BENCH TERRACING INCORPORATING DEEP CONTOUR TILLAGE ON SHALLOW COASTAL SOILS OF NATAL

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Abstract

The principles are discussed of bench terracing and deep tined tillage, on the level contour, applied to selected shallow soils on steep slopes of the Ifafa area on the Natal south coast. Results from 36 month old timber (*Eucalyptus grandis*) and 14 month old sugarcane (N16) grown on bench terraces are reported and compared with current practices. The implications of this site-specific technique on water management, soil loss and conservation are examined. The use of a computer model to predict changes in total evaporation as a result of deep contour tillage is demonstrated. Initial results show that this site-specific technique of bench terracing can produce high yielding crops of timber and cane on a wide range of slopes.

Introduction

Forestry in Spain and Portugal makes use of deep contour tillage techniques to improve the marginal sites allocated to plantations. Contour tillage, including bench terracing and deep ripping, has resulted in the successful establishment of large commercial plantations of *Eucalyptus globulus* on sites with steep slopes, shallow soils and with rainfall as low as 600 mm per annum (Gardiner, 1989). These tillage techniques, including important local adaptations, have resulted in rapid early growth and in even stands of *Eucalyptus grandis* on marginal sites at Ifafa. Results from a trial with sugarcane showed potential for substantial yield improvements. Details of soil and climate at the Ifafa site are given in Table 1.

Although the climate appears well suited to *E. grandis*, the shallow soils, steep slopes and high intensity storms reduce the effectiveness of the rainfall and explain why commercial forestry has not previously been successful in this area, which is only 35 km from a major pulp mill.

The Agricultural Catchment Research Unit (ACRU) model (Schulze, 1988) used daily rainfall records over 51 years to simulate the total evaporation (TE) (Table 2) and to predict changes in TE as a result of conventional tillage versus deep contour tillage (excluding bench terracing). Total evaporation may be taken as a good index of growth as it reflects the plant's water 'consumption', mainly through transpiration.

Conventional forestry tillage assumed ploughing to 0,2 m and ripping to a depth of 0,5 m, whereas deep contour tillage assumed ripping to a depth of 1,2 m using a three-tine ripper with tines one metre apart.

Table 2

Comparison of total evaporation using the ACRU model

Soil type	Deep contour rip 1,2 m × 3 tine	Conventional till 0,5 m
Clay	766 mm	699 mm
Sandy loam	758 mm	685 mm

The ACRU model indicated that 10-11% gains in TE due to deep tillage were possible. The model showed that there were also frequent four to five month periods when the soil moisture content of both the A and B soil horizons were at permanent wilting point. The increase in TE as a result of deep ripping was viewed not only as a factor for increased growth, but also as a buffer against periodic droughts.

The model did not cater for the effect of bench terracing in addition to deep contour ripping and it was assumed that, if deep contour ripping could result in a 10-11% increase in TE, then the large water-holding potential of bench terraces would enhance TE by at least a further 10%. Therefore, at Ifafa, the combination of bench terraces and deep ripping was expected to result in a 20% improvement in TE when compared with conventional tillage (Table 3).

Table 1

Climatic and soil data - Ifafa site

Location	Latitude 30°26' Longitude 30°36' (Natal coast)
Estate area	1 100 ha
Altitude	120 m
Climate	Warm & humid. Summers are hot and winters mild and frost free.
Total evaporation	940 mm*/760 mm**
Rainfall	950 mm (high intensity storms, predominantly summer rainfall)
Windrun	172 km/day
Temperature	Mean maximum 25,0°C Mean minimum 14,1°C
Soils	Shallow 0,45-0,55m effective rooting depth (ERD). Dominant soil form Glenrosa*** - sandy loam 15-30% clay in the A horizon over lithocutanic B.
Topography	Rolling topography, 30-40% slopes common.

* Total evaporation according to Thornthwaite and Mather. (Calculations by Schönau, 1988)

** Total evaporation according to Agricultural Catchment Research Unit (ACRU) model.

*** MacVicar (1977)

Table 3

Comparison of total evaporation for various tillage techniques at Ifafa

ACRU model prediction		Assumption
Conventional tillage to 0,5 m depth	Deep contour ripping 1,2 m	Bench terrace rip to 1,2 m depth
699 mm Base value	766 mm 10% TE increase	840 mm 20% TE increase

Procedures

Silviculture: site-specific techniques and procedures for E.grandis

Company policy was to keep 20% of the area under sugarcane and convert the remaining area to *E. grandis*. All natural forests were to be protected and riparian zones cleared of cane and returned to natural vegetation.

Soil survey

A comprehensive soil survey preceded all planning.

Selection of species

The choice of *E. grandis* was based on the climatic requirements for the species as described by Schönau and Schulze (1984), and Schönau and Grey (1988). These are a minimum mean annual precipitation of 900 mm, a mean annual temperature of more than 16°C with a mean July temperature of greater than 11°C. These requirements were adequately met at Ifafa. *E. grandis* requires a minimum soil depth of 0,6 m but only provides optimum growth on deeper, well-drained dystrophic soils. The soils at Ifafa did not meet the requirements and were corrected through tillage.

Land preparation

Each terrace was surveyed and marked on the level contour at about 4,5 m apart. The need to survey each terrace was most important as it prevented the bulldozer from taking a wrong line and compounding the error down the slope. Terraces were constructed in such a way that the terrace platforms were wide enough to accommodate the bulldozer (2,5-3,0 m), and that they all sloped into the hill. This inward slope gave a minimum of 300 mm freeboard and 0,5 m2 of surface storage space. Terracing and ripping provided adequate planting tilth and no further land preparation was required. The first 250 ha at Ifafa took 6,5 h/ha to complete.

Establishment

The distance between terraces worked was 4,2-4,5 m and seedlings were planted at 1,5 m intervals along the terrace, just inside the outer rip line. The population of 1 480-1 580 stems/ha was sufficiently close to the ideal population of 1 600 stems/ha for *E. grandis*. Because of the low phosphorus fixation of the soils and adequate residual phosphorus from previous fertilizer applications to sugarcane, the trees were fertilized at planting with 100 g of 3:1:4(40) + 0,5% Zn, and top-dressed with the same mixture when the trees were 0,5 m high.

Pest control

A slow release carbosulfan insecticide was used for white ant control.

Weed control

It is company policy to ensure that eucalyptus plantings are kept free of weeds for the first year or until canopy closure. The terrace platform at Ifafa was weeded by hand hoeing the tree line and spraying the remainder with glyphosate or paraquat, depending on the weed spectrum. The recent introduction of cowpeas *(Vigna sinensis)* as a cover crop has proved successful by providing an estimated 40-60 kg/ha of organic nitrogen and as a means of reducing hand cleaning operations from six to two during summer.

Maintenance

Properly constructed terraces require little maintenance. However, during commercial operations the levels and inward slopes are not always perfect. A D4 caterpillar tractor following a D7H ensures that the freeboard area is clearly defined before planting. A hand steered two wheel tractor drawing a reversible mouldboard plough has proved successful in maintaining adequate freeboard after planting.

Conservation

Preservation by the company of all natural forests and the refurbishing of sensitive riparian zones was appreciated by the conservation committees. In addition all natural depressions, waterways or water courses were left untilled.

Procedure for cane on bench terraces

The suitability of bench terraces for other crops, in particular sugarcane, paw-paws and bananas, was apparent. The effects of bench terracing and deep ripping on shallow soils are that on each bench, rooting depth and available soil moisture are increased by the soil water stored in the 1,2 m man-made profile and by water being stored in the freeboard area. This results in a substantial increase in total available moisture from the top to the bottom of the slope and leads to an enhanced moisture gradient when compared with unbenched areas. The moisture gradient is apparent after heavy storms when water is trapped on the freeboard areas across the entire slope. Water in the freeboard areas of the top benches is first to dissipate, followed by that on the midslopes and finally the bottom benches.

For this reason the comparison of bench terracing and deep ripping with conventional tillage does not lend itself to small plot designs and multiple replications. A simple observation trail was therefore conducted at Ifafa to evaluate the performance of sugarcane on terraces. The 1,1 ha site was split, with the left slope (or more northerly aspect) being terraced, and the right slope being used as a control. The soil form was predominantly a shallow Glenrosa with rooting depth varying from 300-400 mm across the site but tending to be deeper on the control slope. Texturally the soil was a sandy clay loam with a high fine sand fraction.

Land preparation

The terrace section of the trial was terraced and deep-ripped to 1,2 m in February 1989. Both terrace and control areas were sprayed with glyphosate to eradicate the old cane crop. They were ridged to a depth of 0,420m with a Caterpillar D4 ripper in December 1989. Rows were 1,0 m apart. Trial areas were planted on 14 December 1989 with variety N16, fertilized with 500 kg 2:3:4(30) and top-dressed after germination with 600 kg 1:0:1(36). The trial was hand weeded until canopy closure.

Six weeks after planting three terraces were selected from which three, 10 m two-row sample plots were chosen at random along the terrace cane rows. The outer cane rows on the terrace were excluded. Three similar sample plots were selected at random on the control site. Height measurements were taken when the cane was three months old. At harvesting (14 months) stalk heights and cane mass were measured on the row sample plots. In addition to the row sample plots, a sample plot 20 x 20 m on the terrace and on the control area was harvested and weighed to estimate cane yield per hectare. Soil profile pits were dug in the terrace and control area. Visible roots were painted and measured to assess rooting depth and area of profile covered.

Results

Output levels for D7H terracing and ripping

The number of machine passes required to construct and rip a terrace depended on the slope. This varied from one pass to cut and one pass to rip on gentle slopes, to five passes of the machine to cut a terrace platform on a 40% slope (Table 4).

Table 4

Output levels for D7H terracing and ripping

Method	Slope
No terracing required	0-12%
Single pass with blade per terrace	12-26%
Up to 5 passes with blade per terrace	26-40%

Per contour

Terrace 1 pass 12-25% slope	Terrace 5 passes 27-40% slope	Output hectares/9 h shift
Nil	Nil	7,03 (ripping only)
100%	-	3,83
80%	20%	3,25
60%	40%	2,83
40%	60%	2,50
20%	80%	2,24
-	100%	2,03

Water holding capacity and resilience of deep ripped benched terraces

In spite of the terraces withstanding two exceptionally heavy storms of 145 mm in 36 hours and 197 mm in 18 hours (Table 5), accompanied by gale force winds (wind run of 524 km), conservation pressures were such that the terraces were subjected to simulated rainstorms under the supervision of the Department of Agriculture. Four sites were tested to determine the storm capacity of newly and recently constructed terraces. Simulated rainfall varied from 175 and 285 mm water applied over two consecutive days, to 270 mm applied over six hours. No bench terraces overtopped despite simulation of the worst storm recorded for the area (Table 6).

Growth and yield

(a) Timber

The first commercial plantings of *E. grandis* at Ifafa were 6,220m high at 12 months (June 1989) and 12,1 m at 24 months (June 1990). Rainfall during these 12 month periods was 920 mm and 1 178 mm respectively. This growth rate equals that found in some of the best growing conditions in South Africa, and fits the Institute for Commercial Forestry Research (ICFR) (1990) growth model for 25 to 30 t/ha/annum (a mean annual increment of approximately 36 m3/ha/annum).

Table 5

Rainfall records for the period July 1988 to February 1991 (Ifafa)

Month	Year			
	1988	1989	1990	1991
January	—	36	110	114
February	—	290(145)	84	23
March	—	8	210(100)	—
April	—	199(197)	27	—
May	—	11	5	—
June	—	0	20	—
July	17	40	0	—
August	88	0	102	—
September	41	103(65)	47	—
October	49	121	120	—
November	52	389(275)	27	—
December	129	69	101	—

(145) = Storm element in 24 hour period

Table 6

Particulars of water applied to each site as simulated rainfall

Site No.	Average wetted area(m²)	Depth of application (mm)	Intensity of application (mm/h)
1	180	550	58
2	140	280	57
3	180	260	48
4	200	370	41

An official trial monitored by the ICFR at Ifafa showed that at six months the growth response to terrace and rip vs deep rip vs pit on old cane sites was 1,18 m, 0,8 m, and 0,6 m respectively (Figure 1). The trial laid out in autumn on newly constructed terraces received only 52 mm of rain during the first four months of growth.

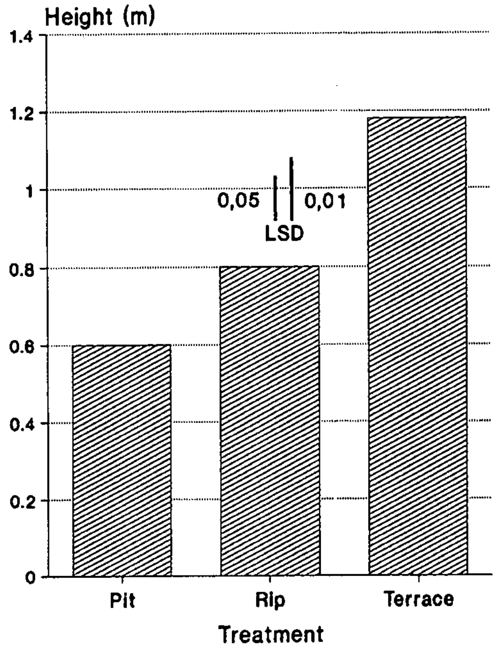

FIGURE 1 Height comparison of *Eucalyptus grandis* at six months using different land preparation techniques.

(b) Cane

Tables 7 and 8 summarise cane yields and height measurements from the 20 x 20 m plots and the row plots respectively. These were harvested when the crop was 14 months old.

Table 7

Trial comparing the growth of cane (variety N16) on bench terraces vs control tillage

Measurements	Bench Terrace	Control	Difference
Average cane height (3rd leaf) on six random sample plots	576 mm @ 3 months	494 mm @ 3 months	16%
Harvest stalk height	1 660 mm	1 560 mm	6,4%
Area sampled for weighing 20 × 20 m	3 913 kg	3 708 kg	5,3%
Equivalent tons/ha at 14 months	98	93	5,55
Equivalent tons/ha/annum	83,8	79,4	
Equivalent tons cane/ha/month	6,98	6,61	
Tons sucrose/ha/month	0,75	0,72	4,25
Equivalent tons cane/100 mm rainfall	9,46	8,98	
Cane roots (observed) and painted in soil profile)	Bulk of roots in top 550 mm depth. Some roots down to 850 mm depth	Bulk of roots in top 400 mm depth. No roots beyond 500 mm depth	

Table 8

Mean height and yield comparisons of row sample plots

	Control				Terrace			
	Ht. 3 mths mm	Ht. 13 mths mm	Pop. (s/10 m)	Yield (kg/10 m)	Ht. 3 mths mm	Ht. 13 mths mm	Pop. (s/10 m)	Yield (kg/10 m)
Max	650	1 900	145	108	750	2 150	174	159
Min	350	1 250	121	81	400	1 500	152	78
Ave	495	1 593	133	95	577	1 789	163	114
SD	64,33	155,81			76,67	134,55		

Table 7 shows that the terraced plot yielded 178 kg more cane than the control plot. This is equal to an additional 5,3% or 5,1 tc/ha. The equivalent cane yields for the terraced control plots were 98 and 93 t/ha respectively. Sucrose yields were 0,75 and 0,72 ts/ha/month for the terrace and control plots respectively. Stalk heights at harvest were 1 660 mm on the terraced plot and 1 560 mm on the control plot.

Table 8 shows that on the 10 m row sample plots a 20,3% increase in cane mass per metre of row was measured on the terrace plots. Total cane mass on terrace row plots was 687 kg and on the control row plots was 571 kg. This represented an average of 114 kg/10 m of row for cane from the terrace rows compared with 95 kg/10 m of row from the control rows. Cane heights at three months on the row sample plots showed an increase of 16% or 0,08 m on the terrace plots. Average cane stalk population per 10 m was 163 stalks on the terrace row plots and 133 stalks on the control row plots.

Roots in the terraced area extended to 0,85 m and were well distributed throughout the profile. In the control area roots did not extend beyond 0,5 m and were found mainly in the tilled area created by rip ridging.

Discussion

Timber

The site at Ifafa is such that under normal circumstances the ICFR would not recommend the planting of *E. grandis* on these very shallow coastal soils, and therefore the growth achieved to date has been remarkable. Future growth rate will largely depend on the effectiveness of the rainfall as each storm fully re-charges the profile. Under local conditions, *E. grandis* would normally only use the site when four years old and would make maximum demands on available water thereafter. Provided the 950 mm average rainfall at Ifafa is maintained, the excellent growth rate is likely to continue.

The rapid early growth at Ifafa tended to support the TE of 940 mm as predicted by the Thornthwaite and Mather model when compared with the TE of 760 mm predicted by ACRU. When the ACRU model is calibrated to include the additional water-holding capacity of bench terraces, the TE prediction for Ifafa will possibly increase substantially from 760 mm to about 850 mm. This will be verified by growth and water measurements over the next four years.

Sugarcane

The main purpose of the sugarcane trial was to indicate the potential of bench terraces and deep contour tillage to increase yield through improved soil depth and more effective water management.

To gauge the true potential of the system the 5,3% increase in cane mass from the terraced area should be assessed with the 20,3% increase in cane mass from the cane row sample plots. When cutting the trial, it was apparent from weed growth and available sunlight that the unplanted terrace slopes were under-used in most cases. Planting an additional cane row using cane transplants on the terrace slope would largely remedy this situation.

Rainfall over the period was 1 036 mm (Table 4) but the only storm of any consequence (100 mm) was in March 1989. The full potential of the system will only be realised when:

- terrace slopes are included, where necessary, in the planting to ensure a full cover population
- a differential fertilizer application is used to ensure that the inner cane row on the terrace receives adequate nutrition as this row is largely planted on tilled subsoil
- variety selection is used to optimize the created moisture regime.

Yields from the terraced and unterraced trial areas were substantially above the yield potential of 70 tc/ha/annum for the Sezela area (Braithwaite, 1990). The use of a D4 to rip/ridge to 400 mm probably gave the control site an advantage over the commonly practised hand ridging of the area. The root profile showed the prolific root growth down to 400 mm in the ridge lines on the unterraced trial plot. Rip ridging also created considerable water holding potential on the unterraced area which is not typical of steep slope plantings.

Economics

Terracing and deep ripping result in a permanent site change and should be viewed as a long term investment with an interest rate of roughly 17%. Based on a cane price of

R65 per ton (including transport payment), harvesting and transport costs for Ifafa of R18 per ton and 12% additional growing costs to allow for the extra cane rows, a contribution of R45,50 could be expected for every additional ton of cane from terracing (Table 9).

Table 9

Economic evaluation

Additional yield/ha from terracing	Contribution from additional tons/ha	Present value @ 3 yrs (2 cuts)	Present value 6 yrs (4 cuts)
5,3% 5 tons cane @ 18 months	R227,50	R322	R 523
10,7% 10 tons cane @ 18 months	R455,00	R640	R1 037

Based on this amount the additional cost for terracing of R540/ha (terrace cost of R900/ha less cost of hand ridging R360) would be recovered in about six years (four harvests) for a 5 t/ha increase in cane yield, and in three years (two harvests) for a 10 t/ha increase in yield.

With the continuing growth of eucalyptus and sugarcane, the surface storage will increase because of increased canopy interception and associated reduction in rainfall kinetic energy. Also crop litter and the use of cowpeas on exposed terraces will improve ground cover, and root colonization of the benches will strengthen and stabilize the cut/fill slopes.

Conclusion

The introduction of bench terracing, deep ripping and site-specific cropping techniques to the humid summer rainfall area of the Natal south coast has resulted in remarkable early growth of *E. grandis* and good growth of cane on these marginal sites. The technique is not limited to steep slopes. Land shaping for water management in the form of bench terraces, and deep tillage to create increased effective rooting depth, will enhance the site potential of a wide range of shallow coastal soils.

Permanent improvement at the site as a result of bench terracing and deep ripping is expected to increase TE by at least 20%, with most of this going into increased crop growth. The vastly improved water retention of the site markedly increases the effectiveness of rainfall and establishes a buffer against periodic coastal droughts. Base-flows under a system of land shaping and deep contour tillage are shown to exceed those of conventional tillage under wet conditions, and enhance the quality of water leaving the site (Schulze, 1990).

More research is required into the water management of bench terracing and deep contour tillage. Productivity gains in terms of labour and machinery in planting, maintaining, cutting and harvesting cane could be very substantial and also need to be quantified. The system requires highly skilled field management and should not be undertaken without a detailed soil/geology/ climate survey. It is recommended that the Department of Agriculture and the SASA Experiment Station should approve all sites before terracing.

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