International Journal of Agronomy and Agricultural Research (IJAAR)
ISSN: 2223-7054 (Print) 2225-3610 (Online)
Vol. 3, No. 1, p. 17-25, 2013
http://www.innspub.net

RESEARCH PAPER

OPEN ACCESS

Effects of micro-catchment rain water-harvesting on survival and growth of multipurpose trees and Shrubs in Nyando District, Western Kenya

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Article published on January 20, 2013

Key words: Micro-catchments, height, RCD, survival rate, MPTS.

Abstract

The productivity potential of dry lands is usually low hence normal crop production is usually next to impossible. This places greater value on the perennial vegetation, especially multipurpose trees and shrubs which too require some form of water management. *Sesbania sesban, Gliricidia sepium, Casuarina equisetifolia, Grevillea robusta* and *Eucalyptus grandis* seedlings were planted on micro-basins, semi-circular bunds, V-shaped bunds, sunken pits and a control pit at the beginning of the rainy season in March 2007. The experiment was replicated three times. Survival rate, height and root collar diameter measurements were taken during planting and subsequent data collected after every two months throughout the study period of nine months. Data was analyzed by use of GENSTAT 5.0 and the significant means were separated using LSD at $P \leq 0.05$. Use of micro-catchments improved seedling survival by between 32.1% and 85.7% while Individual trees species survival varied from 68.3% to 89.2% with *Grevillea robusta* being the best performer. The different species depicted significantly ($P < 0.05$) better growth in height and Root collar Diameter (RCD) at different levels in micro-catchments as compared to the control. Micro-basins posted comparatively higher growth in both height and growth for all the tree species. The use of micro-catchments can improve the survival and growth of adaptable trees in semi-arid environments.

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Introduction

Land rehabilitation is a key factor in dry lands as they are classified by low poorly distributed and highly variable rainfall and it is almost impossible to plant trees without some form of water management (Rocheleau *et al.,* 1988). Water stress in these areas is the major cause of mortality and poor seedling performance during establishment. It is therefore essential to avoid water stress and the effects of negative microclimatic factors on tree establishment. Therefore, techniques that ensure increased moisture availability, reduced wind speed, and reduced evaporation should be used. Of the few options available, water harvesting technology is currently the most economical means by which survival of young seedlings can be enhanced (Hai, 1996).

Rainwater harvesting is a method for inducing, collecting, storing and conserving local surface runoff for agriculture in arid and semi-arid regions (Boers and Ben-Asher, 1982). Micro-catchment water harvesting (MCWH), which may be defined as the collection of surface runoff from a runoff area over a distance of less than 100 m and storing it for consumptive use in the root zone of an adjacent infiltration basin, is a technique for growing crops in arid areas where precipitation is inadequate and irrigation water is lacking (Boers and Ben-Asher, 1982; Sharma *et al.*, 1986; Oweis *et al.*, 1999; Yan Li *et al.*, 2005).

In Kenya, micro-catchments have been used to establish trees in Machakos and west Pokot Districts (Cheboi 1997). Some of the micro-catchments that have been used include the sunken pits, contour ridges, V-shaped bunds and semi-circular bunds and they have been found to be effective as they act as litter traps, hence, ensuring increased water availability, reduce run-off speed and reduce evaporation. The size and layout of these micro-catchments varies according to the local ecological conditions and the intended use (Rocheleau *et al.*, 1988).

Numerous water-harvesting projects have failed because the technology used proved to be unsuitable for the specific conditions of the site (Siegert, 1994). The success of micro-catchments depends on climate, soil type and slope of the planting site. Ochieng *et al.,* (1989) reported that although micro-catchments had been extensively used in Turkana District, limited research has been done to develop local suitability. Bunch (2000) emphasized on research need for micro-catchment water harvesting conducive to specific agro-climatic and socioeconomic environment.

This study aimed to fill the gap of lacking information on the site suitability of sunken-pits, micro-basins, v-shaped bunds and semi-circular bunds by assessing their effectiveness in the establishment of *Sesbania sesban, Gliricidia sepium, Casuarina equisetifolia, Grevillea robusta* and *Eucalyptus grandis* seedlings in terms of survival rate, RCD (cm) and height (cm) in Nyando District which is characterized by erratic rainfall patterns, seasonal flooding, huge gullies and very shallow top soils (Kung'u and Namirembe, 2012).

Materials and methods

Study area

The experiment was conducted in Nyando District, Western Kenya which lies at 0°9' 32.4" south and 34°58' 51.6" east. It is a Humid to sub humid lowland with an average rainfall (bimodal in nature) of 450 mm to 1000 mm per annum and an altitude of 1,212 m. The temperatures range from 23°C to 30°C (Republic of Kenya, 2007). The soils in the area are clay loam in texture with a hard pan within the first 20 cm and have an impeded drainage (Verchot *et al.*, 2008) and are characterized as Vertisols and Ferralsols with the sub-soils being sodic and having less stable aggregates (Waruru *et al.,* 2003). The vegetation in the area is mainly grassland dominated by Eragrostis spp and Digitaria spp used grazing and shrubs of *Aloe vera*, sisal and *Acacia* spp. It is characterized by small farm sizes (averaging less than 1 ha) and low agricultural potential due to low and erratic rainfall. The site has high levels of poverty and serious environmental degradation, including declining tree cover, serious soil erosion and declining soil fertility (Hijmans *et al.*, 2005)

Experimental design and treatments

The experiment was set up in March 2007. *Sesbania sesban, Grevillia robusta, Eucalyptus grandis, Gliricidia sepun and Casuaria equisitifolia* were planted in different micro-catchments viz: sunken pits, micro-basins, v-shaped bunds, semi-circular bunds and a control (where conventional planting hole was used) were laid down and replicated three times in a split plot design. For each treatment, 8 seedlings of for each species were planted. Therefore, a total of 120 seedlings for each species were planted in each treatment. One shovel full of manure was added and mixed with the soil before filling back the holes. The plots were fenced off to avoid browsing by animals, spot weeding and micro-catchment maintenance was done after every 2 months during data collection.

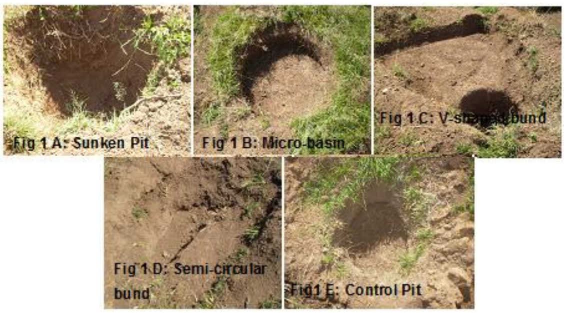

Fig. 1. Different Micro-catchments designs used in Nyando District.

The species used were selected depending on the farmers' preference in the area and were randomly allocated to the various treatments by use of random numbers derived from random number tables.

Construction of micro-catchments

The area for each micro-catchment was calculated, and then delineated on the ground and cleared of vegetation. The planting pits were prepared as follows:

Sunken pits

The pits were dug 40 cm deep, with a top opening of 60 by 60 cm and gradually narrowing towards the bottom, effectively forming a cone-shaped pit. The seedlings were then planted below ground level. Top soil was filled back only to the level of the seedlings root collar, leaving the plant in protected hole, with the root collar approximately 25 cm below ground level (Fig 1A).

Micro-basins

The basins had a diameter of 30 cm and a depth of 20 cm (Fig. 1B).

V-shaped bunds

The V-shaped micro-catchments had a top opening of 1m and a height of 1m. The pit size was 30 cm by 30 cm while the bund had a height of 20 cm with a base width of 20 cm and crest width of 10 cm (Fig. 1C).

Semi circular bunds

Semi-circular bunds were constructed with their tips along the contour. The heights of the bunds decreased from the center to the tips. The semi-circles were 30 cm in radius with height of 40 cm; the bund had a base width of 20 cm and crest width of 10 cm. The planting hole of the semi-circular bund was 20 cm by 20 cm (Fig. 1D).

Control pit

This consisted of pits with dimension of 40 by 40 by 40 cm. For the planting, virtually all the soil removed was filled back in to the planting hole, thus establishing the seedling at ground level (Fig. 1E).

Data collection

Parameters measured included; survival rate (%), height (cm) and root collar diameter (cm). Measurements were taken at time of planting as well as the number of seedlings recorded and subsequent data collected after every two months for nine months where all saplings were systematically measured. All the surviving seedlings planted were counted and considering survival is not always a clear-cut parameter; it was taken to refer to the presence of living trees, even if it is not completely healthy (Wood *et al.,* 1991). The height (cm) was directly measured at the highest point above ground attained by the main stem of the seedling (Wood *et al.,* 1991) by use of a height stick. RCD (cm) was measured on the stem at the point close to the ground level by use of a venier caliper.

Data analysis

Data was analyzed by use of GENSTAT 5.0 and the significant means were separated using LSD at P ≤ 0.05.

Results and discussion

Survival rate of different MPTS in the different micro-catchments in Nyando District

The overall survival was 78.3% for the different treatments and species. *Grevillea robusta* had the highest survival of 89.2% compared to the rest of the tree species: *Casuarina equisetifolia* 80.0%, *Eucalyptus grandis* 74.2%, and *Gliricidia sepium* 82.5% while *Sesbania sesban* exhibited the least survival of 68.3%. For the different micro catchments, survival was highest in the micro basins (86.7%) and also in the semi-circular bunds (85.8%). V-shaped bunds had an average survival rate of 81.7%. Sunken pits had the lowest survival of 78.3% in comparison to the other micro-catchments while the control had the least overall survival of 60.8%. The survival of the different tree species in the different micro catchments is shown in Fig. 2.

The micro-catchments improved survival by between 28.8 and 42.5 % in comparison to those planted in the control. The results strongly indicate that micro-catchments can significantly increase tree establishment and their long term survival in dry lands as the trees grown in the micro-catchments posted better survival. These results are similar to that reported by Ochieng *et al.,* (1989) that micro-catchments improved survival rate of tree seedlings by about 42 %.

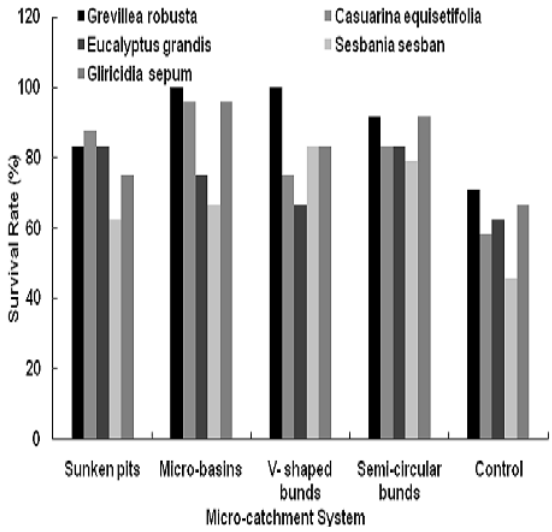

Fig. 2. Survival rate of the MPTS in micro-catchments in 9 months after transplanting.

The survival rate of different tree species varied in the dry lands and was mainly affected by the availability of moisture for growth, their degree of resistance to water stress and resistance to water logging. Soil type, that is, clayey loam soils (Macviar, 1977) and the presence of hard pan within the first 20 cm of the soil profile in the area also played a great role on survival as it could hold water for longer periods during the rainy seasons and at the onset of the dry spells. The high survival in *Grevillea robusta* was due to the fact that they can do well in warm, humid and sub-humid areas (Doran and Turbull, 1997). Their survival failures could be attributed to water logging as they favor well drained soil (Fenton *et al.,* 1997). The survival of *Casuarina equisetifolia* was relatively average; this can be attributed to the soil type in Nyando that was quite heavy for their survival as they cannot tolerate heavy soils (Wagner *et al.,* 1999). A lapse in soil moisture during early growth of *Eucalyptus grandis* became threat to its survival (NAS, 1980) while the partial water logging in some treatments boosted their survival although the lack of free draining soil could have also lead to failures in some instances (NAS, 1980). Although *Gliricidia sepium* require high rainfall for their survival, their average survival could be attributed to the presence of moisture in the soil accumulated in the micro-catchments (Maundu and Tengnäs, 2005). Although *Sesbania sesban* attained the greatest heights and RCD compared to the other species, its survival of was generally low. The low survival could be attributed to the soil type in the Nyando area and also the altitude was quite high as it does best in areas that are below 1200 m above sea level (Maundu and Tengnäs, 2005).

Micro-basins posted the highest survival in comparison to the other micro-catchments, this could be attributed by the fact that it could hold a lot of water but not too much to choke the seedlings due to its size (smaller in comparison to the other micro-catchments). Excess water in the semicircular and V-shaped bunds which could otherwise have led to water logging was discharged in the spaces between two consecutive bunds (FAO, 2005). Further, in semi-circular and V-shaped bunds, water was collected in the hoop (near the planting hole) to allow greater infiltration. Sunken pits could hold the most water but depicted the least survival among the four micro-catchments. This was due to water logging and those species that could not tolerate some degree of water logging could not survive.

Performance of MPTS in the micro-catchments at 9 months in Nyando District

Table 1. Growth in RCD of different MPTS in micro-catchments in Nyando District 9 months after transplanting.

Micro-catchment	RCD (CM)				
	Sesbania sesban	*Casuarina equisetifolia*	*Gliricidia sepium*	*Eucalyptus grandis*	*Grevillea robusta*
Sunken pits	1.70[bc]	0.90[ab]	0.91[bc]	0.70[a]	0.93[c]
micro-basins	1.80[ab]	0.93[a]	1.14[a]	0.67[ab]	1.16[a]
V shaped bunds	1.73[b]	0.87[b]	0.97[b]	0.70[a]	1.03[b]
Semi-circular bunds	1.97[a]	0.90[ab]	0.94[bc]	0.60[b]	1.17[a]
Control	1.43[c]	0.77[c]	0.89[c]	0.60[b]	0.77[d]

*Means not connected by same letter within a column are significantly different according to LSD at P≤0.05.

Table 2. Growth in height of different MPTS in micro-catchments in Nyando District 9 months after transplanting.

Micro-catchment	Height (CM)				
	Sesbania sesban	*Casuarina equisetifolia*	*Gliricidia sepium*	*Eucalyptus grandis*	*Grevillea robusta*
Sunken pits	216.5[b]	157.9[d]	81.3[ab]	157.8[b]	79.7[bc]
micro-basins	258.9[a]	170.5[b]	83.7[a]	162.0[ab]	90.3[a]
V shaped bunds	242.4[ab]	174.7[ab]	78.2[b]	165.2[a]	84.3[b]
Semi-circular bunds	221.7[b]	179.5[a]	84.7[a]	161.0[ab]	84.6[b]
Control	167.3[c]	164.1[c]	74.6[c]	147.4[c]	73.1[c]

*Means not connected by same letter within a column are significantly different according to LSD at P≤0.05.

The growth in RCD and height of MPTS varied in the different micro-catchments at the end of the study period as shown in Table 1 and Table 2. Of the different MPTS, *Sesbania sesban* attained the greatest height and RCD by the end of the study period. *Sesbania sesban* grown in micro-catchments performed significantly better than those grown conventionally by 18.9-37.8 % in RCD (Table 1) and

29.4-54.8 % in height (Table 2). Its good growth can be attributed to the fact that *Sesbania sesban* is generally fast growing and can reach 4-5 m in just 6 months on the right sites (Maundu and Tengnäs, 2005). *Sesbania sesban* can also tolerate water-logging and is ideally suited to seasonally waterlogged environments with a minimal dry season (Evans and Macklin, 1990) which was the case in micro-catchments. The growth in height of *Sesbania sesban* was comparable to that obtained by Nzioka *et al*., (1991) of 244.0 cm growth in height within six months in semi-arid environment of Eastern Kenya.

The growth rate of *Casuarina equisetifolia* was relatively average as indicated in Table 1 and Table 2. *Casuarina equisetifolia* planted in micro-catchments performed significantly better than those grown in the control. In the different micro-catchments, semi-circular bunds attained the greatest height while those in sunken pits posted the least growth in height. Although *Casuarina equisetifolia* can withstand partial water logging for some time, they grow poorly on heavy soils such as clay soil (Wagner *et al.,* 1999) which is the soil type in Nyando area. Sunken pits could hold water for a long period hence the planting site was actually flooded during the rainy season. Lack of free draining soil and a flooded planting hole could have led to the poor development of *Casuarina equisetifolia* seedlings especially in the sunken pit whose growth in height was 3.7 % lower as compared to the control (Table 2). On the other hand, the RCD in the sunken pits (Table 1) was 16.9 % greater than the control. Altitude might have also influenced the growth of this species as it does well in lower altitudes of up to 1 500 m (Duke 1983; Snyder 1992). The growth in height and RCD of *Casuarina equisetifolia* was generally lower in comparison to that reported in coastal Kenya of annual height increase of 2.2 m and 1.3cm in diameter per annum increase in 9 years of tree growth (Whistler and Elevitch, 2006).

Although *Gliricidia sepium* requires high rainfall (Maundu and Tengnäs, 2005), their performance in height and RCD could be attributed to the presence of moisture in the soil accumulated in the micro-catchments. The species attained a height of 76.2-84.7 cm in 9 months (Table 2) in the different micro-catchments and was higher than the control by 4.6-13.5 %. The growth in height and RCD was generally lower as the tree grows rapidly at a rate of 1–2 m/yr in height and 2 cm/yr in RCD in early years (Elevitch and Francis. 2006). Despite the fact that *Gliricidia sepium* can tolerate rocky (shallow or skeletal) soil, it grows poorly on poorly aerated soils as is the case in Nyando. Its performance could also be attributed to the erratic rainfall in the region as the species requires evenly distributed rainfall throughout the year (Elevitch and Francis. 2006).

Height and RCD growth in *Eucalyptus grandis* was relatively lower than the expected 2-3m height increment annually under optimal environmental conditions over the first 10 years (Norman *et al.,* 1970). *Eucalyptus grandis* planted in the micro-catchments performed better that those in the control attaining a height and RCD that was 7.1- 12.2 % and 11.6-16.6 % higher respectively (Table 1 and Table 2). The lower growth rate could be as a result if the limited moisture in the area and also the shallow clay loam soils that are not free draining (Boland *et al.* 1986). This is so as *Eucalyptus grandis* needs a deep, free-draining soil, and does best on fertile loam or clay-loam soils.

The growth in *Grevillea robusta* in height and RCD was significantly higher in the micro-catchments (8.5-23.5 %) in comparison with the control. There were differences in the performance of the tree also in the different micro-catchments with those established in micro-basins being significantly different in height from the others by 7.2-13.5% (Table 2). The height and RCD of trees planted in sunken pits were significantly lower than trees planted in micro-catchments. This observation can be attributed to the fact that *Grevillea robusta* requires free draining with enough precipitation for its optimal growth (Maundu and Tengnäs, 2005). Sunken pits were generally water logged during the rainy season where as the control pits could not hold any water to support maximum tree growth rates and hence the low increment in height and RCD of *Grevillea robusta* in the two treatments. Although the growth of was low compared to the expected increments in conducive environments of 2 m in height and 2 cm in diameter annually over the first five years (Booth and Jovanovic, 1988), it was comparable to the mean annual increment of from 1.3 to 3.3 cm in diameter and from 0.5 to 3.4 m in height obtained in 21 different sites in Uganda (Kriek, 1967)

Conclusion

The use of micro-catchments in Nyando District for tree establishment in the farms has the capacity to improve the survival and growth of the established tree. This can be deduced from the results of the experiment as all the seedlings planted in the micro-catchment systems not only posted a better survival but also had a higher growth rate as compared to those raised in the conventional planting method.

This study showed that, a combination of better species selection with the use of appropriate micro-catchments in Nyando District has the capacity to greatly increase tree survival and growth. It is also important to select appropriate micro-catchment systems to be used as the different micro-catchment systems posted different survival and growth rates. The ability of an individual micro-catchment system to not only hold enough water but to discharge excess water and hence enhance survival of different tree species is an important attribute to be considered while choosing a micro-catchment system.

Better species selection in Nyando District has the capacity to greatly increase forest establishment and cover in the area. This is so as the different tree species responded differently in terms of their survival and growth to the use of micro-catchments. Therefore, the search for more adaptive and productive species could lead to greater tree establishment over time in the area.

Acknowledgement

The authors would like to acknowledge World Agroforestry Centre (ICRAF) through ANAFE programme for their funding.

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