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Determination of Optimal Replanting Cycles for Sugarcane Production in Sri Lanka

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This paper suggests an alternative approach for determining optimal replanting cycles for sugarcane based on finding maximum allowable yield loss in successive ratoon crops in relation to reference yield, beyond which total net return per unit expenditure on all crops in a cycle starts to decline and corresponding break-even yield of the ratoon crop. This method was empirically applied to determine the near-optimal replanting cycles for the variety Co 775 grown under rain-fed/irrigated conditions and/or settler/out-grower situations at Sevanagala, Pelwatte and Hingurana sugar mill areas in Sri Lanka using the farm-level data collected from 1990/91 to 1994/95 cropping years. The results showed that in the rain-fed settler farms at Sevanagala and Pelwatte replanting should be undertaken when the cane yield reduced to 32 t/ha which corresponds with 8th ratoon in both areas. In the out-grower situations at Pelwatte cane crop should be replanted after 11th ratoon or when the cane yield dropped to 21 t/ha. In the irrigated settler situations at Sevanagala and Hingurana replanting should be undertaken after the fifth ratoon. This corresponds with ratoon cane yield of 52 t/ha. In the out-grower situations at Hingurana replanting should be undertaken after fourth ratoon or when the cane yield dropped to 75 t/ha.

KEYWORDS : Sugarcane, Optimal replanting cycles, Ratoon crops, Yield loss, Sri Lanka

INTRODUCTION

Sugarcane is a semi-perennial crop capable of producing ratoons from the underground stubble after each harvest (King *et al.*, 1965). This is an important characteristic which contributes to increase profitability in cane farming since ratoon cropping is relatively less costly because of no land preparation and planting costs, rapid initial growth and low cultivation costs due to early covering of the soil (Blume, 1985; Chapman, 1988). However, cane yield tends to decline in the successive ratoon crops due to loss of soil tilth since ratoon cropping does not involve intensive soil management, soil compaction due to use of machinery, damages caused to roots physically or by pests and diseases, weakening of root system, building up of diseases such as ratoon stunting disease, etc. (Blume 1985). This decline in cane yield is occurred by reduction in stalk population, stalk weight and increase in stalk mortality (Midmore, 1979; Chapman, 1988). Thus, profitability of sugarcane farming can be improved by raising as many number of ratoon crops as practicable and by replanting at correct time decided depending on the rate of yield decline in the successive ratoon crops (Chapman, 1988).

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There is a great variation in the number of ratoon crops raised in different sugarcane-growing countries. It has been reported raising of one ratoon crop in India (International Sugar Organisation, 1978) and as many as up to 25 ratoons in Cuba (Rao *et al.*, 1983). However, 2 - 6 ratoons are common in most sugarcane-growing countries. For example, raising of 2 ratoons in wet areas and more than 2 ratoons in dry areas of Indonesia (Djojonegoro *et al.*, 1994) and in the Mississippi delta of the USA (Matherne *et al.*, 1972) and 2 - 3 or 4 ratoons in Australia (King *et al.*, 1965; Anonymous, 1980) and in Pakistan (Rao *et al.*, 1983) have been reported. In Mauritius, 4 - 8 and sometimes up to 10 ratoons are taken (International Sugar Organisation, 1976).

Generally, cane yields tend to decline from the first ratoon but it has been reported that rain-fed cane yield in Sri Lanka starts to decline from the second ratoon crop (Keerthipala, 1997). In Jamaica also, Chinloy and Shaw (1973) reported higher cane yields in the first ratoon than in the plant crop. Even though

Table - 1 : Average levels of cane yields of plant and ratoon crops of Co 775 at Sevanagala, Pelwatte and Hingurana, Sri Lanka.

Location	Growing condition	Farm type	Cane yield (t/ha)			
			Plant crop	Ratoon I	Ratoon II	Ratoon III
Sevanagala	Irrigated	Settler	142	106	91	82
	Rain-fed	Settler	74	77	72	75
Pelwatte	Rain-fed	Settler	75	75	70	66
	Rain-fed	Out-grower	63	68	58	55
Hingurana	Irrigated	Settler	102	78	71	60
	Irrigated	Out-grower	101	95	88	78

Source : Keerthipala (1997).

the ratooning ability of sugarcane is a varietal character, yields of successive ratoon crops are also determined by growing environments and the management practices adopted (King *et al.*, 1965; Chapman *et al.*, 1992). In Sri Lanka on average, 2-3 ratoons are raised (Mettananda, 1990) and average levels of cane yields of the variety Co 775, the predominant variety grown under various production systems in the main sugarcane growing-areas in Sri Lanka, namely irrigated and rain-fed cultivation in settler farms[1] at Sevanagala, rain-fed cultivation in settler and out-grower farms[2] at Pelwatte and irrigated cultivation in settler and out-grower farms at Hingurana reported by Keerthipala (1997) are given in Table 1. It shows that cane yields and their rapidity of decline in successive ratoon crops under irrigated conditions are remarkably higher than those under rain-fed conditions. Further, ratoon cane yield decline under rain-fed conditions is irregular mainly due to the effect of erratic nature of rainfall.

As explained earlier, establishment of a sugarcane plant crop is a costly operation and generally more profits can be earned from the ratoon crops mainly due to reduced costs. However, since the ratoon yields tend to decline over the years, maintenance of a ratoon crop after a certain level of yield may not be lucrative to farmer because of decline of profitability and hence it is not rational to maintain the crop further. Thus, replanting that land after reaching a certain level of yield is important to increase both productivity and profitability of sugarcane cultivation.

For a given variety, the determination of the yield level after which the crop should be replanted, i.e. break-even yield for optimising replanting is important not only to maximise the farmers' income, but also to increase the cane supplies to mills and hence sugar outturn and the profitability of sugar manufacture. Replanting in an optimum crop cycle is also important to optimise the use of production resources in cane production and sugar manufacture.

This paper aims at determining near-optimal[3] replanting cycles for sugarcane variety Co 775 grown under different systems in sugar mill areas in Sri Lanka by devising a more rational and practical method.

MATERIALS AND METHODS

Determination of an Optimum Replanting Cycle for Sugarcane

Different methods have been suggested to determine optimum replanting cycles for sugarcane. Chinloy and Shaw (1969 and 1973) suggested a criterion based on maximisation of profit per unit area per annum. According to them, replanting should be started at a point where profit per unit area per annum starts to decline. Tonta *et al.* (1988) and Tonta and Smith (1998) used the same criterion but based on maximisation of cumulative net present value per hectare per year. Keerthipala (1997) used the criterion of maximisation of profit per hectare per year to determine the near-optimal replanting cycles for the variety Co 775 grown at Sevanagala, Pelwatte and

[1] Cane allotments given to farmers in the sugar projects
[2] Cane land owned by independent growers outside the sugar projects
[3] The ratoon crop number which produces a yield level closest to the yield level beyond which replanting should be undertaken.

Table - 2 : Near-optimal replanting cycles for sugarcane grown in Sri Lanka

Location	Growing condition	Farm type	Near-optimal replanting cycle
Sevanagala	Irrigated	Settler	PC+2RC
	Rain-fed	Settler	PC+3RC
Pelwatte	Rain-fed	Settler	PC+3RC
	Rain-fed	Out-grower	PC+3RC
Hingurana	Irrigated	Settler	PC+2RC
	Irrigated	Out-grower	PC+2RC

Source : Keerthipala, 1997.
Note : PC=Plant crop, RC= Ratoon crop

Hingurana under different production systems of Sri Lanka and the results for average farm situations are given in Table 2. However, as the farm situations vary to a great extent and so do the cane yields and the rapidity of their decline, and hence sometimes adoption of these replanting cycles may not be rational in the individual farms.

Further, determination of optimum replanting cycles based on the maximisation of profit/ha/year suffers from some shortcomings. One such drawback is that even when the profit per unit area per year is declining, the profit generated by individual ratoon crop could be even higher than that of the plant crop and hence replanting after reaching the maximum profit per hectare per annum would not be rational from the point of view of maximising farmers' total profit. Another shortcoming in this method, though it can be applied to individual farm situations, is that it does not directly show the extent to which the cane yield should decline from the highest yield of the plant or the first ratoon crop, to start replanting. It would be more practical if the recommendation for replanting is made based on the decline of yield from its maximum level.

Simms (1982) suggested a criterion based on cumulative loss of revenue due to yield decline from its peak and replanting cost. Accordingly, replanting should be done when the cumulative decline of yield is equal to or greater than the replanting cost (land preparation and crop establishment) divided by price of cane, i.e. cumulative loss of gross revenue should be equal to or greater than the replanting cost (maintenance costs on plant and ratoon crops are assumed to be the same). This method has the following drawbacks :

1. The definition of cumulative yield loss is not correct. Simms has defined the cumulative yield loss as the sum of the difference between the peak yield and the individual crop yield. However, in reality the cumulative decline from the peak is the summation of the yield difference between successive crops starting from the crop which gives the highest yield. In other words, the cumulative yield decline up to a given crop is the difference between the peak yield and the yield of that crop. Thus in the Simms' definition, the cumulative yield decline is overestimated.
2. When decision on replanting is made by comparing cumulative loss of revenue with replanting cost, distribution of land preparation and seed and planting costs among the plant crop and ratoon crops are not taken into account. In the case of criterion of profit per unit area per year, this aspect is taken into consideration to a certain extent.
3. Practically, in most of the situations maintenance costs of plant and subsequent ratoon crops may not be the same. Thus, consideration of replanting cost only is not correct for maximisation of profits.

Shaw (1988) also suggested the same concept of accumulated yield decline and the criterion for determining the optimum replanting cycle as suggested by Simms (1982) through an index called Ratoon Performance Index (RPI). Only difference in this method is specification of a reference yield, i.e. the annualised yield of the most productive cane class, to determine the accumulated yield loss. Since this method is also the same as the method suggested by Simms (1982), it is also fraught with the shortcomings mentioned above.

In this paper, a criterion based on maximisation of cumulative net return per unit cumulative expenditure of all crop classes, i.e. cumulative return on investment (CROI) is suggested as a more practical and rational guide in determining the near-optimal replanting cycles and this approach is explained in detail in the next section.

An Alternative Approach for Determining Optimal Replanting Cycles

One of the approaches for making a rational decision on when to replant or the number of crops between successive replantings is on the basis of profit maximisation of a cropping cycle of sugarcane. When the criterion is maximisation of profit per unit area per year as suggested by Chinloy and Shaw (1969, 1973), the shortcomings explained earlier will occur. Similarly, if the criterion is maximisation of profit of the individual crops, even after the maximum profit level, the ratoon crops would produce considerably higher profit than that of the crops raised before. On the other hand, cumulative profit will reach its maximum when a ratoon crop gives no profit. Thus, replanting when the cumulative profit at its maximum is not rational. These shortcomings could be avoided by using total net return per unit expenditure of all crop classes, i.e. cumulative return on investment (CROI) in all crop classes in relation to the total decline of yield from the peak yield obtained either in plant crop or in the first or second ratoon crop as the basis (reference yield). At the optimum level, the ratio of cumulative net return to cumulative cost should be at maximum and greater than zero (if it is negative, that crop is making loss). The total yield loss up to the ratoon crop beyond which the CROI starts to decline can be determined. The corresponding yield of the ratoon crop where CROI is at maximum, i.e. break-even yield can be determined by deducting cumulative yield decline from the reference yield. When the yield of a ratoon crop declined to this break-even yield, the crop should be replanted. This approach would be more rational and practicable to be used in both the average farm situations and individual farms and can be expressed mathematically as shown in equations (1) - (4) :

Equation (1) calculates the CROI :

$$CROIi = \frac{P\sum_{i=1}^{n}Yi - R + \sum_{i=1}^{n}Mi + H\sum_{i=1}^{n}Yi}{R + \sum_{i=1}^{n}Mi + H\sum_{i=1}^{n}Yi} \qquad (1)$$

where CROIi = cumulative net return per unit cost up to ith crop class

Yi = cane yield of the ith crop class (t/ha) (i = 1, 2, ..., n); i = 1 for plant, 2 for ratoon 1, etc.)

R = replanting cost (costs on land preparation and crop establishment) (Rs/ha)

Mi = maintenance cost of the ith crop class (Rs/ha)

H = harvesting, loading and transport cost (Rs/t)

P = price of cane (Rs/t)

The total yield loss from the reference yield to the yield of ith crop class is calculated in equation (2):

$$CYDi = Yr - Yi \qquad (2)$$

where CYDi = cumulative yield loss up to ith crop class (t/ha)

Yr = reference yield (peak yield) (t/ha)

In order to determine mathematically the CYD where CROI is at maximum, equation (3) can be defined.

$$CROI = f\,(CYD) \qquad (3)$$

If the maximum point of the equation (3) is CYDm, i.e. the maximum yield loss that can be allowed without making any loss to the farmer, the yield of that ith ratoon crop (i = m), Ym is :

$$Ym = Yr - CYDm \qquad (4)$$

Thus, the farmer should decide to replant after the mth ratoon for which the yield is Ym t/ha for the reference yield of Yr t/ha.

Determination of Near-optimal Replanting Cycles for Sugarcane Production in Sri Lanka

The method described in the foregoing section was applied to determine the near-optimal replanting cycles for sugarcane variety Co 775 grown under different systems at sugar mill sites of Sri Lanka, namely irrigated and rain-fed cultivation in settler situations at Sevanagala, rain-fed cultivation in settler and out-grower situations at Pelwatte and irrigated cultivation in settler and out-grower situations at Hingurana using the farm-level data collected from 1990/91 to 1994/95 cropping years with a sample of 480 farms, 80 farms from each system. Data could be collected up to the 5th ratoon crop and hence the cane yields and maintenance costs of further ratoon crops were estimated using this data. All monitory values were expressed in terms of 1991 prices by deflating using GNP price deflator values reported by the Central Bank of Sri Lanka (Appendix 1). The average level of cane yield to which the ratoon yield should drop to start replanting was determined for each sugarcane production system by estimating the equation (3) by the OLS method and by using equation (4). The results of this analysis are discussed in the following section.

RESULTS AND DISCUSSION

Sevanagala Irrigated Crop

Under irrigated conditions at Sevanagala, the highest cane yield (152 t/ha) was reported in plant crop and there was a yield decline of 33% (102 t/ha) in the first ratoon crop. Levels of cumulative decline in cane yields in the successive ratoon crops from second to fifth crop were 43% (87 t/ha), 54% (70 t/ha), 50% (77 t/ha) and 65% (53 t/ha) respectively (Table 3).

The return on investment of the plant crop at Sevanagala, though less than one, was comparatively high (0.94). Cumulative return on investment (CROI) from the first ratoon was greater than one (1.11) and increased up to fourth ratoon (1.15) since profits of these crops were higher than their costs. However, after the fourth ratoon, costs exceeded the net profits and hence the CROI started to decline.

The relationship between CROI and cumulative yield decline (CYD) in the square root form is shown in equation (5) :

$$CROI = 0.9424 - 0.0022CYD + 0.0400CYD^{0.5} \quad (5)$$

$$R^2 = 0.95$$

According to equation (5), CROI reaches its maximum when the yield decline is 100 t/ha and hence it is not rational to maintain a ratoon crop for which the total yield decline is greater than this amount. Thus, in average farm situations it is rational to maintain ratoon crops up to declining yield level to 52 t/ha which corresponds with the yield of the fifth ratoon and is 34% of the reference yield. The near-optimum replanting cycle for irrigated cropping at Sevanagala is a plant crop and five ratoon crops.

Sevanagala Rain-fed Crop

Cane yields under rain-fed conditions at Sevanagala were more or less stable and the highest yield of 68 t/ha was reported in the second ratoon crop. Cane yields of the plant crop and the first ratoon crop were nearly one tonne lower (67 t/ha) than the cane yield of the second ratoon crop. In the successive ratoon crops from third to eighth ratoon, cane yield declined by 6% (64 t/ha), 14% (58 t/ha), 24% (51 t/ha), 36% (43 t/ha), 50% (34 t/ha) and 64% (25 t/ha) respectively (Table 4).

Because of low yields of the rain-fed crop compared to those of irrigated crop, return on investment was low and was less than one showing that cost was higher than net return. However, CROI increased from

Table - 3 : Cane yields and costs and returns of irrigated crop at Sevanagala, Sri Lanka

	PC	R1	R2	R3	R4	R5
Cane yield (t/ha)	152.16	102.48	86.58	69.69	76.60	52.54
Yield decline (t/ha)		49.68 (32.63)	65.58 (43.07)	82.47 (54.16)	75.56 (49.63)	99.62 (65.43)
Gross revenue (Rs/ha)	115015	76906	59520	51267	52640	35374
Cost of land preparation (Rs/ha)	13755					
Cost of crop establishment (Rs/ha)	10404					
Total cost of replanting (Rs/ha)	24159					
Cost of crop maintenance (Rs/ha)	12833	16077	15153	14137	9450	10515
Cost of harvesting and loading (Rs/ha)*	22219	15511	13085	10788	11719	8415
Total cost (Rs/ha)	59211	31588	28238	24925	21169	18930
Net return (Rs/ha)	55804	45318	31281	26342	31471	16444
CROI	0.94	1.11	1.11	1.10	1.15	1.12

*Transport cost was not added as it is paid by the sugar company
PC = plant crop, R1, R2, etc. = ratoon 1, ratoon 2, etc.
Figures in parentheses are cumulative % of yield decline

Table - 4 : Cane yields and costs and returns of rain-fed crop at Sevanagala, Sri Lanka

	PC	R1	R2	R3	R4	R5	R6	R7	R8
Cane yield (t/ha)	66.67	66.53	67.70	63.62	58.41	51.18	43.06	34.19	24.71
Yield decline (t/ha)				4.08 (6.03)	9.29 (13.72)	16.52 (24.40)	24.64 (36.40)	33.51 (49.50)	42.99 (63.50)
Gross revenue (Rs/ha)	41691	41603	42335	39783	36526	32004	26927	21380	15452
Cost of land preparation (Rs/ha)	7551								
Cost of crop establishment (Rs/ha)	11304								
Total cost of replanting (Rs/ha)	18855								
Cost of crop maintenance (Rs/ha)	8816	6696	7071	7301	7410	7236	6677	5526	3439
Cost of harvesting and loading (Rs/ha)*	8348	8331	8477	7967	7314	6409	5392	4281	3094
Total cost (Rs/ha)	36019	15027	15548	15268	14724	13645	12069	9807	6533
Net return (Rs/ha)	5672	26576	26787	24516	21802	18359	14858	11573	8919
CROI	0.16	0.63	0.89	1.02	1.09	1.12	1.13	1.14	1.15

*Transport cost was not added as it is paid by the company
PC - plant crop, R1, R2, etc. - ratoon 1, ratoon 2, etc.
Figures in parentheses are cumulative % of yield decline

Table - 5 : Cane yields and costs and returns of settler farms at Pelwatte, Sri Lanka

	PC	R1	R2	R3	R4	R5	R6	R7	R8
Cane yield (t/ha)	79.66	75.10	72.64	66.10	61.10	54.61	47.35	39.12	30.51
Yield decline (t/ha)		4.56 (5.72)	7.02 (8.81)	13.56 (17.02)	18.56 (23.30)	25.05 (31.45)	32.31 (40.56)	40.54 (50.89)	49.15 (61.70)
Gross revenue (Rs/ha)	57731	54426	52644	47904	44280	39577	34315	28351	22111
Cost of land preparation (Rs/ha)	9376								
Cost of crop establishment (Rs/ha)	13293								
Total cost of replanting (Rs/ha)	22669								
Cost of crop maintenance (Rs/ha)	7610	6426	5580	5552	4799	4370	3946	3518	3078
Cost of harvesting, loading and transport (Rs/ha)	19361	18253	17655	16066	14850	13273	11508	9508	7415
Total cost (Rs/ha)	49640	24679	23235	21618	19649	17643	15454	13026	10493
Net return (Rs/ha)	8091	29747	24409	26286	24631	21934	18861	15325	11618
CROI	0.16	0.51	0.69	0.78	0.85	0.90	0.92	0.94	0.95

PC - plant crop, R1, R2, etc. - ratoon 1, ratoon 2, etc.
Figures in parentheses are cumulative % of yield decline

Table - 6 : Cane yields and costs and returns in out-grower farms at Pelwatte, Sri Lanka

	PC	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
Cane yield (t/ha)	58.75	68.85	56.03	55.09	47.62	42.47	37.86	33.74	30.07	26.79	23.86	21.25	18.93
Yield decline (t/ha)			12.82 (18.62)	13.76 (19.99)	21.23 (30.84)	26.38 (38.32)	30.99 (45.01)	35.11 (50.99)	38.78 (56.33)	42.06 (61.09)	44.99 (65.34)	47.60 (69.14)	49.92 (72.51)
Gross revenue (Rs/ha)	43711	51225	41687	40988	35430	31598	28168	25103	22372	19932	17752	15810	14084
Cost of land preparation (Rs/ha)	8521												
Cost of crop establishment (Rs/ha)	10955												
Total cost of replanting (Rs/ha)	19476												
Cost of crop maintenance (Rs/ha)	8959	7629	6180	6507	5123	4697	4312	3964	3649	3362	3101	2862	2644
Cost of harvesting, loading and transport (Rs/ha)	13003	15238	12401	12193	10539	9399	8379	7467	6655	5929	5281	4703	4190
Total cost (Rs/ha)	41438	22867	18581	18700	15662	14096	12691	11431	10304	9291	8382	7565	6834
Net return (Rs/ha)	2273	28358	23106	22288	19768	17502	15477	13672	12068	10641	9370	8245	7250
CROI	0.05	0.48	0.65	0.75	0.82	0.86	0.89	0.92	0.93	0.94	0.95	0.96	0.96

PC = plant crop, R1, R2, etc. = ratoon 1, ratoon 2, etc.
Figures in parentheses are cumulative % of yield decline

the first ratoon at a deceasing rate and by the eighth ratoon CROI increased to 1.15.

The CROI and CYD equation estimated in square root form given in equation (6) below shows that CROI starts to decline after a cane yield decline of 36 t/ha.

$$CROI = 0.8850 - 0.0072CYD + 0.0864CYD^{0.5} \quad (6)$$

$R^2 = 0.99$

Thus under rain-fed conditions at Sevanagala, maintenance of a ratoon crop beyond a cane yield of 32 t/ha which is about 47% of the reference yield is not economical. Accordingly, in an average rain-fed farm at Sevanagala which produces 68 t/ha of cane yield in the second ratoon, it is rational to replant after raising 8 ratoon crops.

Settler Farms at Pelwatte

In the settler farms at Pelwatte average cane yield in the plant crop was about 80 t/ha and in the successive ratoon crops, cane yields decline. By the first and second ratoons, there was a marginal decrease in cane yield of 6% (75 t/ha) and 9% (73 t/ha) respectively. From third to eighth ratoon the successive levels of cane yield decline were 17% (66 t/ha), 23% (61 t/ha), 31% (55 t/ha), 41% (47 t/ha), 51% (39 t/ha) and 62% (31 t/ha) respectively (Table 5).

Table - 7 : Cane yields and costs and returns of settler farms at Hingurana, Sri Lanka

	PC	R1	R2	R3	R4	R5	R6
Cane yield (t/ha)	99.33	69.48	64.73	60.02	56.01	52.25	48.77
Yield decline (t/ha)	29.85 (30.05)	34.60 (34.83)	39.31 (39.58)	43.32 (43.61)	47.08 (47.40)	50.56 (50.90)	
Gross revenue (Rs/ha)	66071	46216	43056	39924	37256	34755	32440
Cost of land preparation (Rs/ha)	6224						
Cost of crop establishment (Rs/ha)	16067						
Total cost of replanting (Rs/ha)	22291						
Cost of crop maintenance (Rs/ha)	15784	13061	12146	12417	12524	12647	12785
Cost of harvesting and loading (Rs/ha)*	13847	9686	9023	8367	7808	7284	6799
Total cost (Rs/ha)	51922	22747	21169	20784	20332	19931	19583
Net return (Rs/ha)	14149	23469	21887	19140	16924	14824	12857
CROI	0.27	0.50	0.62	0.67	0.70	0.70	0.70

*Transport cost was not added as it is paid by the company
PC - plant crop, R1, R2, etc. - ratoon 1, ratoon 2, etc.
Figures in parentheses are cumulative % of yield decline

Table - 8 : Cane yields and costs and returns of out-grower farms at Hingurana, Sri Lanka

	PC	R1	R2	R3	R4	R5	R6
Cane yield (t/ha)	100.27	95.76	92.50	81.12	74.15	67.77	61.93
Yield decline (t/ha)	4.51	7.77	19.15	26.12	32..50	38.34	
	(4.50)	(7.75)	(19.10)	(26.05)	(32.41)	(38.24)	
Gross revenue (Rs/ha)	64013	61134	59053	51788	47338	43265	39537
Cost of land preparation (Rs/ha)	5815						
Cost of crop establishment (Rs/ha)	10852						
Total cost of replanting (Rs/ha)	16667						
Cost of crop maintenance (Rs/ha)	13768	13723	13872	13268	13263	13257	13251
Cost of harvesting and loading (Rs/ha)*	12604	12037	11627	10197	9321	8519	7785
Total cost (Rs/ha)	43039	25760	25499	23465	22584	21776	21036
Net return (Rs/ha)	20974	35374	33554	28323	24754	21489	18501
CROI	0.49	0.82	0.95	1.00	1.02	1.01	1.00

*Transport cost was not added as it is paid by the company
PC - plant crop, R1, R2, etc. - ratoon 1, ratoon 2, etc.
Figures in parentheses are cumulative % of yield decline

The return on investment in the plant crop was very low (0.16) because of low net return. The CROI values increased at a decreasing rate up to the eighth ratoon crop (0.95) and they were always below one showing that cumulative net returns were lower than cumulative costs.

The relationship between CROI and CYD estimated in square root form given in equation (7) below shows that the maximum allowable cane yield decline is 47 t/ha.

$$CROI = 0.1515 - 0.0169CYD + 0.2326CYD^{0.5} \quad (7)$$

$$R^2 = 0.99$$

Thus, maintenance of ratoon crops beyond a cane yield of 32 t/ha or 41% of the reference yield is not rational and hence in an average settler farm at Pelwatte eight ratoon crops could be maintained to maximise return.

Out-grower Farms at Pelwatte

In the out-grower farms at Pelwatte, cane yields were lower than those in the settler farms (Table 6). The highest cane yield was reported for the first ratoon crop (69 t/ha) and the plant crop yield averaged 59 t/ha. Ratoon crop yield after the first ratoon declined but at a slower rate than that in the settler farms. Table 6 shows that cane yield declines in the successive ratoon crops from the second to twelfth are 19% (56 t/ha) and 20% (55 t/ha), 31% (48 t/ha), 38% (42 t/ha), 45% (38 t/ha), 51% (34 t/ha), 56% (30 t/ha), 61% (27 t/ha), 65% (24 t/ha), 69% (21 t/ha), 73% (19 t/ha) respectively.

The return on investment in the plant crop was very low (0.05) because of marginal net returns. However, CROI increased up to 0.96 by the tenth ratoon crop at a decreasing rate. The relationship between CROI and CYD in quadratic form is given in equation (8).

$$CROI = 0.4740 + 0.0200CYD - 0.0002CYD^2 \quad (8)$$

$$R^2 = 0.98$$

According to this equation, maximum allowable yield decline is 48 t/ha which occurs in the 11th ratoon crop when the cane yield dropped to 21 t/ha or 30% of the reference yield (69 t/ha). Thus maximum of 11 ratoon crops can be economically raised in an average out-grower farm at Pelwatte.

Settler Farms at Hingurana

In the settler farms at Hingurana, plant crop produced an average cane yield of 99 t/ha and each successive ratoon crop gave a lower yield than that of the previous crop. Cane yield decline from plant crop to ratoon 1 was 30% (69 t/ha). From second to sixth ratoon, the successive yield declines were 35% (65 t/ha), 40% (60 t/ha), 44% (56 t/ha), 47% (52 t/ha) and 51% (49 t/ha) respectively (Table 7).

Return on investment in the plant crop was low (0.27). CROI increased at a decreasing rate with increasing number of ratoon crops up to sixth ratoon, but the values were less than one. The relationship between CROI and CYD in cubic form is given in equation (9):

$$CROI = 0.2723 - 0.0196CYD + 0.0015CYD^2 - 0.000018CYD^3 \quad (9)$$

$$R^2 = 0.99$$

The maximum allowable yield decline for obtaining the highest return was 47 t/ha. Thus, replanting should be started when the yield dropped to 52 t/ha, i.e. 53% of the reference yield (99 t/ha). This yield level corresponds with the fifth ratoon crop.

Out-grower Farms at Hingurana

Cane yields in the out-grower farms at Hingurana were little higher than those in the settler farms, but the decline in cane yield in successive ratoon crops was comparatively low. The highest cane yield which reported in the plant crop (100 t/ha) marginally dropped (5% or 96 t/ha) by the first ratoon. From the second to sixth ratoon, the successive cane yield declines were 8% (93 t/ha), 19% (81 t/ha), 26% (74 t/ha), 32% (68 t/ha) and 38% (62 t/ha) respectively (Table 8).

The return on investment in the plant crop in out-grower farms (0.49) was higher than that in the settler farms. CROI increased at a decreasing rate to 1.02 by the fourth ratoon crop and declined thereafter. The relationship between CROI and CYD in square root form is given in equation (10).

$$CROI = 0.4859 - 0.0214CYD + 0.2145CYD^{0.5} \quad (10)$$

$$R^2 = 0.98$$

This equation shows that it is not rational to maintain a ratoon crop beyond a yield decline of 25 t/ha, i.e. when the ratoon crop yield reaches 75 t/ha or 75% of the reference yield (100 t/ha). This corresponds with the fourth ratoon crop. In the out-grower farms, decline of maintenance costs in the

Table - 9 : Summary of the results of determination of near-optimal number of ratoon crops for sugarcane at Sevanagala, Pelwatte and Hingurana, Sri Lanka

Farm condition/situation	Reference yield (t/ha)	When to replant			
		Yield decline (t/ha)	Cane yield (t/ha)	% of ref. yield	No. of ratoons
Sevanagala (settler) ·					
Irrigated	152.16	100.00	52.16	34.28	5
Rain-fed	67.70	36.09	31.61	46.69	8
Pelwatte (rain-fed) :					
Settler	79.66	47.39	32.27	50.51	8
Out-grower	68.85	48.13	20.72	30.09	11
Hingurana (irrigated) :					
Settler	99.33	46.89	52.44	52.79	5
Out-grower	100.27	25.20	75.07	74.87	4

successive ratoon crops was not considerable and hence though cane yields were more stable than in the settler farms, the near-optimal replanting cycle was found with a fewer number of ratoon.

CONCLUSIONS

An alternative method for determining the optimum replanting cycles for sugarcane based on cumulative return on investment and cumulative decline of cane yield in the successive ratoon crops was devised and applied to data farm-level collected from 1990/91 to 1994/95 in sugar mill sites at Sevanagala, Pelwatte and Hingurana in Sri Lanka. The near-optimal number of ratoon crops together with the yield levels for deciding replanting of sugarcane grown under/in different farm conditions/situations in these three sugarcane-growing areas in Sri Lanka are shown in Table 9.

The results showed that sugarcane grown under rain-fed conditions, both cane yields and their decline in the successive ratoon crops were lower than those for irrigated crop and cumulative returns on investment were less than unity. Because of stability of cane yield under rain-fed conditions number of ratoon crops that should be maintained for maximum return was higher than that under irrigated conditions. In average rain-fed farms at Sevanagala and in settler farms at Pelwatte the replanting should be undertaken when their cane yield declined to 32 t/ha. This corresponds with 47% and 51% of the reference yield under rain-fed conditions at Sevanagala and in settler situations at Pelwatte respectively. However, in the out-grower farms at Pelwatte maintenance of ratoon crop can be continued up to cane yield declines to 21 t/ha which is 30% of the reference yield. Thus, the near-optimal number of ratoon crops for Sevanagala rain-fed cultivation and Pelwatte settler farm situations was 8 and that for out-grower farms at Pelwatte was 11.

On the other hand under irrigated conditions, cane yield as well as its decline in the successive ratoon crops were comparatively high. Thus, replanting has to be undertaken after few number of ratoon crops are maintained. The results showed that in the average irrigated farms at Sevanagala and in settler farms at Hingurana the crop should be replanted after fifth ratoon or when the cane yield reduced to 52 t/ha which is 34% and 53% of the reference yield for the Sevanagala irrigated farms and Hingurana settler farms respectively. In the out-grower farms at Hingurana, replanting should be undertaken after the fourth ratoon or when the cane yield dropped to 75 t/ha which is 75% of the reference yield.

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APPENDIX

Implicit GNP price deflator (GNPD) values 1991-1995.

Year	GNPD	1991 value
1991	11.20	100.00
1992	10.00	110.00
1993	9.50	120.45
1994	9.40	131.77
1995	8.30	142.71

Source : Central Bank of Sri Lanka, 1998.

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