such components have been shown in previous research conducted in the West African Semi-Arid Tropics (WASAT).

The beneficial effect of using animal traction for plowing and ridging is the transformation of soil profile to increase porosity and reduce soil resistance (Nicou, 1975). This permits better root growth that can increase drought tolerance and make better use of soil water reserves (Chopart and Nicou, 1976). Significant reductions in labor use had also been observed where animal traction had been used for ridging and weeding (ICRISAT, 1985) instead of manual cultivation.

The poor fertility status of the sandy soils of the WASAT is well-documented. In general, phosphorus deficiency tends to be more important than that of nitrogen (Pichot and Roche, 1972; Poulain, 1976). Results of trials conducted in the WASAT show that the major millet-producing areas are low in phosphorus and that millet responds well to phosphorus application (IRAT, 1975; Bationo et al., 1985). Such increases have been achieved with local, improved as well as exotic cultivars. However, though local varieties are well-adapted to prevailing environmental conditions, they usually respond less favorably to increases in fertility (Fussell et al., 1987).

The millet/cowpea intercrop is a major crop enterprise in the Sahel because of the importance of cowpea as a source of fodder for livestock, income as well as food for farm households. However, densities of cowpea in the traditional cropping systems are very low. Lastly, Henning et al. (1982) indicate that the maintenance of a suitable crop rotation sequence gives such benefits as

1. improved nutrient use efficiency;
2. possible reduction in diseases and pests; and
3. improvement in weed control capability.

Table 1 presents the 13 treatments and their components. There were eight replications per treatment and the plot size for each replicate was 500m^2. The average levels of inputs and outputs for each set of eight replications were used in the evaluation of the treatments. Average yields per treatment are reported in appendices 1, 2 and 3.

METHODOLOGY

Inputs used and outputs produced in the 13 treatments differed in types and levels across treatments. With the availability of data on prices or opportunity costs, labor time for all farm operations as well as input and output levels, data analysis could involve the use of either programming or simple budgeting procedures.

The preferred programming approach is a simple model that allows for choice on the basis of tradeoffs between expected income and risk. "Target MOTAD" technique allows for comparison between solutions from a common risk reference point or target income (Watts 1984) and all unique solutions produced are members of second-degree stochastic efficient set (Tauer, 1983). This latter property of "Target MOTAD" permits the generalization of the resulting solutions irrespective of the nature of farmer utility functions. However, data on minimum household income or food requirements (for use as income targets) as well as data on household resources were not available since the trial was conducted on-station. Moreover, it would be more appropriate to use data on the performance of the technologies, generated from on-farm trials, to match data on household resources and target incomes in a realistic programming approach. Therefore, the simple budgeting procedure was judged to be the relevant tool for analysing the available on-station data.

Returns to factors of production

Three financial measures calculated from budgets and used for analysis are: gross returns to household labor (assumed to be 96% of the total farm labor usage); returns to capital (expenses); and returns to land.

Returns per hour of household labor were calculated by deducting all non-labor input costs, costs associated with the use of animal traction, and hired labor costs from crop value and then dividing net returns by total hours spent by household labor on all farm activities.

Table 1 Treatments in operational scale trials at Sadore

Treatment components	Year		
Rainfall (mm)	1986 656	1987 448	1988 699
1 Traditional	M/C	M/C	M/C
2. 13 kg ha^{-1} Phosphorus and animal traction[a]	M/C	M/C	M/C
3. 13 kg ha^{-1} Phosphorus, animal traction and crop rotation	M/C	C	M/C
4. Same as in 3.	C	M/C	C
5 13 kg ha^{-1} Phosphorus and hand cultivation	M/C	M/C	M/C
6. 13 kg ha^{-1} Phosphorus, hand cultivation and rotation	M/C	C	M/C
7. Same as in 6	C	M/C	C
8. 13 kg ha^{-1} Phosphorus and animal traction.	M	M	M
9. 13 kg ha^{-1} Phosphorus, animal traction and rotation	M	C	M
10. Same as in 9.	C	M	C
11. 13 kg ha^{-1} Phosphorus and hand cultivation	M	M	M
12. 13 kg ha^{-1} Phosphorus, hand cultivation and rotation	M	C	M
13. Same as in 12.	C	M	C

Notes: M = millet; C = cowpea, M/C = millet/cowpea intercrop
Sadore local millet and cowpea varieties were used in the traditional package. In the other treatments, ITMV 8001 for millet and TVX 3236 for cowpea were used.

The 13 kg ha^{-1} phosphorus was obtained from the application of 65 kg ha^{-1} of triple superphosphate

[a] Animal traction was used for ridging and weeding

Due to differences in costs associated with the different technology packages, returns to capital outlay were calculated. Returns to capital were calculated as crop value minus the imputed value of household labor and then divided by the total variable costs.

Returns to land and management were calculated from crop value minus total variable costs and minus the value of household labor.

These measures were used to evaluate the comparative worth of the different technological packages.

Valuation of inputs

All inputs used, including hours spent for labor on all each farm activity, were monitored for each plot. Triple superphosphate was applied at a rate of 65 kg ha^{-1} (equivalent to 13 kg ha^{-1} of phosphorus) while the insecticide "cymbush" was applied at the rate of between 2.34 and 2.5 litres ha^{-1} (the recommended rate of 0.75 litres ha^{-1} was exceeded because of the lack of skill of the laborers). Prices over the period were 75 FCFA kg^{-1} for triple superphosphate and 1910 FCFA $litre^{-1}$ for "cymbush". Seeding was at the rate of 8 kg ha^{-1} for sole millet; 4 kg ha^{-1} for millet and 4 kg ha^{-1} for cowpea in millet/cowpea mixtures; and 30 kg ha^{-1} on pure cowpea plots. There was, however, a lot of replanting, particularly of millet and therefore, the actual quantities of seed valued exceeded these standard seeding rates. Table 2 presents the purchase prices for seeds in June, prior to the planting period, used in valuing the quantities of seed sown in the treatments.

Table 2. Cost of seeds in June.

Seed type	Cost of seed (FCFA kg^{-1})		
	1986	1987	1988
Local millet[a]	120	59	105
Improved millet	90	65	95
Improved cowpea	140	125	195

[a] Local millet seed prices were the market prices in June. Where seeds were not purchased, these prices represent the opportunity costs. Prices for local cowpea seed were not available and hence prices of the improved seed were assumed as opportunity costs.

In the Sahelian zone of Burkina Faso, the average amount of hired labor was 4% of the total farm labor (Matlon and Fafchamps, 1988). Based on a survey of labor wages conducted at Dakindi near Sadore, the average hourly labor wage was about 130 FCFA. This includes the value of food given to farm laborers in addition to daily payments. The average hourly wage was roughly the same for the principal farm activities for which labor is normally hired: sowing, weeding and harvesting. This wage is only slightly lower than the hourly wage of 180 FCFA that ICRISAT pays to its hired laborers from the neighboring villages. Household labor was valued at two opportunity cost assumptions: 100% hired labor wage and 50% of the hired labor wage. The rationale for these assumptions on the value of household labor are

1. It is possible that household labor has the option of earning hired labor wage, and
2. It is possible that only 50% of the total family labor could earn the hired labor wage, since labor markets for children and women may not exist in the rural moslem social context

A set of animal traction equipment (consisting of basic frame, plow, ridger, cultivator with three spring tines, and three bladed shares) cost 47,311 FCFA. The estimated lifetime is 10 years (Roy van Midde, personal communication). However, farmers at Dakindi who financed their purchases of animals and implements with loans were required to amortize their debts in four years after a year's grace period. Therefore, to simulate the effects of the cash flow requirements, the values of implements and animals less their salvage values were amortized over a five-year period. The salvage value of the traction implements after five years was conservatively estimated at 15000 FCFA. From a market survey conducted at Niamey, two 3-year old bullocks cost 140,000 FCFA but can be sold for 240,000 FCFA after 5 years. At 9% rate of interest on borrowed funds, there is an annual capital recovery cost of 12,489 FCFA on both animals and implements. Jaeger (1986) found that in Burkina Faso, annual feed and medicine costs are about 16,000 FCFA per oxen. Since there are no known estimated expenditures on feed and medicine in the Sadore area, the same costs were assumed. Expenditures on feed and medicines are necessary if the animals are to be strong enough to work the fields well.

Farmers follow a learning curve in their usage of animal traction technology. Therefore, the size of plots cultivated with animal traction depends on the level of experience with its usage. The use of animal traction is not a common practice in the Sadore area and therefore empirical data from a similar Sahelian environment in Burkina Faso were used for guidance as to the appropriate number of hectares over which to spread costs associated with the usage of animal traction usage. Millet/cowpea intercrop and sole millet are the predominant crop enterprises in Niger. The average plot sizes on which Sahelian farmers in Burkina Faso used animal traction were 4.5 hectares on millet/cowpea intercrop fields and 2.8 hectares on sole millet plots. These average plot sizes were assumed to correspond to medium usage of animal traction and hence the plot sizes for "learners" could be somewhat less. In the Sahelian region of Burkina Faso, farmers who cultivated their plots manually averaged only 2.75 hectares for millet/cowpea intercrop and

1.74 hectares for sole millet (Matlon and Fafchamps, 1988). On the basis of these empirical evidence, two land area scenarios of 2.0 and 4.5 hectares were assumed and used to show the necessity of economies of size if animal traction for ridging and weeding is to be relatively profitable than manual cultivation.

Valuation of output

The recorded outputs for the trials were millet and cowpea grains as well as residues. Cowpea grain prices reported by the Niger state purchasing agent (SONARA)[1] were: 80 FCFA kg^{-1} from 1986 to 1987; 80 FCFA kg^{-1} from 1987 to 1988; and 90 FCFA kg^{-1} from 1988 to 1989. Millet prices reported by the state grain purchasing agent (OPVN)[2] in the "arrondissement" of Say near Sadore, at harvest time in November, were: 70 FCFA kg^{-1} in 1986, 63 FCFA kg^{-1} in 1987, and 51 FCFA kg^{-1} in 1988. Markets exist at both Say and Niamey for residues of cowpea and millet. Cowpea residue prices averaged between 36 FCFA kg^{-1} and 40 FCFA kg^{-1}. However, large price per kilogram differences were observed due primarily to wide variations in the weights of bundles sold for either 100 FCFA or 125 FCFA. The lower limit of 36 FCFA kg^{-1} was assumed and used for valuation of cowpea hay. Average market prices for millet residue were 4.75 FCFA kg^{-1} for the proportion of residue used as livestock feed, and 8.32 FCFA kg^{-1} for millet stalks suitable for construction. It was assumed that farmers harvest about 60% of millet residue suitable for livestock feed and 70% stover suitable for construction before their farms became common grazing grounds. Since it is easier to adjust only two prices instead of quantities of millet residue for all the treatments, on the basis of these percentage harvest assumptions, the millet residue prices used in valuation were 3 FCFA kg^{-1} for fodder material and 6 FCFA kg^{-1} for stalks used in construction. In the absence of price information on crop residues in 1987 and 1986, the above prices were assumed. Since 1988 was generally a better cropping year (rainfall at Sadore totaled 699mm) than the preceding two years (rainfall totals were 658mm in 1986 and 448mm in 1987), the assumed prices may probably underestimate the values of crop residues. Based on the percentage composition of millet observed in 1986 for traditional millet, the assumed percentage distribution of millet stover was 31% for leaves used as livestock feed while the stalk constituted 69%[3].

1. SONARA is the acronym for "societe nigerienne de commercialisation del l' arachide". The prices quoted exclude the 5000 FCFA/tonne commission paid to intermediaries who purchase the grains. These SONARA prices may be lower than actual market prices and hence underestimate the market value of cowpea grains. They are used in valuation in the absence of reliable market price information.

2. OPVN is the acronym for "office de produits vivriers du niger". OPVN puts out monthly reports on surveys of grain prices at selected markets.

3. The exact percentage distribution of millet shoot into the leaves, immature panicles and stalk components depends on the variety and growing conditions.

In the valuation of production, two scenarios were assumed: grain value plus value of cowpea residue, and grain value plus value of residues from both cowpea and millet. The rationale for the two scenario assumption is that although markets exist for millet residues, the relative strength of opportunities for trade in them depend on agro-pastoral conditions of a location and the predominant mode of construction. The two scenarios show the choices that should be made if crop values to farmers really correspond to any one of the two situations.

Due to the inclusion of 3-year rotations in the treatments, future values[4] for 1986 and 1987 costs and returns were calculated at an assumed compounded rate of 8%, being interest rate that can be earned by individuals on bank deposits. The single payment compounded factors, corresponding to the 8% interest rate were: 1.08 for 1987 and 1.1664 for 1986. Appendixes 4 through 16 present detailed financial budgets.

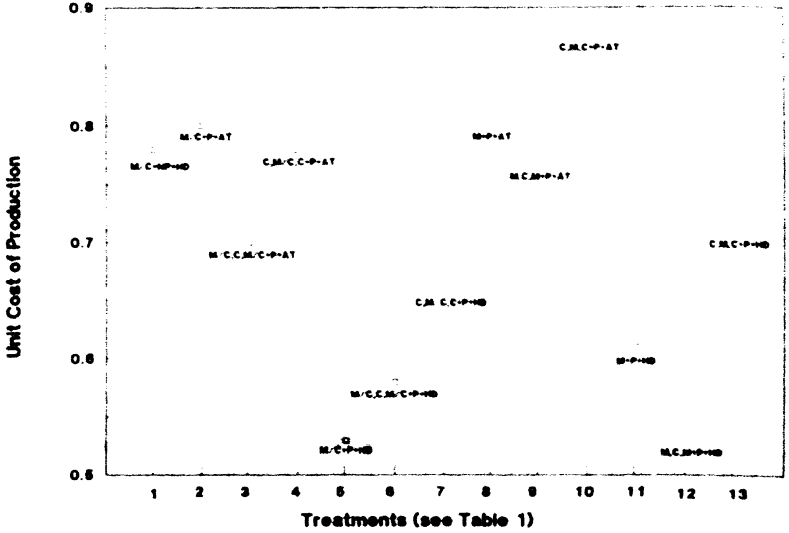
DISCUSSION

Figures 1 and 2 show plots of unit costs of production per return at two assumed values of household labor. These costs per unit return were calculated as ratios of all variable costs plus value of household labor to crop value under the scenario where grains and residues of both cowpea and millet were valued. Therefore, lower costs per unit return are preferred and values that exceed 1 are undesirable. Figure 1 shows that when household labor was assumed to earn only half the hired labor wage, ratios for all the treatments were less than 1 while improved millet/cowpea intercrop and rotations (treatments 5 and 12) had the lowest costs per unit return. However, when household labor was assumed to earn the full hired labor wage of 130 FCFA hr^{-1}, only seven packages had ratios less than 1. Continuous millet with animal traction (treatment 8) had the least cost per unit return because of labor savings (Figure 2). On the other hand, the traditional system produced a high ratio due to costs associated with the large amount of household labor used. The plots in Figures 1 and 2 show that the actual value of farm household labor is crucial to choice between the technologies.

To identify packages that lay on frontiers of production, net benefits were plotted against values of household labor under two wage assumptions of 65 FCFA hr^{-1} and 130 FCFA hr^{-1}. Figure 3 shows that treatments 8, 11, 12, 5 and 6 are obvious production frontier candidates. However, when household labor was valued at the full hired labor wage, only treatments 8, 9, 5 and 3 lay on the production frontier (Figure 4). Therefore, only treatments 8 and 5 lie on a production frontier over the range of household labor values considered. Treatment 8 involves continuous millet crop with animal traction while treatment 5 involves manually cultivated annual millet/cowpea intercrops. Although these preliminary observations are instructive, analysis of partial budgets and returns to factors of production are necessary to provide clear choices between all the packages.

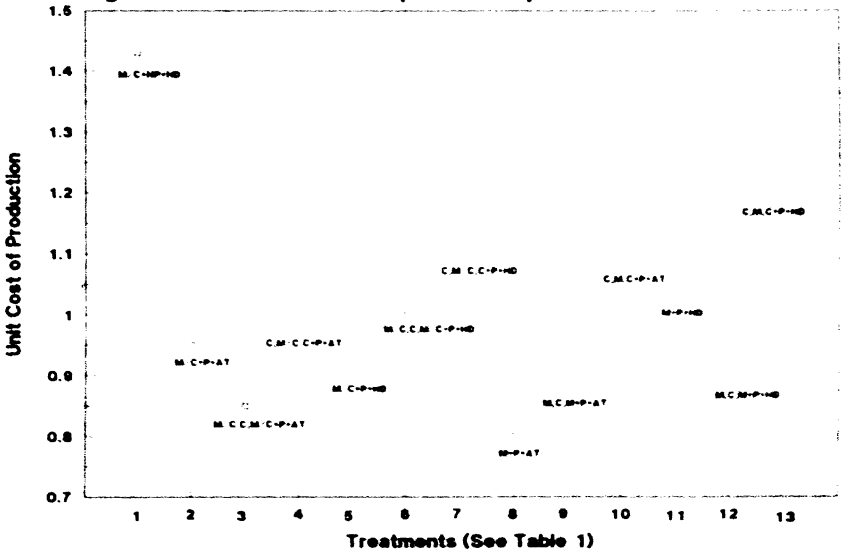
4. Since the analysis is ex-post instead of ex-ante, compounded future values in 1988 were calculated instead of net present values in 1986.

Figure 1. Plot of unit cost of production per return *.



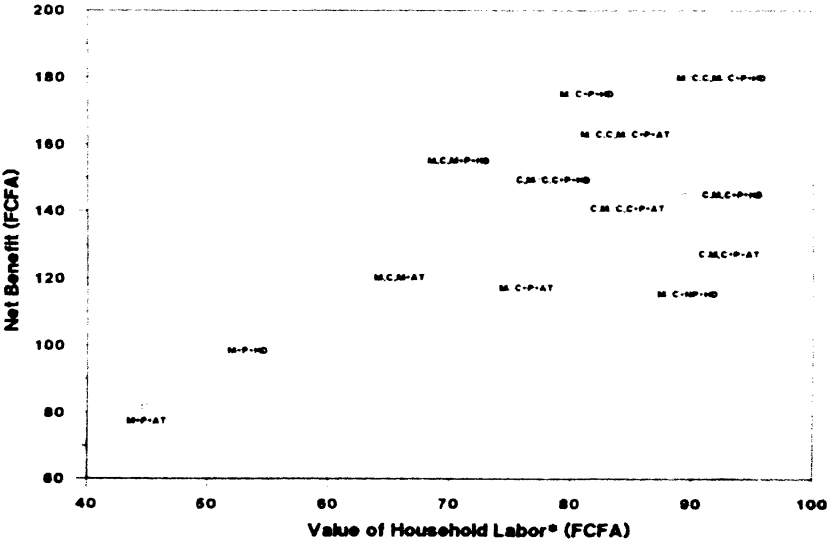
* Household labor was valued at half the hired labor wage (65 FCFA / hr).

Figure 2. Plot of unit cost of production per return*.



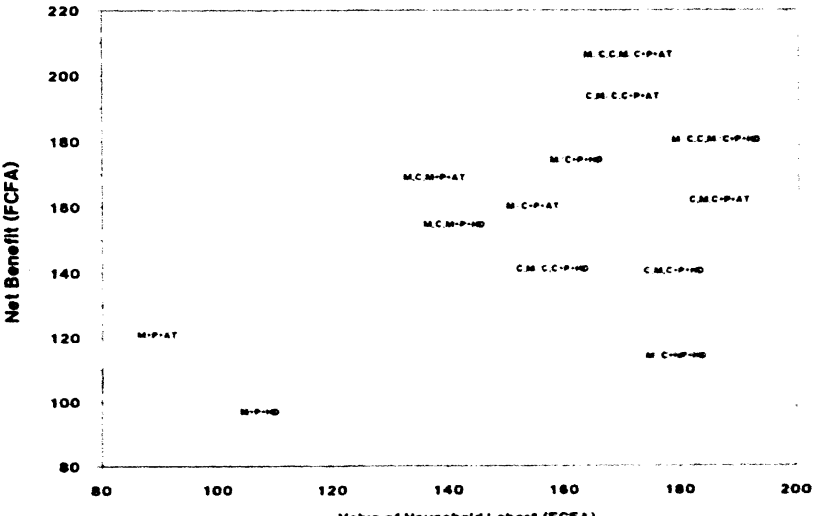
* Household labor was valued at the full hired wage (130 FCFA. hr).

Figure 3. Plot of net benefit and value of household labor.



* Valued at half the hired labor wage (66 FCFA/hr).

Figure 4. Plot of net benefit and value of household labor.



* Valued at the full hired labor wage (130 FCFA / hr).

Table 3 presents partial budgets that show changes in cost structures and crop values over the three-year period for grains and residue of both millet and cowpea (MCR). Most of the improved practices permitted the realization of small savings in cost of hired labor, when compared with levels of labor utilization under the traditional system. Also, with the exception of the manual continuous millet cropping system, the improved practices produce increments in compounded crop values. The decline in crop value accompanied by an increase in total variable costs make the improved manual continuous millet system worse than the traditional practice.

Table 3. Partial budgets for improved cropping systems.

Treatment	(Changes in costs and returns (thousand FCFA)) Crop value[a]	Nonlabor costs	AT costs	Hired labor costs	Total variable costs
Cont'd M/C+P+AT	92.0	12.7	78.2 [34.8]	-1.0	89.9 [46.5]
M/C,C,M/C+P+AT	139.4	14.0	78.2 [34.8]	-0.4	91.9 [48.5]
C,M/C,C+P+AT	137.7	34.3	78.2 [34.8]	0.3	112.7 [68.8]
Cont'd M/C+P+HD	71.6	12.7	0.0	0.7	12.0
M/C,C,M/C+P+HD	79.2	13.4	0.0	0.3	13.7
C,M/C,C+P+HD	58.6	33.6	0.0	-0.8	32.8
Cont'd M+P+AT	46.3	8.9	78.2 [34.8]	-3.7	83.5 [40.1]
M,C,M+P+AT	88.4	10.4	78.2 [34.8]	-1.6	87.0 [43.6]
C,M,C+P+AT	113.5	31.8	78.2 [34.8]	0.3	110.4 [67.0]
Cont'd M+P+HD	-10.5	8.9	0.0	-3.0	5.9
M,C,M+P+HD	49.1	11.0	0.0	-1.6	9.4
C,M,C+P+HD	58.3	32.3	0.0	0.1	32.4

Notes: [a] Crop value for grains and cowpea hay only. Numbers in brackets are for assumed land area of 4.5 hectares while all the non-bracketed numbers are for 2.0 hectares.

P =phosphorus
AT=animal traction
HD=hand or manual cultivation

A comparison of the trade-offs between incremental crop value and incremental total variable costs for the improved cropping systems suggests that manually cultivated practices usually required small increments in costs but the returns to those incremental costs were comparatively substantial. Those small incremental costs per hectare are affordable if a farmer sells one sheep or goat. However, although much higher incremental crop values were obtained for some treatments on which animal traction was used, these were inversely associated with large cost increments beyond the means of resource-poor farmers with no access to institutional credit facility. However, choice between the packages cannot be made without the benefit of information on comparative changes in household labor usage.

Table 4. Changes in labor usage and incremental value/cost ratio

Treatment	Value/TVC ratio[a]	Value/TVC ratio[b]	Changes in total Household labor 1986-1988 (hrs/ha)
Cont'd M/C+P+AT	1.0 [7.0]	0.9 [1.8]	-175
M/C,C.M/C+P+AT	1.5 [2.9]	1.4 [2.7]	53
C.M/C.C+P+AT	1.7 [2.0]	1.3 [2.1]	27
Cont'd M/C+P+HD	6.0	4.8	-120
M/C.C.M/C+P+HD	5.8	5.2	60
C.M/C.C+P+HD	1.8	2.1	108
Cont'd M+P+AT	0.6 [1.2]	0.3 [0.6]	-606
M.C.M+P+AT	1.0 [2.0]	0.8 [1.6]	-256
C.M.C+P+AT	1.0 [1.7]	1.1 [1.8]	103
Cont'd M+P+HD	1.8	2.6	-493
M.C.M+P+HD	5.2	4.1	-247
C.M.C+P+HD	1.8	2.2	31

[a] Changes in crop value for grains plus both millet and cowpea residue (MCR)

[b] Changes in crop value for grains plus only cowpea residue (CR)

All abbreviations are defined in Tables 1 and 3.

The negative signs for changes in labor utilization show labor savings on the traditional system.

Table 4 shows the trade-offs between the ratio of incremental crop values to incremental total variable costs and savings (or increments) in household labor utilization. Pairwise comparisons of the improved practices, using the trade-offs between ratios and changes in labor utilization as the decision criteria, produced four treatments that were not dominated:

1. manual millet/cowpea/millet,
2. manual continued millet/cowpea,
3. millet/cowpea/millet with animal traction; and
4. continued millet with animal traction.

Table 5. Returns to capital for undominated improved practices

Cropping enterprise and treatment	Household labor assumption	Returns to Capital (FCFA FCFA^{-1}) CR	MCR
Manual annual M/C (ITMV 8001, TVX 3236, P, and high plant density)	A	3 1	4 2
	B	0 5	1 6
Manual M, C, M rotation (ITMV8001, TVX 3236, P, and high plant density)	A	3 1	4 1
	B	0 6	1 6
Continuous M + animal traction (ITMV8001, TVX 3236, P, and high plant density)	A	1 0 [1 7]	1 4 [2 4]
	B	0 5 [0 9]	0 9 [1 6]
M, C, M rotation + animal traction (ITMV8001, TVX 3236, P, and high plant density)	A	1 1 [1 9]	1 5 [2 5]
	B	0 5 [0 8]	0 8 [1 4]

Nuabers in brackets are returns to capital when land area was assumed to be 4 5 hectares while those not in brackets are returns when land area was assumed to be 2 0 hectares
CR = value of grains and cowpea residue

MCR = value of grains, cowpea and millet residue
P = application of phosphorus

While the two manual treatments had comparatively large incremental value to cost ratios, the other two treatments on which animal traction was used had comparatively large savings in household labor usage. Eventual choice between these four improved practices depends on the value of household labor and returns to factors of production.

Tables 5, 6, and 7, show the relative magnitudes of returns to land, capital or household labor, respectively, for the four cropping practices that were not dominated. In the computation of returns to land or capital, household labor was valued at 100% hired labor wage (labor assumption B) or 50% hired labor wage (labor assumption A). The relative magnitudes of returns to land or capital or household labor show that the two manual systems generally produced superior performances over the undominated systems

in which animal traction was used. However, improvements in returns to treatments where animal traction was used occurred under land area assumption of 4.5 hectares. This points to the need for economies of size if superior performances are to be realized from the use of animal traction technology.

Table 8 presents a summary of the percentage changes in returns due to the effects of specific improved practice(s) such as rotation and animal traction, as well as the combined effect of improved seeds, application of phosphorus and increased plant densities.

The effects of rotation were examined by comparing sole millet in rotation with cowpea to continuous sole millet system. The rotation of millet with cowpea produced improvements of between 80% and 130% in returns to land; 37% and 55% in returns to capital, and 17% and 24% in returns to household labor. Financial benefits from rotation were more evident in the manually cultivated systems than similar systems where animal traction was used due to the increased cost associated with using animal traction.

Table 6. Returns to land for undominated improved practices

Cropping enterprise and treatment	Household labor assumption	Returns to land (Thousand FCFA ha $^{-1}$) CR	MCR
Manual annual M/C (ITMV 8001, TVX 3236, P, and high plant density)	A	66.0	97.9
	B	-14.6	17.1
Manual M, C, M rotation (ITMV8001, TVX 3236, P, and high plant density)	A	59.0	88.3
	B	11.7	18.1
Continuous M + animal traction (ITMV8001, TVX 3236, P, and high plant density)	A	- 4.6 [38.9]	36.8 [80.3]
	B	-49.4 [- 5.9]	- 8.0 [35.4]
M, C, M rotation + animal traction (ITMV8001, TVX 3236, P, and high plant density)	A	13.4 [56.8]	51.1 [94.5]
	B	-55.8 [-12.3]	-18.1 25.4

Numbers in brackets are returns to land when land area was assumed to be 4.5 hectares while those not in brackets are returns when land area was assumed to be 2.0 hectares.

CR = value of grains and cowpea residue

MCR = value of grains, cowpea and millet residue

P = application of phosphorus

Table 7. Returns to household labor for undominated improved practices

Cropping enterprise and treatment	Returns to household labor (FCFA hr^{-1}) CR	MCR
Manual annual M/C (ITMV 8001, TVX 3236, P, and high plant density)	131	159
Manual M, C, M rotation (ITMV8001, TVX 3236, P, and high plant density)	130	160
Continuous M + animal traction (ITMV8001, TVX 3236, P, and high plant density)	63 [132]	129 [197]
M, C, M rotation + animal traction (ITMV8001, TVX 3236, P, and high plant density)	84 [128]	122 [166]

Numbers in brackets are returns to labor when land area was assumed to be 4.5 hectares while those not in brackets are returns when land area was assumed to be 2.0 hectares

CR = value of grains and cowpea residue

MCR = value of grains, cowpea and millet residue
P = application of phosphorus

Percentage changes in returns to land, household labor, and capital for manual versus animal traction in millet/cowpea intercrops in rotation with cowpea show that relative benefits from the use of animal traction could be realized only on larger farms. Returns to land and labor where animal traction was used as compared to returns where land was manually cultivated, were inferior (indicated by the negative percentage changes) when assumed land area was only 2.0 hectares but superior when land area was assumed to be 4.5 hectares. If returns to capital were to be the choice criterion, then even when the land area was assumed to be 4.5 hectares it might be preferable to forego the use of animal traction

Although the traditional cropping system in the Sadore area is usually characterized as millet/cowpea intercrops, the cowpea plant populations are generally so low that in effect the farms are not very different from sole millet systems. Therefore, comparison of the manual sole millet cropping system with the traditional system gives an indication of the financial benefits from using improved seed, phosphorus and

Table 8. Percentage changes in returns due to improved practice(s)

Effect of	Cropping system	Changes in returns due to effect (%) Land[a] CR	MCR	Labor CR	MCR	Capital[a] CR	MCR
1. Rotation							
a) Manual	MCM vs MMM	130	80	24	17	55	37
b) Traction	MCM vs MMM	[46]	39 [18]	33 [3]	5 [-16]	10 [12]	7 [4]
2. Traction	M/C,C,M/C	[53]	11 [37]	-3 [27]	1 [25]	50 [17]	55 [24]
3. New seed, P, and density increases							
a)	M/C vs Trad	489	230	62	66	94	67
b)	MMM vs Trad.	129	66	30	43	25	15

Notes: [a] Household labor opportunity cost of 65FCFA per hour was assumed.

Numbers in brackets are changes in returns when land area was assumed to be 4.5 hectares while those not in brackets are returns when land area was assumed to be 2.0 hectares

CR = value of grains and cowpea residue

MCR = value of grains, cowpea and millet residue

increased plant density. The comparison shows improvements of 55% to 130% in returns to land; 15% to 25% in returns to capital; and 30% to 43% in returns to household labor. Even greater improvements in returns were realized when improved and traditional annual millet/cowpea intercrops were compared.

CONCLUSIONS

The financial calculations suggest that the application of phosphorus in a manually cultivated rotation of millet with cowpea or annual millet/cowpea intercrop may be the packages to recommend to farmers. Such recommendations are especially relevant for farmers who have little or no experience in the usage of animal traction technology, cultivate only two hectares or less or cannot afford large cash expenses from their own resources or have no access to institutional credit. Choice between the annual millet/cowpea intercrop and the rotation of millet with cowpea depends on the availability of adequate household labor

and cash as well as the true opportunity costs of these resources. For maximum benefit from nitrogen fixation by cowpea, farmers would have to rotate planting sites for millet and cowpea in the continuous millet/cowpea intercrop treatment. This could prove a little more complicated to farmers than the millet/cowpea rotation. Moreover, the respective dates of planting and plant densities have to be managed carefully if neither millet nor cowpea is to be unduly disadvantaged. On the other hand, it is inconceivable that a farmer who has only one farm will agree to forego the cultivation of millet and plant pure cowpea every other year. Therefore, in practical terms, it may be necessary for such a farmer to partition his plot and rotate pure cowpea and pure millet cultivation. The exact percentages allocated to either crop depends on household food security and income goals.

The analysis showed that economies of size are necessary for relative profitability of using animal traction.

Low post-harvest product prices were used to calculate the budgets, therefore, the use of marketing strategies that take advantage of peak prices for grains and fodder could permit substantial improvements upon the calculated returns. On the other hand, technologies that show superior on-station performance typically experience substantial yield gaps under farmer management (Matlon, 1985) and hence the actual sizes of incremental returns would be lower in on-farm situations.

Finally, the analysis could only identify packages that significantly improved returns over the three-year trial period. No reliable inferences can be made about the relative sustainabilities of the packages given the short duration of the trials and the absence of information on land characteristics. Good comparative inferences on sustainability would require data from at least three rotational cycles, the definition of a reference standard minimum performance criterion and at least data on changes in soil physical and chemical characteristics over the trial periods.

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Appendix 1. Grain and residue yields recorded in 1986

Treatment # & components	Average yields (kg ha^{-1})* Millet Grain	Millet Residue	Cowpea Grain	Cowpea Residue
1 Traditional M/C each year	300	1145	261	273
2. 13 kg ha^{-1} Phosphorus and animal traction[a]	750	2217	308	412
3. 13 kg ha^{-1} Phosphorus, animal traction and crop rotation.	981	2922	206	500
4. Same as in 3	..	..	814	628
5. 13 kg ha^{-1} Phosphorus and hand cultivation.	616	3068	185	537
6. 13 kg ha^{-1} Phosphorus, hand cultivation and rotation.	664	2078	209	443
7. Same as in 6.	..	..	602	482
8. 13 kg ha^{-1} Phosphorus and animal traction.	886	3265	..	..
9. 13 kg ha^{-1} Phosphorus, animal traction and rotation.	956	3087	..	..
10. Same as in 9.	..	..	784	532
11. 13 kg ha^{-1} Phosphorus, hand cultivation.	638	1918	..	..
12. 13 kg ha^{-1} Phosphorus, hand cultivation and rotation.	727	2113	..	..
13. Same as in 12.	..	..	705	482

* Yields were rounded up to whole figures.

.. Denotes a crop that was not grown in the treatment.

Appendix 2. Grain and residue yields recorded in 1987

Treatment # & components	Average yields (kg ha^{-1})* Miller Grain	Residue	Cowpea Grain	Residue
1. Traditional M/C each year	299	822	15	199
2. 13 kg ha^{-1} Phosphorus and animal traction	368	945	88	425
3. 13 kg ha^{-1} Phosphorus animal traction and crop rotation			405	668
4. Same as in 3	477	1471	46	235
5. 13 kg ha^{-1} Phosphorus and hand cultivation	404	1011	32	268
6. 13 kg ha^{-1} Phosphorus, hand cultivation and rotation			247	318
7. Same as in 6	569	1570	46	190
8. 13 kg ha^{-1} Phosphorus and animal traction	511	1364	--	--
9. 13 kg ha^{-1} Phosphorus, animal traction and rotation			501	661
10. Same as in 9	576	1782		
11. 13 kg ha^{-1} Phosphorus, hand cultivation.	383	877	--	--
12. 13 kg ha^{-1} Phosphorus, hand cultivation and rotation			413	380
13. Same as in 12	515	1277	--	--

* Yields were rounded up to whole figures

-- Denotes a crop that was not grown in the treatment

Appendix 3 Grain and residue yields recorded in 1988

Treatment # & components	Average yields (kg ha^{-1}) Millet Grain	Millet Residue	Cowpea Grain	Cowpea Residue
1 Traditional M/C each year	268	1410	45	332
2 13 kg ha^{-1} Phosphorus and animal traction[a]	557	1780	57	464
3 13 kg ha^{-1} Phosphorus, animal traction and crop rotation.	1124	3972	43	460
4 Same as in 3.	..	..	657	1218
5 13 kg ha^{-1} Phosphorus and hand cultivation	482	1587	53	477
6 13 kg ha^{-1} Phosphorus, hand cultivation and rotation	927	2745	48	362
7 Same as in 6.	..	..	425	714
8 13 kg ha^{-1} Phosphorus and animal traction	696	2912	..	..
9 13 kg ha^{-1} Phosphorus, animal traction and rotation.	962	3838	..	..
10 Same as in 9.	..	..	768	1052
11. 13 kg ha^{-1} Phosphorus, hand cultivation	498	1480	..	..
12 13 kg ha^{-1} Phosphorus, hand cultivation and rotation	937	3277	..	..
13 Same as in 12.	..	..	479	687

* Yields were rounded up to whole figures

.. Denotes a crop that was not grown in the treatment

Appendix 4. Financial budget for [illegible] each year

Financial costs and returns

	CR	MCR
1.0 Crop Value (FCFA ha^{-1})	11915	17568
2.0 Variable costs (FCFA ha^{-1})		
2.1 Non-labor input costs (seeds)	11362	11362
2.2 Animal traction costs		
i. spread over 2.0 ha	0	0
ii. spread over 4.5 ha	0	0
2.3 Hired labor costs	7429	7429
2.4 Total variable costs		
i. 2.0 ha. assumption	18791	18791
ii. 4.5 ha. assumption	18791	18791
3.0 Household labor costs (FCFA ha^{-1})		
A: @ 50% hired labor wage	89153	89153
B: @ 100% hired labor wage	178306	178306
4.0 Returns to		
4.1 Capital (FCFA FCFA^{-1})		
A:	1.6 [1.6]	2.6 [2.6]
B:	1.2 [1.2]	2.2 [2.2]
4.2 Household labor (FCFA hr^{-1})	81 [81]	96 [96]
4.3 Land (FCFA ha^{-1})		
A:	11208 [11208]	29624 [29624]
B:	77945 [77945]	59529 [59529]

Note: Numbers in brackets correspond to returns under 4.5 hectares land assumption while the other numbers correspond to 2.0 hectares assumption.

Appendix 5 Financial budget for Annual M/C + P + traction

Financial costs and returns

	CR	MCR
1 0 Crop Value (FCFA ha^{-1})	202393	229642
2 0 Variable costs (FCFA ha^{-1})		
2.1 Non-labor input costs (seeds)	24074	24074
2.2 Animal traction costs		
i spread over 2.0 ha	78245	78245
ii spread over 4.5 ha	34775	34775
2.3 Hired labor costs	6353	6353
2.4 Total variable costs		
i 2.0 ha assumption	108672	108672
ii 4.5 ha assumption	65202	65202
3 0 Household labor costs (FCFA ha^{-1})		
A: @ 50% hired labor wage	76240	76240
B: @ 100% hired labor wage	152481	152481
4 0 Returns to:		
4.1 Capital (FCFA FCFA^{-1})		
A:	1.2 [1.9]	1.4 [2.4]
B:	0.5 [0.8]	0.7 [1.2]
4.2 Household labor(FCFA hr^{-1})	88 [129]	114 [154]
4.3 Land (FCFA ha^{-1})		
A:	17481 [60951]	44730 [88200]
B:	-58760 [-15290]	-31511 [119959]

Note: Numbers in brackets correspond to returns under 4.5 hectares land assumption while the other numbers correspond to 2.0 hectares assumption.

Appendix 6. Financial budget for M.C. (C. M.C. + P. + traction)

Financial costs and returns

	CR	MCR
1.0 Crop Value (FCFA ha^{-1})	251205	277024
2.0 Variable costs (FCFA ha^{-1})		
2.1 Non-labor input costs (seeds)	25442	25442
2.2 Animal traction costs		
i. spread over 2.0 ha	78245	78245
ii. spread over 4.5 ha	34775	34775
2.3 Hired labor costs	7034	7034
2.4 Total variable costs		
i. 2.0 ha assumption	110721	110721
ii. 4.5 ha assumption	67251	67251
3.0 Household labor costs (FCFA ha^{-1})		
A: @ 50% hired labor wage	84410	84410
B: @ 100% hired labor wage	168821	168821
4.0 Returns to:		
4.1 Capital (FCFA FCFA^{-1})		
A:	1.5 [2.5]	1.7 [2.9]
B:	0.7 [1.2]	1.0 [1.6]
4.2 Household labor(FCFA hr^{-1})	118 [155]	140 [177]
4.3 Land (FCFA ha^{-1})		
A:	56074 [99544]	81893 [125363]
B:	28337 [15133]	2518 [40952]

Note: Numbers in brackets correspond to returns under 4.5 hectares land assumption while the other numbers correspond to 2.0 hectares assumption.

Appendix 7. Financial budget for C, M/C, C + P + traction

Financial costs and returns

	CR	NCR
1.0 Crop Value (FCFA ha^{-1})	264519	275313
2.0 Variable costs (FCFA ha^{-1})		
2.1 Non-labor input costs (seeds)	45692	45692
2.2 Animal traction costs		
i. spread over 2.0 ha	78245	78245
ii. spread over 4.5 ha	34775	34775
2.3 Hired labor costs	7052	7052
2.4 Total variable costs:		
i. 2.0 ha. assumption	130989	130989
ii. 4.5 ha. assumption	87519	87519
3.0 Household labor costs (FCFA ha^{-1})		
A: @ 50% hired labor wage	84623	84623
B: @ 100% hired labor wage	169246	169246
4.0 Returns to:		
4.1 Capital (FCFA FCFA^{-1})		
A:	1.4 [2.1]	1.5 [2.2]
B:	0.7 [1.1]	0.8 [1.2]
4.2 Household labor(FCFA hr^{-1})	110 [145]	118 [154]
4.3 Land (FCFA ha^{-1})		
A:	48907 [92377]	59701 [103171]
B:	-35716 [7754]	-24922 [18548]

Note: Numbers in brackets correspond to returns under 4.5 hectares land assumption while the other numbers correspond to 2.0 hectares assumption.

Appendix 8 Financial budget for annual manual M/C + P

Financial costs and returns

	CR	MCR
1.0 Crop Value (FCFA ha^{-1})	177295	209194
2.0 Variable costs (FCFA ha^{-1})		
2.1 Non-labor input costs (seeds)	24061	24061
2.2 Animal traction costs		
i. spread over 2.0 ha	0	0
ii. spread over 4.5 ha	0	0
2.3 Hired labor costs	6713	6713
2.4 Total variable costs		
i. 2.0 ha. assumption	30774	30774
ii. 4.5 ha. assumption	30774	30774
3.0 Household labor costs (FCFA ha^{-1})		
A: @ 50% hired labor wage	80555	80555
B: @ 100% hired labor wage	161109	161109
4.0 Returns to:		
4.1 Capital (FCFA $FCFA^{-1}$)		
A:	3.1 [3.1]	4.2 [4.2]
B:	0.5 [0.5]	1.6 [1.6]
4.2 Household labor(FCFA hr^{-1})	131 [131]	159 [159]
4.3 Land (FCFA ha^{-1})		
A:	65966 [65966]	97865 [97865]
B:	-14588 [-14588]	17311 [17311]

Note: Numbers in brackets correspond to returns under 4.5 hectares land assumption while the other numbers correspond to 2.0 hectares assumption.

Appendix 9 Financial budget for manual M/C, C, M/C + P

Financial costs and returns

	CR	MCR
1.0 Crop Value (FCFA ha^{-1})	190606	216808
2.0 Variable costs (FCFA ha^{-1})		
2.1 Non-labor input costs (seeds)	24788	24788
2.2 Animal traction costs		
i. spread over 2.0 ha	0	0
ii. spread over 4.5 ha	0	0
2.3 Hired labor costs	7736	7736
2.4 Total variable costs		
i. 2.0 ha. assumption	32524	32524
ii. 4.5 ha. assumption	32524	32524
3.0 Household labor costs (FCFA ha^{-1})		
A @ 50% hired labor wage	92831	92831
B @ 100% hired labor wage	185662	185662
4.0 Returns to:		
4.1 Capital (FCFA FCFA^{-1})		
A:	3.0 [3.0]	3.8 [3.8]
B:	0.2 [0.2]	1.0 [1.0]
4.2 Household labor(FCFA hr^{-1})	122 [122]	142 [142]
4.3 Land (FCFA ha^{-1})		
A:	65251 [65251]	91453 [91453]
B:	-27580 [-27580]	-1378 [-1378]

Note: Numbers in brackets correspond to returns under 4.5 hectares land assumption while the other numbers correspond to 2.0 hectares assumption.

Appendix 10. Financial budget for manual C, M/C, C + P

Financial costs and returns

	CR	MCR
1.0 Crop Value (FCFA ha^{-1})	188119	196169
2.0 Variable costs (FCFA ha^{-1})		
2.1 Non-labor input costs (seeds)	44997	44997
2.2 Animal traction costs		
i. spread over 2.0 ha	0	0
ii. spread over 4.5 ha	0	0
2.3 Hired labor costs	6582	6582
2.4 Total variable costs		
i. 2.0 ha. assumption	51579	51579
ii. 4.5 ha. assumption	51579	51579
3.0 Household labor costs (FCFA ha^{-1})		
A: @ 50% hired labor wage	78983	78983
B: @ 100% hired labor wage	157965	157965
4.0 Returns to:		
4.1 Capital (FCFA $FCFA^{-1}$)		
A:	2.1 [2.1]	2.3 [2.3]
B:	0.6 [0.6]	0.7 [0.7]
4.2 Household labor(FCFA hr^{-1})	121 [121]	128 [128]
4.3 Land (FCFA ha^{-1})		
A:	57557 [57557]	65607 [65607]
B:	.21425 [.21475]	.13375 [.13375]

Note: Numbers in brackets correspond to returns under 4.5 hectares land assumption while the other numbers correspond to 2.0 hectares assumption.

Appendix 11. Financial budget for Continuous millet + P + traction.

Financial costs and returns

	GR	NGR
1.0 Crop Value (FCFA ha^{-1})	142564	183932
2.0 Variable costs (FCFA ha^{-1})		
2.1 Non-labor input costs (seeds)	20299	20299
2.2 Animal traction costs		
i spread over 2.0 ha	78245	78245
ii spread over 4.5 ha	34775	34775
2.3 Hired labor costs	3737	3737
2.4 Total variable costs		
i. 2.0 ha assumption	102281	102281
ii. 4.5 ha. assumption	58811	58811
3.0 Household labor costs (FCFA ha^{-1})		
A: @ 50% hired labor wage	44841	44841
B: @ 100% hired labor wage	89682	89682
4.0 Returns to:		
4.1 Capital (FCFA $FCFA^{-1}$)		
A:	1.0 [1.7]	1.4 [2.4]
B:	0.5 [0.9]	0.9 [1.6]
4.2 Household labor(FCFA hr^{-1})	63 [132]	129 [197]
4.3 Land (FCFA ha^{-1})		
A:	-4558 [38917]	36810 [80280]
B:	-49399 [-5929]	- 8031 [35439]

Note: Numbers in brackets correspond to returns under 4.5 hectares land assumption while the other numbers correspond to 2.0 hectares assumption

Appendix 12. Financial budget for M. C. M + P + traction.

Financial costs and returns

	CR	NCR
1.0 Crop Value (FCFA ha^{-1})	188307	226018
2.0 Variable costs (FCFA ha^{-1})		
2.1 Non-labor input costs (seeds)	21785	21785
2.2 Animal traction costs		
i. spread over 2.0 ha	78245	78245
ii. spread over 4.5 ha	34775	34775
2.3 Hired labor costs	5763	5763
2.4 Total variable costs		
i. 2.0 ha. assumption	105793	105793
ii. 4.5 ha. assumption	62323	62323
3.0 Household labor costs (FCFA ha^{-1})		
A: @ 50% hired labor wage	69158	69158
B: @ 100% hired labor wage	138317	138317
4.0 Returns to:		
4.1 Capital (FCFA FCFA^{-1})		
A:	1.1 [1.9]	1.5 [2.5]
B:	0.5 [0.8]	0.8 [1.4]
4.2 Household labor(FCFA hr^{-1})	84 [128]	122 [166]
4.3 Land (FCFA ha^{-1})		
A:	13356 [56826]	51067 [94537]
B:	-55803 [-12333]	-18092 [25378]

Note: Numbers in brackets correspond to returns under 4.5 hectares land assumption while the other numbers correspond to 2.0 hectares assumption.

Appendix 13. Financial budget for C, M, C + P + traction.

Financial costs and returns

	CR	MCR
1.0 Crop Value (FCFA ha^{-1})	241731	251084
2.0 Variable costs (FCFA ha^{-1})		
2.1 Non-labor input costs (seeds)	43208	43208
2.2 Animal traction costs:		
i. spread over 2.0 ha	78245	78245
ii. spread over 4.5 ha	34775	34775
2.3 Hired labor costs	7738	7738
2.4 Total variable costs:		
i. 2.0 ha. assumption	129191	129191
ii. 4.5 ha. assumption	85721	85721
3.0 Household labor costs (FCFA ha^{-1})		
A: @ 50% hired labor wage	92860	92860
B: @ 100% hired labor wage	185721	185721
4.0 Returns to:		
4.1 Capital (FCFA FCFA^{-1})		
A:	1.2 [1.7]	1.2 [1.9]
B:	0.4 [0.7]	0.5 [0.8]
4.2 Household labor(FCFA hr^{-1})	84 [116]	91 [123]
4.3 Land (FCFA ha^{-1})		
A:	19680 [63150]	29033 [72503]
B:	-73181 [-29711]	-63828 [-20358]

Note: Numbers in brackets correspond to returns under 4.5 hectares land assumption while the other numbers correspond to 2.0 hectares assumption.

Appendix 14. Financial budget for continuous annual millet + P

Financial costs and returns

	CR	MCR
1.0 Crop Value (FCFA ha^{-1})	103542	127078
2.0 Variable costs (FCFA ha^{-1})		
2.1 Non-labor input costs (seeds)	20307	20307
2.2 Animal traction costs		
i. spread over 2.0 ha	0	0
ii. spread over 4.5 ha	0	0
2.3 Hired labor costs	4431	4431
2.4 Total variable costs		
i. 2.0 ha assumption	24738	24738
ii. 4.5 ha assumption	24738	24738
3.0 Household labor costs (FCFA ha^{-1})		
A: @ 50% hired labor wage	53176	53176
B: @ 100% hired labor wage	106353	106353
4.0 Returns to:		
4.1 Capital (FCFA $FCFA^{-1}$)		
A:	2.0 [2.0]	3.0 [3.0]
B:	-0.1 [-0.1]	0.8 [0.8]
4.2 Household labor(FCFA hr^{-1})	105 [105]	137 [137]
4.3 Land (FCFA ha^{-1})		
A:	25628 [25628]	49164 [49164]
B:	-27549 [27549]	-4013 [- 4013]

Note: Numbers in brackets correspond to returns under 4.5 hectares land assumption while the other numbers correspond to 2.0 hectares assumption.

Appendix 15 Financial budget for manual M, C, M + P

Financial costs and returns

	CR	MCR
1.0 Crop Value (FCFA ha^{-1})	157394	186702
2.0 Variable costs (FCFA ha^{-1})		
2.1 Non-labor input costs (seeds)	22375	22375
2.2 Animal traction costs		
i. spread over 2.0 ha	0	0
ii. spread over 4.5 ha	0	0
2.3 Hired labor costs	5849	5849
2.4 Total variable costs		
i. 2.0 ha assumption	28224	28224
ii. 4.5 ha assumption	28224	28224
3.0 Household labor costs (FCFA ha^{-1})		
A: @ 50% hired labor wage	70182	70182
B: @ 100% hired labor wage	140364	140364
4.0 Returns to:		
4.1 Capital (FCFA FCFA^{-1})		
A:	3.1 [3.1]	4.1 [4.1]
B:	0.6 [0.6]	1.6 [1.6]
4.2 Household labor(FCFA hr^{-1})	130 [130]	160 [160]
4.3 Land (FCFA ha^{-1})		
A:	58988 [58988]	88296 [88296]
B:	-11194 [-11194]	18114 [18114]

Note: Numbers in brackets correspond to returns under 4.5 hectares land assumption while the other numbers correspond to 2.0 hectares assumption.

Appendix 16. Financial budget for manual C, M, C + P

Financial costs and returns

	CR	MCR
1.0 Crop Value (FCFA ha^{-1})	188932	195895
2.0 Variable costs (FCFA ha^{-1})		
2.1 Non-labor input costs (seeds)	43747	43747
2.2 Animal traction costs		
i. spread over 2.0 ha	0	0
ii. spread over 4.5 ha	0	0
2.3 Hired labor costs	7452	7452
2.4 Total variable costs		
i. 2.0 ha assumption	51199	51199
ii. 4.5 ha assumption	51199	51199
3.0 Household labor costs (FCFA ha^{-1})		
A: @ 50% hired labor wage	89419	89419
B: @ 100% hired labor wage	178838	178838
4.0 Returns to:		
4.1 Capital (FCFA FCFA^{-1})		
A:	1.9 [1.9]	2.1 [2.1]
B:	0.2 [0.2]	0.3 [0.3]
4.2 Household labor(FCFA hr^{-1})	108 [108]	114 [114]
4.3 Land (FCFA ha^{-1})		
A:	48314 [48314]	55277 [55277]
B:	-41105 [-41105]	-34142 [-34142]

Note: Numbers in brackets correspond to returns under 4.5 hectares land assumption while the other numbers correspond to 2.0 hectares assumption.