Natural Resources Institute

SOIL AND WATER CONSERVATION IN SEMI-ARID KENYA

Bulletin 61

Overseas Development Administration

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LIST OF ABBREVIATIONS

ACZ	Agro-climatic zone
AEZ	Agro-ecologic zone
AWS	Available water storage
CEC	Cation exchange capacity
CIMMYT	International Maize and Wheat Improvement Center
Cv	Coefficient of variation
DAP	Double ammonium phoshspate
Ec	Electrical conductivity
FAO	Food and Agriculture Organization of the United Nations
GoK	Government of Kenya
IFAD	International Fund for Agricultural Development
KARI	Kenya Agricultural Research Institute
KGGCU	Kenya Grain Growers Central Union
Ksh	Kenya shilling
me	milli-equivalents
NPV	Net present value
NRI	Natural Resources Institute
ODA	Overseas Development Administration
ODI	Overseas Development Institute
ppm	Parts per million
S&WC	Soil and water conservation
SARC	Sustainable Agriculture Research Centre
SIDA	Swedish International Development Authority
UNESCO	United Nations Education and Scientific Council
USDA	United States Department of Agriculture

Note: Chemical symbols, abbreviations for units of measurement and for the purpose of tables or figures are not included.

Summaries

SUMMARY

Sub-Saharan Africa is beset by an increasing population putting stringent demands on a declining resource base. Soil and water conservation (S&WC) is often seen as the primary means to arrest the inevitable decline in soil quality and maintain the productivity of farming systems upon which the majority of the populace rely for their precarious living standards. Yet S&WC programmes have a patchy record: in humid areas they may be relatively successful, but in semi-arid areas there is neither evidence of widespread adoption of S&WC nor increased production. These marginal areas, economically and climatically present the most intractable challenge to natural resource managers.

This study investigates the performance of S&WC in rainfed cropping in the drier parts of Kenya, paying particular emphasis to the yield benefits and economic viability of crop production systems for the small scale and most vulnerable of the rural land users. Results are based upon a series of experiments conducted over three crop growing seasons on three soils, testing 10 S&WC-based crop production systems with a monocrop of 75-day (short-season) maize (*Zea mays L.*: var. Makueni composite). The S&WC measures range from physical techniques of contour tillage, tied ridging and terraces to a partly biological technique of trashlines. Hand tillage was taken as the control. In this marginal environment (agro-climatic zones IV and V), the typical situation of small-scale farmers adding no fertilizer was compared with currently recommended levels of application of fertilizer and manure.

Assessment of the effects of S&WC on crop yield

Crop yield is influenced by the complex interactions of rainfall amount and distribution, soil physical properties such as infiltration, surface storage and plant-available soil water storage and soil fertility. S&WC directly affects all these except the first.

The yield response and a significant positive interaction between physical S&WC and soil fertility indicated that crop yields increases are achievable only with improved fertility. When soil fertility is not limiting, the largest yield increases are obtained in high rainfall seasons. Under prevailing poor fertility conditions, trashlines which do not only conserve moisture but also input nutrients give the best yield results, especially in soils which have good physical properties. S&WC by itself is only partially beneficial, being effective in alleviating drought stress in plants only in soils of poor physical state. These results confirm that S&WC-based crop production strategies must target increasing soil moisture availability and soil fertility either individually or integrally. The degree of yield benefits is soil specific.

Trashlines was the single most effective S&WC measure without manure or fertilizer additions, except soils with poor physical properties where tied ridging and terraces were better, albeit with only modest increase in yield. With improved fertility, trashlines were joined by tied ridging as the most effective on soils with good physical properties and tied ridging alone on the soils with poor physical properties.

Economic assessment of the S&WC-based crop production systems

An assessment of the costs in S&WC-based maize production systems found that the improvement of soil fertility is very much more costly than construction of S&WC while implements are comparatively cheap. The economic viability of the crop production systems depends upon the balance of these costs according to S&WC needs, the labour demand on other crop production activities and the conditions of the soils. Two scenarios for labour costs were employed.

With hired labour at seasonal market rates for all farm operations, S&WC-based maize production is only profitable in the short and long term with improved soil fertility in soils with high plant nutrient deficiency and good physical properties. Systems with trashlines, tied ridging and terraces also become profitable in the long term in soils with moderately good soil physical properties. It is only with trashlines that maize production is profitable in the short and long term with or without improved soil fertility in most soils.

With family labour at zero opportunity cost, most the systems are profitable. Greatest profits are obtained with improved fertility on soils with low initial fertility and good physical properties. Returns to soil fertility improvement diminish on poorer soils. In contrast, without additions of fertilizers or manure, physical S&WC is unprofitable in good physical property soils but profitable in poor soils. Nevertheless, in all cases S&WC measures improve the financial returns even though the whole system may remain unprofitable.

Overall, the most economically profitable system in all soils is non-fertilized trashlines. The performance of the other systems depends on soil quality, but generally fertilized systems perform worse than non-fertilized systems because of the high cost of fertilizer and manure.

Conclusion

Both the technical and economic analyses demonstrate the superiority of trashlines and the importance of site conditions of soils. Although the yield results appear to indicate that physical S&WC without improving soil fertility is ineffective, economic analysis suggests that such a crop production system is rational for resource-poor farmers. Only on good physical property soils with low fertility is it economical to enhance fertility along with introducing S&WC. Therefore, although some S&WC techniques hold generally good scope – e.g. trashlines – and some S&WC-based maize production system give both short- and long-term benefits, there are no easy solutions to sustainable agriculture and assured livelihoods. Blanket recommendations of S&WC measures and improvement of soil fertility are likely to fail. Nevertheless, carefully designed S&WC programmes do hold significant scope for increasing crop production, ensuring economic profitability to investments in resource management, and maintaining a secure future for rural poor in this marginal environment.

RÉSUMÉ

L'Afrique sub-saharienne est assiégée par une population croîssante, imposant des demandes rigoureuses sur une base de ressources en baisse. Il est fréquemment perçu que la conservation des sols et de l'eau (CS&E) constitue le principal moyen d'enrayer le déclin inévitable de la qualité des sols et de maintenir la productivité des systèmes agricoles sur lesquels la majorité des populations s'en remettent pour assurer leurs conditions précaires de vie. Les antécédents des programmes de la CS&E sont inégaux: dans les régions humides, ils peuvent être relativement couronnés de succès, tandis que dans les régions semi-arides, l'on n'observe ni témoignages de l'adoption répandue de la CS&E, ni un accroissement de la production. Ces régions marginales présentent, au point de vue économique et climatique, le défi le plus rebelle aux gestionnaires de ressources naturelles.

Cette étude examine les performances de la CS&E dans les cultures arrosées par les pluise dans les régions plus sèches du Kenya, accordant une attention toute particulière aux avantages des rendements et à la viabilité économique des systèmes de production des cultures pour les petits, et les plus vulnérables, exploitants agricoles ruraux. Les résultats sont basés sur un ensemble d'expériences ayant été effectuées au cours de trois campagnes de production de cultures sur trois sols, mettant à l'essai 10 systèmes de production de cultures basées sur la CS&E, avec une monoculture de maïs (*Zea mays L.*: var. Makueni Composite) de 75 jours (campagne courte). Les mesures de la CS&E vont des techniques physiques de labours en bandes de niveau, de buttages assujettis et de terrasses jusqu'à la technique partiellement biologique des tiges en bande pour la lutte anti-érosive (trashlines). Le buttage manuel a été utilisé à titre de émoin. Dans ce milieu marginal (régions agro-climatiques IV et V), on a comparé la situation typique des petits exploitants agricoles n'ajoutant aucun engrais aux niveaux actuellement préconisés en matière d'application d'engrais et de fumier.

Evaluation des effets de la CS&E sur le rendement des cultures

Les interactions complexes des hauteurs des précipitations et de leur répartition ont une influence sur le rendement des cultures, les propriétés physiques des sols, tels que l'infiltration, le stockage des eaux de surface et le stockage de l'eau dans les sols disponible aux plantes et la fertilité des sols. La CS&E a une influence directe sur l'ensemble de ce qui précède, à l'exception de la première citée.

La réponse des rendements et une interaction positive significative entre la CS&E physique et la fertilité des sols indiquent que les augmentations des rendements de cultures ne sont réalisables qu'avec une amélioration de la fertilité. Lorsque la fertilité des sols ne constitue pas un limitation, les plus importantes augmentations de rendements sont obtenues pendant la saison des fortes précipitations. Dans les conditions prédominantes de fertilité médiocre, la technique des tiges en bande pour la lutte anti-érosive (trashlines) qui non seulement conserve l'humidité mais également apporte des éléments nutritifs permet d'obtenir les meilleurs rendements et plus particulièrement dans les sols ayant de bonnes propriétés physiques. Par ellemème, la CS&E n'est que partiellement

salutaire, étant efficace au plan du soulagement des contraintes de la sécheresse des plantes, uniquement dans les sols dont l'état physique est médiocre. Ces résultats confirment que les stratégies de production de cultures basées sur la CS&E doivent viser l'augmentation de la disponibilité de l'humidité aux sols et la fertilité des sols, soit à titre individuel, soit global. Le degré des avantages sur les cultures est spécifique aux sols.

Les tiges en bande pour la lutte anti-érosive (trashlines) ont été la mesure de CS&E la plus efficace sans l'adjonction d'engrais ou de fumier, à l'exception des sols de médiocres propriétés physiques où les mini-crêtes liées pour la lutte anti-érosive (tide ridging) et les terrasses étaient plus performants, bien que ne présentant qu'une augmentation modeste du rendement. Avec la fertilité améliorée, les tiges en bande pour la lutte anti-zaerosive (trashlines) ont été rejointes par les mini-crêtes liées pour la lutte anti-érosive (tied ridging) seuls, sur les sols présentant des propriétés physiques médiocres.

Evaluation économique des systèmes de production de cultures basées sur la CS&E

Il a été observé dans une évaluation des coûts dans les systèmes de production de maïs basés sur la CS&E, que l'amélioration de la fertilité des sols est bien plus coûteuse que l'élaboration de la CS&E tandis que les mises en oeuvre sont relativement peu onéreuses. La viabilité économique des systèmes de production des cultures dépend de l'équilibre de ces coûts conformément aux exigences de la CS&E, de la demande en main-d'oeuvre sur les autres activités de production de cultures ainsi que des états des sols. Il a été employé deux scénarios pour les frais de main-d'oeuvre.

La production de maïs basée sur la CS&E, avec la main-d'oeuvre aux tarifs saisonniers en vigueur pour toutes les activités agricoles, n'est rentable à moyen et à long terme qu'avec une fertilité améliorée des sols présentant une carence élevée en éléments nutritifs des plantes et de bonnes propriétés physiques. Les systèmes avec les tiges en bande pour la lutte anti-érosive (trashlines), les mini-crêtes liées pour la lutte anti-érosive (tied ridging) et les terraces deviennent aussi rentables à long terme sur les sols présentant des caractéristiques physiques de moyenne qualité. La production de maïs, à court et à long terme, n'est rentable qu'avec les tiges en bande pour la lutte anti-érosive (trashlines) avec et sans amélioration de la fertilité des sols poour la plupart des sols.

Avec la main-d'oeuvre familiale constituant un coût d'opportunité nul, la plupart des systèmes sont rentables. On obtient les bénéfices les plus élevés avec une fertilité améliorée sur les sols de fertilité initiale faible et présentant de bonnes propriétés physiques. Les recettes par rapport aux améliorations de la fertilité des sols sont en baisse sur les sols pauvres. Par contraste, sans adjonctions d'engrais ou de fumier, la CS&E physique est peu rentable sur les sols présentant de bonnes propriétés physiques, mais rentable sur les sols pauvres. Dans tous les cas quoi qu'il en soit, les mesures de CS&E améliorent les recettes financières, même si dans son ensemble, le système demeure peu rentable.

Globalement, le système le plus rentable au plan économique dans tous les sols est celui des tiges en bande pour la lutte anti-érosive (trashlines) sans engrais. Les performances des autres systèmes dépendent de la qualité des sols, toutefois les performances des systèmes avec engrais sont généralement inférieures à celles des systèmes sans engrais, en raison de coûts élevés des engrais et du fumier.

Conclusion

L'analyse technique et économique fait la démonstration de la supériorité des tiges en bande pour la lutte anti-érosive (trashlines) et de l'importance des conditions des sols sur le terrain. Bien que les résultats des rendements semblent indiquer que la CS&E physique, sans amélioration de la fertilité des sols est inefficace, l'analyse économique suggère qu'un tel système de production des cultures est rationnel pour les exploitants agricoles dépourvus de ressources. Il n'est économique d'améliorer la fertilité avec l'introduction de la CS&E que sur les sols présentant de bonnes propriétés physiques et une faible fertilité. Par conséquent, bien que certaines techniques de CS&E bénéficient généralement de bonnes perspectives d'avenir, par exemple les tiges en bande pour la lutte anti-érosive (trashlines), et que certains systèmes de production du maïs basés sur la CS&E ont des avantages à court et à long terme, il n'existe pas de solutions faciles pour assurer une agriculture et des moyens d'existence soutenables. Il est vraisemblable que les recommandations générales des mesures de la CS&E et de l'amélioration des sols ne seront pas menées à bien. Néanmoins, des programmes de CS&E rigoureusement élaborés présentent en effet des perspectives d'avenir significatives pour augmenter la production des cultures, assurant la rentabilité économique des investissements en matière de gestion des ressources et en maintenant un avenir assuré pour les populations rurales démunies dans cet environnement marginal.

RESUMEN

El Africa Subsahariana se está viendo acosada por un aumento demográfico que está imponiendo fuertes demandas sobre una base de recursos en declive. A menudo se considera que la conservación de suelos y aguas (S&WC) es el principal método para detener la inevitable disminución de la calidad de las tierras y mantener la productividad de los sistemas agrícolas, de la que depende la mayor parte de la población para conservar su precario nivel de vida. Y, sin embargo, el palmarés de los programas S&WC no es particularmente alentador. Si bien en zonas húmedas han demostrado ser relativamente satisfactorios, en las zonas semiáridas no existe evidencia alguna de una adopción generalizada del sistema ni de que haya llevado a un incremento de la producción. Tanto económica como climáticamente, estas zonas marginales constituyen el reto de más difícil solución para los directores de recursos naturales.

En este estudio se investiga el rendimiento de los programas S&WC en cultivos de las zonas más secas de Kenya alimentados por la lluvia, con particular énfasis sobre los beneficios de rendimiento y viabilidad económica de los sistemas de producción para el sector más vulnerable, constituido por los agricultores en pequeña escala. Los resultados están basados sobre una serie de experimentos llevados a cabo durante tres temporadas de cultivo en tres tipos distintos de tierras, habiéndose examinado diez sistemas de producción de cultivos a base de S&WC con maíz (*Zea mays* L, variedad Makueni Composite) de 75 días (temporada corta) en régimen de monocultivo. Las medidas S&WC van desde técnicas físicas de labranza en curvas de nivel, caballones de desechos (trashlines) y cultivo en terrazas a una técnica parcialmente biológica de caballones de desechos (trashlines). En estos estudios, el control estuvo constituido por la labranza manual. En este medio ambiente marginal (zonas agroclimáticas IV y V), se comparó la situación típica de agricultores en pequeña escala, que no utilizaban fertilizantes, con niveles actualmente recomendados de aplicación de abonos y estiércol.

Evaluación del impacto de los programas S&WC sobre el rendimiento de los cultivos

El rendimiento de los cultivos se ve influenciado por las complejas interacciones de la cantidad y distribución de la pluviosidad, propiedades fisicas de los suelos, tales como infiltración, almacenamiento superficial y aguas freáticas disponibles para las plantas y fertilidad del suelo. A excepción del primero, los programas s&WC afectan directamente todos estos factores.

El rendimiento obtenido y una interacción positiva signficativa entre las técnicas S&WC fisicas y la fertilidad del suelo indicaron que solamente era posible conseguir un incremento en el rendimiento de los cultivos con una mejora de la fertilidad. En aquellos casos en que la fertilidad del suelo no representa un factor límite, los mayores rendimientos se obtienen en temporadas con elevada pluviosidad. Bajo las condiciones de escasa fertilidad prevalecientes, caballones de desechos (trashlines) que no solamente conservan la humedad, sino que constituyen una fuente de elementos nutritivos proporcionan los mejores resultados, particularmente en suelos con buenas propiedades fisicas. De por sí, las técnicas S&WC solamente resultan parcialmente beneficiosas, ya que únicamente alivian el estrés de la sequía sobre las plantas en suelos con una condición fisica deficiente. Estos resultados vienen a confirmar que las estrategias de producción a base de S&WC deberán dirigirse a incrementar la disponibilidad de la humedad y fertilidad del suelo, bien individual o integralmente. El grado de beneficios de rendimiento depende del suelo.

Los caballones de desechos (trashlines) representaron la medida S&WC individual más eficaz sin la adición de abonos o estiércol, excepto en suelos con pobres propiedades físicas, en donde los minicaballones (tied ridging) y las terrazas proporcionaron mejores resultados, si bien con un modesto incremento solamente en el rendimiento. Con mejora de la fertilidad, los caballones de desechos (trashlines) fueron, junto con los minicaballones (tied ridging), el método más eficaz para suelos con buenas propiedades físicas. En tierras con pobres propiedades físicas, el mejor método fueron los minicaballones (tied ridging).

Evaluación económica de los sistemas de producción de cultivos a base de S&WC

Al evaluar los costes de sistemas de producción de maíz a base de S&WC se observó que la mejora de la fertilidad del suelo es muy superior a la de la construcción de S&WC, mientras que los aperos son comparativamente más económicos. La viabilidad económica de los sistemas de producción de cultivos depende del equilibrio de estos costes de acuerdo con las exigencias de S&WC, demanda de mano de obra sobre otras actividades de producción de cultivos y condiciones de los suelos. Dos fueron los planteamientos por cuanto al coste de la mano de obra.

Con mano de obra contratada a tarifas de mercado estacional para todas las operaciones agrícolas, la producción de maíz a base de S&WC solamente resulta rentable, tanto a corto como a largo plazo, con mejora de la fertilidad de las tierras en terrenos con elevada deficiencia de elementos nutritivos vegetales y buenas propiedades físicas. De igual modo, los sistemas con caballones de desechos (trashlines), minicaballones (tied ridging) y terrazas se hacen rentables a largo plazo en suelos con propiedades físicas moderadamente buenas. La producción de maíz

solamente resultó rentable a corto y largo plazo en la mayor parte de los suelos con los caballones de desechos (trashlines), con o sin mejora de la fertilidad del suelo.

Con mano de obra familiar de coste nulo, la mayor parte de los sistemas son rentables. Se consiquen grandes beneficios con mejora de la fertilidad en suelos con baja fertilidad inicial y buenas propiedades fisicas. Los beneficios de la mejora de la fertilidad del suelo decrecen para suelos más pobres. Por el contrario, sin la adición de abonos o estiércol, las técnicas de S&WC no son rentables en suelos con buenas propiedades físicas, pero sí que lo son en suelos pobres. Sin embargo, las medidas de S&WC mejoran en todos los casos los beneficios financieros, aunque el sistema total continúe sin ser rentable.

En líneas generales, el sistema con mayor rentabilidad económica en cualquier tipo de suelo son los caballones de desechos (trashlines) sin abonos. Si bien el rendimiento de los otros sistemas depende de la calidad del suelo, normalmente, la rentabilidad es inferior en sistemas que requieren la aplicación de abonos que en sistemas sin fertilizantes, como resultado del elevado coste de los fertilizantes y del estiércol.

Conclusion

Tanto desde el punto de vista técnico como económico, este análisis ha demostrado la superioridad de los caballones de desechos (trashlines) y la importancia de la condición del suelo. Si bien los resultados de rendimiento parecen indicar que las técnicas S&WC fisicas son ineficaces sin mejora de la fertilidad del selo, el análisis económico parece sugerir que dicho sistema de producción es racional para agricultores con escasos recursos. Solamente en suelos con buenas propiedades físicas y baja fertilidad resulta económico mejorar la fertilidad junto con la introducción de S&WC. Así, pues, si bien algunas de las técnicas S&WC poseen, en general, buenas poosibilidades -- por ejemplo, los caballones de desechos (trashlines) – y ciertos sistemas de producción de maíz a base de S&WC proporcionan beneficios a corto y largo plazo, no existen soluciones fáciles para el logro de una agricultura sostenible y preservación de los medios de subsistencia. Toda recomendación generalizada de técnicas S&WC y mejora de la fertilidad de los suelos se encuentra probablemente llamada al fracaso. Sin embargo, no cabe duda de que programas S&WC cuidadosamente preparados poseen buenas probabilidades de mejorar la producción de los cultivos, consequir rentabilidad económica de la inversión en gestión de recursos y lograr un futuro seguro para la población rural de este medio ambiente marginal.

Chapter 1

Introduction

THE ROLE OF SOIL AND WATER CONSERVATION IN CROP PRODUCTION

In Sub-Saharan Africa soil erosion seriously threatens agricultural production and the livelihoods of millions of rural land users. As IFAD (1992) points out, the link between land degradation, worsening poverty and the further marginalization of rural people is inescapable. With declining soil quality, the capacity of the land and water resources to support a growing population is in severe jeopardy. For sheer survival, this increased population extensifies cultivation and overstocks the reduced rangelands, thereby exacerbating an already perilous situation.

Soil and water conservation must, therefore, be the primary means of securing the resources base, increasing soil and vegetation productivity and halting the decline in living standards of the land users. At the core of any strategy of soil and water conservation (S&WC) in the poor subsistence economies of rural Africa are the maintenance and enhancement of food crop production on rainfed agricultural land. While irrigation has obvious local applications and forests and rangelands management are important to some communities, it is the sustainable production of rainfed crops that is at the heart of food security and hence the key to rural and agricultural development. Most of the rural poor communities have no financial and technical means with which to join the development process. The focus of S&WC for these people must, therefore, be on increasing the productivity of the land, not on saving the soil. Hence, the theme of this bulletin is very firmly on how S&WC may improve immediate production for vulnerable land users, living at the margins, who have no resources with which to apply advanced technologies, no room to apply risky techniques and no time to wait for the assumed benefits of classical methods of S&WC.

What are the major influence of erosion on soil productivity and hence what aspects of soil quality might be most profitably targeted in a S&WC strategy? The availability of soil moisture has been identified as the most crucial constraint in most areas but especially in semi-arid zones (Arnon, 1972; Hudson, 1987; Stocking, 1984; Biot, 1988). Erosion selectively removes the finer soil particles and organic matter, and reduces soil depth and rooting volume thereby causing water stress in plants during periodic breaks in rain; erosion reduces plant biomass and hence replenishment of organic matter; erosion affects surface soil structure, increasing runoff and reducing infiltration rates (Becher, 1983; Mbagwu, 1988; Lal, 1981). An associated factor which has received somewhat greater attention is erosion's impact on soil nutrients and inherent chemical fertility. The loss of the soil fine fraction and organic matter reduces the total available nutrients. Equally, erosion is very effective in removing applied inorganic nutrients, either dissolved in runoff and ground water or attached to the cation exchange of clays and organic matter. Despite the technical importance of understanding these processes, this bulletin is not solely concerned with the problems of maintaining plant available water and nutrient availability as a means of S&WC. If the problems were as simple as this, there would be no food security crisis in Africa. Instead S&WC programmes and projects have been notorious in their inability to meet targets and be institutionally sustainable (Hudson, 1991). The challenge, therefore, is only partly technical; social acceptability, economic viability and practicability within the resources of the land users must be the principal criteria for soil and water conservation for improved crop production (Stocking and Abel, 1992)

SOIL AND WATER CONSERVATION SERVICES IN KENYA

Soil conservation services were established in Kenya as definable activity as early as 1937 and have undergone considerable development especially in implementation of projects (GoK/SIDA, 1982; 1985). With its many projects Kenya is often quoted as a success story (Hudson, 1987). Work was, however, concentrated on the humid (high and medium potential) areas where the constraints are fewer and the opportunities significantly greater. The low potential, semi-arid zones have until recently been neglected and attempts to transfer the experience gained in other parts of the country to these areas have run into major technical and implementation problems. What works for high potential areas does not perform on low potential resource-poor farms. Certainly, there has been no reliable evidence of improved productivity in the semi-arid areas through S&WC.

The information base for the transfer and adaptation of technologies of S&WC suitable to the specific environmental and social conditions of semi-arid Kenya is inadequate. This study makes a research contribution towards assessing the performance of S&WC measures specifically for rainfed cropping in the drier parts of Kenya with particular emphasis on ensuring viable crop production for the small-scale and most vulnerable of the rural land users.

OBJECTIVES OF THIS RESEARCH

This study investigates the performance in crop production and the applicability to small-farm conditions of a set of S&WC measures. The main goal is to assess the effectiveness of these measures in increasing the crop yields and improving the livelihoods of the land users. The primary aims are, therefore, twofold:

- to determine crop production benefits with S&WC, as assessed by crop yields, in specified semi-arid cropping system; and
- to assess the economic feasibility of S&WC-based crop production systems, as an indicator of likely acceptability.

Chapter 2

The study area and the trial sites

THE STUDY AREA

The study was carried out in a semi-arid area situated in the eastern footslopes of Mt Kenya, in the Embu and Meru districts of the eastern province. Field surveys were undertaken at representative sites in 1990. In order to derive quantitative data and develop and test a theoretical model of crop yield in relation to conservation-specific variables, experimental plots were set up at three sites and run through three growing seasons in 1990 and 1991.

The semi-arid area in Kenya is in agro-climatic zones (ACZ) IV and V according to Sombroek *et al.* (1982) or agro-ecological zones (AEZ) 4, 5 and 6 according to Jaetzold and Schmidt (1983). The ratio of average annual rainfall to average annual potential evaporation is 0.25-0.5, and average temperature ranges from 18°C to 30°C. The annual growing period is between 110 to 235 days (Sombroek *et al.*, 1982) and is described as very short to short (Jaetzold and Schmidt, 1983). The main land use zones are described as marginal cotton, millet-livestock and ranching or extensive grazing. On the eastern footslope of Mt Kenya, the semi-arid area occupies the lower altitude parts of Embu, Meru and Isiolo Districts (*see* Figure 1).

Mean annual rainfall based on four meterological stations in the area varies from 716 mm to 892 mm. Variability is not only great spatially but also temporally (the coefficient of variation ranging from 24 to 41), indicating the likelihood of drought. The rainfall pattern is bimodal with one season lasting from mid-March to mid-May (approximately 60 days) and the other from mid-October to mid-January (approximately 80 days) (*see* Figures 2a to d). The season starting in October is, therefore, longer than that starting in March, although the rainfall amount is higher in the March season. This is different from other parts of the country where long rains are in the season starting in March, locally referred to as April rains, while the short rains are in the season starting in October, locally referred to as November rains. Seasonal rainfall is also variable (Cv 30-66%) indicating a high likelihood of seasonal drought in the area.

The physiography of the area is complex. The main physiographic units are mountains, hills, uplands and dissected plains, bottomlands and minor valleys of a complex drainage system (van der Weg and Mbuvi, 1975; Sombroek *et al.*, 1982; Kiome *et al.*, 1990). The predominant physiographic unit is the erosional uplands which are characterized by undulating to rolling landforms intensively dissected by a dendritic system of minor valleys of the drainage system.

Sombroek *et al.* (1982) identified the major soils in the area as *ferric, orthic, rhodic or chromic Acrisols, Ferralsols,* and *Luvisols.* Kiome *et al.* (1990, unpublished) and de Meester and Legger (1988) in soil surveys covering the northern part of the area have described soil mapping units comprising various subgroups of *Luvisols, Cambisols, Lithosols, Acrisols* and *Regosols* with varying degrees of stoniness, rockiness and soil depth. Van der Weg and Mbuvi (1975), in

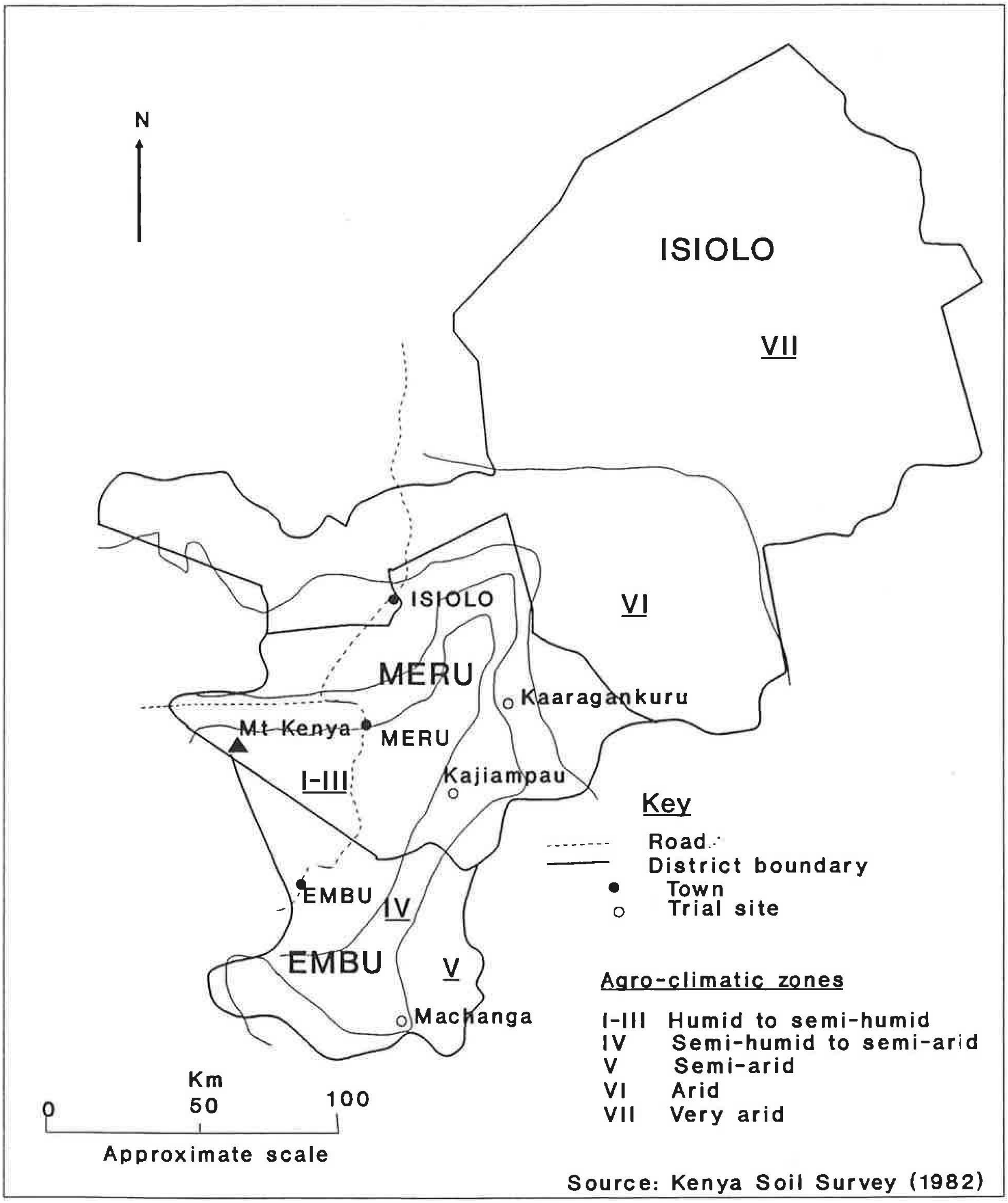


Figure 1 Agro-climatic zones and location of the trial sites

a soil survey covering the southern part of the area, have described soil mapping units comprising of *Luvisols, Cambisols, Lithosols, Acrisols Regosols, Ferralsols and Arenosols* also with varying degree of stoniness, rockiness and soil depth.

The general attributes of the farming system in the area are:

- small-scale, subsistence type of farming using a low level of technology;
- the common food crops range from cereals such as maize, sorghum and millet and legumes such as various varieties of peas, grams and pulses. The main cash crops, cotton and sunflower, are grown only to a small extent;

- land is cultivated continually but short periods of fallowing are still practised in the drier areas;
- crops are usually intercropped and rotated. Cereals are usually intercropped with legumes but the rotation pattern is not defined; and
- livestock (cattle, sheep and goats) are kept on the farm and grazed extensively.

THE EXPERIMENTAL SITES

The trial sites were selected to represent agro-climatic zones IV and V, two of the major soils in the area and landforms which are primarily used for cultivation of crops. Three sites, namely: Machanga, Kajiampau and Kaaragankuru were selected on this basis. The climate, geology, landforms and soil characteristics were determined in detail using various field and laboratory methods and procedures (*see* Kiome, 1992).

Location

The location of the sites is shown in Figure 1 and Table 1. The Machanga trial site was located in the southern part of the area at an elevation of about 1067 m while Kaaragankuru was in the northern part of the area at an altitude of 643 m. Kajiampau was in the central part of the area at an elevation of 758 m. The three sites are situated within 0° to 0° 50′S latitudes and 37° 41′ to 38° 02′E longitudes.

Table 1 Location, soils and ACZ of the trial sites

Site name	Latitude	Longitude	Altitude (m)	Soils	ACZ	Land form
Machanga	0° 47′S	37° 41′E	1067	*orthic Ferralsols*	IV	Middle uplands
Kajiampau	0° 44′S	37° 51′E	758	*chromic Luvisols*	IV	Middle uplands
Kaaragankuru	0° 00′S	38° 02′E	643	*chromic Luvisols*	V	Lower uplands

Geology and topography

According to Schoeman (1951), the area consists of Precambrian Basement Systems rocks which comprise heterogenous gneisses, granulites and schists. These are invaded in many places by masses of gabbroic, perkinitic and granitic intrusions. The main rock types are classified as plagioclase-hornblende gneiss, quartzite, granitic migmatites, granulites, granitoid gneiss and gabbro-norite.

At Machanga, the rocks were identified as granitoid gneiss consisting of muscovite and quartz as the predominant minerals, with biotite and feldspars in small proportions. At Kajiampau and Kaaragankuru the rocks were classified as hornblende-biotite gneiss, consisting of hornblende and quartz as the predominant minerals and biotite and feldspars in small proportions. Quartzitic and granitic migmatites occur in the vicinities of the sites forming tors.

The landform at the trial sites is undulating to gently undulating uplands with convex slopes, 50-150 m long, dissected by gullies and scattered with termite mounds and tors. At Machanga, the average slope is 6% while at Kaaragankuru it is 7%. Kajiampau has the lowest slopes of 5%.

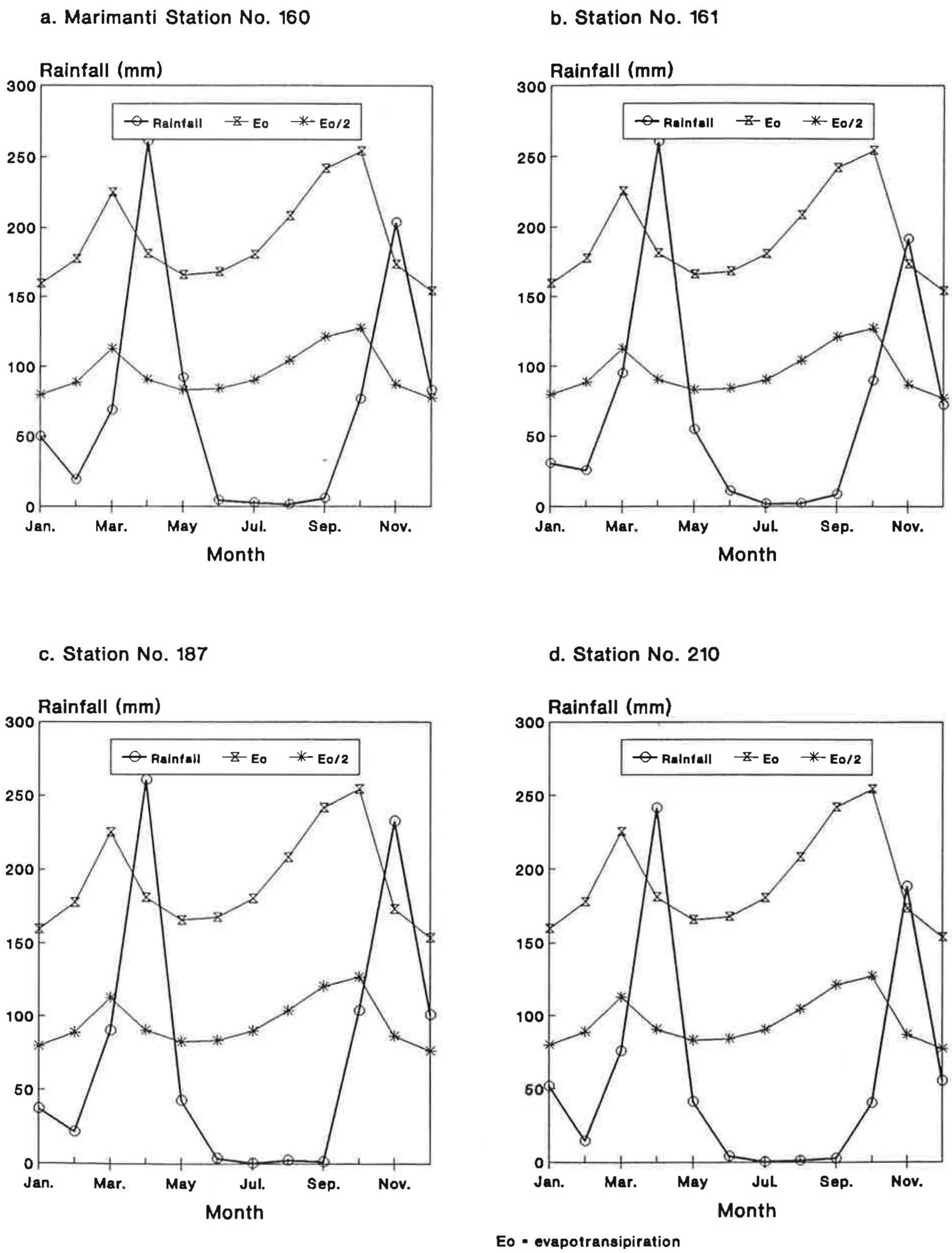


Figure 2 Average monthly rainfall and potential evaporation at four stations in the semi-arid area of Embu and Meru districts

Climate

Rainfall and evaporation

During the period of the trials, rainfall was above average in the long rains of 1990 and below average in the short rains of 1991 as shown in Table 2. At Machanga it was 325 mm during the long rains and only 172 mm during the short rains. Kajiampau and Kaaragankuru had higher rainfall than Machanga during the two seasons but it was much higher in the long rains than the short rains. The long rains of the October 1990 season are, therefore, considered as a relatively wet season while the short rains of March 1991 season were a 'drought' season. The number of rain days were below the average of 10 years recorded at Marimanti during the drought season and above average during the wet season, except at Machanga. Potential evaporation at the trial sites was also comparable to the 10 years' mean recorded at Marimanti.

Table 2 Climatic factors at a representative station and the trial sites

Station	Period	Rainfall (mm)	R-days	Eo* (mm)
Marimanti, mean of 10 years	Annual	853.0	57	2236
	Short rains	429.9	27	571.6
	Long rains	397.7	27	723.7
Machanga	Annual (1990)	879.8	51	1878.4
	Short rains (1990)	416.4	17	468.8
	Long rains (1990)	325.8	22	625.8
	Short rains (1991)	172.6	11	486.6
Kajiampau	Long rains (1990)	643.6	41	622.1
	Short rains (1991)	340.8	17	
Kaaragankuru	Long rains (1990)	548.8	39	749.0
	Short rains (1991)	343.1	17	

Note: * evapotranspiration

Temperature and relative humidity

Average monthly temperatures at Machanga ranged between 22°C and 26°C with the average maximum of 31.3°C and minimum of 12.8°C in most months. At the trial sites temperature and relative humidity are comparable to the 10 year average recorded at Marimanti. Kaaragankuru has slightly higher average temperatures and relative humidity than the other two trial sites. The Machanga and Kajiampau trial sites were considered to belong to the same agro-climatic zone IV while Kaaragankuru was considered to be representative of zone V.

Soils

As mentioned below the major soils in the study area include *Luvisols* and *Ferralsols*. However local differences occur in soil depths, soil physical, chemical and fertility properties. Difference in surface features such as stoniness, rockiness, micro-relief, erosion and surface sealing also occur.

Soils at Machanga

Description. Well drained, moderately deep to deep, yellowish red (5YR4/6) to strong brown (7.5YR4/6) when moist, friable sandy clay loam. The soils were classified as *haplic Ferralsols, plinthic phase* (FAO-UNESCO, 1989) or *plinthic Haplustox* (USDA, 1990). The underlying material is a mixture of iron and manganese concretions, nodules (plinthite) and quartz gravel. The topsoil is strong brown (7.5YR4/6) to brown (7.5 YR4/4), fine sand to sandy loam varying in depth from 15 cm to 25 cm. At the surface there is an overwash of sand, indicating slight sheet erosion, and sparsely scattered termite mounds. A thin and weak surface sealing also occurs on bare soil.

Physical properties. The physical and chemical properties of the soil are summarized in Table 3. The soil profile is loamy sand to sandy clay loam but clay increases slightly with depth. Average bulk density ranges from 1.35g/cm³ to 1.55 g/cm³, also increasing with depth. Available water storage (AWS) is low, and increases with depth. The average fraction of soil moisture (over the whole profile) at permanent wilting point (tension of 15 bar, i.e. pF 4.2) is 0.023 and at field capacity (tension of 0.2 bar, i.e. pF 2.3) is 0.198 (v/v). The basic infiltration rate is quite variable at the location, ranging between 16 cm/h to 28 cm/h. This is considered as very rapid (Landon, 1984) indicating that runoff is unlikely except in the most intense storms.

Table 3 Summary of soil physical and chemical properties of the soils at Machanga

Depth	0-22 cm	22-40 cm	40-80 cm	80-100 cm
Bulk density (g/cm³)	1.35	1.42	1.55	1.45
Available water storage (v/v) (%)	12	13	28	30
Sand (%)	71	65	63	66
Silt (%)	17	14	14	11
Clay (%)	12	21	23	23
Texture (class)	LS	SCL	SCL	SCL
pH-H_2O	5.47	5.24	5.29	5.43
pH-KCl	4.50	4.08	3.98	4.06
Electrcial conductivity (mmhos/cm)	0.05	0.03	0.04	0.03
C (%)	0.39	0.33	0.27	0.35
Cation exchange capacity (me/100 g soil)	5.07	7.90	7.98	7.33
Ca^{++} (me)	1.35	1.16	0.99	0.43
Mg^{++} (me)	0.34	0.61	0.48	0.29
K^{+} (me)	0.28	0.22	0.15	0.13
Na^{+} (me)	0.23	0.20	0.23	0.36
Sum of Ca^{++}, Mg^{++}, K^{+} and Na^{+}	2.19	2.20	1.89	1.51
Base saturation (%)	45.67	29.70	24.80	24.17
Exchange acidity (me)	2.89	5.40	6.13	5.84

Chemical properties and soil fertility. The pH-H_2O of the soil ranges from 4.5 to 5.5 and the exchangeable complex is dominated by Al^{++} ions as shown by the high exchangeable acidity. Organic carbon, base saturation and cation exchange capacity (CEC) are low throughout the profile. The soil is strongly weathered as indicated by the high silt:clay ratio.

The soils are low in all the plant nutrients as shown in Table 6. Aluminium toxicity and phosphorus fixation are likely as indicated by high exchangeable aluminium and the low pH. Leaching of nutrients and fertilizer, if applied, will be likely due to the high infiltration rate. The soils can therefore be said to be poor in nutrient availability for plant growth.

Soils at Kajiampau

Description. Well drained, shallow to deep, yellowish red (5YR4/6) to dark reddish brown (2.5YR4/4) when moist, friable sandy clay loam to clay. The soils were classified as *chromic Luvisols* (FAO-Unesco, 1989) or *udic Rhodustalfs* (USDA, 1990). The underlying material is soft weathering rock and the top soil is dark greyish brown (10YR2/2) to dark brown (10YR4/4 – 7.5YR3/2), varying in thickness from 15 cm to 25 cm and granular in structure. Slightly stony patches occur at the surface.

Physical properties. The summary of the physical and chemical properties is shown in Table 4. The texture is sandy clay to clay, increasing significantly with depth and bulk density is about 1.53 g/cm³. Available water storage is moderately high and decreases slightly with depth. The average fraction of soil moisture content at permanent wilting point is 0.101 and at field capacity it is 0.288 (v/v). Basic infiltration rate varies within the location from 10 cm/h to 13 cm/h and is considered as moderately rapid (Landon, 1984).

Table 4 Summary of soil physical and chemical properties of soils at Kajiampau

Depth	0-15 cm	15-50 cm	50-100 cm
Bulk density (g/cm^3)	1.56	1.54	1.53
AWS (v/v) %	20	18	18
Sand (%)	50	49	31
Silt (%)	10	10	10
Clay (%)	41	41	59
Texture (class)	C	C	C
pH-H_2O	6.75	6.25	6.85
pH-KCl	6.0	4.95	5.60
Electrical conductivity (mmhos/cm)	0.09	0.05	0.12
C (%)	0.35	0.25	0.40
Cation exchange capacity (me/100g soil)	12.85	13.15	15.55
Ca^{++} (me)	3.90	4.35	5.50
Mg^{++} (me)	3.00	3.05	4.65
K^+ (me)	0.65	0.20	0.10
Na^+ (me)	0.15	0.18	0.19
Sum of Ca^{++}, Mg^{++} K^+ and Na^+	7.70	7.78	10.44
Base saturation (%)	63.24	60.13	67.30

Chemical properties and soil fertility. The soil pH-H_2O ranges from 5.5 to 6.5 and base saturation is over 50% throughout the profile. Organic carbon, hence organic matter content, is very low throughout the profile. The exchange complex is dominated by Ca^{++} although the CEC is generally low.

The soils are relatively poor in potassium and nitrogen but plant-available phosphorus is high due to usage of fertilizer in the past. Micronutrients are also low, but the high base saturation and medium infiltration rate are favourable for the retention of plant nutrients. The chemical and fertility conditions can be said to be fairly good for plant growth.

Soils at Kaaragankuru

Description. Well drained, moderately deep to deep, dark red (2.5YR3/6) to dark reddish brown (5YR3/4) when moist, friable clay loam to clay. The soils are classified as *chromic Luvisols* (FAO-UNESCO, 1989) or *udic Rhodustalfs* (USDA, 1990). The underlying material is weathered rock and in places there is a stoneline at 40-60 cm. The topsoil is thin (5-15 cm) and in places the B horizon is exposed due to sheet and rill erosion. The surface is capped by a thick (3-5 mm) surface seal. Patches of stones and gravel occur at the surface and the micro-relief is mainly rills and gullies.

Physical properties. Soil physical and chemical properties are summarized in Table 5. The texture ranges from clay loam to clay, increasing with depth. The soil is very compact, with bulk density of about 1.6 g/cm^3 throughout the profile. Available water storage is low and increases with depth. The average fraction of soil moisture at permanent wilting point is 0.182 and at field capacity is 0.353 (v/v). The basic infiltration rate ranges from 1 cm/h to 2 cm/h which is very slow (Landon, 1984).

Chemical properties and soil fertility. The soil pH-H_2O is 6.5-7 and the base saturation is more than 50% throughout the profile. Organic matter content is very low and the exchange complex is dominated by Ca^{++} although CEC is low.

Table 5 Summary of physical and chemical properties of the soils at Kaaragankuru

Depth	0-20 cm	20-80 cm
Bulk density (g/cm^3)	1.60	1.63
AWS (v/v) (%)	14	17
Sand (%)	54.0	46.0
Silt (%)	8.0	6
Clay (%)	36	48
Texture (class)	SCL	C
pH-H_2O	6.5	6.55
pH-KCl	5.4	5.68
Electrical conductivity (mmhos/cm)	0.06	0.10
C (%)	0.26	0.21
Cation exchange capacity (me/100g soil)	13.38	10.58
Cation exchange capacity (me/kg clay)	3.72	2.2
Ca^{++} (me)	4.35	3.60
Mg^{++} (me)	2.21	2.36
K^{+} (me)	0.34	0.28
Na^{+} (me)	0.35	0.23
Sum of Ca^{++}, Mg^{++}, K^{+} and Na^{+}	7.25	6.46
Base saturation (%)	56.51	60.77

The soils are relatively poor in nitrogen and potassium but have fairly high amounts of available phosphorus. The micronutrients are also low but the high base saturation and low infiltration rate indicate high nutrient retention. Hence the chemical and soil fertility conditions can be considered as relatively good for crop growth, but the high bulk density could be a hindrance to root development.

Table 6 Soil fertility properties at the trial sites

Site	pH-H_2O	Na^{+} (me)	K^{+} (me)	Ca^{++} (me)	Mg^{++} (me)	Mn^{++} (me)	P (ppm)	N (%)	C (%)	Organic matter (%)
Kaaragankuru	6.59	0.43	0.99	6.99	4.19	0.79	67.6	0.03	0.24	0.45
Kajiampau	6.51	0.24	0.23	7.89	3.73	0.45	137.6	0.06	0.39	0.79
Machanga	5.07	0.20	0.25	1.38	0.60	0.19	11.8	0.03	0.36	0.61

Chapter 3

The field experiments

Field experiments were conducted for three rainfall seasons, between March 1990 and July 1991. The experiment was piloted and tested at Machanga during the first season. Improvements were made and the experiments were then conducted at two other sites. Location and details of the trial sites are given in Chapter 2, *The Experimental Sites*.

MATERIALS AND METHODS

The treatments

The two factors considered to be the major limiting factors in crop production and influenced by S&WC measures are: soil chemical fertility and soil moisture availability. Because of the expected interactions between plant nutrients and water availability, the experiments were designed to hold one of these factors constant while the other was allowed to vary. Soil chemical fertility was varied by fertilizer application while soil moisture variability is largely a function of the conservation technique. Two levels of soil fertility and five types of S&WC were tested.

Soil and water conservation measures

Hand tillage: land is tilled by hand implements (hand hoes). This is common with farmers who do not practise any conservation method, and may be considered as the control.

Trashlines: this is a traditional method in which the organic materials are placed in a surface strip along the contour to form a barrier to runoff. It is a common practice in the area but there is no technical specification for spacing. Gichuki (1991) put trashlines with grass strips as a contour farming S&WC measure. He mentions that they have been effectively used to control soil and water losses and to develop bench terraces, but there is no research on their effectiveness in either controlling soil erosion or improving crop yield. In this study, the maize residues from the previous season were placed along the contour 3.3 m apart (three trashlines per plot) equivalent to 3300 m of trashlines per ha.

Contour tillage: this is tilling the land along the contour leaving a set of small ridges and furrows to intercept and temporarily store overland water flow. Land tillage by ox-drawn mouldboard plough along the contour is a common practice in the area. Agricultural extension workers and the farmers do not normally consider such tillage as an S&WC measure. Nevertheless it is widely recognized as such (e.g. Johnson *et al.*, 1979; Muchiri and Gichuki, 1982). Some studies in the tropics have reported significant reduction in soil loss and runoff (Baffoe-Bonnie and Quansah, 1975; Weatherly and Dane, 1979; Khatibu *et al.*, 1984; Johnson *et al.*, 1979) but little has been done on their comparative improvement of crop production.

Tied ridging: ridges are made at 0.5-1.0 m spacing along the contour and then 'tied' by cross ridges to form a set of depressions giving a large surface water storage (*see* Figure 3). Studies indicate that tied ridging is effective in controlling soil loss and runoff and, under certain conditions, improving crop production (Krishna, 1989; Dagg and McArtney, 1968; Marimi, 1977; Njihia, 1977, 1988; Liniger, 1988). However it has a high risk of failure (Kiome, 1992) and demands a great deal of labour. There is little information on its comparative advantage over other measures in improving crop production and the cost of construction. In this study the tied ridges were made with hand implements at intervals of 75 cm to conform with the plant row spacing. The cross 'ties' were made at spacings of 60 cm.

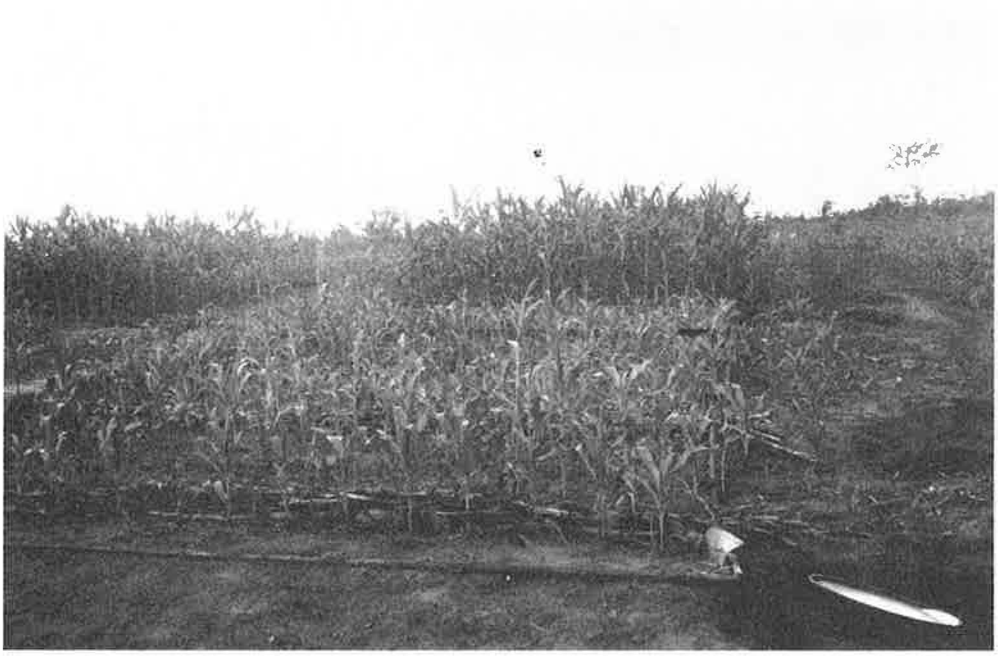


Figure 3 Tied ridging

Note: Poor crop of maize in non-fertilized level in the foreground with a very good crop in the fertilized level in the background

Fanya juu terrace: this is a type of backslope bench terrace made by digging a trench and throwing the soil up-slope to form an embankment (*see* Figure 4). It was introduced to Kenya in about 1956 as an alternative to the normal narrow based terrace. Several authors describe the origin application and design specification of the *fanya juu* terrace (Gichungwa, 1972; Wenner, 1981; Barber *et al.*, 1981; Thomas and Biamah, 1989). All sediment and runoff is intended to be entrapped and these terraces have a reputation of being very effective. Some studies also indicate that crop production is increased (Holmberg, 1985; Lindgren, 1988). It is a practice which is promoted by the agricultural extension services and it is used by many S&WC programmes as an indicator of their success. Gichuki (1991) states that by 1977 *fanya juu* had become the most popular method of developing bench terraces despite its high labour demand for construction and maintenance. However there is very little reliable information on its comparative advantage in improving crop yield and the cost of construction. In this study the terraces were made using the standard design specification. A horizontal interval of 10 m was used to conform with the size of the plots. The embankment was made to a height of about 70 cm and compacted to avoid breaking. Soil was piled at both ends to ensure that most of the runoff was contained in the plot.

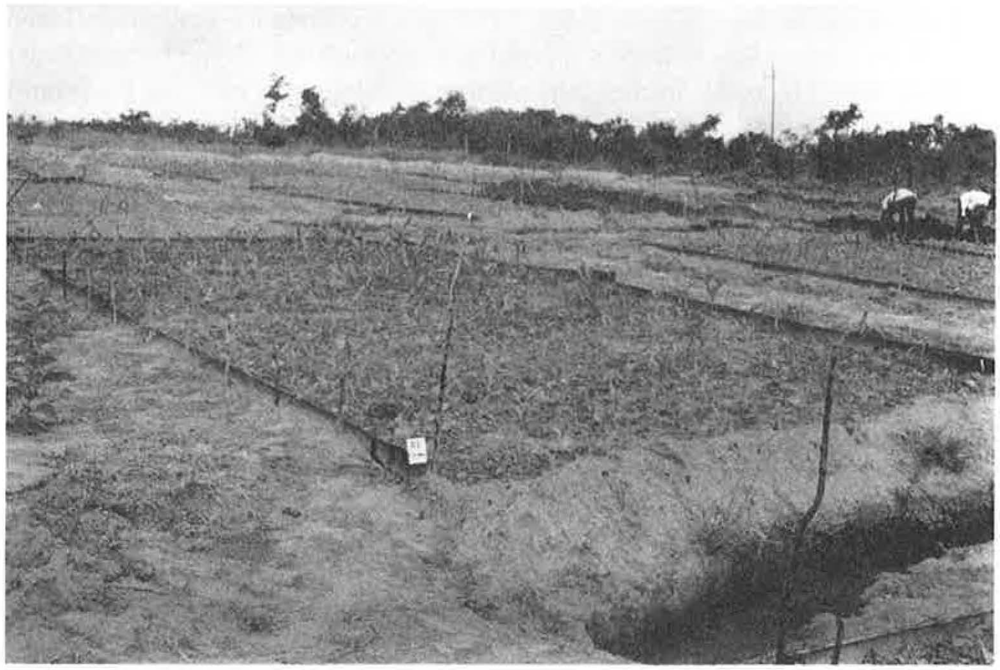


Figure 4 *Fanya juu* terrace

Soil fertility levels

The soils in the area are generally infertile (*see* Chapter 2, *Soils* and Table 6). Where soil fertility is poor, the roots of the crop will not develop to extract the moisture from the soil at deeper levels even if moisture is available. Since the effects of S&WC on crop production in a semi-arid area are primarily through the improvement of soil moisture, it is essential to vary soil fertility levels while investigating the effectiveness of conservation measures on crop yield.

As a control, one treatment had no fertilizer or farmyard manure applied. The second treatment had 120 kg/ha of N; 230 kg/ha of P_2O_5 and 25 kg/ha of K applied in the form of double ammonium phosphate (DAP); N:P 23:23 and muriate of potash fertilizers. The P_2O_5 application was very high because of using compound fertilizers with a low nitrogen content. Thus, the amount of fertilizer required to supply a reasonable amount of nitrogen gives high levels of P_2O_5. Two split applications of fertilizer were used: the DAP as a starter; and the mixture of N:P and muriate of potash as a top dressing when the maize plants were about 30 cm high. In addition, about 5 t/ha of manure were applied at the beginning of the first season only, to supply some micronutrients, to improve soil structure, and to increase nitrogen.

Statistical design and layout

The statistical design of the experiments was 5x2 factorial, split-plot with three replicates. The S&WC factor was assigned the main units while the soil fertility factor was assigned the sub-units. The plots were 10 m long and 5 m wide with a path of 4 m between to allow oxen to turn during tillage. Subplots were separated by 2 m and the blocks were separated by 5 m paths for accessibility. The arrangement of blocks was such that there were two blocks down the slope and two blocks across the slope, as shown in Figure 5, in order to cover for lack of homogeneity in land form and the topsoil. Despite the slight difference in slope direction and land form, the layout of the plots was the same at all the trial sites.

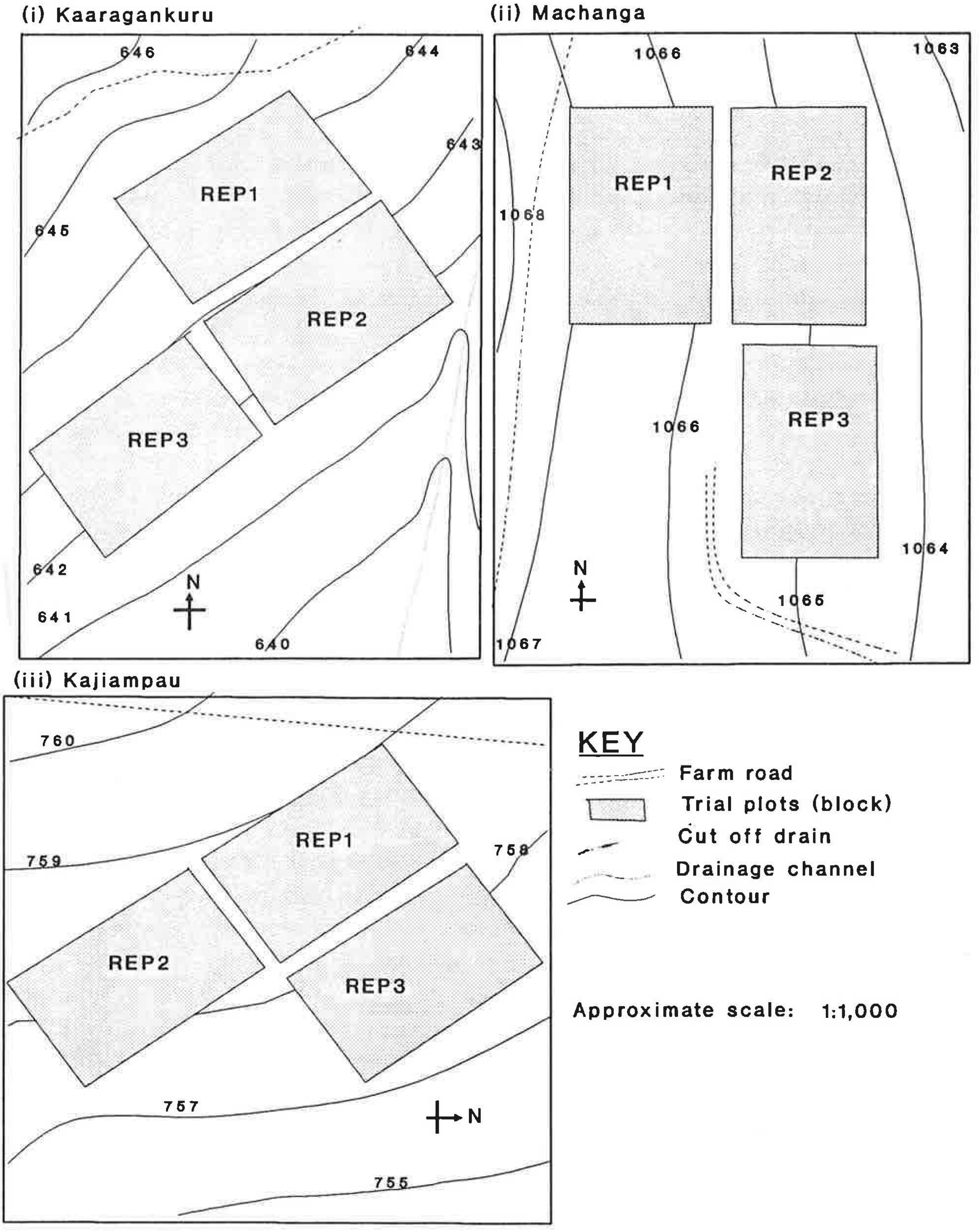


Figure 5 Plan of layout of the experimental plots

Crop management and farm operations

A monocrop of maize (*Zea mays L.*), a short period cultivar, Makueni composite, recommended for semi-arid areas and said to out-yield Katumani composite B, was used as the test crop. The same crop management was applied at all three experimental sites. The plant and soil management was, whenever possible, the same as recommended for the land use.

Land preparation and planting

All the plots were tilled before the onset of the rainy season. The plots with tied ridges, terraces and contour tillage were prepared with an ox-drawn mouldboard plough; the others with a hand hoe. The crop was planted about 1 week before the expected onset of rains. Row spacing was 75 cm with plants 30 cm apart giving 13 rows/plot and 17 plants/row. Thinning, replanting and transplanting were also carried out to ensure that there were 220 plants/plot and a plant population of 44,000/ha.

Manure and fertilizer application

Manure was applied by hand, a few days before planting, along the row to be planted. During the test season (March 1990) the DAP was placed at a pre-marked hole to be applied before planting and mixed thoroughly with the soil. It was observed that germination was poorer in fertilized than in non-fertilized plots. This may have been either because the fertilizer absorbed the soil moisture which would have been used by the seeds for germination, or it 'burnt' and killed the seedling during germination. In the following season, the basal fertilizer application was carried out immediately after the emergence of the seedlings by placing the fertilizer around the plant and mixing it with the soil. Care was taken to place the fertilizer about 5 cm away from the plant to avoid 'burning' the seedling. This gave a good and even germination. The top-dressing was applied in the same way when the plants were about 30 cm high.

Plant management

Weeding was carried out with hand implements as often as necessary to keep the plots weed free. Three weedings were found to be sufficient. The common pests of maize in the area are kiwi beetle, stalk borer complex, chaffer grub and cutworms. The chemicals used were Dipterex, Karate and Furadan to control kiwi beetle, stalk borer and chaffer grub and cutworms respectively. These were applied at the recommended concentration by hand or hand sprayer, whenever an incidence of the pest was noticed. One application each season was found to be sufficient.

Harvesting

The cobs were harvested by hand from the stalks, peeled and put in bags. They were threshed after air drying for about 2 weeks.

Monitoring crop growth, development and yield

The parameters of crop development and production monitored were development stages, grain and biomass yield. Plant height was also measured to investigate the patterns of crop growth (*see* Kiome, 1992).

Development stages

In cereals such as maize, crop development stages are based on observation of the development of certain plant organs (Shaw and Thom, 1951; Rees, 1986; Yunusa, 1987). The main development stages are identified as follows.

0. *Germination* – when there is nearly 100% germination.
1. *Tasselling* – is the beginning of the flowering stages (anthesis) when tassels are observed in about 50% of plants.
2. *Flowering* – is the full flowering stage when ears can be seen in about 50% of the plants.

3. *Seed development* – is the beginning of the seed development stage when the ears are fully developed in about 50% of the plants and the seeds can be felt by hand.
4. *Physiological maturity* – when the ears are fully developed in about 75% of the plants, the silks have dried and the kernels have dents.

Biomass and grain yield

Dry biomass yield was calculated from a random sample of 20 plants/plot while grain yield was measured from the whole plot (*see* Kiome, 1992). The plants and the grains were dried in the sun for two weeks before weighing and corrected for moisture content using a sample dried in the oven overnight at 70 °C to calculate the dry weight.

RESULTS AND DISCUSSION

Crop development stage

There were no differences in crop development with the conservation measures. Because of lower altitude, crop development was faster at Kaaragankuru than at the other two sites (*see* Figures 6a to d). Generally, vegetative growth and seed development stages were also faster in fertilized than in non-fertilized levels. In the fertilized crop these stages took a longer time during the long rains than the short rains, implying a lower rate of vegetative growth in a wet season than in a drought season. A similar phenomenon was observed in non-fertilized crop except at Machanga. The main explanations for these observations are the difference in soil fertility, moisture and temperature. Firstly, in cases of nutrient deficiency, as was the case in non-fertilized levels, vegetative and seed development may be slow. Secondly, a fertilized crop performs better, hence extracts more water than a non-fertilized crop. At a given time, soil moisture is, therefore, higher in the non-fertilized levels especially early in the season. Consequently, the temperature will be lower, leading to a lower rate of vegetative growth in non-fertilized levels. Thirdly, during a drought season, soil moisture is lower than in a wet season. Assuming that air temperature is not significantly different between the two seasons, soil temperature will be higher in a drought season, resulting in faster crop development. The exception at Machanga in non-fertilized levels is because of the combined effect of extremely poor soil fertility and good soil physical properties. With high infiltration rates soil moisture will be high even in a drought season. Nutrient deficiency, especially of nitrogen and phosphorous as was the case at Machanga, will cause poor crop performance and hence low water extraction by transpiration. Therefore there will be a lower soil temperature and subsequently low vegetative growth in non-fertilized crops.

However, the crop reached physiological maturity at about the same time in both fertility levels except at Machanga. This may be because: (i) evaporation eventually extracts water from the soil to make the soil moisture conditions in both fertilization levels nearly the same, late in the growing period; (ii) seed development may be faster in plants which had delayed tasselling and flowering stages; and (iii) the crop withered before reaching full physiological maturity. The exception at Machanga was because of the combined effect of poor soil fertility conditions and high infiltration rates.

It was not possible to determine how long the crop took to reach physiological maturity at Kaaragankuru and Kajiampau during the short rains because the plants started to dry before reaching full maturity because of moisture stress. However, from the data of the long rains at all the trial site and for both seasons at Machanga, it is evident that on average the crop takes 30 days to tasselling, 45

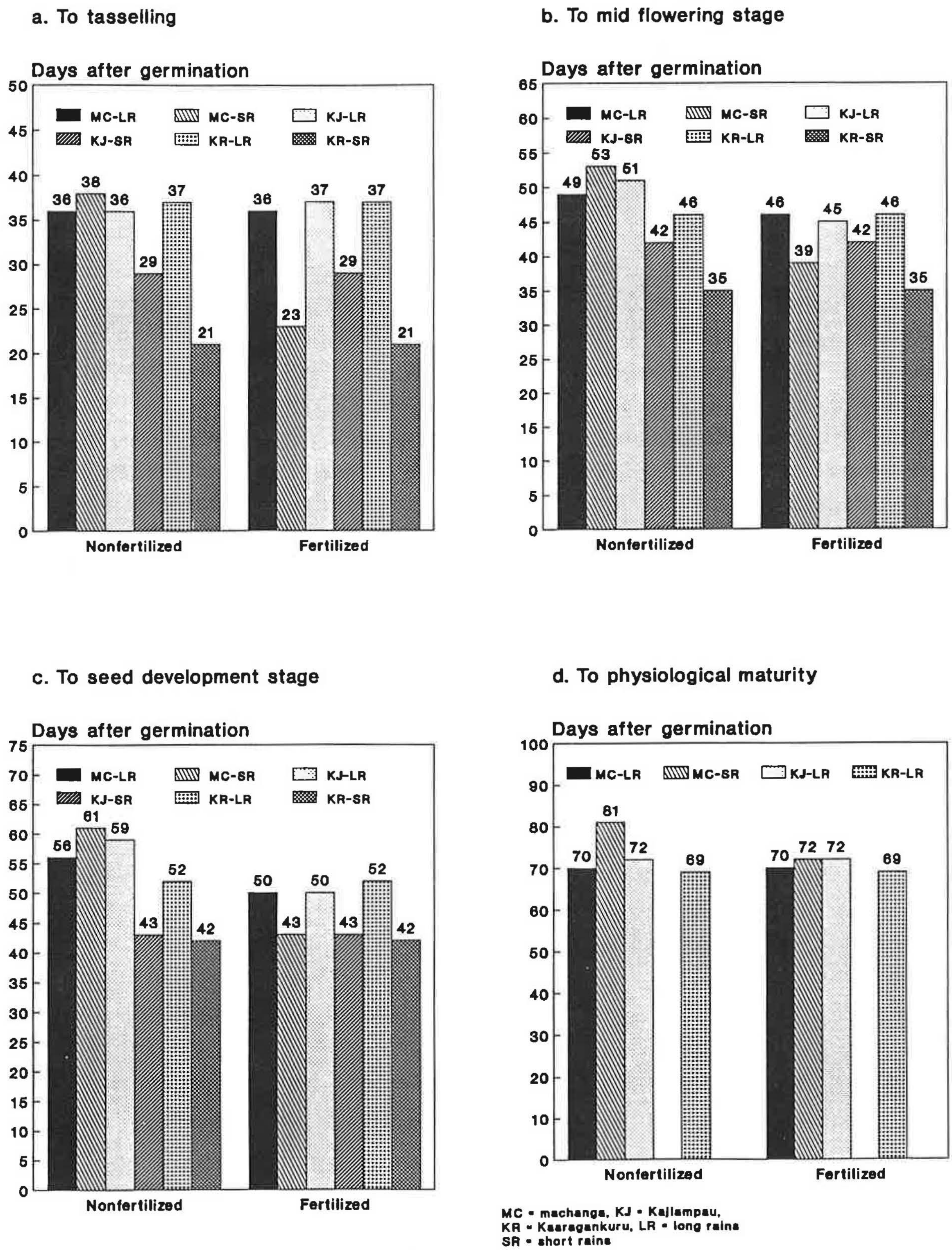


Figure 6 Length of various development stages of Makueni composite maize (*Zea mays L.*) (days from germination)

days to seed and 70 days to reach physiological maturity when nutrient and soil moisture availability are not severely limiting.

Grain and biomass yield

The mean grain yield during the two seasons at the three trial sites varied from 342 kg/ha to 1719 kg/ha in non-fertilized levels and from 612 kg/ha to 5574 kg/ha in the fertilized levels (*see* Table 7). The highest as well as the lowest yields were obtained at Machanga from the fertilized and the non-fertilized tied ridging during the long and short rains respectively. On average, yield in the fertilized levels was highest at Machanga and lowest at Kaaragankuru during both seasons. These are the sites which have contrasting soil characteristics as indicated in Chapter 2, *The Experimental Sites*. In the non-fertilized levels it was lowest at Machanga and highest at Kajiampau during the drought season and Kaaragankuru during the wet season. This was caused by the combined effects of poor soil fertility and physical properties of the soil as will be shown later. Table 7 also shows the yield increase at each site, for each season and for various soil fertility levels compared with hand tillage. The increase in non-fertilized trash-lines at Machanga is exceptionally high, although still much lower than in the fertilized levels. It is also very high for the same conservation method at Machanga and Kajiampau at both soil fertility levels. At Kaaragankuru fertilized tied ridging treatment has the highest increase in the drought season. It is also notable that there was significant yield decrease in non-fertilized tied ridging at Machanga.

The harvest index (grain/biomass ratios) ranged from 0.08 to 0.38. Low harvest indices were observed when the grain yield was low, implying that the effects of nutrient deficiency and water stress are higher in grain than in biomass yield. This is because seed formation which takes place late in the growing season is more likely to be affected by moisture stress and nutrient deficiency.

Statistical analysis

Pooled analysis of variance for site, season and the treatment (S&WC and fertility levels) factors showed significant differences in grain yield between the levels of each of the four factors (*see* Appendix 1A). The differences between the sites is mainly due to the differences in soil characteristics. The difference between seasons was mainly because of the difference in rainfall, which was about twice as high during the short rains than during the long rains.

Interactions between any two of the factors were also significant, implying that yield response to S&WC depends on soil fertility level, rainfall regime and soil type. Similarly the response of grain yield to fertilizer depends on rainfall regime, S&WC measure and the soil type. These interactions show the complexity of crop production in these areas and indicate the necessity to investigate the effect of one while the others are held constant. There was significant interaction between three of the factors, that is, S&WC, soil fertility and season, implying that the response of grain yield to any one of these factors is different when any of the other two are different. There was no significant interaction between the four factors together because the interactions of some were positive, while others were negative.

Biomass yield was also significantly different between the levels of any of the four factors except the S&WC measures. The only significant interactions in biomass yield were between soil fertility and sites and between S&WC, soil fertility and season. The difference between the results of the analysis for grain and biomass yield, especially in interactions, could be caused by high non-experimental errors as indicated by the coefficient of variation in the results of

Table 7 Grain yield of Makueni composite maize and increase due to S&WC measures

Site	Treatment	October season (long rains) Yield (kg/ha)	Increase (%)*	HI (G/B)†	March season (short rains) Yield (kg/ha)	Increase (%)	HI (G/B)
Kaaragankuru	*Non-fertilized*						
	Trashlines	1650	20.9	0.30	471	20.2	0.11
	Hand tillage	1366	0.0	0.21	392	0.0	0.09
	Contour tillage	1387	1.6	0.29	494	26.3	0.13
	Tied ridging	1719	25.8	0.31	462	17.9	0.12
	Terraces	1710	25.2	0.32	417	6.5	0.08
	Fertilized						
	Trashlines	3326	13.8	0.33	612	-2.7	0.10
	Hand tillage	2921	0.0	0.31	629	0.0	0.10
	Contour tillage	2918	-0.1	0.31	947	2.9	0.13
	Tied ridging	3197	9.6	0.32	1388	120.9	0.24
	Terraces	3012	3.1	0.31	801	27.2	0.09
Kajiampau	*Non-fertilized*						
	Trashlines	1417	0.6	0.20	1097	67.9	0.17
	Hand tillage	1328	0.0	0.20	653	0.0	0.11
	Contour tillage	1335	0.5	0.20	983	50.5	0.12
	Tied ridging	1589	19.4	0.25	859	31.5	0.18
	Terraces	1562	17.7	0.24	696	6.5	0.15
	Fertilized						
	Trashlines	3338	11.4	0.29	2355	74.4	0.21
	Hand tillage	2997	0.0	0.28	1350	0.0	0.16
	Contour tillage	3386	13.0	0.33	1317	-2.4	0.13
	Tied ridging	4859	62.2	0.35	1711	26.7	0.17
	Terraces	4529	51.1	0.34	1878	39.1	0.18
Machanga	*Non-fertilized:*						
	Trashlines	1251	90.1	0.21	2293	435.3	0.20
	Hand tillage	659	0.0	0.16	428	0.0	0.14
	Contour tillage	657	-0.2	0.16	416	-2.9	0.11
	Tied ridging	542	-7.7	0.20	373	-12.8	0.09
	Terraces	718	9.0	0.16	511	36.5	0.11
	Fertilized						
	Trashlines	4463	13.2	0.33	4764	79.2	0.31
	Hand tillage	3944	0.0	0.38	3194	0.0	0.28
	Contour tillage	3802	-3.6	0.31	3566	11.7	0.29
	Tied ridging	5574	41.3	0.37	4234	32.6	0.28
	Terraces	3996	1.3	0.31	4024	26.0	0.30

Notes: * increase is in percentage relative to hand tilled treatment for each soil fertility level and site
† HI = harvest index in grain/biomass (G/B) ratio.

biomass yield (*see* Appendix 1A). The methods of handling and drying the biomass could have led to inconsistent losses.

To investigate further the effect of S&WC measures alone, two way analysis of variation was also carried out on grain yield/site, season and soil fertility level. No significant differences were observed between S&WC measures in the non-fertilized treatment except at Machanga during the short rains (*see* Appendix 1B). This implies that when soil fertility is limiting, S&WC measures are not effective in improving crop production. The exception at Machanga was caused by a decrease in grain yield in the tied ridging contour tillage as shown in Table 7, which could have been caused by leaching of the nutrients. This illustrates how sometimes S&WC measures have a negative effect on crop yield.

In the fertilized levels significant differences were observed between S&WC measures at all the trial sites and during both seasons, confirming that when soil fertility is not seriously limiting, S&WC increases crop production because of better water availability and nutrient use efficiency.

Interaction

The interaction between S&WC measures and site is mainly caused by differences in soil physical characteristics. One of the distinctly different soil characteristics between these sites was the infiltration rate. On this basis, the site can be classified as: (i) Machanga – rapid infiltration rate; (ii) Kajiampau – moderate infiltration rate; and (iii) Kaaragankuru – low infiltration rate. Figures 7a and b show the interaction between selected S&WC measures and site (on the basis of infiltration rate) in non-fertilized and fertilized levels respectively. There is high interaction between this site characteristic and S&WC measures in non-fertilized levels, with positive response to decreasing infiltration rate. This implies that under poor soil fertility conditions the S&WC methods are more effective in soils with low infiltration rates. This should be interpreted cautiously because the initial soil fertility conditions were not the same at all the trial sites. However, although the soils at site 2 (Kajiampau) had better soil fertility status (*see* Table 4), yield was lower than at site 3 (Kaaragankuru) except during the short rains, when soil moisture stress was severe. In fertilized levels, there is also a high interaction but the response is negative, implying that when nutrient availability is not severely limiting, S&WC measures are more effective in soils with high infiltration rates.

This interaction between S&WC measures and season is illustrated with data for Kajiampau in Figure 7c. Similar trends were observed at the other sites differing only in the levels of interaction. There was a high interaction in the fertilized levels and positive response to increasing rainfall, indicating that the effectiveness of S&WC measures in increasing crop yields improves with higher rainfall. This is contrary to the common belief that conservation methods may be more effective in drought conditions. S&WC may reduce the risk of crop failure during drought but the response is not necessarily positive. There is no significant interaction in the non-fertilized levels implying that the effect of S&WC measures does not vary significantly with the rainfall regime under low soil fertility conditions.

The interaction between S&WC measures and soil fertility levels is illustrated with the data for Kajiampau in Figure 7d. The data from the trashlines were excluded from this analysis because the method has an additional effect of improving soil fertility. There was positive interaction, increasing with rainfall. This confirms that the response to soil moisture increases with nutrient availability. Similarly, the response to fertilizer application is higher with S&WC measures. Similar trends were observed at the other two sites.

Discussion

Effects of drought

The influence of rainfall regime is reflected in the difference in yield at all the trial sites and all the treatments except in the trashlines at Machanga as shown in Table 7 and Figure 8. It is evident that the crop experienced soil moisture stress during the short rains, when the rainfall was low and soil fertility, especially in the non-fertilized levels, had declined. The exception of trashlines is because of the accumulation of organic matter which increases nitrogen availability and improves the soil structure, thus resulting in an overall increase in water availability. The trashlines also enhance the water availability by shading the soil, thus reducing surface evaporation. Assuming that the yield difference between seasons was mainly because of drought, the effects can further illustrated by the percentage yield decrease during the short rains as shown in Table

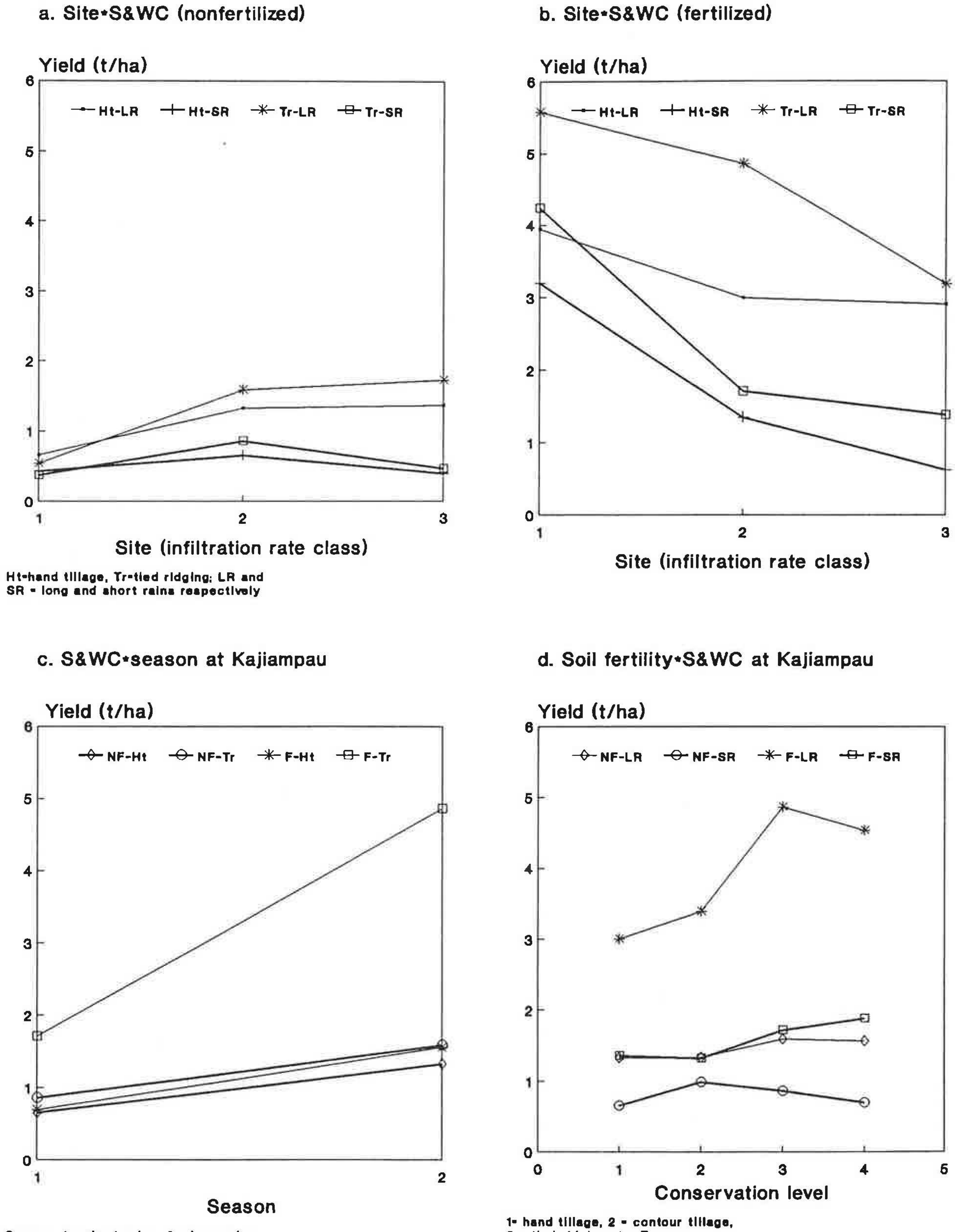


Figure 7 Interaction between S&WC measures and site, season and fertility levels

7. The effect varies with sites, with the highest at Kaaragankuru, followed by Kajiampau and the lowest at Machanga, although rainfall was lowest at the latter site. There was no yield reduction in fertilized trashlines and terraces at this site. This indicates that the soils at Kajiampau and Kaaragankuru are very sensitive to drought, but the effect is higher at Kaaragankuru than Kajiampau. At these sites, the reduction in fertilized treatments is higher than in non-fertilized treatments for all conservation measures except tied ridging and terraces at Kaaragankuru, implying the need for S&WC measures if fertilizer is used.

Table 8 Yield reduction because of drought

	Percentage yield reduction		
Conservation method	Machanga	Kajiampau	Kaaragankuru
Non-fertilized:			
Hand tillage	54	103	248
Contour tillage	58	36	181
Trashlines	5	34	250
Tied ridging	45	85	272
Terrace	41	124	310
Fertilized:			
Hand tillage	23	122	364
Contour tillage	7	157	208
Trashlines	–6	42	443
Tied ridging	32	184	130
Terrace	–1	141	276

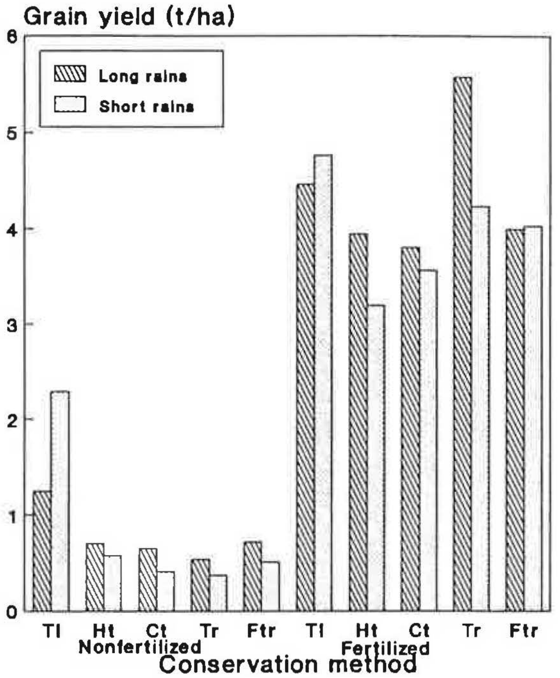
Effects of fertilizer application and soil properties

The effect of fertilizer application is illustrated by the yield differences between the fertilized and the non-fertilized treatments, per conservation method and season, as shown in Figure 8. This difference is more clearly shown by the percentage yield increase due to fertilizer application as shown in Table 9. At Machanga, fertilizer application had very high yield benefits, with yield increase ranging from 257-1035%. At this site higher increases were obtained during the drought season. At Kajiampau the yield increase due to fertilizer application ranged from 34-206%, while at Kaaragankuru it was 30-200%. On average, higher yield increases were obtained during the wet season, except in tied ridging at Kaaragankuru, where it was higher during the drought season.

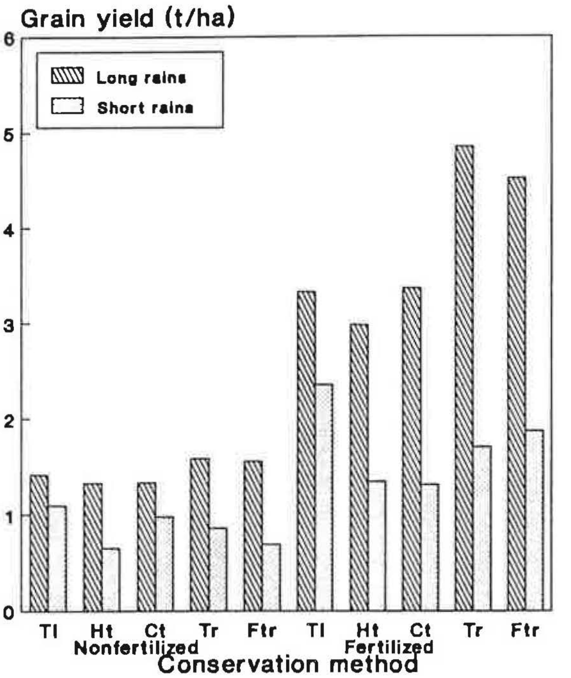
Table 9 Yield increase due to fertilizer and manure application

		Percentage yield increase		
Site	Conservation measure	Long rains	Short rains	Average
Machanga	Hand tillage	498	646	557
	Contour tillage	479	757	587
	Trashlines	257	299	278
	Tied ridging	928	1035	972
	Terrace	457	687	553
Kajiampau	Hand tillage	126	107	119
	Contour tillage	154	34	103
	Trashlines	127	115	122
	Tied ridging	206	99	168
	Terrace	190	170	184
Kaaragankuru	Hand tillage	114	60	102
	Contour tillage	110	92	105
	Trashlines	102	30	86
	Tied ridging	86	200	110
	Terrace	76	92	79

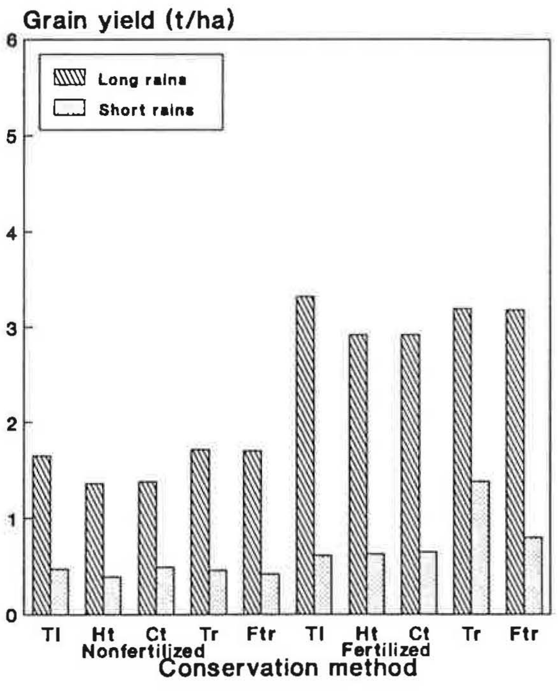
a. At Machanga



b. At Kajiampau



c. At Kaaragankuru



Note: Tl = trashline, Ht = hand tillage
Ht = contour tillage, Tr = tied ridging
Ftr = Terrace

Figure 8 Grain yield of Makueni composite maize S&WC measures

During the wet season the yields from the non-fertilized treatment were higher at Kaaragankuru (*see* Table 7), which has soils in poor physical condition, than at the other two sites in all the conservation treatments. In the drought season the yields from the same soil fertility level were higher at Kajiampau, which has soils with better initial soil fertility conditions, than at the other two sites, except in the trashlines where it was higher at Machanga. This illustrates the changing role of soil fertility and soil physical conditions. In a wet season, the soils with high infiltration rates are likely to lose the nutrients through leaching. Thus, even with increased soil moisture availability, there would be no benefit in crop production. However in a drought season, the soils with poor soil physical conditions will lose the little rainfall in runoff and the crop would suffer from moisture stress. In the fertilized levels, the yields were higher at Machanga than at the other two sites during both seasons and in all the conservation treatments, despite the fact that Machanga had the lowest rainfall. Thus, the best response of crop yield to S&WC measures is obtained in soils with favourable soil physical properties (loamy soils, with good structure and high infiltration rates) when nutrient availability is not severely limiting.

Effects of conservation measures

In the non-fertilized levels, although the difference between conservation measures was not statistically significant, there was a slight increase in yield in all the conservation treatments compared to the hand tillage (*see* Table 7 and Figure 8) except at Machanga, where there was a decrease during the short rains as mentioned earlier. The yield was highest in trashlines during the March season, despite the low rainfall, implying that the effect of trashlines improves with time.

In the fertilized level, the yields from all conservation measures were higher than that from hand tillage except in the contour tillage treatment. The conservation measures which conserve more moisture, such as tied ridging and terraces, had higher yields during the wet season. During the drought season the trashlines had the highest yield increase at Machanga and Kajiampau, but at Kaaragankuru the tied ridging had the highest. This illustrates how the effectiveness of the S&WC measures is site specific. Simple measures such as trashlines may be suitable during a drought season for soils with good physical properties. However, S&WC measures which conserve more moisture, such as the tied ridging, are better in soils with poor physical properties.

The performance of each S&WC can also be illustrated by the percentage yield increase in each soil and water conservation measure calculated on the basis of lowest yield in each soil fertility level and sites. This is then grouped in the following classes:

1. greater than 81%
2. 61%-80%
3. 41%-60%
4. 21%-40%
5. less than 21%.

The performance of S&WC measures, based on these classes is shown in Table 10. In non-fertilized levels, trashlines is the best method, except at Kaaragankuru where tied ridging and terrace perform better, although the yield increase is small. The methods do not generally perform better in a drought season, thus they do not reduce the risk of drought. However at Kajiampau the trashlines perform better during the drought season, due to the cumulative improvement of soil fertility and physical properties. This does not happen at Kaaragankuru, either because there is little accumulation of organic matter, or it takes longer for the poor soil physical conditions to change significantly.

In fertilized levels tied ridging has the overall best performance at Kajiampau and Machanga. Nevertheless, it has no advantage during a drought season, implying that it does not serve to reduce the risk of drought. Trashlines perform better during the drought season because of the cumulative effect of improving soil fertility and physical conditions. This indicates that the trashlines method is useful in averting the risk of drought and if continued over further seasons it would surpass the other measures. At Kaaragankuru the yield increase in tied ridging during the drought season is more than 81%, demonstrating that the technique serves to avert the risks of drought.

It is notable that terracing, which is promoted by the extension services in Kenya, does not rank highest at any site during any season in both fertilized and non-fertilized levels. Its best ranking is third at Kajiampau during both seasons and at Machanga during the wet season. It, therefore, does not serve the purpose of reducing the risks of drought. This is mainly because runoff accumulates only on a small portion of the terrace near the embankment. Hence, spatial soil moisture distribution is very poor and only a small portion of the crop will benefit (*see* Kiome 1992).

Table 10 S&WC maize yield increase ranking matrix

	Non-fertilized									Fertilized								
Conservation measure	Machanga a*	bt	c‡	Kajiampau a	b	c	Kaaragankuru a	b	c	Machanga a	b	c	Kajiampau a	b	c	Kaaragankuru a	b	c
Hand tillage	4	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Contour tillage	4	4	5	4	5	3	4	4	4	5	5	5	5	5	5	5	5	3
Trashlines	1	1	1	4	5	2	5	5	5	4	5	3	4	5	2	5	5	5
Tied ridging	5	5	5	5	5	4	4	4	5	4	3	4	2	2	4	4	5	1
Terrace	4	4	4	5	5	4	4	4	5	5	5	4	3	3	3	5	5	4

Notes:
* classes based on the average grain yield increase for the two seasons
† classes based on yield increase during the long rains (wet season)
‡ classes based on yield increase during the short rains (drought season)

CONCLUSIONS AND RECOMMENDATIONS

S&WC measures do not appear to affect crop growth development of Makueni composite maize. Factors which do are: availability of plant nutrients, the rainfall regime and geographic location. While some of these factors may in the longer term be influenced by S&WC measures, effects are mainly caused by altitude, nutrient deficiency, soil moisture and consequently soil temperature. However, some compensatory growth processes may take place later in the growing season, so that except with a severe nutrient deficiency, the whole length of the growing period is not significantly different. On average a growing period of 75 days is sufficient in both ACZ IV and V for the crop to reach physiological maturity. Hence, with the average growing period of 60-70 days (*see* Chapter 2, *The Study Area*), and assuming moisture storage which can sustain the crop for at least 10 days, Makueni composite maize can be grown in these ACZs without risks of moisture stress.

The effect of S&WC measures on crop yield in semi-arid areas is complex. Yield depends on the amount and distribution of the rainfall during the specific season, together with soil physical and chemical conditions. The individual effect of soil characteristics (site), rainfall regime (season) and soil fertility are highly significant. These factors interact with the main factor influenced by S&WC measures: water availability. Under improved soil fertility, the conservation measures significantly increase the yield even during a drought season. Contrary to what might have been expected, the response to S&WC measures increases with higher rainfall and infiltration rate. Thus, in semi-arid areas, large yield benefits from S&WC will be obtained primarily in wet seasons, provided that soil chemical fertility is not limiting. This important finding on the significant positive interaction between S&WC measures and soil fertility in dry areas stresses a vital necessity either, (i) for measures which individually address water availability to plants and nutrient supply or, (ii) integral measures which manage to combine the positive interactions. Although in most cases there is a small yield increase, S&WC measures which do not increase soil fertility do not significantly increase the yield of Makueni composite maize, under the prevailing soil fertility conditions. Under low soil fertility conditions, the response to S&WC measures does not depend on the rainfall regime, but increases with poor soil physical properties such as low infiltration rate.

The influence of drought on yields depends on the soil properties. It is notable that in soils such as those at Machanga, there was no significant yield reduction in fertilized levels even when only 172 mm of rain fell. In soils with poor soil physical properties, such as those at Kaaragankuru, yield reduction is severe for both fertilized and non-fertilized conditions, being most marked at the higher soil fertility level. The simplistic assumption that S&WC can assist in averting drought effects on yields is therefore partially true. Soil physical and chemical status are essential to realize positive benefit.

Yield increase from fertilizer application is very high but related to soil physical properties. It is highest in soil with poor initial soil fertility and good physical properties, such as can be found in soils at Machanga. Thus, this is where application of manure, fertilizer or S&WC methods which have the primary effect of increasing soil fertility should be targeted. In soils with poor physical properties, such as at Kaaragankuru, yield increase is relatively modest, although still more than 70% for most conservation measures. In such soils, application of fertilizer or manure may require to be combined with physical S&WC methods to enhance soil moisture availability. These findings again illustrate the importance of understanding the prior physical and chemical status of soils before recommending fertilizer or S&WC or both.

Generally yield increases brought about by S&WC measures are considerable. With physical S&WC measures and fertilizer application, yield increases range from 0% to 120%, depending on soil characteristics and rainfall regime. However, in a non-fertilized crop the increase is less than 40%. In tied ridging and contour tillage, yields decrease in soils with high infiltration rates as in Machanga. Trashlines are very effective in increasing yields except in soils with poor physical properties such as those at Kaaragankuru. In these soils, tied ridging is the most effective method. These again are soil-specific findings, indicating that knowledge of soil is essential before recommending land management changes.

On the basis of yield increase, without fertilizer or manure application, trashlines is the best S&WC method, except in soils with poor soil physical properties. In these soils, tied ridging and terraces are better although the increase in yield is small. With fertilizer application, trashlines and tied ridging are the best in soils such those at Machanga. For soils similar to those at Kajiampau and Kaaragankuru, tied ridging is the best method. However, trashlines serves the purpose of reducing the effect of drought except in soils with poor physical properties where only tied ridging is effective.

Recommendations

- For crop production in semi-arid areas, it is inappropriate to apply physical S&WC measures without addressing the problems of soil fertility. Benefits from manure or fertilizer will be greater with S&WC measures which have the effect of increasing the soil moisture availability. Increasing soil moisture by S&WC and amelioration of soil fertility should, therefore, be addressed simultaneously.
- Recommendations for S&WC methods should be site-specific and related to the intended land use. On the basis of the increase in Makueni composite maize yield, without fertilizer or manure application, only trashlines are suitable for the slopes and soils (i.e. medium slopes and relatively good physical properties). This conservation method serves the purpose of both minimizing the yield reduction due to drought and increasing crop yield when there is no drought. However, for the purpose of reducing soil loss this method may be risky and less effective (*see* Kiome, 1992) and may need to be combined with terraces. In compact soils with low infiltration rate and surface capping such as those at Kaaragankuru, contour tillage and tied ridging are sufficient, although the increase in yield is small. Although, erosion is high in such soils these methods reduce soil loss significantly but are risky (*see* Kiome, 1992).
- With sufficient fertilizer or manure application, tied ridging or trashlines are suitable in areas with soil similar to those at Machanga and Kajiampau. Trashlines serve the purpose of minimizing the effects of drought, while tied ridging is better during a wet season. In compact soils with low infiltration rate such as the soils at Kaaragankuru, tied ridging is the only reliable method suitable to avert the risks of crop failure during drought, although the increase in crop yield during a wet season is small.
- If terraces or other physical S&WC methods have to be applied because of steep slopes and high runoff it is advisable, given the remarkable benefits of trashlines, to combine this biological S&WC method with the physical ones. Design factors such as optimum number of trashlines and whether or not to peg merit further investigations. In view of the relatively poor performance of most physical S&WC measures, a greater research emphasis on biological control would appear to be justified, even in this semi-arid environment, focusing on water balance competitiveness for plant-available water and the improvement of soil fertility.

Chapter 4

Economic assessment of the soil and water conservation measures

INTRODUCTION

Research in the United States has suggested that erosion control practices are unprofitable in the short run and of dubious economic interest to the land users in the long run (Mueller *et al.*, 1985; Swanson *et al.*, 1986). Obviously, land use, farming systems, economic environment and techniques of soil and water conservation vary between the United States and sub-saharan Africa. Nevertheless, there are significant doubts as to the rationality of the individual African farmer to invest his or her hard-won labour, land and capital in S&WC measures. No matter how technically effective a measure of S&WC might be, there is no point in promoting it if the returns to the farmer are insufficient to cover both the risks of failure and the investments of resources. This section examines within the context of typical semi-arid farming systems the economics of various methods of S&WC using the technical and yield-benefit information in sections and including research information on current cost of implementing S&WC.

Farmers grow crops for food and cash. In semi-arid sub-saharan Africa, few wholly commercial crops can be grown profitably. Therefore, food crops have to provide for both subsistence needs and for cash income and S&WC must ensure the continuity (or sustainability) of production. Livelihoods are precarious. While land users may treat farming in business terms (Blaike and Brookfield, 1987; Napier, 1989), the African farmer is crucially dependent on both quantity and reliability of production. For an S&WC technology to be justified, it must increase crop yield and provide sufficient farm income. Land use systems as a whole must be a viable economic enterprise.

S&WC is usually delivered with projects and programmes in terms of packages of techniques suited to the physical environment: for example, biological means of soil protection, tillage techniques, cropping strategies (including multiple cropping and agro-forestry) and physical structures. All methods have costs in installation and maintenance; all should have realizable benefits to the land users, mostly in greater income-generating opportunities from the land use system. Within a typical project cycle which includes an S&WC-natural resource inventory; a socio-economic survey, technical assessment of technologies, economic analysis (Dixon *et al.*, 1988; IFAD, 1992) – social and economic analysis has been poorly served because of a paucity of data upon which to base an assessment of the economic rationale of any one technique. Such data and analysis are crucial for decision-making as to adoption and promotion of technologies. The following sections describe the use of the data derived in this research from semi-arid Kenya in an economic analysis with the objective of determining the most profitable S&WC land use system, **from the perspective of the farmer**.

METHODOLOGY

This economic assessment compares land use both with and without S&WC in order to determine the marginal difference of S&WC to the farming system. Because of the variety of ways in which S&WC can be effected, the whole crop production cycle is considered. The methodology partly follows guidelines for the economic analysis of development projects generally (Dixon, *et al.* 1988) and for S&WC projects particularly (Bojo, 1987)

An assumption in the analysis is that S&WC is in a crop production system dependent on the market value of goods. Under such an assumption, it is appropriate to utilize 'change in productivity' and 'opportunity cost' approaches. Main criteria for short-term benefits are the gross margins, net benefits and marginal rates of return; for long term, Net Present Values (NPV) over a specified period of time are more appropriate.

In S&WC (as indeed in many enterprises and all environmental projects), the time horizon is important. Initial investment costs are usually high while benefits accrue only in the longer term when the value of money has declined. Economic evaluations are typically conducted over a 10-30-year cycle, representing the normal project time horizon. For this assessment at the farm level, 10 years is taken because within that period, virtually all techniques of S&WC will have needed reconstructing and reinvestment at least once. Within the major project cycle, activities in production will take place at various frequencies. The shortest production period which can practically be taken is the single growing season. In most of Kenya, there are two growing seasons/year with farmers undertaking different cropping strategies in each season in order to meet food and cash needs. It is sensible, therefore to take the shortest time horizon as being one year with annual costs and benefits calculated from the sum of the two seasons. The 10-year cycle is then constructed from the year-on-year investment and returns in crop production and S&WC. For the purpose of the analysis, typical normal seasons are assumed, although it must be noted that rainfalls in semi-arid areas are extraordinarily variable from season to season.

Accurate determination of the financial cost and benefits is essential for a reliable economic evaluation. For this reason, consideration is given only to those S&WC-based crop production systems which were used in the experiments (*see* Chapters 1-3), namely the cultivation of Makueni composite maize with good management (optimum weed and pest control) at two fertility levels (with and without fertilizer and manure) and five different S&WC treatments. The experimental design gives 10 permutations of S&WC-based crop production systems as described fully in Chapter 3, *The treatments.* These 10 are evaluated at the three field experimental sites, representing different soils of semi-arid Kenya, to give a total of 30 specific assessments. One of the primary purposes of this assessment is to examine and explain the variations between sites. This gives a better understanding of the physical controls that affect the economic viability of the implementation of S&WC techniques at the farm level.

DETERMINATION OF COST AND BENEFITS OF SOIL AND WATER CONSERVATION-BASED CROP PRODUCTION SYSTEMS

Cost factors

In each S&WC-based crop production system, cost is incurred on various items. At farm level these are in:

- land;

- labour;
- implements;
- farm inputs; and
- construction of S&WC measures.

Loss of nutrients is also often mentioned as a cost; and conversely the retention of nutrients by S&WC as a benefit. However such benefits are reflected in the increase in yield and they are, therefore, invalid in this analysis.

Land

Most farmers in the study area own land by inheritance. A few immigrant or wealthy farmers purchase or hire land at relatively low prices. The cost of land is, therefore, small and not considered further in the analysis.

Labour

Labour is the single most important factor in small-scale crop production with S&WC measures (Stocking and Abel, 1992). It is also the most difficult factor to quantify accurately, especially in small-scale farming where farmers keep no records and there is no mechanization. The labour needed for a specific S&WC measure or farm operation varies with land form (mainly slope) and soil type. It is more difficult to dig compact and stony soils than loose non-stony soils. It also takes more time to dig terraces in steeply sloping land than in relatively flat land. Quantification of labour is also confounded by gender and age differentiation. For example, terracing is considered men's work while many other S&WC and farm operations are done by women and children. Although labour measurements are converted to person-day equivalents, there are no standard conversion factors. Because of these reasons, data on labour from questionnaire surveys are very variable even though most economic evaluation of development projects rely on it. Labour data from experimental plots are rare and are said not to represent the farmers' situation (CIMMYT, 1988).

The timing of labour inputs for specific farm operations is a major problem in small-scale crop production. Most farm operations, (e.g. fertilizer application, weeding, pest and diseases control) have to be done at a specific time of the growing period in order to achieve good results. In the study area most farm operations are done in April and November creating a high labour demand and consequently high opportunity cost. Some conservation measures (e.g. terraces and tied ridges) can be constructed during the dry period when there are few other farming activities and the opportunity cost for labour is much lower. Although it is also recommended to till the land either immediately after harvest or before the onset of the rains to allow for early planting, the soil might be so compact that it is either impossible or very costly in time. In such cases, land preparation will be after the onset of the rains, thereby exacerbating the labour demand and its cost. It is, therefore, crucial to understand the labour profiles under which the economic analysis is carried out. The way these operations were carried out during the field experiments (*see* Chapter 3, *Materials and Methods*) is assumed to represent a farm model.

Even after determining the quantity of labour required for specific farm operation, the costing of labour is still difficult because of the different sources. Although wealthy farmers may employ a farm worker, most farm operations are done by members of the household and the unemployed population whose opportunity cost is variable. In peak periods or for hard labour, farmers may hire labour on daily or 'piecework' basis at relatively high prices. They may also be assisted by relatives and neighbours (borrowed labour) at very low cost. This is commonly done for farm operations such as weeding, hand tillage, harvesting and processing. It is, therefore difficult to represent the labour availability or cost for these farmers reasonably.

In this analysis the price of labour for farm and S&WC operations is assumed to be constant. Two scenarios of labour costs are represented. First the opportunity cost of labour, whatever the source, is considered to be equivalent to hired labour and costed as such. This provides the maximum likely cost for the whole crop production system. In the second scenario, it is assumed that household and borrowed labour is free, i.e. at zero opportunity cost. In this case, the cost of labour for farm operations such as weeding, fertilizer application, harvesting and pesticide application, known to be carried out mainly by household or borrowed labour is neglected. This provides a view where primarily it is tillage and the addition of S&WC that carry a labour cost.

Time taken to carry out each of the farm operations was recorded at the experimental plots for each site each season. These were converted to person-days/ha. Labour costs were calculated from the official daily price of hiring casual labourer at 1990/91 prices.

Implements

Implements are often provided to farmers by donor agencies or government institutions as incentives for practising S&WC measures. This may be justifiable if the implements are not available in the local markets and/or their total cost is large as a proportion of needed inputs in the crop production system.

Data on the type and number of implements required for the farm operations and construction of each S&WC technique were obtained from a field survey conducted at one of the trial sites. The most basic requirements for tillage and weeding are hand hoe and machetes. Bags are also need for for harvesting and storage. Since pest and disease control are considered essential, a hand sprayer is also necessary for applying pesticides. At least one wheelbarrow is necessary for manure application and containers are needed for fertilizer application. No additional implements are required for hand and contour tillage. Since contour tillage was by ox-plough, fewer hand implements are required than in hand tillage. In tied ridging, additional hand hoes are needed while in terracing, pick axes, spades or shovels and additional hand hoes are required. The market prices of these implements in 1990/91 were used to determine the costs. The cost of transportation and time taken to obtain these implements varies from place to place. However, farmers tend to buy them when they are shopping for other household needs and no additional cost is included.

Farm inputs

The farm inputs are seeds, agro-chemicals, manure and fertilizers. For good crop management, the minimum farm inputs are improved seeds and pesticides to control common pest and diseases (*see* Chapter 3, *Monitoring Crop Growth, Development and Yield*). Although there may be small differences depending on crop performance, it is assumed that the same amounts are applied in each treatment. Fertilizer and manure application levels are given in Chapter 3, *The Treatments*. Manure can be obtained from the farm livestock, but in this analysis it is assumed that manure is purchased. Availability of fertilizers is often difficult, but it is assumed that institutional interventions are available at no cost to the farmers. One fertilizer application/season and one manure application/two seasons are required for the improved soil fertility level. Market prices extant in 1990/91 were used but no attempts to included differential transport costs were made.

Installation of conservation measures

In addition to implements, S&WC also requires labour to make and maintain. Hand tillage was taken as the control whose cost is the labour for land preparation. Contour tillage was by ox-drawn plough. Although some farmers own a plough and oxen, these will not be considered as a cost for the S&WC-based crop production systems because they are often rented to other farmers for cash. Contour tillage is also land preparation and the only cost is for hiring the oxen and plough. The times taken for hand tillage and to make trashlines, tied ridging and terraces were recorded for each site and each season. These were converted to person-days per hectare and labour costs were calculated from the cost of hiring casual labourers at 1990/91 prices. Installation of S&WC measures also requires additional tools considered under implements.

Benefits

The main direct benefits from S&WC-based crop production systems are the grain yield and biomass. These factors were measured during the field experiments and the results are discussed in Chapter 3, *Grain and Biomass Yield* and *Materials and Methods* (*see* also Table 5).

Grain yield is directly marketable. As long as markets are operational, the value of yield is convertible to money. In Kenya the two main markets for maize are the Kenya Grain Growers Central Union (KGGCU) and the local markets. The prices at the KGGCU are determined by the government and are adjusted periodically. The prices at the local markets are more variable but usually higher. While much is sold at the local markets, fluctuations in prices make this a difficult basis on which to value grain output. Therefore, the prices at the KGGCU were used to ensure that the benefits were not overestimated. The KGGCU is the sole official buyer, distributor and retailer of the grain produce, and it buys in bulk (not less than one 90 kg bag). In 1990/91 the KGGCU price for maize was Ksh 300 per 90 kg bag or Ksh 3.33/kg.

Biomass may be used to make trashlines, thereby improving soil structure and fertility, or used as animal fodder, thus reducing the cost of livestock production. These are indirect benefits which are realized eventually in increased production. In the farm model used in this assessment, biomass produced is used as fodder, except where trashlines are included, when 5 t/ha are diverted for this S&WC purpose. The benefits of biomass are estimated using the local price for fodder at Ksh 0.02/kg.

Under conditions where nutrients are not limited, productivity of S&WC-based crop production systems is unlikely to change significantly with soil erosion over 10 years. However, the fertilizer application rates used in the experiments were not sufficient for production that could be achieved. Residual effects of fertilizer and manure application will increase crop yield. The residual effects will decrease with increasing soil moisture limitation. Soil moisture limitation was low at Machanga, moderate at Kajiampau and high at Kaaragankuru. Yield increases of 5%, 3% and 0%/year are, therefore, assumed for all fertilized systems at Machanga, Kajiampau and Kaaragankuru respectively. In non-fertilized systems yield changes with time depend on soil physical properties and also on initial soil chemical fertility. At Machanga, where initial soil fertility was low, there was a small yield decrease with conservation measures during the second season, except with trashlines where there was a significant increase. Therefore a yield increase of 15% in trashlines and no yield changes with other S&WC measures are assumed. At Kajiampau, where soil moisture was slightly limiting and soil fertility relatively good, yield increases of 10%, 5% and 3%/year in trashlines, tied ridging, and terraces respectively and no yield change in contour and hand tillage are assumed. At Kaaragankuru, where soil moisture was severely limiting and soil fertility relatively good, the most effective S&WC method was tied ridging but there was a small increase with other conservation measures. Yield increases of 3%, 5%, 10%, and 5% for contour tillage, trashlines, tied ridging and terraces respectively are therefore assumed. Although the potential production at these sites was calculated and shown to be about 16.2 t/ha, (Kiome, 1992) the maximum for these systems will be fixed at 12 t/ha/year. The harvest index will be assumed to be the same as was obtained in the field experiments, hence biomass production will be proportional to the grain yield.

ECONOMIC ANALYSIS

Costs

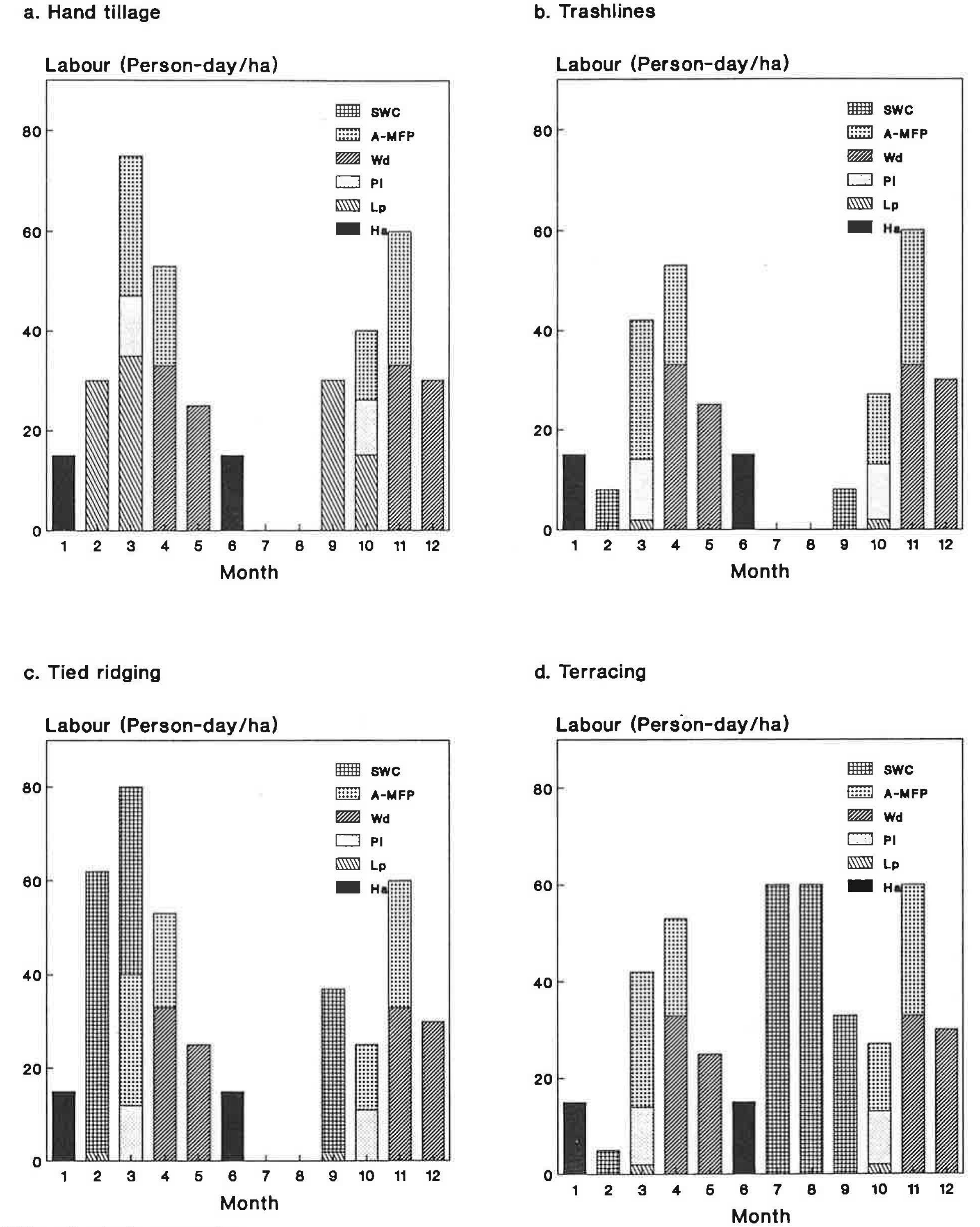
Labour

The labour profiles for the model farm of one hectare used in this analysis are illustrated in Figure 9. S&WC activities are allocated the period when there are few other farming activities. For example, terraces are constructed during the dry period of July to September when the opportunity cost of labour is low and equivalent to the cost of hired labour. With tied ridging, land has to be prepared early to allow time for constructing the ridges. This causes high labour demand early in the season. Contour tillage and trashlines have low labour demand. There is high labour demand in tied ridging and terrace systems although the latter can be constructed during the dry period.

The amount and cost of labour for S&WC measures and the farm operations during each season are shown in Table 11. Tillage in trashlines, tied ridging and terrace systems is considered as a farm operation, while hand and contour tillage systems are considered as an S&WC measure. There are small variations between sites caused by differences in soil type. The labour needed for the system without any conservation measures, hand tillage, is relatively high at 62-67 person-days/ha in the first season. That means that an average household with three adult members working on the farm will require about 23 days. The dry period between the long and the short rains is about one and a half months. An average household would, therefore, have only just enough labour to cultivate one ha before the onset of the rains. Tillage using the ox-plough is relatively cheap. For this reason, many farmers have turned to ox-ploughs for land preparation. There are differences between seasons because tillage during the second and following seasons is less laborious.

Construction of the trashlines needs little labour if in-field crop residues are used, but more labour would be required if residues were brought from outside the farm. For this analysis trashlines are assumed to be made with residues from previous crops on site. Tied ridging and terracing are relatively labour intensive, the labour requirement often being too high for an average household. The time required for tied ridging in the second season is much less because the ridges remain from the first season. The ridges usually have to be reconstructed after two seasons. Variation in labour requirements in terracing is caused by differences in slope and soil type between sites. For similar reasons the 136-281 person-days/ha quoted by Wenner (1980) are considerably more than the labour needed on those slopes which are less than 8%.

The labour required for other farm operations is significant. This is required at peak periods when the opportunity cost may be high. For example, weeding and pesticide application together require 59-64 person-days/ha. Although these operations are simple and easy and can be done by most members of the household, they need to be done at a specific time in the growing period. Delay



SWC = soil and water conservation;
A-MFP = application of fertilizer, manure and pesticide; Wd = weeding

Pl = planting; Lp = Land preparation;
H = Harvesting and processing

Figure 9 Labour profile for selected S&WC-based crop production systems

Table 11 Labour costs of carrying out S&WC measures and farm operations

Site/operation	1st season Labour P-d*/ha	1st season Cost Ksh/ha	2nd season Labour P-d/ha	2nd season Cost Ksh/ha	Annual Labour P-d/ha	Annual Cost Ksh/ha
Machanga:						
Terrace	122	3660	3	90	125	3750
Tied ridging	78	2340	25	750	103	3090
Hand tillage	65	1950	45	1350	110	3300
Trashlines	8	240	8	240	16	480
Contour tillage†	1	1080	1	1080	2	2160
First weeding	33	990	30	900	63	1890
Second weeding	25	750	28	840	53	1590
Manure application	14	420	0	0	14	420
First fertilizer application	14	420	14	420	28	840
Second fertilizer application	14	420	14	420	28	840
Planting	12	360	11	330	23	690
First pesticide application	3	90	4	120	7	210
Second pesticide application	3	90	3	90	6	180
Harvesting	15	450	14	420	29	870
Kaaragankuru:						
Terrace	133	3990	3	90	136	4080
Tied ridging	100	3000	35	1050	135	4050
Hand tillage	67	2010	55	1650	122	3660
Trashlines	8	240	6	180	14	420
Contour tillage	2	1200	2	1200	4	2400
First weeding	34	1020	28	840	62	1860
Second weeding	26	780	24	720	50	1500
Manure application	16	480	0	0	16	480
First fertilizer application	14	420	14	420	28	840
Second fertilizer application	14	420	14	420	28	840
Planting	14	420	13	390	27	810
First pesticide application	4	120	3	90	7	210
Second pesticide application	4	105	3	90	7	195
Harvesting	7	210	5	150	12	360
Kajiampau:						
Terrace	125	3750	3	90	128	3840
Tied ridging	82	2460	30	900	112	3360
Hand tillage	62	1860	45	1350	107	3210
Trashlines	6	180	4	120	10	300
Contour tillage	1	1100	1	1100	2	2200
First weeding	30	900	21	630	51	1530
Second weeding	22	660	18	540	40	1200
Manure application	13	390	0	0	13	390
First fertilizer application	13	390	14	420	27	810
Second fertilizer application	13	390	14	420	27	810
Planting	12	360	13	390	25	750
First pesticide application	4	120	3	75	7	195
Second pesticide application	3	90	2	60	5	150
Harvesting	10	300	7	210	17	510

Notes: * P-d=person-day
† cost of hiring ox-plough

can cause considerable reductions in yield. There is a small variation between sites and season because of differences in the type and growth rates of weeds.

Implements

The type, number and cost of implements required for a model farm of one ha are shown in Table 12. For hand tillage and other farm operations such as weeding and harvesting a minimum of 5 machetes, 3 hoes, and 5 bags for harvesting are needed. A hand sprayer is also necessary for applying pesticide and other agro-chemicals. In contour tillage and trashlines only 1 hand hoe is needed because land is prepared with a hired ox-plough. In tied ridging, although land is prepared with an ox-plough, 3 hand hoes are needed for constructing the ridges. In terraces additional implements include spades and pick axes. A wheelbarrow and a spade are needed for manure application, while at least 2 plastic basins are needed for fertilizer application. The cost of these implements is calculated from the market prices at KGGCU.

Table 12 Implements for a model farm of one hectare/farm to carry out operations and S&WC measures

	Implement								
Operation	Bag	Machete	Hand hoe	Pick axe	Spade	Sprayer	Wheelbarrow	Plastic container	Cost (Ksh)
Hand tillage	0	5	3	0	0	0	0	0	610
Contour tillage	0	5	1	0	0	0	0	0	370
Trashlines	0	5	1	0	0	0	0	0	370
Tied ridging	0	5	3	0	0	0	0	0	610
Terracing	0	5	3	1	2	0	0	0	1160
Pesticide application	0	0	0	0	0	1	0	0	600
Manure application	0	0	0	0	1	0	1	0	600
Fertilizer application	0	0	0	0	0	0	0	2	100
Harvesting	5	0	0	0	0	0	0	0	100

Based on the field experiments, the amounts and cost of other farm inputs are as shown in Table 13. In practice, other types of fertilizer and pesticides may be used but the total cost should not be significantly different. Most farmers will use previous season's seed for the following season unless all has been consumed or sold. The market prices at KGGCU were used to calculate the cost of each of these inputs.

Table 13 Amounts and cost of farm inputs

Input	Amount (kg or l/ha)	Cost (Ksh/ha)
Fertilizer		
Farm yard manure	8000	1928
Double ammonium phosphate (DAP)	442	3035
Compound of nitrogen and phosphorous (NP: 23:23)	221	1388
Muriate of potash (MoP)	41	181
Seed		
Katumani composite maize	50	187
Pesticide		
Karate	5	141
Dipteryx	3	235

Costs of S&WC-based crop production systems

The costs of the main components and seasonal and annual totals of each S&WC-based crop production system are shown in Table 14. The total seasonal as well as annual production costs in fertilized systems are more than 2.5 times higher than the non-fertilized systems because of the cost of fertilizer and manure. The total cost in the first season is also significantly higher than in the second season because of the initial capital investment on implements and construction of some S&WC measures. Non-fertilized contour tillage has the lowest annual production cost and it is lower than hand tillage because of the differences in the cost of land preparation. The annual production cost for non-fertilized trashlines is also relatively low. The highest cost is for fertilized terraces. The costs of S&WC are low compared to the cost of farm inputs in fertilized levels and the cost of other farm operations. The difference between the cost of labour for the construction of S&WC methods and the cost of implements depends on the system. In non-fertilized systems the cost of S&WC measures is higher than the cost of inputs as well as the implements, except for trashlines and contour tillage. Furthermore, the cost of farm implements in all the S&WC measures except trashlines is more than twice as high as the cost of farm inputs in non-fertilized systems. This indicates that in non-fertilized systems the cost of farm implements may be the main constraint in the adoption of S&WC measures. For high-input fertilized systems, implements are a far lower proportion of the total costs and the same constraints may not operate. These results suggest differential targeting of incentives through the use of subsidized implements.

Table 14 Cost of maize production for each S&WC-based crop production system (1990/1991 market prices)

Site/ system	Implements	Inputs S1	Inputs S2	S&WC S1	Farm operation S1	S&WC S2	Farm operation S2	Total S1	Total S2	Annual
Machanga										
NF-Ht	1360	563	563	1950	2730	1350	2700	6603	4613	11216
NF-Ct	1120	563	563	1080	2730	1080	2700	5493	4343	9836
NF-Tl	1120	563	563	240	3810	240	3450	5733	4253	9986
NF-Tr	1360	563	563	2340	3810	750	3780	8073	5093	13166
NF-Ftr	1910	563	563	3660	3810	90	3780	9943	4433	14376
F-Ht	2460	7095	5167	1950	3990	1350	3540	15495	10057	25552
F-Ct	2220	7095	5167	1080	3990	1080	3540	14385	9787	24172
F-Tl	2220	7095	5167	240	5070	240	4290	14625	9697	24322
F-Tr	2460	7095	5167	2340	5070	750	4620	16965	10537	27502
F-Ftr	3010	7095	5167	3660	5070	90	4620	18835	9877	28712
Kajiampau										
NF-Ht	1360	563	563	1860	2430	1350	1935	6213	3848	10061
NF-Ct	1120	563	563	1100	2430	1100	1935	5213	3598	8811
NF-Tl	1120	563	563	180	3530	120	3035	5393	3718	9111
NF-Tr	1360	563	563	2460	3530	180	3035	7913	3778	11691
NF-Ftr	1910	563	563	3750	3530	90	3035	9753	3688	13441
F-Ht	2460	7095	5167	1860	3600	1350	2775	15015	9292	24307
F-Ct	2220	7095	5167	1010	3600	1100	2775	13925	9042	22967
F-Tl	2220	7095	5167	180	4700	120	3875	14195	9162	23357
F-Tr	2460	7095	5167	2460	4700	180	3875	16715	9222	25937
F-Ftr	3010	7095	5167	3750	4700	90	3875	18555	9132	27687
Kaaragankuru										
NF-Ht	1360	563	563	2010	2655	1050	2280	6588	3893	10481
NF-Ct	1120	563	563	1200	2655	1200	2280	5538	4043	9581
NF-Tl	1120	563	563	240	4855	180	3480	5778	4223	10001
NF-Tr	1360	563	563	3000	4855	180	3480	8778	4223	13001
NF-Ftr	1910	563	563	3990	4855	90	3480	11318	4133	14451
F-Ht	2460	7095	5167	2010	3825	1050	3120	15390	9337	23727
F-Ct	2220	7095	5167	1200	3825	1200	3120	14340	9487	23827
F-Tl	2220	7095	5167	240	6025	180	4320	14580	9667	24247
F-Tr	2460	7095	5167	3000	6025	180	4320	17580	9667	27247
F-Ftr	3010	7095	5167	3990	6025	90	4320	19120	9577	28697

Notes:
S1 first season
S2 second season
NF non-fertilized
F fertilized
Ht hand tillage
Ct contour tillage
Tl trashlines
Tr tied ridging
Ftr *fanya juu* terrace

Benefits

The cash revenues generated from each production system are shown in Table 15 and are based on the results of the field experiments discussed in detail in Chapter 3.

Table 15 Revenues generated from S&WC-based maize production systems (Ksh/ha, 1990/91)

System	Machanga			Kajiampau			Kaaragankuru		
	S1	S2	Annual	S1	S2	Annual	S1	S2	Annual
NF-Ht	2285	1511	3797	4556	2302	6858	4687	1395	6082
NF-Ct	2271	1465	3735	3915	2468	6383	4720	1730	6450
NF-Tl	4189	7772	11961	4766	3680	8447	5526	1555	7081
NF-Tr	1857	1325	3183	5424	2961	8385	5847	1619	7466
NF-Ftr	2485	1798	4283	5339	2416	7755	5808	1494	7302
F-Ht	13352	12186	25539	10207	4671	14878	9924	2214	12138
F-Ct	12920	10903	23823	11493	4591	16084	9914	3271	13185
F-Tl	15147	16109	31256	11355	8075	19430	11107	2166	13273
F-Tr	18877	14419	33296	16477	5910	22387	10855	4753	15608
F-Ftr	13575	13685	27260	15359	6463	21822	10236	2839	13074

Notes: S1 first season
S2 second season
NF non-fertilized
F fertilized
Ht hand tillage
Ct contour tillage
Tl trashlines
Tr tied ridging
Ftr *fanya juu* terrace

Cost-benefit analysis

The financial cost of various variables determined from the market prices have to be adjusted to be translated into economic cost for cost-benefit analysis. The main adjustment factors for the economic analysis at farm level are depreciation rate and the period to be covered by the non-recurrent investment. It is also important to determine an appropriate discount rate for NPV criteria.

Depreciation rate

There is little information on depreciation rates of farm implements because their cost in small-scale farming is usually relatively small. The rates vary with the type of implement, although most authors use a single value of 20%/year (Bojo, 1986). For example, wheelbarrows and hand sprayers last for a long time but bags cannot last for more than a few years. In this analysis, different rates are used for different implements.

Discount rate

Discounting is a mathematical model which allows a series of sums of money at different dates to be condensed into a sum of money at a single date. By such a model all the monetary benefits and costs of an investment can be condensed into a single figure called *net present value* (Yafrey, 1992). In financial analysis, the discount rate is usually equivalent to the bank interest rate of capital investment assuming a constant or zero inflation rate. In economic analysis of agricultural projects, economists have developed several approaches for determining and justifying a discount rate (*see* Gittinger, 1982) on the basis of interest rates and inflation rates. Ideally there should be a national figure available for discounting in cost-benefit analysis. However, in developing countries where interest rates of borrowing and investing capital as well as the inflation rates are characteristically erratic, it is difficult to determine a discount rate. In this analysis, a discount rate of 15% will be assumed, which is close to the local cost of borrowing capital and sensitivity analysis carried out using discount rates of 10%, 25% and 50%.

Net benefits and marginal rates of return

The economic cost for the main production variables in each production system is obtained after accounting for the depreciation rate and averaging the non-recurrent investments over specific periods as follows:

- hand hoes, machetes and spades are assumed to have a depreciation rate of 20%/year while the wheelbarrow and sprayer have a rate of 10%/year. The plastic containers have a fixed depreciation rate of 33.3%, while bags for harvesting grain storage are rated at 100% because of the need to be replaced annually;
- the cost of construction of terraces was averaged over 10 years. The difference in the cost of tied ridging between the first and the second season was averaged over one and a half years;
- other costs have to be incurred annually.

The adjusted costs of the main production variables, net benefit and savings for each S&WC-based maize production system at each site are shown in Table 16. The cost of construction of S&WC measures was relatively small compared to the cost of other farm operations. Similarly the cost of implements is also relatively small compared to the cost of farm inputs at both soil fertility levels. This indicates that the main financial constraints in these systems are farm operation and inputs, but not S&WC and implements. Thus, assuming that availability of implements is not a problem, to alleviate financial constraints in small-scale S&WC-based crop production, financial support and subsidy should be directed to farm operations and inputs.

In the first scenario, where the cost of labour for all farm operations is included, the S&WC-based maize production system had a positive net benefit at Machanga for all S&WC measures in fertilized levels and for trashlines without fertilization. At Kajiampau and Kaaragankuru, there was net loss in all systems except in non-fertilized trashlines at Kajiampau. These observations imply that if all farm inputs, implements, and labour for both S&WC measures and farm operations are valued at market prices, maize production is economically viable only at Machanga with fertilizer application for all conservation methods and without fertilizer application with trashlines.

In the second scenario (where the opportunity cost of labour for farm operations is taken to be zero), there was a net benefit in all the systems at Machanga and Kajiampau except for non-fertilized hand tillage and tied ridging at Machanga and fertilized hand tillage at Kajiampau. At Kaaragankuru, net positive benefits were obtained in non-fertilized systems, but not in fertilized systems, except with tied ridging, which had a small benefit. The net benefits with non-fertilized trashlines were notably high at all the sites. These observations indicate that with family and borrowed labour at no opportunity cost, S&WC-based crop production is economically viable with and without fertilizer application at Machanga and Kajiampau, except for non-fertilized hand tillage. At Kaaragankuru, the systems are profitable only without fertilizer and manure application.

The relative differences between the systems and sites are illustrated in Figure 10. In fertilized systems, net benefits are clearly related to the initial quality of the soils. As soil physical conditions deteriorate, there are diminishing economic returns with manure and fertilizer application. High net benefits are obtained in soils with good physical properties as was the case at Machanga, but there are economic losses in soils with poor physical properties as in those at Kaaragankuru. The converse applies to the non-fertilized systems. Good benefits are obtained for soils with moderately good physical properties and initial soil

Table 16 Cost and net benefits from S&WC-based maize production systems

	Variable cost					Benefits			
System/ site	Imp	Imp	S&WC	F-Op	Total	Gross	Net-Sc1	Net-Sc2	from S&WC
Machanga									
NF-Ht	307	1126	3300	5430	10163	3797	–6366	–936	
NF-Ct	259	1126	2160	5430	8975	3736	–5239	191	1127
NF-Tl	259	1126	480	7260	9125	11962	2837	10097	9203
NF-Tr	307	1126	1810	7590	10839	3183	–7656	–66	–1290
NF-Ftr	417	1126	456	7590	9589	4283	–5306	2284	1060
F-Ht	527	12273	3300	7530	23630	25536	1906	9436	
F-Ct	479	12273	2160	7530	22442	23825	1383	8913	–532
F-Tl	479	12273	480	9360	22592	31256	8664	18020	6758
F-Tr	527	12273	1908	9690	24300	33299	7994	17684	6088
F-Ftr	637	12273	456	9690	23056	27262	4206	13896	2301
Kajiampau									
NF-Ht	307	1126	3210	4365	9008	6859	–2149	2216	
NF-Ct	259	1126	2200	4365	7950	6384	–1566	2799	583
NF-Tl	259	1126	300	6565	8250	8447	197	6762	2347
NF-Tr	307	1126	1950	6565	9948	8386	–1562	5003	587
NF-Ftr	417	1126	465	6565	8573	7756	–817	5748	1332
F-Ht	527	12273	3210	6375	22385	14879	–7506	–1131	
F-Ct	479	12273	2200	6375	21327	16086	–5241	1134	2265
F-Tl	479	12273	300	8575	21627	19232	–2396	6179	5111
F-Tr	527	12273	1950	8575	23325	22389	–936	7639	6570
F-Ftr	637	12273	465	8575	21950	21824	–127	8448	7380
Kaaragankuru									
NF-Ht	307	1126	3660	4935	10028	6083	–3945	990	
NF-Ct	259	1126	2400	4935	8720	6450	–2270	2665	1675
NF-Tl	259	1126	420	7335	9140	7081	–2059	5276	1887
NF-Tr	307	1126	2350	7335	11118	7467	–3651	3684	294
NF-Ftr	417	1126	489	7335	9367	7303	–2064	5271	1881
F-Ht	527	12273	3660	6945	23405	12139	–11266	–4321	
F-Ct	479	12273	2400	6945	22097	13186	–8911	–1966	2355
F-Tl	479	12273	420	9345	22517	13074	–9443	–98	1823
F-Tr	527	12273	2350	9345	24495	15609	–8886	459	2380
F-Ftr	637	12273	489	9345	22744	13075	–9669	–324	1597

Notes:
Imp implements
Inp farm inputs
F-Op farm operation
Sc1 first scenario
Sc2 second scenario
NF non-fertilized
F fertilized
Ht hand tillage
Ct contour tillage
Tl trashlines
Tr tied ridging
Ftr *fanya juu* terrace

fertility conditions, similar to those at Kajiampau, but significant benefits are also obtained for soils with relatively poor physical properties such as those at Kaaragankuru. In soils with poor physical properties such as those at Machanga only conservation methods which improve soil fertility conditions such as trashlines would provide benefits.

Since this analysis is concerned with S&WC, it is necessary to analyse the net benefit from applying the different S&WC technologies whether the whole system is profitable or not. This is obtained by subtracting the benefits in hand tillage (no S&WC measures) in each soil fertility level and site from the net benefits of the other systems. The results for scenario one are shown in Table 14. These benefits were greater for fertilized than non-fertilized levels at Machanga and Kajiampau, except for trashlines at Machanga. At these sites, the benefits from S&WC measures were greater than the costs, except for contour tillage at both sites and tied ridging at Machanga. This indicates that in soils with relatively

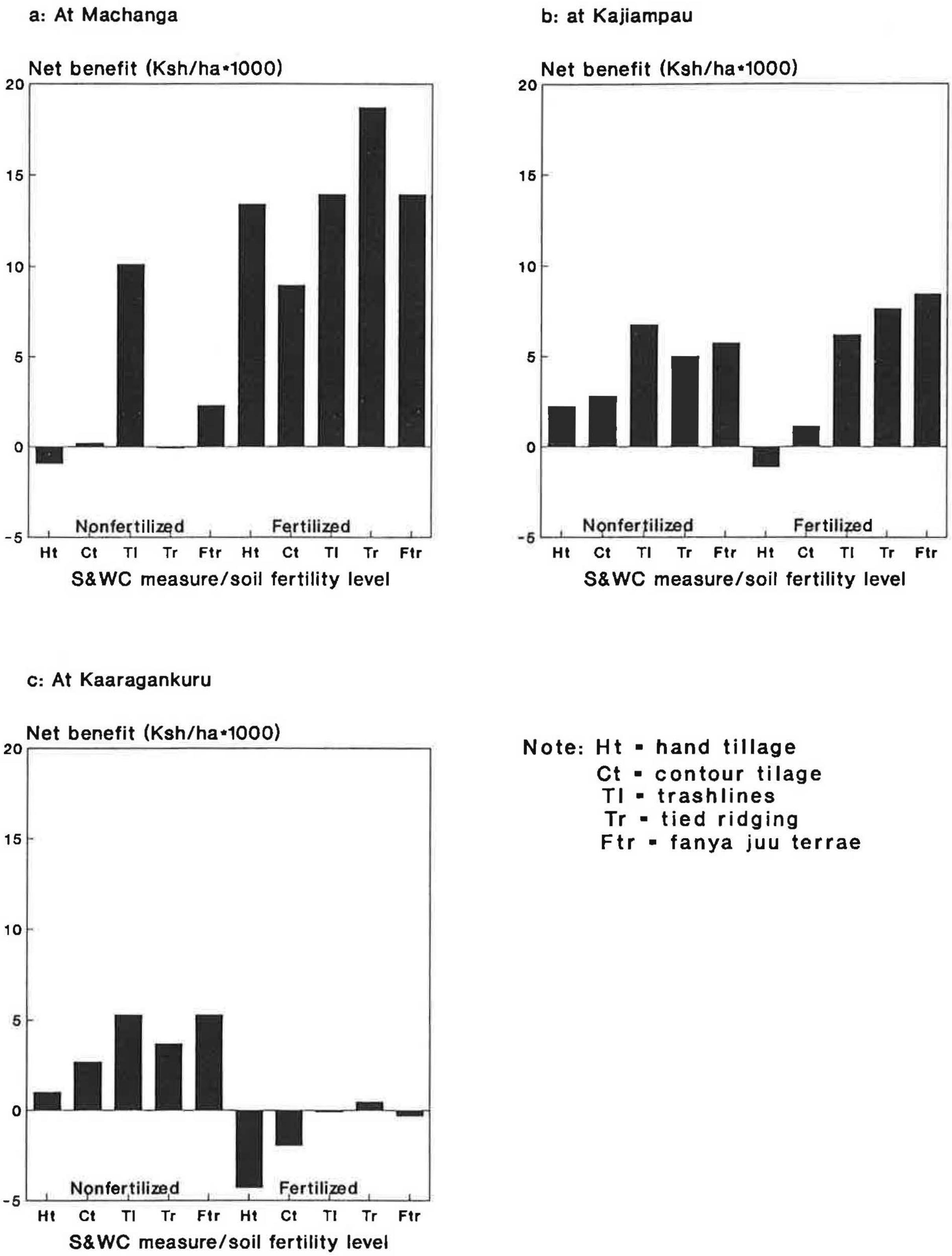


Figure 10 Net benefits of S&WC based-maize production systems

good physical properties, S&WC measures are generally financially profitable and their benefits increase with improved soil fertility conditions. It is notable that there is no benefit in tied ridging in non-fertilized levels at Machanga. At Kaaragankuru the benefits were also considerable, but the difference between fertilized and non-fertilized systems is small, indicating that in soils with poor physical properties, S&WC measures may be profitable, but the benefits do not significantly increase with improved soil fertility.

The economic performance of the systems is further illustrated with the marginal rates of return shown in Table 17. In the first scenario, the marginal rates of return are all less than 38% at all the sites. It would, therefore be irrational for a farmer to practise these S&WC-based crop production systems. However in the second scenario, closer to farmers' situations, the marginal rate of return is convincingly high for some systems. In the non-fertilized levels, it is more than 100% for trashlines and terraces at all the sites. In fertilized systems trashlines, tied ridging and terraces have returns of more than 100% at Machanga, while tied ridging and terraces have more than 50% at Kajiampau. At Kaaragankuru the returns are still unacceptably low in the fertilized levels. This leaves the somewhat uncomfortable conclusion that on this type of soil a maize production system is only profitable if no fertilizer is added, whether or not conservation is implemented. With these soils non-fertilized trashlines should be encouraged and terracing is also convincingly profitable. The marginal rates of return are much higher for non-fertilized trashlines than for all the other systems at all the sites. Next are non-fertilized terraces followed by non-fertilized tied ridging, except at Machanga where fertilized tied ridging performed better.

Overall, non-fertilized trashlines are indicated to be preferable to any other system in this semi-arid environment. Non-fertilized terraces have significantly lower marginal rates of return, but are still attractive for all sites where the opportunity cost of labour is zero (scenario 2) Non-fertilized tied ridging is good except on soils similar to those at Machanga where the addition of fertilizer turns a negative rate of return to an acceptable positive rate. These results show the need for considering carefully the type of soil when assessing potential economic benefits from S&WC-based crop production systems.

Table 17 Marginal rates of return for S&WC-based maize production systems

	Scenario one			Scenario two		
System	Machanga	Kajiampau	Kaaragankuru	Machanga	Kajiampau	Kaaragankuru
NF-Ht	-63	-24	-39	-20	48	19
NF-Ct	-58	-20	-26	5	78	70
NF-Tl	31	2	-23	541	401	292
NF-Tr	-71	-16	-33	-2	148	97
NF-Ftr	-55	-10	-22	114	286	259
F-Ht	8	-34	-48	56	-7	-26
F-Ct	6	-25	-40	60	8	-13
F-Tl	38	-11	-42	136	47	-1
F-Tr	37	-4	-36	128	52	3
F-Ftr	18	-1	-43	104	63	-2

Notes: NF non-fertilized
F fertilized
Ht hand tillage
Ct contour tillage
Tl trashlines
Tr tied ridging
Ftr *fanya juu* terrace

Net present value criteria

Net present value (NPV) predicts the economic value of capital investment in the longer term. In an economic assessment of land use systems at farm level, the main factors influencing NPV are initial capital investment, discount rate, time horizon and changes in crop yield with time. The accuracy of the predictions depend on the accuracy of discount rate, changes in market prices and the benefits over time. Initial non-recurrent capital investment for the systems used in this study is relatively small compared to recurrent expenditure. The results of the analysis will, therefore be quite different from, say, a business venture or mechanized crop production where initial capital investment is high. Since this analysis deals with the economic value of the S&WC-based crop production systems at farm level rather than at national level, the changes in market prices in relation to foreign exchange are unimportant. Most implements and inputs except fertilizers are produced locally and are unsubsidized. The effects of changes in the local market prices are, therefore, implicitly included in the compound discount rate the importance of which is tested in sensitivity analysis. If the systems are unprofitable within 10 years they are likely to be unprofitable in a longer time horizon because the initial capital investment is low.

For each S&WC-based crop production system which registered an increase in yield (*see* Chapter 4, *Benefits*) the gross benefits also increase. Taking the results of the short-term field experiment and extrapolating the measured effects over 10 years gives the gross benefits as shown in Figure 11. Note that these are estimates which may need to be verified in long-term field experiments.

The 10 year NPVs at a discount rate of 15% are shown in Table 18. In the high cost first scenario market prices for labour, all the non-fertilized systems, except trashlines at Machanga and Kajiampau have large negative values, indicating that they are unprofitable in the long run. All the fertilized systems have positive values at Machanga and negative values at Kaaragankuru. This is a similar pattern to the observations of short-term benefits drawn from the net benefit analysis. At Kajiampau, fertilized trashlines, tied ridging and terraces have positive values over 10 years, although they are not viable in the short term (*see* Chapter 4, *Net Benefits and Marginal Rates of Return*).

Table 18 Net present values (10-year) of S&WC-based maize production systems at 15% discount rate

	Net present value (Ksh/ha)					
	Scenario one			Scenario two		
System/site	Machanga	Kajiampau	Kaaragankuru	Machanga	Kajiampau	Kaaragankuru
NF-Ht	-37038	-10940	-20492	-4175	12984	9217
NF-Ct	-35573	-8158	-9982	-2711	16418	19720
NF-Tl	54441	26966	-11155	99702	66479	39012
NF-Tr	-54095	-10854	-17523	-8412	34829	32643
NF:Ftr	-33087	-1737	-12680	12174	37776	37486
F-Ht	43981	-28291	-65219	85691	10079	-23418
F-Ct	37657	-16304	-42192	79307	22065	-390
F-Tl	94008	13566	-41862	137705	57262	-61
F:Tr	87301	16582	-65302	130998	60278	-3038
F:Ftr	68102	23431	-46296	111799	67127	-2600

Notes: NF non-fertilized
F fertilized
Ht hand tillage
Ct contour tillage
Tl trashlines
Tr tied ridging
Ftr *fanya juu* terrace

In the low-cost second scenario – zero opportunity cost of labour, all the fertilized systems and the non-fertilized terraces and trashlines will be profitable at Machanga. Non-fertilized contour tillage which appeared profitable in the short term is unprofitable in the longer term. At Kajiampau, all the systems are profitable but at Kaaragankuru only the non-fertilized systems are profitable. In contrast to the short-term benefits, fertilized tied ridging at Kaaragankuru will not be profitable in the long term.

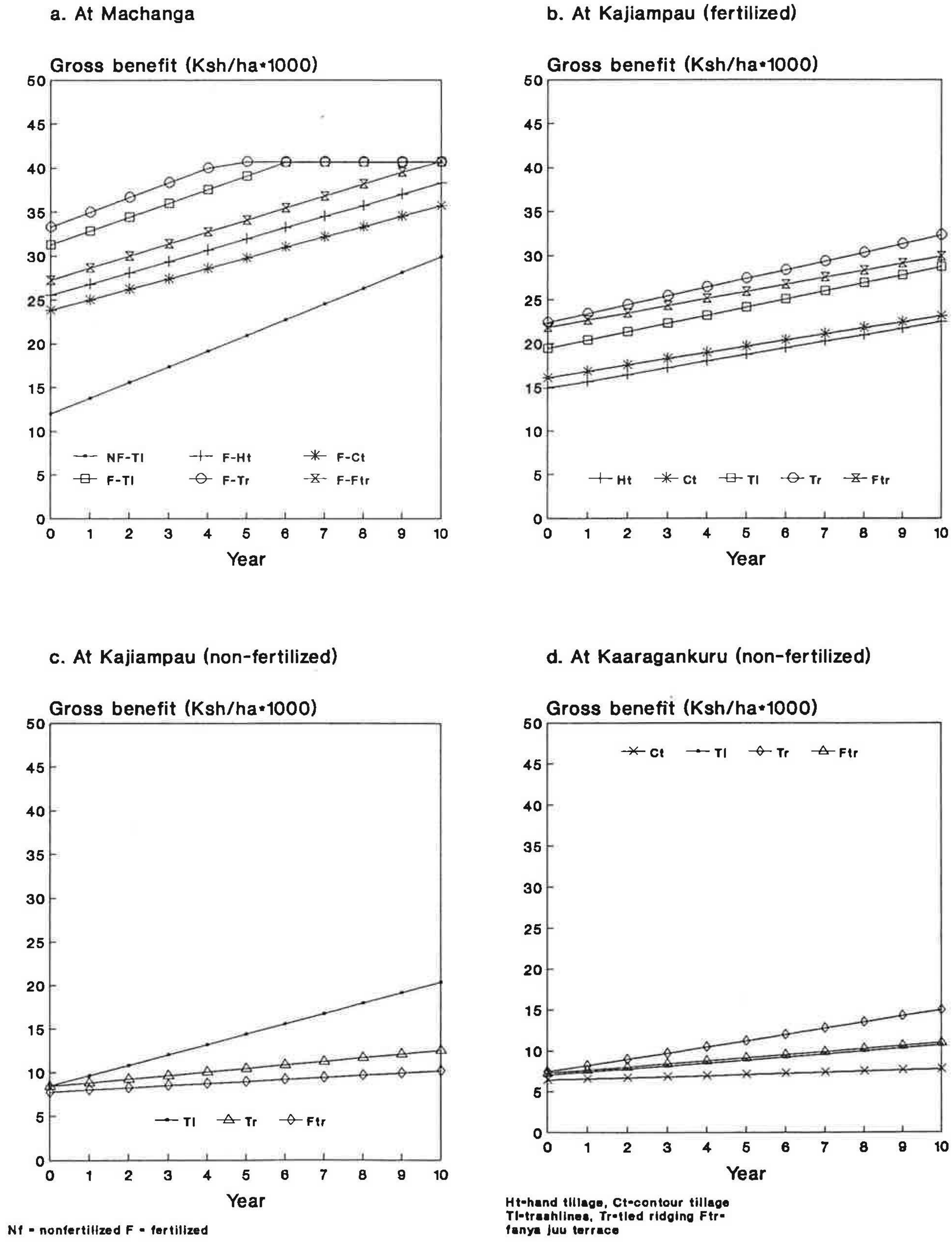


Figure 11 Gross benefits of S&WC-based maize production with time

Discount rate sensitivity analysis

Although many of the systems are profitable at high discount rates, the effect on magnitude of NPV is large, as illustrated in Figures 12a-d for the profitable system at the low-cost scenario. Relative placing of each system is unaffected by discount rate. The curves with the highest NPV are the most profitable systems.

Sensitivity to changes in discount rate is greatest in the range 10-30% with the higher values at Machanga particularly showing a steep decline in NPV with increasing discount rates. A few systems are unprofitable at high discount rates, for example, fertilized trashlines at Kaaragankuru at 10% (Figure 12d). Therefore, while discount rate changes do not affect the overall conclusions of the economic analysis, they are important in determining the net benefits by NPV criteria over the longer term.

CONCLUSIONS

This analysis has dealt with the balance of cost factors in S&WC-based maize production systems in semi-arid Kenya. Farm inputs to improve soil fertility, despite promising yield increases, may be prohibitively costly. In contrast S&WC measures are relatively cheap and on some soils bring good yield benefits. On other soils yield increase through better water availability to plants by S&WC is not possible because of nutrient deficiencies.

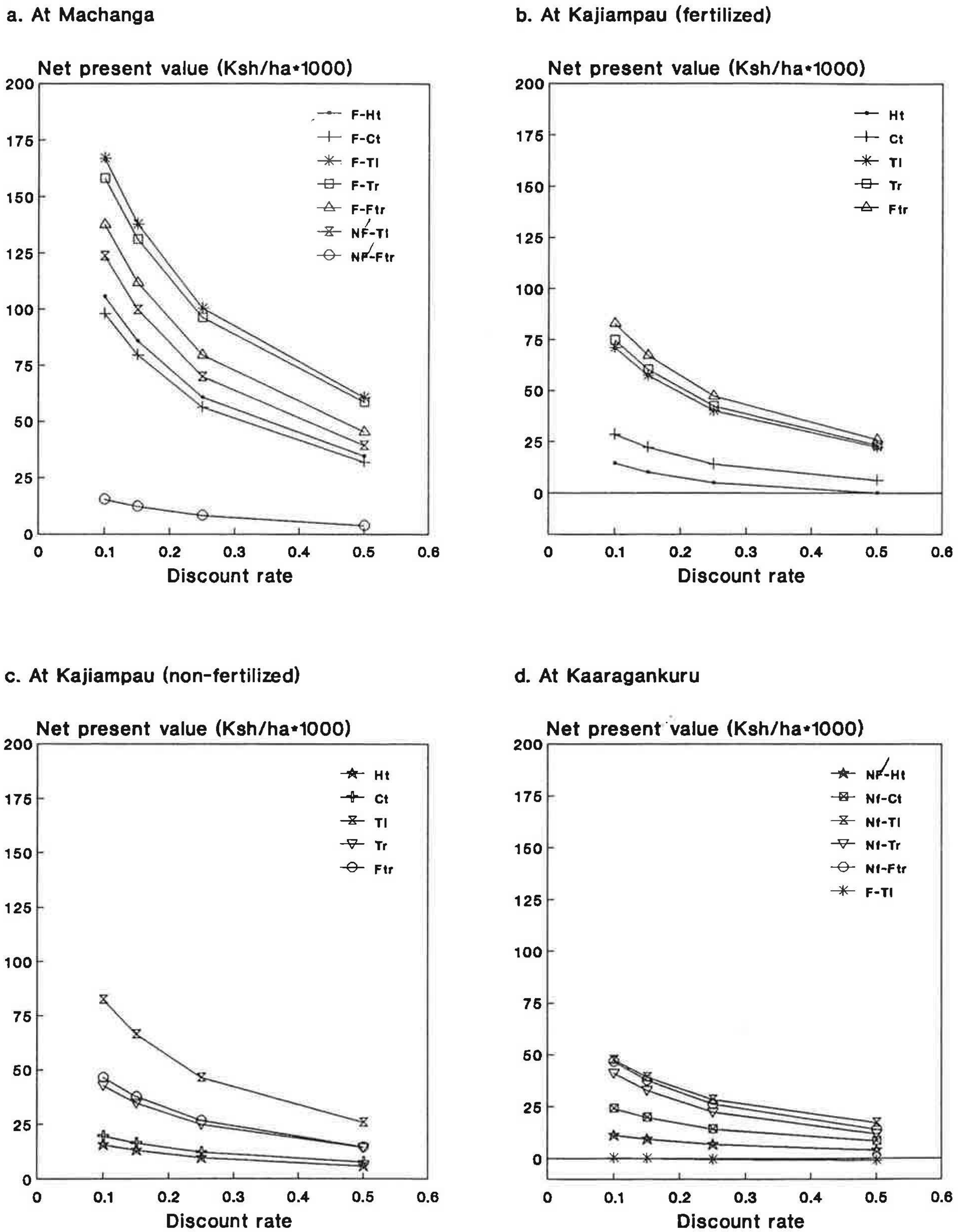
Short-term net benefits and longer-term NPV criteria show that economic viability of S&WC-based crop production systems is site specific. This emphasizes the importance of knowledge of the land resources, land use systems and their productivity response to management in recommending S&WC technologies.

With hired labour for carrying out all S&WC and farm operation activities, the S&WC-based crop production systems analysed in this study are economically profitable in both the short and long term in soils with good physical properties but low fertility when soil fertility is improved with the addition of fertilizer and manure. In soils with moderately good physical properties, the systems with trashlines, tied ridging and terraces with improved soil fertility are not profitable in the short term but will be profitable in the long term. All the other systems, except trashlines, are not profitable. With trashlines, the systems are profitable at both soil fertility levels provided soils exhibit good physical properties (Machanga) and only without improved fertility in soils with moderately good physical properties (Kajiampau).

It is only with zero opportunity cost of labour for farm operations that most S&WC-systems become profitable in the three soils. The returns to improved soil fertility diminish with poor soil physical properties and only the non-fertilized systems are profitable. It is, therefore, irrational to apply fertilizer even with S&WC measures which efficiently conserve soil moisture such as tied ridging. Conversely, in soils with high nutrient deficiency it is only with improvement of soil fertility that physical S&WC measures are profitable.

When an S&WC-based crop production system is unprofitable, the S&WC measures still have the effect of reducing the financial losses. From the marginal rates of return it is conclusive that the most profitable system in all three soils is non-fertilized trashlines. Non-fertilized terraces are the second best option in soils with moderately good and poor physical properties. Fertilized trashlines and tied ridging are the second best in soils with poor soil fertility but good physical properties.

These conclusions are drawn from data from a set of controlled field experiments designed with actual farm conditions in mind. They therefore give



Nf = non-fertilized, F = fertilized.
Ht = hand tillage, Ct = hand tillage

Tr = tied ridging, Tl = trashlines,
Ftr = fanja juu terrace

Figure 12 Net present value-discount rate sensitivity curves baseline indications of the economic feasibility of S&WC-based crop production systems. They may not be fully representative of the on-farm conditions because of differences in farm size, household labour allocation, availability, and opportunity costs. On-farm yields may also be significantly lower than the yields from the field experiments, but the costs will be proportionately lower. The opportunity cost of biomass for making the trashlines also depends on the benefit of feeding the livestock, which will vary with season and household. The benefit of feeding livestock during drought is higher than during a wet season when grass and other sources of fodder are plentiful. The yield changes with time may also be different in on-farm conditions. In the study area, intercropping and livestock rearing are also common land use systems which remain untested in this analysis.

The methodology developed here should, therefore, be extended to on-farm conditions and by results of farmer-participatory research. The inclusion of the S&WC technologies tested here along with other biological measures, land use systems and whole farming systems is recommended.

Chapter 5

Summary of conclusions and recommendations

This research study has compared and contrasted the response of crop yield to S&WC against an assessment of the economic benefits. Both sets of analysis are supportive of each other, with the economic analysis casting additional light on the rationality of the land users' decisions. The performance of S&WC-based crop production systems is demonstrably site specific, emphasizing the need for good understanding of the land resources and the land use system. Blanket recommendations of S&WC measures for crop production will fail.

While the yield analysis suggests it is inadvisable to practise physical S&WC measures without the improvement of soil fertility, the economic analysis indicates this is so only in soils with high nutrient deficiency and good soil physical properties. In soils with poor physical properties, economic analysis indicates that, with improved soil fertility, even tied ridging, which can considerably improve soil moisture availability, will not be economical in the long term. Application of fertilizers in these soils is therefore inadvisable. Both the economic and the yield analysis reveal the superiority of the trashlines. Trashlines combine soil moisture and nutrient enhancement, rendering it unnecessary to use manure or fertilizer in an economically profitable crop production system. While the yield analysis precludes terraces without improved soil fertility, economic analysis indicates that this is the second best option in soils with moderate or poor soil physical conditions. Terracing for moisture and soil conservation and trashlines for moisture and fertility enhancement is, therefore, a particularly good combination.

From both economic and yield analysis, the use of trashlines is recommended without the improvement of soil fertility for most soils in the study area. It is imperative that this S&WC method, which has been overlooked in the past, be given serious consideration in food crop production in the semi-arid areas. For high crop yields, physical S&WC measures are appropriate with improved soil fertility only in soils with severe nutrient deficiency and good physical properties. It is both uneconomic and of no yield benefit to practise highly labour-intensive physical S&WC measures, such as terraces or tied ridging, on such soils. On other soils, physical S&WC methods should be combined with cheap biological methods to improve soil fertility. If terraces have to be applied to control soil erosion, they should also be combined with measures to improve soil fertility. Trashlines are ideal for this purpose. High levels of fertilizer application in soils with poor physical properties are to be discouraged. Cheap methods which improve soil chemical fertility as well as soil physical properties may be the only viable solution for increased crop production.

Although this technical and economic assessment of S&WC-based crop production systems clearly indicates the yield and economic benefits of applying specific S&WC measures in a semi-arid environment, it is evident that there are no easy solutions. Blanket recommendations are likely to fail, but carefully designed S&WC programmes have the potential of increasing crop yields, being economically profitable and thus ensuring sustainable livelihoods for the rural farmers.

In view of the limitations of the cropping system used in the study and the uncertainties in economic analysis, it is recommended that further research on the response of crop production and economic factors to S&WC measures be carried out on-farm. Such research should include the measures recommended here and cheap biological techniques. It is imperative to investigate cheap means of improving soil fertility such as green manuring, composting and 'trash farming' in this marginal environment.

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APPENDIX

Appendix1 Summary of the results of analysis of variance for grain and biomass yield

A Pooled analysis of variance (all factors)

Source of variation	Grain yield	Biomass yield
	F-ratio	F-ratio
S&WC measures	15.32**	3.60^{ns}
Soil fertility levels	495.93**	15.61**
S&WC*Fer.	5.11*	3.10^{ns}
Site	79.86**	21.52**
S&WC*Site	4.69**	0.12^{ns}
Fer*Site	118.89**	11.98**
S&WC*Fer*Site	1.69^{ns}	1.04^{ns}
Season	416.05**	6.49**
S&WC*Season	6.83**	1.10^{ns}
Fer*Season	103.25**	0.58^{ns}
S&WC*Fer*Season	2.88*	0.61^{ns}
Site*Season	71.68**	1.91^{ns}
S&WC*Site*Season	2.15^{ns}	1.07^{ns}
Fer*Site*Season	14.39**	0.64^{ns}
S&WC*Fer*Site*Season	0.677^{ns}	0.38^{ns}
Cv	19.05%	56.35%

Notes:
Fer. soil fertility levels
t total
** and * significant at 1 and 5% levels respectively
^{ns} not significant

B Two-way analysis of variance per site, season and fertility

Site/season	Source of variance	Non-fertilized F-Ratio	Fertilized F-Ratio
Machanga:			
Long rains	S&WC	2.81^{ns}	6.44*
	Cv	47%	16%
Short rains	S&WC	121.77**	5.38*
	Cv	11%	11%
Kajiampau:			
Long rains	S&WC	4.57^{ns}	5.15*
	Cv	9%	11%
Short rains	S&WC	1.16^{ns}	9.13**
	Cv	24%	12%
Kaaragankuru:			
Long rains	S&WC	1.62^{ns}	8.14**
	Cv	23%	11%
Short rains	S&WC	0.08^{ns}	5.7*
	Cv	55%	29%

Notes:
^{ns} not significant
** and * significant at 1% and 5% levels respectively

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