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DRY LAND FARMING IN THE SEMI-ARID TROPICS OF KENYA: ACIAR PROJECT EXPERIENCE

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ABBREVIATIONS

CSIRO:	Commonwealth Scientific and Industrial Research Organisation
ACIAR:	Australian Centre for International Agricultural Research
KARI:	Kenyan Agricultural Research Institute
FAO:	Food and Agriculture Organization of the United Nations

1. INTRODUCTION [1]

1.1 Background information

The Australian Centre for International Agricultural Research (ACIAR) was established in 1982 to mobilise Australian agricultural research expertise to support the overseas development cooperation program. ACIAR commissions collaborative research projects that involve a developing country and Australian institutions and focus on high priority, agricultural problems of mutual interest. From working in the world's driest continent, Australian agriculturalists have developed a special interest and competence in dryland farming and climatic risk management. Semi-arid Kenya, along with much of sub-Saharan Africa, shares with tropical Australia the problems of high risk of crop failure due to drought, low soil fertility, and high rates of soil erosion. Consequently, in 1983, the Kenyan Government and ACIAR sponsored a workshop in Nairobi to compare and contrast the Kenyan and Australian experience in dryland farming, and plan a collaborative research project between the Kenyan Agricultural Research Institute (KARI) and the Division of Tropical Crops and Pastures of the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

The scientific literature from the period 1935 to 1985 on agriculture in the semi-arid lands of Kenya deals extensively with the problems of dryland farming. Keating et al. (1992) identified the following key research themes:

- tailoring plant populations to optimise use of limited water and nitrogen resources;
- optimising planting dates to minimise the probability of plants facing water deficits;
- fertilisation;
- intercropping;
- fallowing and rotations to optimise between-season transfer of water and nitrogen;
- genotypic adaptation;
- soil surface management to minimise runoff and increase infiltration of water into soils;
- analysis of climate constraint focussing on amounts and variability of rainfall; and
- crop yield – climate modelling relating crop growth and yield to climate variables.

The past Kenyan research yielded a considerable knowledge base and some proposed solutions, the most important of which was the idea of response farming[2] in the Kenyan context (Stewart and Faught, 1984, Stewart and Kashasha, 1984). This and other work provided a foundation for the research that was undertaken under two projects funded by ACIAR and assessed in this paper.

1 This section is based on McCown et al (1993). We would like to acknowledge the assistance of the following scientists at KARI, Katumani who spared their time to discuss these two projects with the first author in September 1994: Dr Muthoka, Director of KARI, Katumani, S. Nguluu, B. Ikombo, L. Muhammad, S. Kitheka, and P. Audi.

2 This is a tactical response to erratic climate where nitrogen fertiliser applications and plant spacings are varied according to predictions of the seasons. A farmer in the semi-arid tropics would be better off using this approach. However, the approach requires a high level of skill, judgement and effort on the part of each farmer (Lee,1993).

This paper reports on the outcomes and presents an impact assessment of two joint ACIAR-CSIRO-KARI projects which were both entitled 'The improvement of dry land agriculture in the African semi-arid tropics' and whose aim was to find effective management responses and affordable technological innovations as solutions to some of the problem of dryland farming in the semi-arid tropics. The projects lasted for 10 years and were conducted in three main phases. Phase 1 was funded under ACIAR project number 8326 from 1983 to 1987 and phases 2 and 3 were funded under ACIAR project number 8735 from 1988 to 1993.

The broad goals of the projects were:

- to understand the climatic and soil-related constraints to increased crop and forage production in the semi-arid zones of eastern Kenya;
- to use this understanding to devise and test (mainly on farms) improved technologies for management of soil, water and soil fertility that might lead to reduced climatic risk and increases in production and that can be readily and profitably adopted by small scale farmers both in this region and in similar environments elsewhere in sub-Saharan Africa;
- to improve the research capability of Kenyan scientists and institutions responsible for research on agricultural land management in semi-arid regions; and
- to conduct research in Australia to support and complement the research in Kenya using facilities and expertise at CSIRO laboratories in northern Australia.

1.2 The project and its objectives

Phase 1 studied the farming systems practised on a range of farms in semi-arid Kenya, evaluated about 150 pasture legume species for use as ley plants, and researched a number of agronomic issues on maize, namely, planting time, water supply, nitrogen fertiliser, plant populations, and their interactions. The objectives of the research in Phase 1 were:

- to analyse the social and economic environment of production systems in the region to determine constraints to productivity—results from this research provided direction to scientists developing technological solutions in the area;
- to compare the ability of forage and grain legumes to contribute nitrogen for subsequent cereal crops; and
- to explore the use of forage legumes in rehabilitating degraded grazing lands.

Phase 2 studied climatic risk management, soil and water conservation and soil fertility. The objectives of the climatic risk sub-project were:

- to verify predictions of maize yield by the modified version of the CERES-Maize model using weather, soil management and production data from farms;

- to analyse the climatic risk to maize production within the project area under both existing and experimentally promising management practices;
- to critically evaluate the feasibility of response farming; and
- to explore the use of the calibrated maize model for maize yield forecasting in the project area.

Using the model, estimates of the long-term probabilities of success of various management strategies were produced. During this phase soil fertility also received attention.

The objectives of the soil and water conservation sub-project were:

- to evaluate the technical and economic feasibility of innovative agronomic practices that improve water and soil conservation; and
- to improve the methods for predicting runoff and soil erosion in this climatic zone.

Adapted forage legumes formed an important part of a novel pitting system developed to rehabilitate and protect eroded grazing lands. Farmers' perceptions of and attitudes towards risk were studied to provide the understanding required to address issues related to adoption of technology.

The objective of the soil fertility sub-project was to compare the nitrogen contribution to subsequent maize crops from adapted forage and alley-crop legumes with that from the existing grain legumes.

Phase 3 of the project allowed the integration of results of research in both space and time. Risk analyses were done on the effects of various crop management options using climatic data from a large number of stations in Machakos and Kitui districts in Kenya. The effects of a 'fertiliser-augmented soil enrichment' strategy devised to help farmers escape from the poverty trap were examined.

ACIAR projects 8326 and 8735 aimed at improving dry land crop and forage production in the semi-arid tropics by increasing the knowledge of sustainable dry land cropping and by increasing the research capacity of Kenyan scientists to select, evaluate and test new technologies for use by smallholders in semi-arid Kenya and the rest of semi-arid sub-Saharan Africa.

The project had three main economic impacts:

- the direct welfare impacts: the emphasis here is on whether the project has made a difference to farmers in the countries where the research was undertaken (Kenya and Australia) the analysis is based on the five technologies advanced under the project and the impact of these technologies on producers of maize, sorghum, food legumes and livestock in Kenya and Australia;
- the impact on scientific knowledge of dry land farming, and therefore potential contribution to future research on improved technologies; and
- the impacts on human capacity building: that is, training of research scientists and equipping them with the tools, and enhanced capacity to research and develop solutions relevant to dry land agriculture in the semi-arid tropics.

1.3 Outline of the paper

The rest of the paper covers the following: section 2 discusses the approach adopted in estimating the impact of the project on producers and consumer welfare. Section 3 discusses the impacts of projects 8326 and 8735 on farmers and producers in Kenya, Australia and the rest of the world with the emphasis placed on the impact arising from changes in the cost of producing maize, sorghum, beef and milk. Section 3 concludes with a discussion of the internal rates of return and the net present values of welfare effects of the project. Section 4 discusses the scientific and human capital impacts of the two projects. Section 5 makes some concluding remarks.

2. AN OVERVIEW OF ECONOMIC MODELS FOR ESTIMATING WELFARE RETURNS TO LAND CONSERVATION MEASURES

ACIAR projects 8326 and 8735 adopted a farming-systems approach to research on the problems of semi-arid eastern Kenya. There are two possible approaches to estimating direct welfare gains of a project with a farming-system orientation:

- a linear programming approach model; and
- an approach using a set of separate, or single industry, partial, equilibrium models.

The information requirements of each of these approaches is different, with the first approach being the most demanding, and the second approach requiring less information.

A linear programming approach requires first, specifying a smallholder's objective function. The objective function is usually the maximisation of net revenue where net revenue is equal to gross revenue from farm crop and livestock production less crop losses, seed stock and home consumption less the costs of production (fertilisers, seed, labour, feedstuffs for livestock and veterinary services). Second, it is necessary to construct and parameterise the constraints facing the smallholder. Constraints include labour availability, land availability and the requirement that production must meet minimum family food needs. A recent example of this approach to a problem, similar to that addressed in projects 8326 and 8735, is the approach used by Day and Aillery (1988) when estimating farm-level impacts of alternative ways of coping with soil and water limitations in Mali.

This paper uses the second approach. It uses a set of separate single sector, or single industry, partial-equilibrium models to estimate the impact of research on the producers and consumers of maize, sorghum, beef and milk. This approach uses standard research evaluation models developed by Davis et al. (1987). The technologies that ACIAR projects 8326 and 8735 developed were on-farm technologies. Thus a key aspect of this approach is the estimation of the change in cost produced by the research. Then, this cost change, together with price information, production levels and elasticities of demand and supply, is used to estimate the change in the welfare of producers and consumers affected by the research project.

The second approach could incorporate a Bayesian decision-theory approach which begins with a prior probability distribution, estimated from historical data, of outcomes from a yield-influencing action. These probabilities are revised in the light of new information. The new information is often generated using a set of simulation models. An example of this approach is McCown et al. (1990), who used a Bayesian decision-theory approach to compare the efficacy of two seasonal rainfall predictors in reducing uncertainty and to compare the economic performance of various input allocation strategies of smallholders in Kenya.

3. THE IMPROVEMENT OF DRY LAND CROP AND FORAGE PRODUCTION IN THE SEMI-ARID TROPICS

3.1 Before research

3.1.1 Climatic risk: before and after research

Crops are generally produced in the semi-arid tropics under rain-fed conditions on soils of low fertility. Potential yields are generally low in this zone and the high yield variability is strongly tied to climatic factors (Carberry and Abrecht, 1990). This paper uses the season types developed by McCown et al. (1990), to characterise climatic risk in the semi-arid tropics in Kenya. McCown et al. (1990) classify seasons in eastern Kenya into good, fair and poor based on rainfall data from the Katumani Research Station, near Machakos for 1957–1988. These seasons are characterised as shown in Table 1:

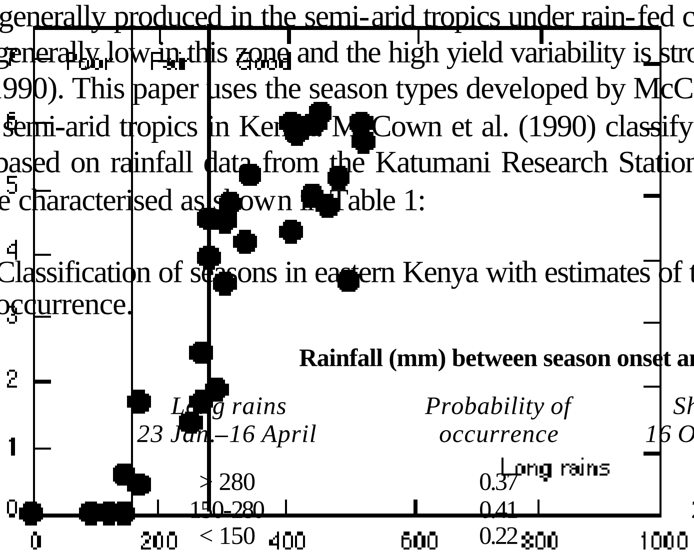

Table 1. Classification of seasons in eastern Kenya with estimates of the probabilities of their occurrence.

Season type	Rainfall (mm) between season onset and maize maturity			
	Long rains 23 Jan.–16 April	*Probability of occurrence*	*Short rains 16 Oct.–23 Nov.*	*Probability of occurrence*
Good	> 280	0.37	> 330	0.40
Fair	150-280	0.41	230-330	0.44
Poor	< 150	0.22	< 230	0.16

Source: McCown et al (1990).

The smallholder in eastern Kenya is exposed to the risk of unreliable rainfall. The season type depends also on the onset of rainfall. Thus a good season is associated with early onset of rainfall, where early onset is the earliest date of receipt of 40 mm of rain in 8 days. For the long rains, early onset is set at 23 January while for the short rains it is 16 October. Similarly a poor season is associated with late onset of rain—19 March for the long rains and 3 November for the short rains. These season types and the corresponding probability of occurrence cannot be changed by research. Research is intended to assist smallholders optimise crop and livestock yields given the immutable nature of the region's climatic risks.

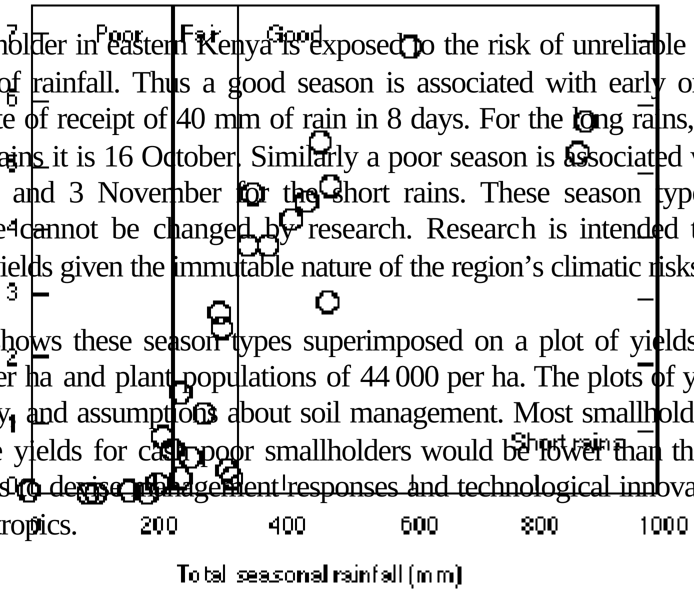

Figure 1 shows these season types superimposed on a plot of yields for a smallholder using 60 kg nitrogen fertiliser per ha and plant populations of 44 000 per ha. The plots of yields are simulated using the rainfall data, soil fertility, and assumptions about soil management. Most smallholders in eastern Kenya do not use fertilisers and so the yields for cash-poor smallholders would be lower than those in shown in Figure 1. The aim of the project was to devise management responses and technological innovations to increase smallholder yields in the semi-arid tropics.

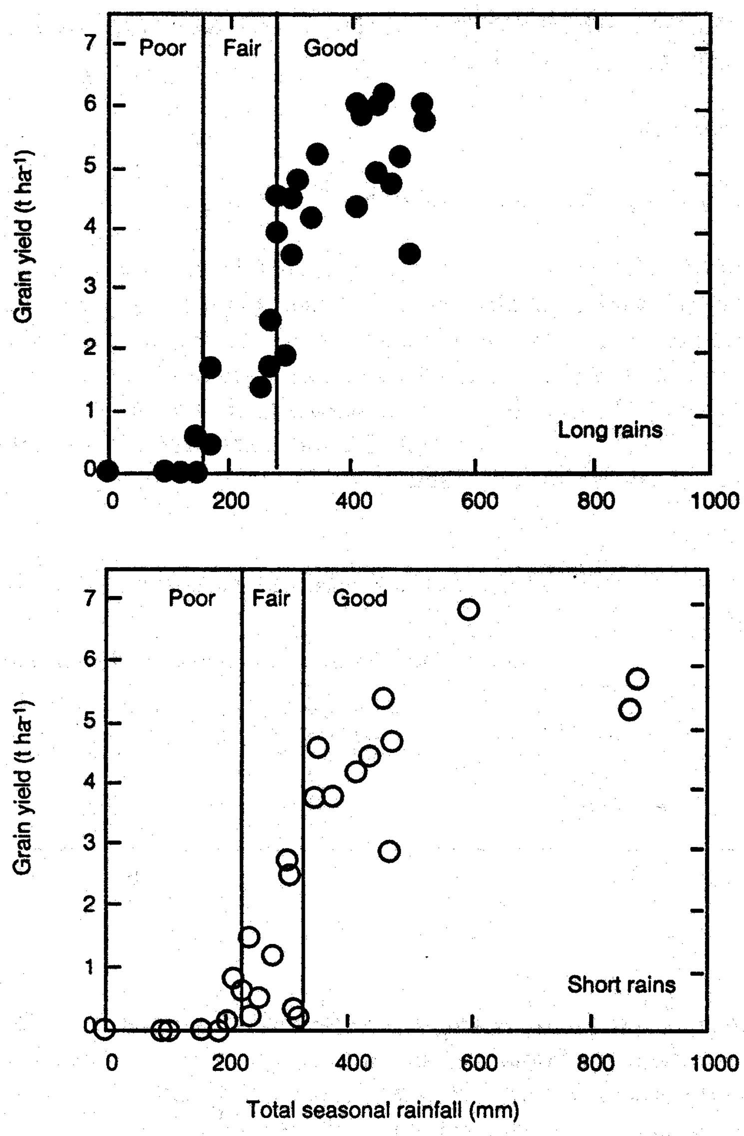

Figure 1. The relationship between maize grain yield and total rainfall during the maize growing season assuming that a smallholder uses 60 kg ha^{-1} of nitrogen fertilisers and 44 000 plants ha^{-1}

Source: McCown et al (1990).

3.1.2 Soil type and the crops in the farming system before and after research

Soil type

In two ACIAR projects (8326 and 8735) seven locations in the semi-arid zone of eastern Kenya were studied. The experiments were on two types of soils; the chromic luvisol and the deep acrisols which are representative of the soils in the region. The estimated distribution of the different soil types in the seven sites is as shown in Table 2:

Table 2. The estimated distribution of different soil types in the semi-arid zones of eastern Kenya.

Site	*Agro-climatic zone*	*Zonal descriptions*[d]	*Percent of soil that is chromic luvisol (shallow sandy soil)*	*Percent of soil that is deep acrisol (deep clay soil)*
Iveti	LH2	Lower Highlands with altitude greater than 1800 m, mean annual rainfall > 1100 mm, humid.	20[a]	80[a]
Kitui	UM4	Upper Midlands with altitude 1300-1800 m, mean annual rainfall 650-800 mm, semi-arid.	29[b]	71[b]
Katumani	UM4	ditto	29[b]	71[b]
Makueni	LM4	Lower Midlands with altitude 800-1300 m, mean annual rainfall 650-800 mm, semi-arid.	75[c]	25[c]
Zombe	LM5	Lower Midlands with altitude 800-1300 m, mean annual rainfall 500-650 mm, semi-arid.	75[c]	25[c]
Makindu	LM5	ditto	75[c]	25[c]
Konza	UM6	Upper Midlands with altitude 1300-1800 m, mean annual rainfall < 500 mm, arid.	25[a]	75[a]

Source: a: Dr Nguluu and Dr Ikombo (Soil chemists, Kenya Agricultural Research Institute, Katumani, personal communication, September 1994).
b: Gicheru and Ita (1987).
c: Muchera (1975).
d: Audi (1992) based on Jaetzold and Schmidt (1983).

Crops in the farming system before and after research

Ockwell et al. (1991) notes the following commodities in the farming system in eastern Kenya: maize, sorghum, millet cowpea, pigeon pea, beans, and livestock (oxen, cattle, goats and sheep). This paper focuses on four commodities in this farming system, namely:

- maize, which is the main crop in the zone;
- sorghum;
- beef and buffalo meat; and
- milk.

In Africa, Kenya is one of the top two producers and consumers of maize (FAO, 1994). The technologies developed by projects 8326 and 8735 focused on the semi-arid tropics. Thus these technologies may not be applicable to other climatic zones. Most of the production of maize, sorghum, beef and milk in Kenya falls in seasonally dry, semi-arid and arid agro climatic zones. Even though the project focussed on Machakos and Kitui districts, the technologies developed under the two projects are applicable to production of the four commodities in other districts of Kenya, according to estimates from ACIAR's Economic Evaluation Unit database that were originally obtained from Oram (International Food Policy Research Institute, personal communication, 1986).

Whether a smallholder adopts a technology or not depends, among other things, on whether the new technology reduces the smallholder's costs of producing crops and livestock favourably. Thus the next subsection discusses the before-research costs of producing maize, sorghum, beef and milk in semi-arid eastern Kenya.

3.1.3 Cost of production before research

The production of maize, sorghum, beef and milk before research is characterised by :

- smallholders use well adapted cultivars of maize and sorghum (Keating et al. 1994);
- very few smallholders use nitrogen fertilisers (McCown and Keating, 1992);
- while boma manure (farm yard manure) is available to smallholders, most of the smallholders apply the manure inefficiently (Probert et al. 1992) ;
- most smallholders use maize stover and other biomass from crop residues to feed livestock (Okwach et al. 1992);
- the practice of mulching and using crop residues to reduce runoff of top soil and for soil conservation purposes is not common because it conflicts with the demand for the same biomass for use as livestock feed (Okwach et al. 1992); and
- significant portions of grazing land is degraded as a result of severe overgrazing and increased pressure from both humans and livestock (Simiyu et al. 1992).

These practices increase production costs in the semi-arid region of Kenya. The remaining part of this section discusses the cost items incurred by smallholders and discusses the estimation of the unit cost of production for the four commodities assumed to be produced on the farm.

Seeds

Keating and Craswell (1990) note that

> 'On the basis of trial results obtained under well-fertilised conditions on research stations, researchers in Kenya and other semi-arid regions had been arguing for years that local farmers had been planting their maize plants too far apart. Kenyan subsistence farmers had not been eager to increase their plant populations, and they apparently have been following the correct strategy for the nitrogen deficient conditions occurring in many of their fields.'

This observation is based on Watiki and Keating's unpublished data at Katumani which indicate that when nitrogen fertiliser inputs are zero as was the case before research in Machakos and Kitui Districts in Kenya, then grain yields are maximised at plant populations of about 3 to 3.7 plants per square metre compared to about 6 plants per square metre when nitrogen fertiliser inputs are 120 kg/ha (Keating, 1989). Seed costs vary with plant population. A smallholder plants 2 seeds each weighing about 0.32 grams at each planting position prior to thinning to a single plant (Probert et al. undated). The seed costs before research do not vary by agro-climatic zone.

Nitrogen fertilisers

Before research, it is assumed that smallholders do not use nitrogen fertilisers in the production of maize and sorghum. Thus the cost of fertiliser to the smallholder is zero for both the materials and the labour costs of applying fertilisers.

Boma manure

The main cost associated with boma manure is the labour for extracting the manure from the boma, and transporting it to the field. The manure is carried from the boma to the crop land by ox-cart or wheelbarrow during August or September each year in the dry season and deposited in heaps before being spread and ploughed in (Lee, 1993). Kiome and Stocking (1993), estimate that in Kenya the labour costs associated with manure are about 420 Kenya shillings per ha annually.

Other costs

Planting, weeding and terracing costs per hectare before research are based on estimates by Kiome and Stocking (1993) for farms in Machanga in semi-arid Kenya. These costs are:

- planting requires about 23 person-days per ha at an annual cost per hectare of 690 Kenya shillings (KShs);
- first weeding requires 63 person-days per ha at an annual cost of KShs 1890/ha;
- second weeding requires 53 person-days per ha at an annual cost of KShs 1590/ha;
- harvesting requires 29 person-days per ha at an annual cost of KShs 870/ha; and
- terracing tasks use up 125 person-days/ha at an annual cost of KShs 3750/ha.

However, these costs do not change after research.

Yields before research

Farming in semi-arid environments, where rainfall is unreliable, is risky. Inevitably there will be some seasons where rainfall is inadequate to obtain reasonable crop yields no matter what the farmer might have done. However, where soil fertility is low, or has been allowed to decline under cropping systems without adequate replacement of the nutrients being removed, poor yields are obtained even in good seasons. This problem confronts most farmers in semi-arid eastern Kenya (McCown et al. 1993). The yields of maize and sorghum in a fair season before research are from Jaetzold and Schmidt (1983). The livestock sector yields in a fair season before research are from Jahnke et al. (1987). The prior probabilities of different season types are derived from McCown et al. (1990).

The unit cost of production per tonne is given by the total cost of production per hectare divided by the expected yield. Table 3 and Table 4 summarises the before research cost of production of maize and sorghum respectively. The two tables contain four options A, B, C, D, which relate to the technologies developed under the two projects. Option A relates to well adapted cultivars. As indicated earlier, the before and after research situation with respect to cultivars was the same. Option B relate to the use of well adapted cultivars but without early planting. Before research, option A and option B are identical in terms of costs of production. Option C relate to the sub-optimal use of boma-manure before research. Option D describes the costs of production with some intercropping before research in Machakos. Finally option E relates to the before research situation where farmers in Machakos were using sub-optimal plant spacing, and did not use enough nitrogen and phosphorus fertilisers. Thus in Table 3 and Table 4, the cost of fertilisers under Option E is zero. This changes after research.

Costs of producing livestock

The most important cost in the production of livestock is the cost of fodder. Kiome and Stocking (1993) estimated the price for fodder at KShs 0.02 per kg. This economic evaluation includes a cost item for reclaiming degraded grazing lands. In the before-research situation, smallholders do not devote any resources to the reclamation of degraded grazing lands. The cost of fodder and the cost of reclamation of degraded lands change as a result of research.

In addition to these costs the smallholder incurs costs for herdsmen to care for the livestock, for veterinary services and treatment of the livestock. These costs are based on estimates in Itty et al. (1987). The last two columns of Table 4 summarise the costs of producing beef and milk before research. Costs are estimated assuming that farmers do not use Katumani pits before research. The after research costs incorporate the introduction of adoption pits in the Machakos livestock production system. Option F thus relates to Katumani pits and their use in the production of beef (option F1) and of milk (option F2).

3.2 After research: Kenya

3.2.1 The technologies developed under projects 8326 and 8735

McCown et al. (1993) indicate that ACIAR projects 8326 and 8735 developed or improved the following technologies:

- *Well adapted cultivars*

Table 3. The before research costs of producing maize in Machakos, Kenya, under selected technologies developed in projects 8326 and 8735.

				Maize OPTION A Aadpted cultivators	**Maize** OPTION B Option A+ no early planting	**Maize** OPTION C Option B+ sub-optimal use of boma manure	**Maize** OPTION D Option C+ some inter-cropping with with nitrogen fixing legumes	**Maize** OPTION E Option D+ sub-optimal plant spacing, use of n-p fertilizer mulch, excess biomass	
Seeds/ha									
	LH2[c]	0.8[a]	0.2[b]	$2.67	$2.67	$2.67	$2.67	$2.67	
	UM4[c]	0.71[a]	0.29[b]	$2.67	$2.67	$2.67	$2.67	$2.67	
	LM4[c]	0.25[a]	0.75[b]	$2.67	$2.67	$2.67	$2.67	$2.67	
	LM5[c]	0.25[a]	0.75[b]	$2.67	$2.67	$2.67	$2.67	$2.67	
	UM6[c]	0.75[a]	0.25[b]	$2.67	$2.67	$2.67	$2.67	$2.67	
Fertilisers/ha									
	LH2[c]	0.8[a]	0.2[b]	$0	$0.00	$0.00	$0.00	$0.00	
	UM4[c]	0.71[a]	0.29[b]	$0	$0.00	$0.00	$0.00	$0.00	
	LM4[c]	0.25[a]	0.75[b]	$0	$0.00	$0.00	$0.00	$0.00	
	LM5[c]	0.25[a]	0.75[b]	$0	$0.00	$0.00	$0.00	$0.00	
	UM6[c]	0.75[a]	0.25[b]	$0	$0.00	$0.00	$0.00	$0.00	
Labour (1st fertiliser application)/ha					$0	$0.00	$0.00	$0.00	$0.00
Labour (2nd fertiliser application)/ha				$0	$0.00	$0.00	$0.00	$0.00	
Boma manure-labour				$12	$12.00	$12.00	$18.00	$14.40	
Planting labour/ha				$20	$19.71	$19.71	$19.71	$19.71	
1st Weeding labour/ha				$45	$45.43	$45.71	$45.71	$45.71	
2nd Weeding labour/ha				$45	$45.43	$45.43	$45.43	$45.43	
Harvesting/ha				$25	$24.86	$35.30	$45.89	$47.98	
Fanya juu terracing cost/ha				$42	$42	$42	$42	$42	
1st pesticide application				$0	$0.00	$0.00	$0.00	$0.00	
1st pesticide application				$0	$0.00	$0.00	$0.00	$0.00	
Total cost/ ha									
	LH2[c]	0.8[a]	0.2[b]	$192	$192	$202	$219	$217	
	UM4[c]	0.71[a]	0.29[b]	$192	$192	$202	$219	$217	
	LM4[c]	0.25[a]	0.75[b]	$192	$192	$202	$219	$217	
	LM5[c]	0.25[a]	0.75[b]	$192	$192	$202	$219	$217	
	UM6[c]	0.75[a]	0.25[b]	$192	$192	$202	$219	$217	
Yield mt per ha									
	Good crop			1.46	1.46	2.07	2.69	2.81	
	Fair crop			0.97	0.97	1.38	1.79	1.87	
	Poor crop			0.39	0.39	0.55	0.72	0.75	
Probability of season type									
	Good season			0.37	0.37	0.37	0.37	0.37	
	Fair season			0.42	0.42	0.42	0.42	0.42	
	Poor season			0.21	0.21	0.21	0.21	0.21	
Expected output/ ha				1.03	1.03	1.46	1.90	1.98	
Output of biomass for use as feed or mulch				1.83	1.83	1.83	1.83	1.83	
Unit cost of maize before research									
	LH2[c]	0.8[a]	0.2[b]	$187	$187	$139	$115	$110	
	UM4[c]	0.71[a]	0.29[b]	$187	$187	$139	$115	$110	
	LM4[c]	0.25[a]	0.75[b]	$187	$187	$139	$115	$110	
	LM5[c]	0.25[a]	0.75[b]	$187	$187	$139	$115	$110	
	UM6[c]	0.75[a]	0.25[b]	$187	$187	$139	$115	$110	
Average unit cost—before research				**$187**	**$187**	**$139**	**$115**	**$110**	

a: This is percentage of soil in a given zone which is chromic luvisols (clay loam).
b: This is percentage of soil in a given zone which is acrisol (sandy loam).
c: For a brief description of the different zones see Table 2.

Table 4. The before research costs of producing sorghum, beef and milk under selected technologies developed in projects 8326 and 8735, in Kenya.

			Sorghum OPTION A Adapted cultivars	**Sorghum** OPTION B Option A + no early planting	**Sorghum** OPTION C Option B + sub-optimal use of boma manure	**Sorghum** OPTION D Option C+ some inter-cropping with nitrogen-fixing legumes	**Sorghum** OPTION E Option D + sub-optimal plant spacing, sub-optimal use of n-p fertiliser, mulch excess biomass	**Beef** OPTION F1 F1= Option E without Katumani pits in the production of beef	**Milk** OPTION F2 F2= Option E without Katumani pits in the production of milk
Seeds/ha									
LH2[c]	0.8[a]	0.2[b]	$2.51	$2.51	$2.51	$2.51	$2.51		
UM4[c]	0.71[a]	0.29[b]	$2.51	$2.51	$2.51	$2.51	$2.51		
LM4[c]	0.25[a]	0.75[b]	$2.51	$2.51	$2.51	$2.51	$2.51		
LM5[c]	0.25[a]	0.75[b]	$2.51	$2.51	$2.51	$2.51	$2.51		
UM6[c]	0.75[a]	0.25[b]	$2.51	$2.51	$2.51	$2.51	$2.51		
Fertilisers/ha									
LH2[c]	0.8[a]	0.2[b]	0	$0.00	$0.00	$0.00	$0.00		
UM4[c]	0.71[a]	0.29[b]	0	$0.00	$0.00	$0.00	$0.00		
LM4[c]	0.25[a]	0.75[b]	0	$0.00	$0.00	$0.00	$0.00		
LM5[c]	0.25[a]	0.75[b]	0	$0.00	$0.00	$0.00	$0.00		
UM6[c]	0.75[a]	0.25[b]	0	$0.00	$0.00	$0.00	$0.00		
Labour (1st fertiliser application)/ha			0	$0.00	$0.00	$0.00	$0.00		
Labour (2nd fertiliser application)/ha				0	$0.00	$0.00	$0.00	$0.00	
Boma manure-labour			$12	$12.00	$12.00	$24.00	$24.00		
Planting labour/ha			$20	$20	$20	$20	$20		
1st Weeding labour/ha			$46	$45.71	$45.71	$45.71	$45.71		
2nd Weeding labour/ha			$37	$37.14	$45.43	$45.43	$45.43		
Harvesting/ha			$25	$24.86	$35.30	$45.89	$50.09		
Fanya juu terracing cost/ha			$42	$41.52	$41.52	$41.52	$41.52		
1st pesticide application				$0	$0.00	$0.00	$0.00	$0.00	
1st pesticide application				$0	$0.00	$0.00	$0.00	$0.00	
Cost of fodder (maize stover) /animal/ year						na	na	na$87	$87
Cost of reclaiming grazing lands				na	na	na	na	$0	$0
Herdsmen costs/ animal/ year				na	na	na	na	$3	$3
Veterinary services costs / animal/ year					na	na	na	$13	$13
Treatment drugs costs / animal/ year				na	na	na	na	$3	$3
Total cost			/ha	/ha	/ha	/ha	/ha	/animal/year	/animal/year
LH2[c]	0.8[a]	0.2[b]	$183	$183	$202	$225	$229	$106	$106
UM4[c]	0.71[a]	0.29[b]	$183	$183	$202	$225	$229	$106	$106
LM4[c]	0.25[a]	0.75[b]	$183	$183	$202	$225	$229	$106	$106
LM5[c]	0.25[a]	0.75[b]	$183	$183	$202	$225	$229	$106	$106
UM6[c]	0.75[a]	0.25[b]	$183	$183	$202	$225	$229	$106	$106
Yield					mt/ha	mt/ha	mt/ha	mt/herd	mt/herd
Good crop			1.46	1.46	2.07	2.69	2.93	0.41	0.30
Fair crop			0.97	0.97	1.38	1.79	1.95	0.27	0.20
Poor crop			0.39	0.39	0.55	0.72	0.78	0.14	0.10
Probability of season type									
Good season			0.37	0.37	0.37	0.37	0.37	0.37	0.37
Fair season			0.42	0.42	0.42	0.42	0.42	0.41	0.41
Poor season			0.21	0.21	0.21	0.21	0.21	0.21	0.21
Expected output/ ha			1.03	1.03	1.46	1.90	2.07	0.29	0.21
Unit cost per ton before									
LH2[c]	0.8[a]	0.2[b]	$179	$179	$139	$119	$111	$365	$492
UM4[c]	0.71[a]	0.29[b]	$179	$179	$139	$119	$111	$365	$492
LM4[c]	0.25[a]	0.75[b]	$179	$179	$139	$119	$111	$365	$492
LM5[c]	0.25[a]	0.75[b]	$179	$179	$139	$119	$111	$365	$492
UM6[c]	0.75[a]	0.25[b]	$179	$179	$139	$119	$111	$365	$492

Average unit cost—before	**$179**	**$179**	**$139**	**$119**	**$111**	**$365**	**$492**

[a] This is percentage of soil in a given zone which is chromic luvisols (clay loam)
[b] This is percentage of soil in a given zone which is acrisol (sandy loam)
[c] For a brief description of the different zones see Table 2

The project demonstrated that the locally bred maize cultivar, Katumani Composite B is well adapted to the rainfall regime in eastern Kenya. There is no change in the cost of production after research as a result of introducing new cultivars.

- *Early planting*

Research under the ACIAR projects showed how important it is to plant as soon as possible after the rains start. Delaying planting by even a few days at the start of the rainy season can greatly reduce the final yields. This technology changes the yields (Lee, 1993 and Appendix 5 of McCown et al. [1993]) and thus the unit costs of producing grains and livestock.

- *Use of boma manure*

Boma manure provides nutrients and improves the soil structure by supplying organic matter. Project scientists showed that the manure being carted to the croplands is of poor quality—it is mixed with a lot of soil that is dug out of the boma along with the manure. Nitrogen, phosphorus and potassium levels in manure were only about one third of those expected in fresh cattle manure. Furthermore, farmers tended to put manure only on those parts of their farms that were close to the boma at the expense of the more distant parts of the farms, and the manure was applied in sub-optimal quantities (Lee, 1993, Probert et al. 1992). The projects provided information leading to more effective utilisation of boma manure by smallholders.

The optimal utilisation of boma manure leads to an increase in the labour costs of applying manure. In addition, the yields increase and this leads to a decrease in the unit cost of production of grains and livestock incurred by smallholders.

- *The use of nitrogen-fixing legumes in the cropping rotation*

The projects demonstrated that on nitrogen-depleted soils, including cowpeas and pigeon peas in the crop rotation, results in an increase in the amount of nitrogen in the soil profile and an increase in the yield of grain crops planted after the nitrogen fixing legumes (Simpson et al. 1992). This assessment does not include the additional output that farmers get from the crop of a legume. This is because the yield changes attributed in this assessment to the use of nitrogen-fixing legumes are higher than those achievable on the farmer's plots. As Lee (1993) notes:

> 'The experiments did not include intercropping the maize and legumes, which is the usual practice in the region. However studies from elsewhere suggest that residual effects from intercropped legumes will be less than those obtained from legume crops alone.'

Including the output of legumes, given that the experimental results used for the main crops are higher than achievable by farmers, would have exaggerated the benefits from the project.

- *The use of nitrogen fertilisers with optimal plant populations*

The projects demonstrated that on nitrogen-impoverished soils, typical of soils in semi-arid eastern Kenya, substantial economic benefits could be obtained from using modest amounts of fertilisers. The projects also demonstrated that optimum plant populations vary with the soil nitrogen supply (Keating et al. 1994).

This technology leads to increases in seed costs and fertiliser costs and the labour cost of applying the fertilisers. The yields also increase by enough to lead to a unit-cost saving despite the increase in total cost.

- *Mulching to minimise runoff and maximise efficient rain-water use*

Farmers in eastern Kenya have no tradition of retaining crop residues for mulching because the residues are valuable as livestock feed. Thus there is a conflict between using maize stover as animal feed and as mulch to protect the croplands. The project demonstrated that mulch had the effect of collecting and retaining water on the surface, thereby increasing infiltration, and reducing runoff and reducing the velocity of the runoff and its power to erode soil (Okwach et al. 1992).

- *The Katumani pitting technique*

The projects developed a pitting system to suit eroded grazing lands (Simuyu et al. 1992). Lee(1993) describes this technique in the following words:

> 'Researchers formed small micro catchments on the sloping eroded land, approximately 2 square metres in area, by digging a crescent-shaped trench along the lower boundary. They heaped the soil from this trench onto the low side to form a loose retaining wall. This wall retained water within the micro catchment. Most of the land in the micro catchment remained undisturbed, so that during storms much of the rain-water would be trapped in the trench. They then planted in each micro catchment a mixture of forage legumes. Excellent pastures have been re-established after protection from grazing for only two seasons. The cost of construction was about Kshs 4400 per hectare, but most of these costs could be recovered by planting cowpea and pigeon pea. These pits are a one-off rehabilitation of the grazing lands.'

The Katumani pits lead to an increase in the supply of livestock feed and reduce the demand for crop residues as livestock feedstuff. This in turn is likely to increase the probability that smallholders will use some of the biomass from crop residues for soil conservation purposes as mulch.
The economic evaluation of the two projects covers the following seven options:

- option A is the adoption of well adapted cultivars;
- option B is the combination of Option A and the adoption of early planting practices;
- option C is a combination of Option C and the optimal use of boma manure;
- option D is the combination of Option C and the practice of intercropping with nitrogen fixing legumes;
- option E is the combination of option D with optimal plant spacing, the optimal use of nitrogen and phosphorus fertilisers and mulching excess biomass to reduce soil runoff;
- option F1 is the combination of option E with the use of Katumani pits in the production of beef; and

- option F2 is the combination of option E with Katumani pits in the production of milk.

Options A, B, and C are non cash using low risk technologies with high probabilities of adoption by the smallholder (Ockwell et al. 1991). Options D, E, F1 and F2 include technologies which are cash-using and high risk.

Response farming

The projects developed a scheme to forecast the potential of the pending season, using rules based on time of season onset and early cumulative rainfall. This scheme provides tactical responses to better match plant populations and fertiliser inputs with seasonal potential. The technology is not included in the assessment of the projects because the projects did not establish its potential impact. For example Wafula et al. (1992) conclude that:

> 'Adjustment of the nitrogen input levels and plant populations to better match the seasonal potential is a logical response with a sound biological basis. How much value to place on the forecast is more difficult to assess.'

Table 5 summarises estimates of the farm level costs of producing maize after the adoption of different technologies developed under projects PN8326 and PN8735. Similarly Table 6 summarises estimates of the farm level costs of producing sorghum, beef and milk after the adoption of different technologies developed under projects PN8326 and PN8735.

3.3 Before and after research: Northern Territory, Australia

In 1978 research began to test a system of cropping, suitable for the 'Top End' of the Northern Territory, with the following features (see McCown et al, 1993):

- a self-regenerating legume ley pasture of 1-3 years duration grown in rotation with maize or sorghum;
- cattle graze native grass pastures during the green season and leys plus crop residues in the dry season;
- crops are planted directly into the pasture which is chemically killed shortly before planting;
- the pasture legume sward which volunteers from hard seed is allowed to form an under storey in the crop; and
- after 1 year of cropping, the pasture is allowed to regenerate.

Table 5. The after research costs of producing maize in Machakos under selected technologies developed in projects 8326 and 8735.

AFTER RESEARCH	$/ha Kenya **Maize** OPTION A Adapted cultivars	$/ha Kenya **Maize** OPTION B Option A + early planting	$/ha Kenya **Maize** OPTION C Option B + optimal use of boma manure	$/ha Kenya **Maize** OPTION D Option C+ inter-cropping with nitrogen-	$/ha Kenya **Maize** OPTION E Option D + optimal plant spacing, n-p fertiliser,

						fixing legumes	mulch excess biomass	
CROP PRODUCTION COSTS								
Seeds/ha								
LH2[c]	0.8[a]	0.2[b]	$2.67	$2.67	$2.67	$2.67	$8.23	
UM4[c]	0.71[a]	0.29[b]	$2.67	$2.67	$2.67	$2.67	$6.19	
LM4[c]	0.25[a]	0.75[b]	$2.67	$2.67	$2.67	$2.67	$3.43	
LM5[c]	0.25[a]	0.75[b]	$2.67	$2.67	$2.67	$2.67	$2.86	
UM6[c]	0.75[a]	0.25[b]	$2.67	$2.67	$2.67	$2.67	$2.29	
Fertilisers/ha								
LH2[c]	0.8[a]	0.2[b]	$0	$0	$0	$0	$39.66	
UM4[c]	0.71[a]	0.29[b]	$0	$0	$0	$0	$39.66	
LM4[c]	0.25[a]	0.75[b]	$0	$0	$0	$0	$39.66	
LM5[c]	0.25[a]	0.75[b]	$0	$0	$0	$0	$39.66	
UM6[c]	0.75[a]	0.25[b]	$0	$0	$0	$0	$39.66	
Labour (1st fertiliser application)/ha			$0	$0	$0	$0	$12	
Labour (2nd fertiliser application)/ha				$0	$0	$0	$0	$12
Boma manure-labour			$12	$12	$18	$14	$14	
Planting labour/ha			$20	$20	$20	$20	$20	
1st Weeding labour/ha			$45	$46	$46	$46	$46	
2nd Weeding labour/ha			$45	$45	$45	$45	$45	
Harvesting/ha			$25	$35	$46	$48	$70	
Fanya juu terracing cost/ha			$42	$42	$42	$42	$42	
1st pesticide application				$0	$0	$0	$0	$6
1st pesticide application				$0	$0	$0	$0	$5
Total cost/ ha								
LH2[c]	0.8[a]	0.2[b]	$192	$202	$219	$217	$320	
UM4[c]	0.71[a]	0.29[b]	$192	$202	$219	$217	$318	
LM4[c]	0.25[a]	0.75[b]	$192	$202	$219	$217	$315	
LM5[c]	0.25[a]	0.75[b]	$192	$202	$219	$217	$315	
UM6[c]	0.75[a]	0.25[b]	$192	$202	$219	$217	$314	
Yield mt per ha								
Good crop			1.46	2.07	2.69	2.81	4.11	
Fair crop			0.97	1.38	1.79	1.87	2.74	
Poor crop			0.39	0.55	0.72	0.75	1.10	
Probability of season type								
Good season			0.37	0.37	0.37	0.37	0.37	
Fair season			0.42	0.42	0.42	0.42	0.42	
Poor season			0.21	0.21	0.21	0.21	0.21	
Expected output/ ha			1.03	1.46	1.90	1.98	2.90	
Unit cost of maize after								
LH2(c)	0.8(a)	0.2(b)	$187	$139	$115	$110	$110	
UM4(c)	0.71(a)	0.29(b)	$187	$139	$115	$110	$110	
LM4(c)	0.25(a)	0.75(b)	$187	$139	$115	$110	$109	
LM5[c]	0.25[a]	0.75[b]	$187	$139	$115	$110	$108	
UM6[c]	0.75[a]	0.25[b]	$187	$139	$115	$110	$108	
Average unit cost -after research				**$186.54**	**$139**	**$115**	**$110**	**$109**
Unit cost saving after research			**$0**	**$48**	**$23**	**$6**	**$1**	

[a] This is percentage of soil in a given zone which is chromic luvisols (clay loam)
[b] This is percentage of soil in a given zone which is acrisol (sandy loam)
[c] For a brief description of the different zones see Table 2

Table 6. The after research costs of producing sorghum, beef and milk in Machakos under selected technologies developed in projects 8326 and 8735.

Cost item	**Sorghum** OPTION A Adapted cultivars	**Sorghum** OPTION B Option A + early planting	**Sorghum** OPTION C Option B + optimal use of boma	**Sorghum** OPTION D Option C+ inter-cropping	**Sorghum** OPTION E Option D + optimal plant spacing,	**Beef** OPTION F1 F1= Option E + Katumani pits in the	**Milk** OPTION F2 F2= Option E + Katumani pits in the

			of milk mulch excess legumes	biomass	manure	with	n-p nitrogen-	production fertiliser,	production of beef fixing
Seeds/ha									
LH2[c]	0.8[a]	0.2[b]	$2.51	$2.51	$2.51	$2.51	$5.03		
UM4[c]	0.71[a]	0.29[b]	$2.51	$2.51	$2.51	$2.51	$5.03		
LM4[c]	0.25[a]	0.75[b]	$2.51	$2.51	$2.51	$2.51	$5.03		
LM5[c]	0.25[a]	0.75[b]	$2.51	$2.51	$2.51	$2.51	$5.03		
UM6[c]	0.75[a]	0.25[b]	$2.51	$2.51	$2.51	$2.51	$5.03		
Fertilisers/ha									
LH2[c]	0.8[a]	0.2[b]	0	0	0	0	$39.66		
UM4[c]	0.71[a]	0.29[b]	0	0	0	0	$39.66		
LM4[c]	0.25[a]	0.75[b]	0	0	0	0	$39.66		
LM5[c]	0.25[a]	0.75[b]	0	0	0	0	$39.66		
UM6[c]	0.75[a]	0.25[b]	0	0	0	0	$39.66		
Labour (1st fertiliser application)/ha			0	0	0	0	$12		
Labour (2nd fertiliser application)/ha				0	0	0	0	$12	
Boma manure-labour			$12	$12	$24	$24	$24		
Planting labour/ha			$20	$20	$20	$20	$20		
1st Weeding labour/ha			$46	$46	$46	$46	$46		
2nd Weeding labour/ha			$37	$45	$45	$45	$45		
Harvesting/ha			$25	$35	$46	$50	$70		
Fanya juu terracing cost/ha			$42	$42	$42	$42	$42		
1st pesticide application				$0	$0	$0	$0	$6	
1st pesticide application				$0	$0	$0	$0	$5	
Cost of fodder (maize stover) /animal/ year					na	na	na	$88	$88
Cost of reclaiming grazing lands				na	na	na	na	$18	$18
Herdsmen costs/ animal/ year				na	na	na	na	$3	$3
Veterinary services costs / animal/ year					na	na	na	$13	$13
Treatment drugs costs / animal/ year				na	na	na	na	$3	$3
Total cost			/ha	/ha	/ha	/ha	/ha	/animal/year	/animal/year
LH2[c]	0.8[a]	0.2[b]	$183	$202	$225	$229	$326	$125	$125
UM4[c]	0.71[a]	0.29[b]	$183	$202	$225	$229	$326	$125	$125
LM4[c]	0.25[a]	0.75[b]	$183	$202	$225	$229	$326	$125	$125
LM5[c]	0.25[a]	0.75[b]	$183	$202	$225	$229	$326	$125	$125
UM6[c]	0.75[a]	0.25[b]	$183	$202	$225	$229	$326	$125	$125
Yield					mt/ha	mt/ha	mt/ha	mt/herd/year	mt/herd/year
Good crop			1.46	2.07	2.69	2.93	4.10	0.53	0.42
Fair crop			0.97	1.38	1.79	1.95	2.73	0.35	0.28
Poor crop			0.39	0.55	0.72	0.78	1.09	0.18	0.14
Probability of season type									
Good season			0.37	0.37	0.37	0.37	0.37	0.37	0.37
Fair season			0.42	0.42	0.42	0.42	0.42	0.41	0.41
Poor season			0.21	0.21	0.21	0.21	0.21	0.21	0.21
Expected output/ ha			1.03	1.46	1.90	2.07	2.89	0.38	0.30
Unit cost after									
LH2[c]	0.8[a]	0.2[b]	$179	$139	$119	$111	$113	$332	$415
UM4[c]	0.71[a]	0.29[b]	$179	$139	$119	$111	$113	$332	$415
LM4[c]	0.25[a]	0.75[b]	$179	$139	$119	$111	$113	$332	$415
LM5[c]	0.25[a]	0.75[b]	$179	$139	$119	$111	$113	$332	$415
UM6[c]	0.75[a]	0.25[b]	$179	$139	$119	$111	$113	$332	$415
Average unit cost -after				**$179**	**$139**	**$119**	**$111**	**$113**	**$332 $415**
Unit cost saving after research			**$0**	**$40**	**$20**	**$8**	**($2)**	**$33**	**$78**

[a] This is percentage of soil in a given zone which is chromic luvisols (clay loam)
[b] This is percentage of soil in a given zone which is acrisol (sandy loam)
[c] For a brief description of the different zones see Table 2

The main impact in Australia from the two projects, PN8326 and PN8735, is related to the contribution of the two projects to the development of the legume ley system in Australia's semi-arid tropics. When looking for ways of increasing the quantity of useable nitrogen compounds in the soil by growing nitrogen-fixing legumes, a little-known plant called Cavalcade (centrosema pascuorum) was assessed. The research under the two projects helped prove that Cavalcade, originally a native of Central and South America, was of value as a legume, particularly in a sorghum-growing system, and showed the best way of integrating it into a system. As well as enriching the soil with nitrogen, Cavalcade also offers green forage for livestock and can be used as hay.

McCown et al (1993) indicate that under this legume ley system the following impacts are achieved:

- average (3 years) annual live-weight gains of steers are about 123 kg/head when the steers graze on native pasture in the growing season, and in the cropping lands in the dry season, compared to 93 kg/head for steers grazing on native pasture continuously;
- two years of Cavalcade can provide 80-120 kg/ha of nitrogen fertiliser to a sorghum crop with a saving of $70 in fertiliser costs;
- only 2 litres/ha Roundup are needed to kill the ley and provide effective weed control; and
- higher yields of sorghum under a legume ley system are achievable compared to yields achievable in the traditional system.

Table 7 shows estimates of costs of producing beef and sorghum in the Northern Territory, before and after research. The before research cost estimates are based on ABARE (1994). Information on herd size was obtained from ABARE (1994) and the data on herd structure was from Furmage (1994). Data on the impact on liveweights of livestock was obtained from McCown (1993) and Price et al (1996). Data on yields of sorghum are from McCown (1993) and Thiagalingam et al(undated). Data on prices of beef and sorghum was obtained from ABARE (1995). Val Hristova (pers comm, Northern Territory Primary Industries and Fisheries, 1996) provide the following estimates of gross margins for gain sorhum growing in the Katherine region:

Inputs	Gross margins for grain sorghum growing in the Katherine region under conventional tillage	Gross margins for grain sorghum growing in the Katherine region under zero tillage
Yield (tons/ha)	2.0	2.5
Price ($/ton)	230	230
Gross Income	460	575
Land preparation	13	20
Planting	47	47
Fertiliser	83	83
Post planting weed control	17	17
Harvesting	13	13
Postharvest	94	118
Total variable costs	267	297
Gross margin per hectare	193	278

These numbers are used as a starting point in the estimation of the before and after research costs in Table 7. While the estimates by Hristova do not include overhead and fixed costs, Table 7 includes estimates of these based on ABARE (1994). While Hristova's estimates do not allow for decreases in fertiliser costs, and no increases in weed control costs, estimates in Table 7 allow for decreases in fertiler costs, and increases in weed control costs after research.

Table 7 indicates that before research it was uneconomic to produce sorghum in the Northern Territory since the price of sorghum (average bulk quote for grain delivered in Sydney region) was lower than the unit cost of producing sorghum in Northern Territory at the time. Research reduces the unit costs of producing both sorghum and beef in the Northern Territory.

3.4 Adoption of technologies

Table 7. The key assumptions about, and estimates of the costs of producing beef and sorghum in Northern Territory, Australia, 1991.

				Beef and sorghum before	Beef and sorghum after
Key assumptions about an average farm					
1	Total revenue [a]	$A, 1991		432615	432615
	Revenue—beef [a]	$A, 1991		431993	431993
	Revenue—sorghum [a]	$A, 1991		622	622
2	Share of revenue—beef	Proportion		0.9985622	0.9985622
	Share of revenue—sorghum	Proportion		0.0014378	0.0014378
3	Herd size [a]	Number		6646	6646
	Calves [b]	Proportion	0.23	1528.58	1528.58
	Cows, Heifers [b]	Proportion	0.56	3721.76	3721.76
	Steers, bullocks [b]	Proportion	0.17	1129.82	1129.82
	Bulls [b]	Proportion	0.03	199.38	199.38
	Average (3 years) annual liveweight gain [c]	Kg		93	123
	Beef cattle sold [a]	Number		1423	1423
	Average weight of carcass [d], [c]			188	210
	Total output—beef	Tonnes		267.524	298.83
	Yield per hectare- sorghum [c], (e)	Tonnes		2.0	2.5

		Beef and sorghum costs before 1991 $A	Beef and sorghum costs after 1991 $A	
Input costs				
Purchases—beef cattle		86,961	86,961	
Hired labour		74,368	78,086	
Fertiliser		2,354	2,284	
Fodder		18,196	18,196	
Crop and pasture chemicals		1,147	1,262	
Fuel, oil and greases		50,806	50,806	
Repair and maintenance		51,430	51,430	
Other materials		35,926	35,926	
Contracts		16,481	16,481	
Rates		2,976	2,976	
Other services		106,385	106,385	
Interest		61,636	61,636	
Rent		4,275	4,275	
Payment to sharefarmers		1,788	1,788	
Other cash costs		19,948	19,948	
Total	Beef and sorghum	534,677	538,440	
Total cost	Beef	534,071	537,829	
Cost per ton	Beef	1,996	1,800	
Cost saving per ton	Beef		197	
Price per ton—beef[f]			**2160**	**2160**

Total cost	Sorghum	606	612
Cost per ton	Sorghum	303.16	244.69
Cost saving per ton	**Sorghum**		**58**
Price per ton—sorghum [f]		**230**	**230**

[a] ABARE (1994)
[b] Furmage (1994)
[c] McCown et al (1993)
[d] Price, et al (1996)
[e] Thiagalingam et al (undated)
[f] ABARE (1995)

The benefits from a technology depend on the level of adoption of the technology by smallholders. In the case of eastern Kenya, Rukandema et al. (1981) and Muhammad and Parton (1992) estimated the adoption levels in eastern Kenya for various technologies as shown in Table 8.

The innovations requiring little direct cash outlays (inorganic fertilisers, terracing and early planting) are the most widely adopted. These comprise the poor person's technology (Muhammad and Parton, 1992). Terracing and boma manure are complementary techniques for improved soil and water management, which place high demands on available labour but do not necessarily require cash for their implementation.

In Australia, Price (pers comm, Department of Primary Industry and Fisheries, Northern Territory, 1996), estimates that, in Northern Territory, there is approximately 5000 - 6000 hectares of mixed grass and centurion pasture and probably another 100 hectares of centurion (Cavalcade) by itself. The total area planted to sorghum in Australia is about 502000 hectares (ABARE, 1995).

3.5 Estimating the direct welfare benefits of the research project: Key parameters

To estimate the direct welfare benefits from project 8326 and 8735, use is made of standard equations for producer and consumer surplus developed by Davis et al. (1987) for projects where research leads to savings in the unit cost of producing a commodity. Since Kenya does not trade significantly in the four commodities that were affected by this project, a closed economy model is applied in the evaluation of the welfare benefits from the project.

The cost savings associated with the different technologies developed under projects 8326 and 8735, and which are included in this economic assessment, are discussed in the next section. Computation using Davis et al. (1987) requires in addition:

- information on production of the commodities which research affects;
- the prices of those commodities; and
- the elasticity of demand and supply for the commodities.

Table 8. Estimates of adoption rates for selected technologies in Machakos, Kenya

Technology	Adopters as proportion 1980[a]	Adopters as proportion 1990[b]

Well adapted cultivar (KCB seed)	0.31	0.30
Early planting date	not estimated	0.56
Medium planting date	not estimated	0.37
Late planting date	not estimated	0.07
Use of boma manure (organic fertilisers)	0.68	0.83
Use of nitrogen fixing legumes	not estimated	0.22[c]
Use of nitrogen fertilisers (inorganic)	0.08	0.18
Pesticides	0.15	0.17
Mulching	0.00	0.00
Terracing	not estimated	0.78[c]

Sources:[a] Rukandema et al (1981)
[b] Muhammad and Parton (1992)
[c] Ockwell et al (1991)

Production

In the case of projects 8326 and 8735, the commodities included in the assessment are maize, sorghum, beef and milk. Important aspects of the analysis of the production data were:

- Given that the project had a focus on dryland land farming, the proportions of commodity production in the seasonally dry, semi-arid and arid climatic zones in the different countries are used to estimate the total production of the commodities targeted by the two projects.
- Since the project focused on Ukambani and not Kenya as a whole, only a fraction of the Kenyan output is used in the analysis. It is estimated that the Ukambani region produces about 111 000 tonnes of maize and about 6000 tonnes of sorghum. These estimates, together with data on Kenya's total production of these commodities, are used to estimate Ukambani's share in Kenya's output of maize and sorghum.
- In Australia account is taken of production of sorghum and beef in the Northern Territory only. Coombs (1994) estimated that production of sorghum in Northern Territory is 500 to 3000 tonnes annually. With respect to beef production, ABARE (1994) shows that Northern Territory produces about 9 percent of beef produced in Australia.

Prices and elasticity of demand and supply

The prices for maize, sorghum, beef and milk used in this assessment were taken from ACIAR's ABARE (1995) while the elasticities of supply and demand were obtained from ACIAR's Economic Evaluation Unit's database and were as follows.

Commodity	Elasticity of demand	Elasticity of supply
Maize	-0.1	0.1
Sorghum	-0.2	0.1
Beef	-0.4	0.4
Milk	-0.04	0.02

4 RESULTS

This section reports the main results on the welfare impacts of projects 8326 and 8735. The preliminary results are divided into three parts as follows:

- the changes in the unit costs associated with the different options;
- the present values of welfare benefits generated by the different options;
- the rates of return due to the project;
- the flow of benefits over time; and
- sensitivity analyses.

4.1 Estimates of changes in the unit costs of the different options

Table 9 summarises the estimates of the unit-cost changes associated with the different options. In the research evaluation model used here, the unit-cost change is one of the most important expressions of the impact of the project. The unit-cost change is the difference between the cost per unit of producing output after research and the unit cost of producing the output before research. A negative unit-cost change means that the research results, if adopted, are likely to generate welfare benefits to the producers and the consumers of the respective commodity. A zero unit-cost change mean that adoption of the option is not likely to generate any welfare benefits. A positive unit-cost change means that the technological option will not be adopted by farmers, since the technology increases unit costs of production.

The results in Table 9 seem to suggest that, in Machakos, the highest unit-cost reduction of $A78/MT is associated with option F in the production of milk. The next highest unit-cost reduction is associated with Option B in the production of maize followed by Option B in the production of sorghum. While from the project scientists' viewpoint, Option E is the most promising, in the analysis it is associated with the lowest unit-cost reductions. In Australia, the largest impact on costs was on the unit cost of producing beef.

Table 9. Estimates of changes in the unit cost reductions associated with the different options

	Option name	Maize ($A/MT)	Sorghum ($A/MT)	Milk ($A/MT)	Beef ($A/MT)
	MACHAKOS				
A	Adoption of well adapted cultivars	0	0	ne	ne
B	Combination of Option A and the adoption of early planting practices	-48	-40	ne	ne
C	Combination of Option C and the optimal use of boma manure	-23	-20	ne	ne
D	Combination of Option C and the practice of intercropping with nitrogen fixing legumes	-6	-8	ne	ne
E	Combination of option D with optimal plant spacing, the optimal use of nitrogen and phosphorus fertilisers and mulching excess biomass	-1	+2	ne	ne
F	Combination of option E with the use of Katumani pits in livestock production	na	na	-33	-78
	AUSTRALIA				
	A legume ley system		-58		-197

na: not applicable
ne: not estimated. Technologies which increase the yields of maize and sorghum increase the production of stover and other residues used as livestock feed in Machakos. Under current practice any increase in crop residues is used for livestock feed. However a major aspect of the project was designed to change farmers' practice so that more of the residues are used to reduce soil erosion.

4.2 Estimates the present values of benefits generated by the options

These estimates are conservative. They are based on benefits accruing to producers and consumers in Ukambani, Machakos only and exclude the possible spillover effects to other semi-arid regions in Kenya and in other parts of the world. Similarly, in Australia, estimates cover only Northern Territory where the research was undertaken, even though the legume ley system may, in the future, be applicable to other semi-arid regions of Australia. Val Hristova (1996, pers comm., Northern Territory Department of Primary Industries and Fisheries, Darwin) indicates that this system is applicable to a number of field crops suited to the conditions at the Top End of Northern Territory. These include maize, sesame, and mung beans. However, these flow on benefits have not been include in the evaluation.

In the case of Machakos, the benefits are estimated using a closed economy model. However, in the case of Northern Territory an open economy model is used, because Northern Territory trades in both beef and sorghum. In both cases, the impact on the rest of the world, through changes in the world prices, is negligible.

Table 10, Table 11 and Table 12 summarise the flow of benefits from the project in nominal dollar values assuming a time horizon of 30 years from the start of the project. Table 10 and Table 11 show the flows of welfare benefits to farmers in Machakos over a 30 year time horizon generated from the adoption of technologies developed under ACIAR projects 8326 and 8735. Table 12 shows estimates of benefits to Northern Territory in Australia. The present values depend on the unit cost reductions, the adoption rates assumed for the different options, the outputs and prices of the different commodities in the Ukambani farming system, the elasticities of demand and supply for the different commodities and the discount rate (assumd to be 8 percent in this paper).

Table 10. Flows of benefits accruing to maize producers in Machakos from the adoption of selected technologies developed during projects PN8326 and PN8735. ($A, '000, unadjusted for inflation)

Year No.	YEAR	**Kenya Maize** OPTION A Adapted cultivars planting manure	**Kenya Maize** OPTION B Option A + early use of boma with nitrogen-	**Kenya Maize** OPTION C Option B + optimal cropping n-p	**Kenya Maize** OPTION D Option C +- inter- plant spacing, fixing legumes	**Kenya Maize** OPTION E Option D + optimal fertilizer, mulch, excess biomass
1	1983	$0	$0	$0	$0	$0
2	1984	$0	$0	$0	$0	$0
3	1985	$0	$0	$0	$0	$0
4	1986	$0	$0	$0	$0	$0
5	1987	$0	$0	$0	$0	$0
6	1988	$0	$0	$0	$0	$0
7	1989	$0	$0	$0	$0	$0
8	1990	$0	$2,843,352	$543,414	$6,118	$615
9	1991	$0	$2,843,352	$543,414	$12,237	$1,229
10	1992	$0	$2,843,352	$543,414	$18,355	$1,844
11	1993	$0	$2,843,352	$543,414	$24,473	$2,458
12	1994	$0	$2,843,352	$543,414	$30,591	$3,073
13	1995	$0	$2,843,352	$543,414	$36,710	$3,687
14	1996	$0	$2,843,352	$543,414	$42,828	$4,302
15	1997	$0	$2,843,352	$543,414	$48,946	$4,916
16	1998	$0	$2,843,352	$543,414	$55,064	$5,531
17	1999	$0	$2,843,352	$543,414	$61,183	$6,145
18	2000	$0	$2,843,352	$543,414	$61,183	$6,145
19	2001	$0	$2,843,352	$543,414	$61,183	$6,145
20	2002	$0	$2,843,352	$543,414	$61,183	$6,145
21	2003	$0	$2,843,352	$543,414	$61,183	$6,145
22	2004	$0	$2,843,352	$543,414	$61,183	$6,145
23	2005	$0	$2,843,352	$543,414	$61,183	$6,145
24	2006	$0	$2,843,352	$543,414	$61,183	$6,145
25	2007	$0	$2,843,352	$543,414	$61,183	$6,145
26	2008	$0	$2,843,352	$543,414	$61,183	$6,145
27	2009	$0	$2,843,352	$543,414	$61,183	$6,145
28	2010	$0	$2,843,352	$543,414	$61,183	$6,145
29	2011	$0	$2,843,352	$543,414	$61,183	$6,145
30	2012	$0	$2,843,352	$543,414	$61,183	$6,145
Discount rate		0.08	0.08	0.08	0.08	0.08
Present value		**$0**	**$17,206,299**	**$3,288,420**	**$247,386**	**$24,847**

Table 11. Flows of benefits accruing to producers sorghum, milk and beef in Machakos from the adoption of selected technologies developed during projects PN8326 and PN8735

($A, '000, unadjusted for inflation)

		Kenya Sorghum	**Kenya Sorghum**	**Kenya Sorghum**	**Kenya Sorghum**	**Kenya Sorghum**	**Kenya Beef**	**Kenya Milk**
		OPTION A Adapted cultivars	OPTION B Option A + early planting	OPTION C Option B + optimal use of boma manure	OPTION D Option C+ inter-cropping with	OPTION E Option D + optimal plant spacing, n-p nitrogen-	OPTION F1 F1= Option E+ Katumani pits in the production fertiliser,	OPTION F2 F2= Option E+ Katumani pits in the production of beef
excess		of milk biomass						fixing mulch legumes
Year No.	YEAR							
1	1983	$0	$0 $0	$0	$0	$0	$0	
2	1984	$0	$0	$0	$0	$0	$0	$0
3	1985	$0	$0	$0	$0	$0	$0	$0
4	1986	$0	$0	$0	$0	$0	$0	$0
5	1987	$0	$0	$0	$0	$0	$0	$0
6	1988	$0	$0	$0	$0	$0	$0	$0
7	1989	$0	$0	$0	$0	$0	$0	$0
8	1990	$2,095	$138,270	$25,699	$499	($51)	$4,128	$86,379
9	1991	$2,095	$138,270	$25,699	$999	($101)	$8,256	$172,757
10	1992	$2,095	$138,270	$25,699	$1,498	($152)	$12,384	$259,136
11	1993	$2,095	$138,270	$25,699	$1,997	($203)	$16,512	$345,515
12	1994	$2,095	$138,270	$25,699	$2,497	($253)	$20,640	$431,894
13	1995	$2,095	$138,270	$25,699	$2,996	($304)	$24,768	$518,272
14	1996	$2,095	$138,270	$25,699	$3,496	($355)	$28,897	$604,651
15	1997	$2,095	$138,270	$25,699	$3,995	($405)	$33,025	$691,030
16	1998	$2,095	$138,270	$25,699	$4,494	($456)	$37,153	$777,409
17	1999	$2,095	$138,270	$25,699	$4,994	($507)	$41,281	$863,787
18	2000	$2,095	$138,270	$25,699	$4,994	($507)	$41,281	$863,787
19	2001	$2,095	$138,270	$25,699	$4,994	($507)	$41,281	$863,787
20	2002	$2,095	$138,270	$25,699	$4,994	($507)	$41,281	$863,787
21	2003	$2,095	$138,270	$25,699	$4,994	($507)	$41,281	$863,787
22	2004	$2,095	$138,270	$25,699	$4,994	($507)	$41,281	$863,787
23	2005	$2,095	$138,270	$25,699	$4,994	($507)	$41,281	$863,787
24	2006	$2,095	$138,270	$25,699	$4,994	($507)	$41,281	$863,787
25	2007	$2,095	$138,270	$25,699	$4,994	($507)	$41,281	$863,787
26	2008	$2,095	$138,270	$25,699	$4,994	($507)	$41,281	$863,787
27	2009	$2,095	$138,270	$25,699	$4,994	($507)	$41,281	$863,787
28	2010	$2,095	$138,270	$25,699	$4,994	($507)	$41,281	$863,787
29	2011	$2,095	$138,270	$25,699	$4,994	($507)	$41,281	$863,787
30	2012	$2,095	$138,270	$25,699	$4,994	($507)	$41,281	$863,787
Discount rate		0.08	0.08	0.08	0.08	0.08	0.08	0.08
Net present value of benefits		**$12,679**	**$836,726**	**$155,516**	**$20,191**	**($2,048)**	**$166,914**	**$3,492,634**

Table 12 Flows of benefits accruing to producers sorghum, and beef in Northern Territory from the adoption of selected technologies developed during projects PN8326 and PN8735.

($A, 1990, millions)

Year number	Year	Sorghum	Beef	Total
1	1983	$0.00	$0.00	$0.00
2	1984	$0.00	$0.00	$0.00
3	1985	$0.00	$0.00	$0.00
4	1986	$0.00	$0.00	$0.00
5	1987	$0.00	$0.00	$0.00
6	1988	$0.00	$0.00	$0.00
7	1989	$0.00	$0.00	$0.00
8	1990	$0.00	$0.00	$0.00
9	1991	$0.00	$2.20	$2.20
10	1992	$0.02	$9.26	$9.28
11	1993	$0.03	$12.73	$12.75
12	1994	$0.03	$15.53	$15.56
13	1995	$0.05	$19.88	$19.93
14	1996	$0.05	$23.39	$23.44
15	1997	$0.07	$28.63	$28.70
16	1998	$0.07	$28.63	$28.70
17	1999	$0.07	$28.63	$28.70
18	2000	$0.07	$28.63	$28.70
19	2001	$0.07	$28.63	$28.70
20	2002	$0.07	$28.63	$28.70
21	2003	$0.07	$28.63	$28.70
22	2004	$0.07	$28.63	$28.70
23	2005	$0.07	$28.63	$28.70
24	2006	$0.07	$28.63	$28.70
25	2007	$0.07	$28.63	$28.70
26	2008	$0.07	$28.63	$28.70
27	2009	$0.07	$28.63	$28.70
28	2010	$0.07	$28.63	$28.70
29	2011	$0.07	$28.63	$28.70
30	2012	$0.07	$28.63	$28.70
Rate of discount		0.08	0.08	0.08
NPV in millions $A, 1991		**$0.0003**	**$0.1186**	**$0.1188**

The highest benefits are from technologies that do not require high levels of cash outlays to adopt, namely early planting, and boma manure. The technologies that require high levels of cash outlays (use of fertilisers) or which are associated with high perceived opportunity costs (mulching) tend to generate lower benefits over the period. The explanation for these low levels of benefits is that there is a lower level of adoption of those technologies.

4.3 Estimates of the rate of return due to the project

Table 13 consolidates the estimates of benefits and incorporates the research cost into the analysis to obtain an estimate of the net present value and the internal rate of return for the project. Table 13 shows that these two projects are likely, by the year 2012, to have generated net welfare benefits (net of research costs) equal to about $A18.5 million with an internal rate of return of just over 20%.

The rate of return of 20% is high given that the two projects focussed on an area that is in the climatically harsh, semi-arid tropics.

Table 13. Flows of benefits accruing to farmers in Machakos, Kenya and Northern Territory from the adoption of selected technologies developed during projects PN8326 and PN8735

($A, 1990, millions)

Year no.	Year	Australia	Kenya	Total benefits	Research costs	Net benefits
1	1983	$0.000	$0.00	$0.00	$2.12	($2.12)
2	1984	$0.000	$0.00	$0.00	$2.21	($2.21)
3	1985	$0.000	$0.00	$0.00	$1.90	($1.90)
4	1986	$0.000	$0.00	$0.00	$0.43	($0.43)
5	1987	$0.000	$0.00	$0.00	$0.54	($0.54)
6	1988	$0.000	$0.00	$0.00	$0.93	($0.93)
7	1989	$0.000	$0.00	$0.00	$0.84	($0.84)
8	1990	$0.000	$3.88	$3.88	$0.08	$3.80
9	1991	$0.002	$3.75	$3.75	$0.08	$3.67
10	1992	$0.009	$3.85	$3.86	$0.03	$3.83
11	1993	$0.013	$3.94	$3.96	$0.00	$3.96
12	1994	$0.016	$4.04	$4.06	$0.00	$4.06
13	1995	$0.020	$4.14	$4.16	$0.00	$4.16
14	1996	$0.023	$4.24	$4.26	$0.00	$4.26
15	1997	$0.029	$4.33	$4.36	$0.00	$4.36
16	1998	$0.029	$4.43	4.46	$0.00	$4.46
17	1999	$0.029	$4.53	$4.56	$0.00	$4.56
18	2000	$0.029	$4.53	$4.56	$0.00	$4.56
19	2001	$0.029	$4.53	$4.56	$0.00	$4.56
20	2002	$0.029	$4.53	$4.56	$0.00	$4.56
21	2003	$0.029	$4.53	$4.56	$0.00	$4.56
22	2004	$0.029	$4.53	$4.56	$0.00	$4.56
23	2005	$0.029	$4.53	$4.56	$0.00	$4.56
24	2006	$0.029	$4.53	$4.56	$0.00	$4.56
25	2007	$0.029	$4.53	$4.56	$0.00	$4.56
26	2008	$0.029	$4.53	$4.56	$0.00	$4.56
27	2009	$0.029	$4.53	$4.56	$0.00	$4.56
28	2010	$0.029	$4.53	$4.56	$0.00	$4.56
29	2011	$0.029	$4.53	$4.56	$0.00	$4.56
30	2012	$0.029	$4.53	$4.56	$0.00	$4.56
Net present value of benefits ($A, m, 1990)		$0.119	$25.57	$25.69	$7.23	$18.46
Internal rate of return (percent)						20.43%

5. THE IMPACT ON SCIENTIFIC KNOWLEDGE AND HUMAN CAPACITY BUILDING BY RESEARCH PROJECT (8326/8735)

5.1 The impact to knowledge

This project has led to two volumes of conference proceedings: Probert (Ed., 1992) and Craswell and Simpson (1994). In addition, more than 20 conference and journal papers were written as part of the project. Details of these papers are in Appendix A.

5.2 Human capacity building impacts

Improving the research capability of Kenyan scientists and institutions responsible for research on agricultural land management in semi-arid regions was one of the goals of the project. At the end of the project there was a core of scientists and support staff placed at the Kenya Agricultural Research Institute—Katumani who are able to continue the research work conducted in the two ACIAR projects. Training was through formal studies at Australian Universities. As part of this activity, 12 theses were written (6 at PhD level and 6 at Masters level). Details of these are in Appendix A.

6. CONCLUDING REMARKS

This paper has discussed the assessment of two ACIAR projects whose aim was to improve dry land crop and forage production in the semi-arid tropics. The results on the direct welfare impacts of the project indicate that these two projects led to a net benefits of about $A 18.5 million and an internal rate of return of about 20% per annum. Most of these benefits are projected benefits since the project was completed only a few years ago. The estimates are conservative since they do not take into account the possible spillovers to other regions and are based on the assumption that the adoption levels remain at the estimated levels in 1990 and do not change over the 30 year period.

In addition to the direct welfare benefits, the project contributed to knowledge of dry land farming in the semi-arid tropics and increased the research capacity of Kenyan scientists and institutions.

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