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Ngoro: an indigenous, sustainable and profitable soil, water and nutrient conservation system in Tanzania for sloping land

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Abstract

The Matengo people, in SW Tanzania, developed the ngoro conservation system several hundred years ago and it is a very effective indigenous manual cultivation practice for steep slopes. It deserves wider recognition and investigation to gain a quantitative understanding of the conservation system processes and its management to see whether it can be adapted to be more cost effective with limited land and labour resources. The objective of the study was to evaluate the effects of pit size in the ngoro cultivation system on soil water conservation and yield of maize (*Zea mays* L.). A field experiment was conducted in 1995/1996 at two sites near Lipumba village on the Matengo highlands in Mbinga District, Ruvuma Region, in southern Tanzania. The ngoro comprise a matrix of pits with surrounding bund walls and this indigenous system is used extensively on the steep slopes (typically 20–50%) of Mbinga District. Grass is cut prior to cultivation and laid out in a matrix, traditionally about 1.5 m × 1.5 m square, soil is then dug from the middle of each square and placed to cover the cut grass to form four bunds surrounding each pit. Crops are planted on these bund walls (ridges), under which buried decomposing plant residues provide nutrients and also ingeniously allow seepage of excessive water across the ngoro system. The ngoro pit size treatments comprised N_1 (1 m × 1 m), $N_{1.5}$ (1.5 m × 1.5 m) and N_2 (2 m × 2 m) laid in a randomised complete block design with four replications. Although ngoro profiles were degraded over time, the net loss of soil from the system was negligible as the majority of soil was redeposited in the pit. N_2 was found to be the most suitable pit size on steep slopes. Pit size did not significantly influence the soil moisture regime as measured in this study. Increase in pit size generally resulted in decreased soil penetration resistance and improved plant growth resulting in the highest grain yield being obtained from the 2 m × 2 m ngoros. Increasing the pit size reduced labour input requirements and thereby markedly boosted the profitability of the system.

Keywords: Ngoro cultivation system; Conservation; Cost–benefits; Grain yield; Labour productivity; Pit size; Soil moisture; Surface roughness index

1. Introduction

Ngoro is a local name for the pitting conservation system of the Matengo tribe in Mbinga District, SW Tanzania, and ngoro has been in use for over 200 years (Allan, 1965). The system is an indigenous and

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ingenious means of soil, water and nutrient conservation for land cultivation on steep slopes but ngoro has not been well documented in the literature and this is one purpose of this paper. It consists of a series of regular pits, traditionally 1.5 m square by 0.1–0.5 m deep with the crops grown on the ridges (bund walls) around the pits. When this matrix of pits is seen from a distance the landform resembles a honeycomb.

The main strengths of the ngoro system are:

- Its proven conservation attributes on steep slopes through water and soil entrapment in the pits, thereby reducing the erosivity of run-off whilst encouraging infiltration and sedimentation. When pits are inundated during and following heavy precipitation, the grass 'sandwich' in the soil bunds allows seepage. This seepage ingeniously reduces the possibility of serious erosion through bund breaching as experienced with systems using impervious soil barriers, typically encountered with 'western' concepts of conservation.
- Soil fertility enhancement from the continual incorporation of plant residues into the soil. This increased soil organic content encourages granulation, aggregate stability and increased soil water holding capacity, since humus on a weight basis, can hold four to five times more water than silicate clays (Brady, 1990).
- Creation of a sheltered microclimate in the pit bottom so that there is a stable air/water interface thereby reducing soil water loss through evaporation.

A combination of these factors allows beans to be grown and cropped on residual soil moisture when planted towards the end of the rains in March/April.

The Matengo people are still the main users of this unique system, which is primarily used for maize and bean production on steep lands within a slope range of 2–65%. Other African pitting systems include the basins and planting pits of the Dogon Plateau, Mali (Kassogue et al., 1990), the *deshek* basins in Bay Region, Somalia, the *Kofyar* of the Jos plateau, Nigeria (Critchley et al., 1994) and *katumani pitting* developed by Gichangi et al. (1989) in Kenya. These systems differ from ngoro, however, in that crops are planted in the pit or on the sides of the ridge as opposed to solely on top of the ridges with ngoro. The cultivation and cropping system most similar to the ngoro is probably tied ridges, the main difference being the length/width ratio of the pit or furrow, which is usually at least 3:1 in tied ridges but rarely greater than 1.5:1 in ngoro.

Although the Matengo pit system of cultivation has been in use for at least 250 years, practically no technical investigations have been carried out into ngoro apart from some basic observations of crop yields in the 1940s (Berry and Townshend, 1972) and 1950s (Allan, 1965). The need for research has become rather urgent with the significant increase in population pressures in recent years. In 1994 a regional environment research project (partially funded by the UK ODA/DFID) was initiated to look at indigenous systems of conservation in Kenya, Tanzania and Uganda (Willcocks and Critchley, 1994). The research began with some socio-economic observations and a participatory rural appraisal was conducted in SW Tanzania (Ellis-Jones et al., 1994). This showed that the average fallow period was estimated at 1.5 years and a general consensus amongst farmers and extension workers was that fallow periods are declining. In densely populated areas, ngoro are used without an extended fallow (traditionally a fallow was 6–7 years in duration) and even in less densely populated areas fallows are decreasing to 4 years. Shorter fallows affect the sustainability of the ngoro system of cultivation (which relies on fallows for soil fertility enhancement) and Temu and Bisanda (1995) reported a decrease in grain yield from 3.8 t/ha many years ago, to 1.9 t/ha now. Furthermore, ngoro construction is labour intensive (as mentioned by Stenhouse, 1944; ICRA, 1991) and some younger people are abandoning the ngoro tradition in favour of lower input but less effective options (e.g. shallow ridge cultural practices that do not control water run-off as effectively) a view reiterated during the participatory rural appraisal (PRA) of this project in Mbinga District (Ellis-Jones et al., 1994).

Considerable variations in the sizes of ngoro (from the historically quoted 5 ft, i.e. 1.5 m) have been observed (Ellis-Jones et al., 1994). Ngoro size will affect the level of labour inputs required and the amount of organic residues buried per pit and these factors will influence soil and water conservation, soil fertility and the ultimate fallow period.

The objective of this study was to evaluate the effects of pit size in ngoro cultivation systems on: labour inputs, soil water conservation, yield of maize and system profitability.

2. Materials and methods

2.1. Site conditions

A field experiment was conducted in 1995/1996 at Lipumba village on the Matengo highlands in Mbinga District, Ruvuma Region, southern Tanzania. The major soils of Matengo highlands are Haplic or humic Acrisols (Oxisols, Ultisols) depending on their position within the land topography. These soils are deeply weathered, well drained, red sandy clays with very low ($5\,g\,kg^{-1}$) to high ($30\,g\,kg^{-1}$) organic carbon content depending on the presence or absence of top soil (ICRA, 1991). The climate is temperate tropical with a unimodal rainfall pattern. Rains usually start in November and stop in May of the following year. The recorded total annual rainfall at Lipumba village was 1033 mm in the experimental year.

The field experiment was conducted on two slopes: Site I at 55% and Site II at 15% slope. The sites had a mean altitude of 1208 m above sea level and a distance of 1.5 km separated them. Prior to initiation of the experiment, Site I and Site II were under bush-grass fallow for 6 and 8 years, respectively.

2.2. Establishment of ngoro system

Ngoro construction is carried out in March/April as follows: Grass is slashed and laid in a matrix of discrete squares or rectangles with side dimensions ranging from 1.5 to 3 m. After drying, the grass lines are covered with soil which has been dug from the centre of each square, forming bunds or ridges on all sides of the pit in the centre. The bunds thus consist of a layer of grass sandwiched between a layer of top soil and the original soil surface underneath. Unless an extended fallow is used, the pits are reformed every two years after a 6–8-month short fallow, in such a way, that what was previously a pit becomes a bund and vice versa.

During November 1995 an area of $32\,m \times 43\,m$ was slashed at each site and the bush-grasses left to dry until the commencement of rains in December 1995. The area was then divided into plots of $10\,m \times 10\,m$. These plots were randomly assigned to the following ngoro pit size treatments based on a randomised complete block design with four replications:

- $N_1 = 1.0\,m \times 1.0\,m$ ($1.00\,m^2$) with 100 pits per plot;
- $N_{1.5} = 1.5\,m \times 1.5\,m$ ($2.25\,m^2$) laid out as 49 pits, equivalent in area to 44.4 pits/plot;
- $N_2 = 2.0\,m \times 2.0\,m$ ($4.00\,m^2$) with 25 pits per plot.

The grass rows were arranged along and across the slope in each plot by an experienced man, resulting in 100, 49 and 25 squares for N_1, $N_{1.5}$ and N_2 sizes of ngoro, respectively. Experienced women using their own hand hoes then formed the pits. The time to dig the pits of different sizes was recorded (without the women knowing). Profitability (to labour) was determined from labour requirements for each ngoro size construction using the International Maize and Wheat Improvement Centre (CIMMYT, 1988) partial budget method. Maize (*Zea mays* L.; cv. Local) was sown manually using dibblers on 5 January 1996. The following plant spacings were used for the three different treatments:

- $N_1 = 1.0$ m between rows by 0.3 m between plants, one row per ridge, resulting in a total of 297 plants within the plot;
- $N_{1.5} = 0.6$ m between rows by 0.45 m between plants, two rows per ridge, giving a total of 308 plants/plot;
- $N_2 = 0.75$ m between rows by 0.45 m between plants, all ridges around the pits were planted giving a total of 297 plants/plot.

This design is shown schematically in Fig. 1. Thinning to one plant per hill was done 3 weeks after planting, resulting in a plant population of approximately 30,000 plants/ha. No fertiliser was applied at planting. Top dressing with 120 kg N/ha was, however, carried out 5 weeks after planting, to offset the high nitrogen deficiency symptoms observed in the crop (this N deficiency was probably due to the high organic matter which is fresh and undecomposed in the initial year of the new ngoro and would traditionally be offset by the planting of beans).

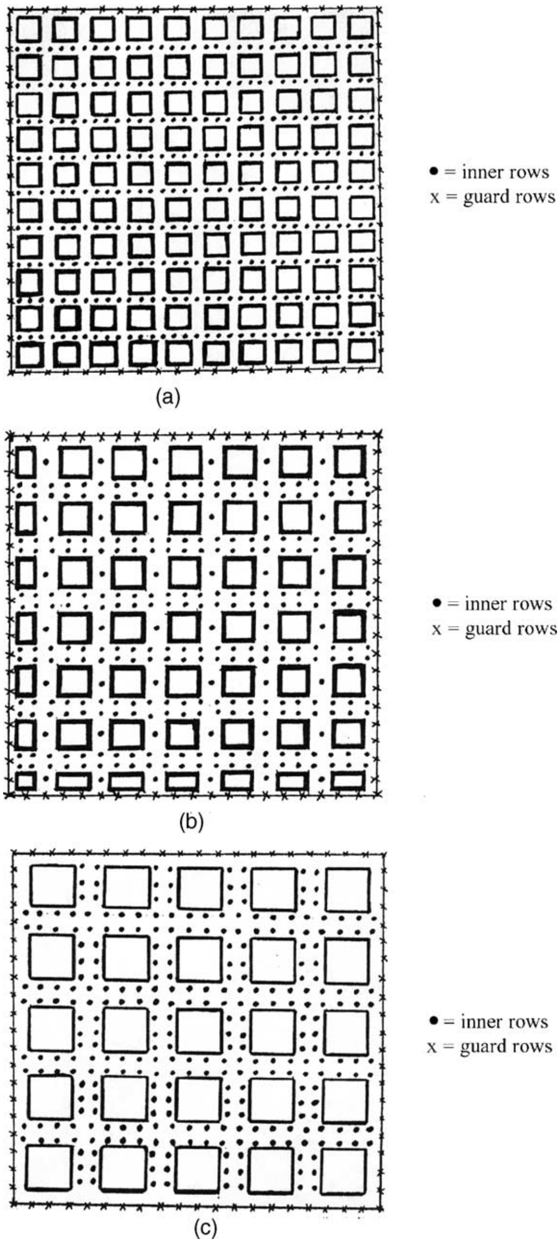

Fig. 1. A diagrammatic sketch of Ngoro cultivation system showing plant arrangements on plots with: (a) 1.0 m × 1.0 m, (b) 1.5 m × 1.5 m and (c) 2.0 m × 2.0 m pit sizes (*original hand drawing from Tanzania*).

2.3. Soil sampling

The purpose of soil sampling, at this stage, was to characterise the soil physical and chemical properties of the two sites and samples were taken before-and-after ngoro construction. Soil bulk density, penetrometer resistance and soil moisture content were measured by standard methods described by Klute (1986).

Soil bulk density was measured on undisturbed cores (50 mm in diameter and 50 mm height) down to 0.3 m depth. Penetrometer resistance on the ridges was measured during the growing season, from 0 to 0.375 m depth in five 75 mm increments, using a field penetrometer (Leonard Farnell) fitted with a cone of 15° semi-angle and 129 mm^2 end area. Soil moisture was monitored at Site I (55% slope) only during the growing season down to 0.12 m depth in 100 mm increments, using a calibrated neutron probe Type I.H. III (Didcot Instrument). Soil pH, total N, organic carbon, available P, exchangeable bases and cation exchange capacity were determined by standard methods according to Page et al. (1982).

Variation and degradation of the soil surface profile (SSP) relief of the Matengo pits down and across the slope were monitored on each of the ngoro size treatments at both sites. This was done using a project developed and locally made soil surface profile gauge (Martin et al., 1996) down and across the slope (see Fig. 2).

Measurements of SSP elevations were made at three locations in each plot, at the same distance down slope, at 40-day intervals during the rainy season. These measurements were used to monitor soil movement and to calculate the pit roughness indices from ridge-top to ridge-top, using the method of Kuipers (1957) expressed as

$$R_k = 100 \log_{10} S \qquad (1)$$

where R_k is the surface roughness index and S the standard deviation of vertical elevations.

Plant height of maize was measured at 35 days after planting (dap). At maturity, all inner rows of each plot were harvested manually, shelled and the grain yield recorded at 13.4% (w/w) moisture content.

2.4. Statistical method

Analysis of variance as stipulated by Theb randomised complete block design was used to assess treatment effects (Little and Hills, 1978). MSTAT

Fig. 2. Measuring the soil surface profile of ngoro conservation structures at an on-farm site in Mbinga District, Tanzania. The conservation structure profile gauge, depicted here, has been designed and developed by the Environment Research Project Team to reliably measure, monitor and compare soil surface profiles (SSP).

computer statistical package (Nissen, 1986) was used for the analysis.

3. Results and discussion

3.1. Soil physical and chemical characterisation of research sites

The soil physical and chemical properties of the research sites are shown in Table 1 and are representative of the area (Msanya et al., 1995, 1996). Soil texture of Site I (55% slope) is clay loam whereas that of Site II (15% slope) is 510 g kg^{-1} clay. Ratings of other soil parameters, according to Landon (1991), are similar on both sites.

3.2. Soil redistribution

Soil surface profiles (SSP) of the ngoro pits were taken down (along) slope (Fig. 3) and across slope (Fig. 4) in December 1995, just after land form construction, and again 40 and 80 days thereafter. At Site I, with the steep 55% slope, soil surface profiles taken 80 days after ngoro construction showed that the pits had progressively filled with soil from the bunds (Figs. 3 and 4) and the ngoro were degraded into flatter pits or gently sloping terraces irrespective of pit size. Degradation on the lesser slope (15% Site II) was less severe. The effect of slope steepness played a major role in profile degradation at Site I (Fig. 3), although the predominance of clay texture at Site II may have contributed to less degradation. These results agree with those reported by Martin et al. (1996) in the same agro-ecological zone of the overall environment project.

As for profiles taken across the slope (Fig. 4) the deposition of sediment in the pits was disproportionate to the amount of erosion on the side bunds, confirming that erosion was more severe on the virtually horizontal bunds across the slope (Fig. 3).

The profile changes in all pit sizes over time were attributed to erosion of soil down from the bund walls

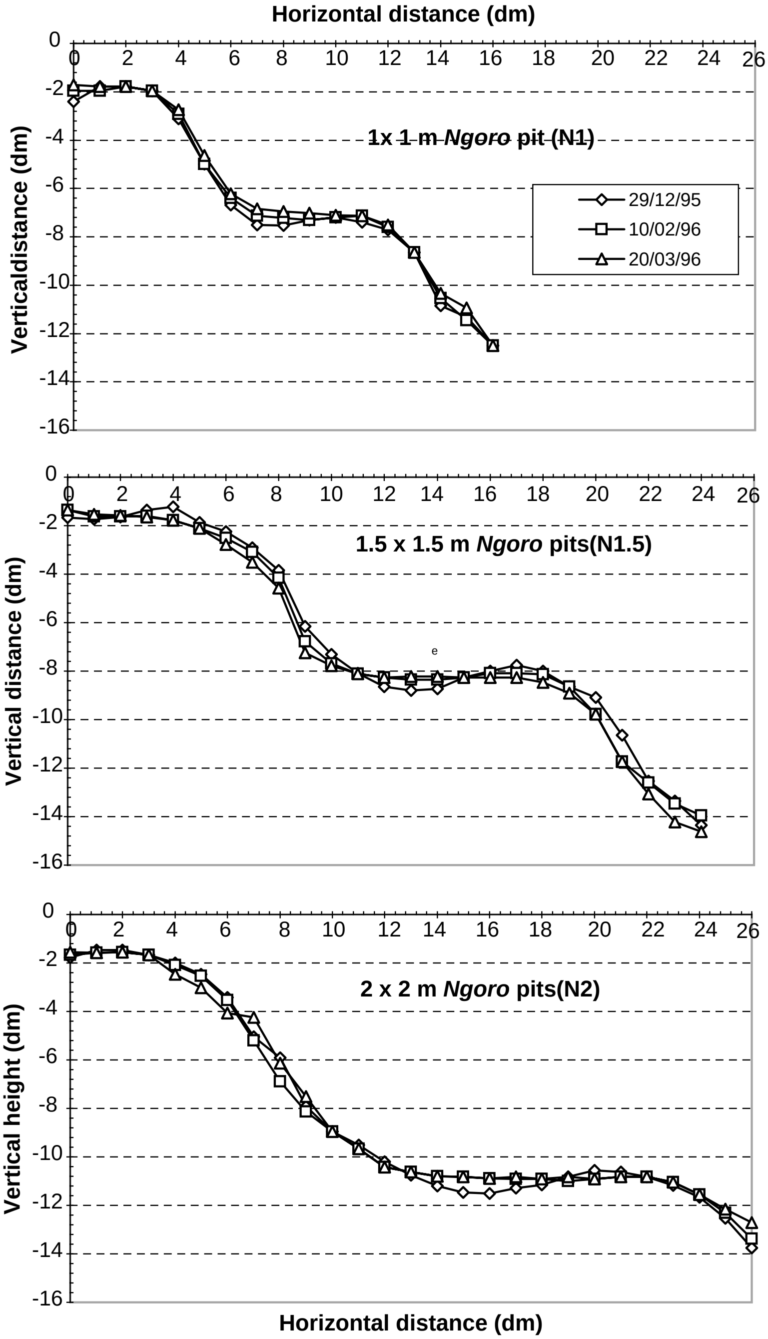

Fig. 3. Pit soil surface profile (SSP) changes down (along) a 55% slope in ngoro conservation systems for 1.0, 1.5 and 2.0 m pits during the rainy season.

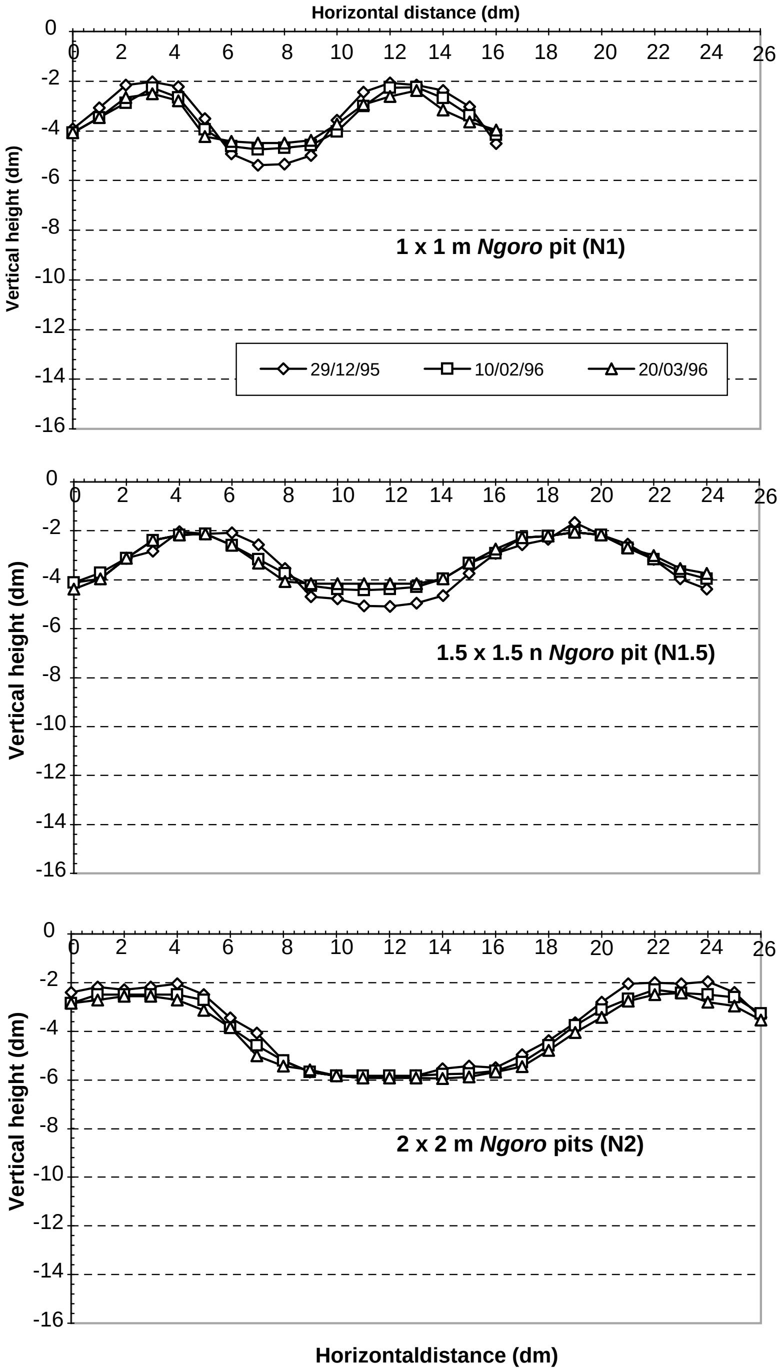

Fig. 4. Pit soil surface profile changes in ngoro cultivation systems when measured across a 55% slope with 1.0, 1.5 and 2.0 m pits during the rainy season.

Table 1
Physical and chemical properties of the top soil (0–33 mm) from each research site and their ratings[a]

Soil parameter	Site I	Rating	Site II	Rating
Slope (%)	55	Steep	15	Moderate
Texture		CL		Clay
Sand (g/kg)	454		334	
Course silt (g/kg)	85		65	
Fine silt (g/kg)	97		92	
Clay (g/kg)	364		509	
Bulk density (Mg m^{-3})	1.30		1.29	
Organic carbon (g/kg)	17.2	Medium	24	Medium
Soil reaction (pH)	6.30	SA	6.10	SA
Available P (mg P/kg)	12.42	Medium	4.46	Low
Total N (g/kg)	0.9	Low	1.6	Medium
Exchangeable bases (g/kg)				
Sodium	0.2	VL	1.0	VL
Potassium	6.4	High	7.9	High
Calcium	49.8	Medium	60.3	Medium
Magnesium	20.1	Medium	21.8	Medium
CEC (meq./100 g)	80.0	Low	93.3	Low
Ca:Mg ratio	24.8	ML	27.7	ML
C:N ratio	18.30	High	15.10	Medium

[a] CL: clay loam, ML: moderately low, SA: slightly acid, and VL: very low.

and the trapping of soil particles in the pit depressions. It was observed that the net loss of soil from the system was negligible, since the erosion was limited to redeposition of soil from the bunds into the pits and evidence of run-off below the plots was not apparent. The role of the pits in the ngoro cultivation system is, therefore, to store run-off with sediments and thereby achieve very effective conservation of soil and water.

3.3. Ngoro surface roughness indices (NR_k's) and soil water content

Ngoro surface roughness indices as affected by pit size are shown in Fig. 5. Generally NR_k's were of high magnitude compared to those reported by Romkens and Wang (1986) for different forms of roughness. Increase in pit size with their higher sides resulted in increased NR_k's which declined with time (Fig. 5).

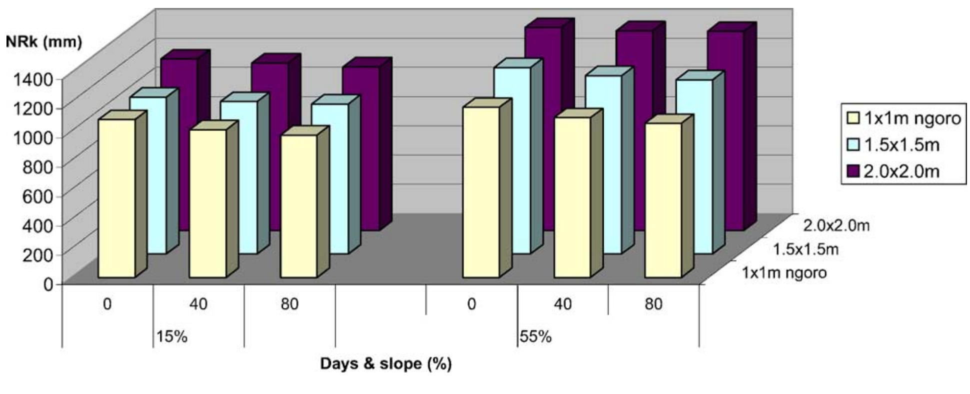

Fig. 5. Effect of pit size on ngoro roughness indices (NR_k) over time.

Table 2
Effect of ngoro pit size on mean soil water content, mm of water in top 0.6 m of soil depth (and the equivalent soil water per metre depth of soil (mm/m)) on the 55% slope[a]

Ngoro bund position	Ngoro pit size[b]		
	N_1	$N_{1.5}$	N_2
Middle	154 (264)	158 (266)	157 (267)
Junction	162 (263)	153 (253)	157 (275)

[a] $N_2 = 2\,\text{m} \times 2\,\text{m}$ ngoro pit ($N_1 = 1\,\text{m} \times 1\,\text{m}$ and $N_{1.5} = 1.5\,\text{m} \times 1.5\,\text{m}$).
[b] Values in parenthesis are given in mm/m.

Pit size significantly ($P \leq 0.01$) increased NR_k's on the 55% slope (Site I) and the resulting crop production performance of the larger pits on steep terrain, indicated the importance of surface roughness in enhancing depression capture and storage of run-off. The 2 m wide ngoro (N_2) is considered, therefore, to be the best pit size, of those tested, for steeper slopes. Few farmers use 2 m wide pits, 1.5 m square being the tradition, and in the light of these findings greater use of wider pits on steeper slopes needs to be encouraged. Pit roughness declined with time and SSP measurements (Figs. 3 and 4) yielded NR_k's that were also significantly different ($P \leq 0.01$) on both slopes (Fig. 5). This marked decline in NR_k's over time, was attributed to the degradation of bunds and the infilling of pit depressions with run-off sediment, which resulted in a reduction of depression storage capacity within the pits.

Mean values of soil water content (0–0.6 m depth) as affected by pit size on a 55% slope are shown in Table 2. Although slight differences were found, no significant differences ($P \leq 0.05$) existed between pit size treatments. The similarity between water contents in the top 0.6 m of the soil profile has also been reported by Martin et al. (1996), who showed that significantly more water was stored under the side and bottom bunds below this depth, when compared with the corner junctions of the bund walls (Fig. 1). In order to obtain a more accurate picture of water storage it is necessary to have at least four monitoring positions in close proximity (viz. left-hand corner, right-hand corner, side bund and bottom bund). The neutron probe has limitations on steep slopes and it is recommended that future work should use dielectric soil moisture sensor techniques (e.g. Thetaprobe) and back up data using gravimetric methods would also be beneficial.

3.4. Penetrometer resistance (PR)

Penetrometer resistance values as affected by pit size treatments are shown in Table 3. Although there were no significant differences (at $P \leq 0.05$) between treatments, trends showed that PR values decreased from N_1 to N_2 in the top 0–150 mm soil layer at both sites.

The decline of PR was of particular importance at Site II (15% slope) because PR values were initially higher than 1 MPa on undisturbed soil. PR values of $\geq$1 MPa have been found to cause substantial reductions in the rate of root growth (Bengough and Mullins, 1990; Townend et al., 1996). At Site II, PR values were reduced to below 1 MPa in the N_1 and $N_{1.5}$ pits in the top 150 mm of soil depth and down to 225 mm depth in N_2 (Table 3).

Table 3
Effect of pit size on mean penetrometer resistance (MPa)

Slope (%)	Pit size	Soil depth (cm)				
		0.0–7.5	7.5–15.0	15.0–22.5	22.5–30.0	30.0–37.5
15	N_1	0.60	0.83	1.06	1.27	1.40
	$N_{1.5}$	0.58	0.78	1.01	1.27	1.39
	N_2	0.35	0.69	0.87	1.12	1.27
		NS[a]	NS	NS	NS	NS
55	N_1	0.37	0.51	0.62	0.66	0.65
	$N_{1.5}$	0.32	0.45	0.64	0.71	0.73
	N_2	0.24	0.39	0.54	0.62	0.66
		NS	NS	NS	NS	NS

[a] Non-significant at $P < 0.05$.

Table 4
Effect of ngoro pit size on plant growth and yield of maize

Slope (%)	Parameter	Treatments			LSD(5%)
		N_1	$N_{1.5}$	N_2	
15	Plant height[a] (mm)	230	250	300	40
	Grain yield (t/ha)	1.66	1.69	1.75	NS
55	Plant height[a] (mm)	150	180	230	30
	Grain yield (t/ha)	1.44	1.66	1.85	NS[b]

[a] 35 days after planting.
[b] Non-significant at $P < 0.05$.

Decreases in penetration resistance with the larger pits were attributed to the need to mechanically loosen greater volumes of earth per pit in order to create the 2 m wide (N_2) ngoros. Correspondingly the N_1 pits with their smaller volume of loosened soil, had a higher PR value than the larger N_2 land forms. The higher PR values at Site II (15% slope) compared to those at Site I (55% slope) could be attributed to the predominant clay texture in the soil profile on this slope (Table 1).

3.5. Crop growth and labour productivity

There were significant differences in the height of maize plants (recorded at 35 dap) between pit size treatments on both slopes (Table 4). N_2 had significantly ($P \leq 0.05$) taller plants than those from other pit sizes. This could be attributed to the higher soil surface roughness index of the 2 m wide pit, whose greater depression storage capacity resulted in increased water conservation and, therefore, improved soil water availability for uptake by maize roots during crop growth. Variation of grain yield with pit size is shown in Table 5 and although statistically insignificant, the 2 m wide ngoro had the highest maize grain yield (1.85 t/ha) compared to the smaller N_1 (1.44 t/ha) and $N_{1.5}$ (1.66 t/ha) pits. Fertiliser was applied after the plant height measurement and this could have masked the effect of pit size on yield by overcoming any nutrient deficiency in the smaller pit sizes.

The size of ngoro pit had a significant impact on labour productivity and the profitability of the pit farming system (Table 5). Increasing the pit size from 1 m (N_1 with 10,000 pits/ha) to 2 m (N_2 with 2500 pits/ha) not only reduced the labour input requirements for construction from 30 Person-days/ha to 20 Person-days/ha, but increased the net cost–benefits ninefold, i.e. 4800 Tsh/ha for the 1 m ngoro (N_1) and 43,250 Tsh/ha for the 2 m ngoro (N_2). Seasonal climatic variations will affect crop yield and profitability but the 33% lower labour input requirements for the 2 m ngoro will remain a significant factor for the promotion of the larger ngoro system. Fig. 6 clearly demonstrates the importance of crop production input costs and how they have an overriding influence when comparing different systems that produce similar grain yields (i.e. not necessarily significantly different), but have very different profit benefits.

Table 5
Effect of ngoro pit size on labour productivity on a 55% slope

Parameter	Ngoro treatments		
	N_1	$N_{1.5}$	N_2
Grain yield (kg/ha)	1,440	1,660	1,850
Return from price of maize grain (July 1996 in Tsh/kg)	45	45	45
Gross benefits (Tsh/ha)	64,800	74,700	83,250
Labour requirements (Person-days/ha)	30	30	20
Labour costs (Tsh/ha)[a]	60,000	60,000	40,000
Net benefits (Tsh/ha)	4,800	14,700	43,250

[a] A Person-day is equivalent to 10 working hours valued at Tanzania Shillings (Tsh) 2000.

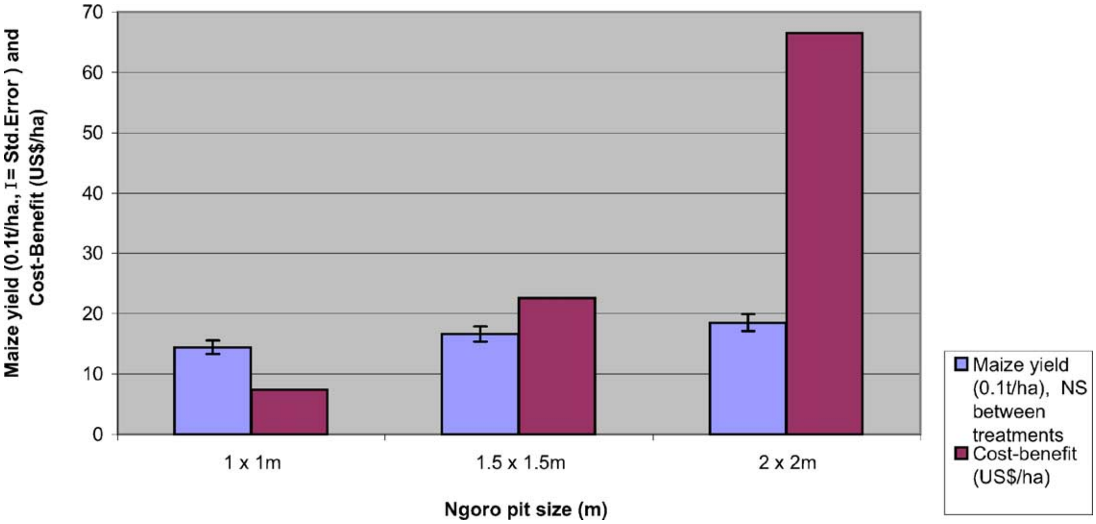

Fig. 6. Productivity outputs from ngoro conservation systems: maize yields and cost–benefits from three pit sizes of ngoro on a 55% slope in SW Tanzania.

4. Conclusions

The following conclusions have been drawn from this research study:

(1) Ngoro production systems effectively conserve water, soil and nutrients on sloping land. There was some degradation of the ngoro over time, but the net loss of soil from the system was negligible as the eroded soil was mainly redeposited in the pit. The sustainability of the steep slope system is evidenced by the use of ngoro to conserve soil for over 200 years.
(2) Pit size did not significantly influence the soil moisture regime, but longer-term monitoring of soil water is recommended for future research.
(3) Larger pit size generally resulted in more favourable edaphic environments for crop root growth, i.e. reduced soil penetration resistance in the 2 m ngoro.
(4) The $2\,m \times 2\,m$ pit size resulted in the highest grain yield of 1.85 t/ha.
(5) Increasing the pit size reduced the labour requirement for construction and, markedly increased the profitability of the system (ninefold in this study).
(6) Further studies should investigate how ngoro can continue to play its vital conservation role with increasing population in the changing economic climate. Larger pit sizes should be promoted, particularly on steep slopes, and evaluation of tied ridging could lead to some form of mechanisation on the lesser slopes. A further participatory rural appraisal with farmers using wider pit sizes is recommended. This would provide a better understanding of the real constraints faced by ngoro farmers and highlight development pathways with local people for the promotion of improved systems and the focus of future research to facilitate this.

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and development programme into indigenous conservation techniques and systems.

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