DOUBLE PROFITS WITH A CONTROLLED TRAFFIC ZERO-TILL IRRIGATION FARMING SYSTEM?

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Abstract

Many guidelines and recommendations for sugarcane farming are aimed at achieving a large number of ratoon crops. One of the reasons for this is that the replanting costs can be considerable when a field is conventionally tilled and replanted. Thus, delaying re-establishment makes financial sense provided the cost savings are greater than any yield and revenue penalties. An alternative is to introduce a controlled traffic and zero-till farming system (CTF), thereby lowering re-establishment costs and potentially allowing for fewer ratoon crops and more frequent green manure or break crops. A rigorous yield, sucrose content, costing and cash-flow analysis, based on published research findings and detailed costing of representative machinery, showed that a CTF system with only three ratoon crops was far more profitable than a conventional farming system involving eight ratoon crops and more intensive tillage operations. A doubling in profitability was shown when the yield benefits reported with break crops and the yield decline rates reported under conventional farming systems were included in the analysis. Substantial gains in water use productivity were also shown, up to nearly 80% improvement over a conventional farming system. Adoption of a CTF system with only three ratoon crops is therefore highly recommended and should be taken very seriously by decision-makers in the sugarcane industry.

Keywords: irrigation, farming systems, controlled traffic, zero-till, economics, green manure

Introduction

Irrigated sugarcane in southern Africa is frequently cultivated as a mono-crop with more than eight ratoon crops harvested before replanting. Replanting sometimes takes place without a fallow period. At each harvest, heavy machinery is often taken into the field, which together with random trafficking and mismatched wheel spacing can result in soil compaction and damage to cane stools (Swinford and Boevey, 1984; Braunack and Hurney, 2000; Norris *et al*., 2000).

Damage to the productive capacity of the soils is indicated when sugarcane grown on virgin land grows and yields relatively well compared to sugarcane grown on 'old' lands. Where this is true it indicates that the farming system used over the years has not sustained crop yields. It is likely that part of the problem can be attributed to compaction and stool damage. The Australians took yield declines very seriously and launched the Sugar Yield Decline Joint Venture, an integrated research programme aimed at understanding why sugarcane yields had apparently reached a plateau and were even declining. The contribution of sugarcane mono-culture to a build-up of pest and diseases, especially those in the soil biota which affect plant roots and thus its nutrient and water supply system, were reported to be a major cause of the yield declines (Garside *et al*., 2001).

Despite the findings of Garside *et al*. (2001) in Australia, Meyer and van Antwerpen (2001) in South Africa, Nixon and Simmonds (2004) in Swaziland and Umrit *et al*. (2009) in Mauritius, all of whom highlighted the benefits of a break crop and the negatives of cane monoculture, many growers and researchers still favour farming systems which are based on at least eight ratoon crops, allowing nine or more seasons to pass between fallow periods. A motivation is that cane re-establishment costs can be very high and frequent replanting, which often involves intensive tillage, has been considered uneconomical.

Technologies such as Global Positioning System (GPS)-guided auto-steer systems and direct drilling seed and cane planting equipment, facilitate a farming system founded on controlled traffic and zero-till principles. With reduced tillage requirements, such systems allow more frequent replanting at a competitive cost. With appropriate planning of the harvest and replant schedule, a rotation crop or green manure can also be grown more frequently with associated agronomic benefits.

The hypothesis investigated in this paper is that a controlled traffic farming system which has relatively few ratoon crops and more frequent rotations with a green manure or break crop will be more profitable than a conventional farming system which involves more ratoon crops and intensive and costly tillage operations. The analysis takes into consideration:

- the time value of money;
- reported and derived relationships between yields, cane age and sucrose content
- yield decline rates;
- machinery requirements including costs for land preparation, planting, harvesting, haulage and GPS guided auto-steer systems;
- irrigation water use productivity (WUP), defined as the total sucrose yield divided by the total amount of irrigation water applied for the plant and all ratoon crops;
- nutrition;
- weed control;
- pest and disease implications;
- implications for plant breeding and guidelines for releasing new varieties.

Methodology

The operations for three different irrigation farming systems were specified to enable associated cash-flows to be determined. The three farming systems compared were:

- conventional or popular farming system with replanting taking place after at least eight ratoon crops (CF);
- controlled traffic farming system with replanting after seven ratoon crops (CTF 7R);
- controlled traffic farming system with replanting after only three ratoon crops (CTF 3R).

All three systems assume an irrigated environment where sugarcane is typically harvested on an annual basis.

Conventional farming system (CF)

In this system an old sugarcane crop is 'ploughed out' in autumn, fallowed during winter, to minimise potential growth loss, and the field replanted to cane in spring. The plant crop is harvested at approximately 14 months of age, around mid-summer. For the field to be ploughed out and replanted, the harvest month is gradually brought forward over the life of the crop so that the field is eventually harvested for the last time in autumn, before re-planting and repeating the cycle. As a result, the average cutting age is less than 12 months. A diagram to illustrate the system is shown in Figure 1. Other fields on the farm would follow a similar pattern but would be out of sequence, such that the mill receives a constant supply of cane.

	Year 1	2	3	4	5	6	7	8	9
April	c / p-out								
May									c
June								c	
July							c		
August						c			
September	pl				c				
October				c					
November		c	c						
December									
January									
February									
March									
Cut Age (months)	11	14	12	11	11	11	11	11	11

Key: c = cut; p-out = plough out; pl = plant

Figure 1. Cutting cycle of the conventional farming system (CF), plant crop plus eight ratoon crops. The shaded months, April to November, represent a typical milling season.

Controlled traffic farming system with replanting after seven ratoons (CTF 7R)

In this system the old sugarcane crop is killed by spraying with herbicide in late summer. A rotation crop such as soybean or a green manure crop such as sunn hemp (*Crotalaria juncea*) is planted by a direct seeder between the cane rows (see Figure 2) shortly after cutting the final cane crop. For this analysis it is assumed that sunn hemp is used as the green manure crop. In late summer the sunn hemp is flattened by a tractor drawn pole and cane is planted directly into the sunn hemp stubble using a double disc direct drill cane planter. Key components of this system are:

- a GPS guided auto-steer system which facilitates trafficking on the exact same place in the field, year after year. As a result of the controlled trafficking, no vehicle related compaction or stool damage takes place in the region where the majority of cane roots grow. Thus, compaction alleviation using energy intensive ploughing and ripping operations is not necessary. The auto-steer system needs to be fitted to all machinery driven in the field and is considered necessary to ensure that compaction will occur only in a well defined and limited traffic lane area (Norris *et al*., 2000);
- consistent wheel spacing on all machines and implements used in the field. A tramline planting arrangement with 0.5 to 0.6 m between the cane plants, and 1.8 to 2.1 m between traffic lanes is suitable for most machinery. Ismael *et al*. (2007) reported that a dual row system with 0.5 m between cane rows and 1.8 m between their centres resulted in higher yields than sugarcane planted 1.6 m apart in conventional single rows;

- a harvesting system which limits machine travel to the traffic lanes. In a manual-cut system this will require, for example, a cut and windrow operation and use of a side-slewing loader with an appropriate wheel spacing of approximately 1.9 m, rather than loaders with mismatched wheel spacings, as often used in conventional farming systems;
- a double disc direct drill sugarcane planter, such as can be used to plant cane directly into the rotation crop or green manure plant stubble (Norris *et al*., 2000). Garside *et al.* (2006) compared direct planting of sugarcane into a non-tilled permanent bed following a soybean break, to a tilled permanent bed without a soybean break. The former system out-yielded the latter by 47%.

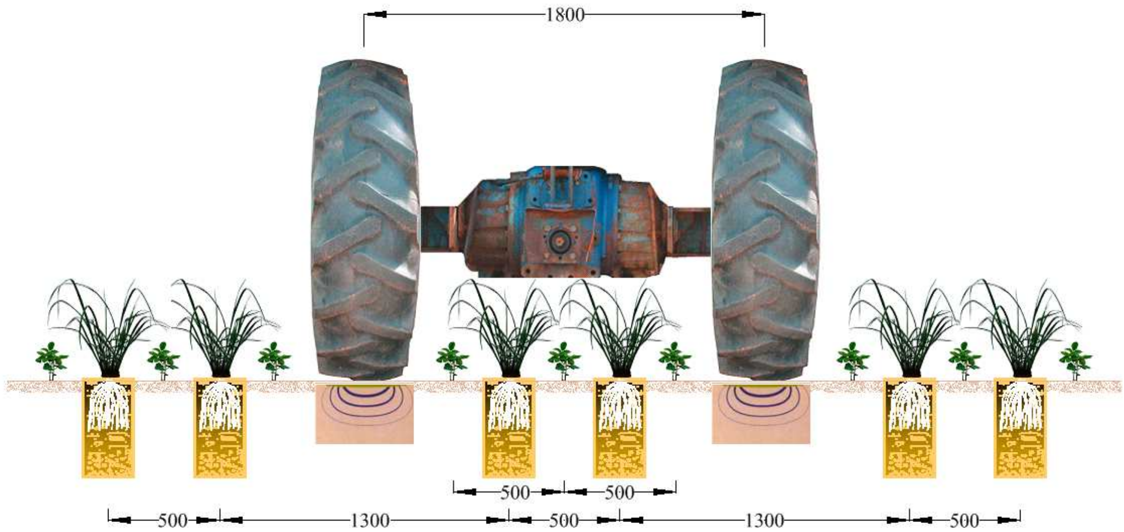

Figure 2. Arrangement of sugarcane rows, wheel-tracks and a green manure or rotation crop.

The plant crop is harvested at approximately 13 months of age in late summer/early autumn, at the start of the milling season. For the field to be sprayed out and replanted again, the harvest month is gradually moved to later in the year so that the cane is eventually harvested for the last time in early to mid-summer before replanting and repeating the cycle. As a result of moving the harvesting month forward, the average cane age after the plant crop is approximately 13 months. A diagram to illustrate the system is shown in Figure 3.

Controlled traffic farming system with replanting after three ratoons (CTF 3R)
This system is similar to the CTF 7R system. The difference is that the average age of cane at harvest is approximately 14 months. As a result, the field is ready for spraying out and replanting after only three ratoons, as shown in Figure 4. Other fields on the farm would follow a similar system, except that, in addition to being out of sequence, half the fields would be harvested in alternate months to ensure a constant supply of cane to the mill.

	Year 1	2	3	4	5	6	7	8	9
April			c						
May				c					
June					c				
July						c			
August							c		
September								c	
October									c
November	c / spr-out								
December									
January									
February									
March	pl								
Cut Age (months)	13	0	13	13	13	13	13	13	13

Key: c = cut; spr-out = spray out; pl = plant

Figure 3. Cutting cycle of controlled traffic farming system with replanting after seven ratoons. The shaded months, April to November, represent a typical milling season.

	Year 1	2	3	4	5
April					
May			c		
June					
July				c	
August					
September					c
October					
November	c / spr-out				
December					
January					
February					
March	pl				
Cut Age (months)	14	0	14	14	14

Key: c = cut; spr-out = spray out; pl = plant

Figure 4. Cutting cycle of controlled traffic farming system with replanting after three ratoons. The shaded months, April to November, represent a typical milling season.

Yield prediction

In order to estimate the relative value (RV) content of cane with different ages, a relationship between sucrose and cane age derived by Inman-Bamber (1994) for variety NCo376 was used. Application of this relationship to determine sucrose content for cane cut at different ages and in different months is shown in Table 1. For the analysis reported here, adjustment of within season sucrose content for cane cut at different times of the year was not done, as this would have been similar for all farming systems and was therefore considered an unnecessary complication for comparative purposes.

The *My Canesim* sugarcane model (Singels, 2007) was used to estimate representative sugarcane yields. When using weather data from the Komatidraai station, latitude 25°30’00” south and longitude 31°55’30” east, average yields varied from 10.88 t/ha/month for 14-month old cane to 8.45 t/ha/month for 11-month old cane, for a range of start and end dates in the milling season and under full irrigation. Although the older cane had higher average monthly yield increments, the yields simulated with *My Canesim* are based on the crop having a consistent radiation use efficiency (RUE). van Heerden *et al*. (2010) reported several cases where RUE was not consistent throughout the life of a crop, and declined well before harvest. RUE is defined as the ratio of biomass accumulated to intercepted radiation (Monteith, 1977). Thus, a reduction in RUE in an older crop would reduce the yield increment (t/ha/month). It was, therefore, considered a reasonable simplification to assume a 10 t/ha/month average yield increment for all farming systems, i.e. efficiency of radiation capture is higher for older crops as indicated by *My Canesim*, but efficiency of radiation use may decline as the crop ages, as shown in several examples reported by van Heerden *et al*. (2010). The decline in RUE which was sometimes observed as the crop aged could be associated with reduced specific leaf nitrogen, amongst other factors (van Heerden, *et al*., 2010).

Table 1. The relationship between cane age and sucrose content, derived using an equation reported by Inman-Bamber (1994).

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Age (months)											
10	4.14	5.95	7.52	8.85	9.94	10.79	11.40	11.77	11.90	11.79	11.44
11	4.56	6.37	7.94	9.27	10.36	11.21	11.82	12.19	12.32	12.21	11.86
12	4.98	6.79	8.36	9.69	10.78	11.63	12.24	12.61	12.74	12.63	12.28
13	5.40	7.21	8.78	10.11	11.20	12.05	12.66	13.03	13.16	13.05	12.70
14	5.82	7.63	9.20	10.53	11.62	12.47	13.08	13.45	13.58	13.47	13.12

For the initial analysis and to illustrate the cash-flows of the various farming systems, it was assumed that the rate of yield decline was 6% per annum. This is regarded as conservative, considering the rigorous analysis of yield data reported by Hoekstra (1976), where the rate of yield decline was closer to 9% per annum. Actual yield declines will be highly case specific and will depend on variety, environment and management interactions, thus a further sensitivity analysis was undertaken with varying rates of yield decline assumed, namely: 0, 3, 6 and 9% per annum.

Irrigation requirements

To estimate irrigation water requirements for the various cropping cycles it was assumed that a 12-month crop would require 1000 mm of water. This translates to an average monthly requirement of 833 m^3/ha. Thus, an 11-month crop would require 11 x 833 = 9163 m^3 of irrigation water per hectare, and a 14-month crop would require 14 x 833 = 11662 m^3 of water per hectare. Electricity costs were assumed to be R0.21/m^3 and water costs R0.12/m^3.

Costing machine operations

The costs of machine operations were calculated according to the methods advocated by the ISSCT (2004). It was assumed that the operating hours for each machine were limited by the time available for each operation and standard work rates, rather than the size of a farm. Summary costs for all operations used in the analysis are given in Tables 2, 3, 4 and 5. The cost of the required GPS guided auto-steer systems were included in the CTF harvest and haulage system costs. The cost of the base station needed for the GPS guidance systems is dependent on topography and area serviced. For this analysis, it was assumed that a base station could service 8000 hectares and the annual cost for this over a ten year lifespan, namely R22/ha, was considered negligible relative to other costs.

Table 2. Cost of land preparation and planting operations for the conventional farming system.

Operation	Cost (R/ha)
Rip	368
Plough (3 furrow reversible mouldboard)	624
Disc harrow	308
Disc harrow	308
Ridge and fertilise	385
Planting (trailer for seedcane)	371
Planting (labour)	1200
Covering (labour)	300
Fertiliser operation 2nd split (mechanical 2 row)	206
Pre-emergent herbicide - boom sprayer	75
Total	**4146**

Table 3. Cost of land preparation and planting operations for the controlled traffic farming systems.

Operation	Cost (R/ha)
Chemical spray - boom sprayer	75
Minimum till seed planter/fertiliser	823
Tractor and pole	155
Minimum till cane planter/fertiliser	897
Trailer for the minimum till planter	552
Labour (seedcane: 4.5 person days/ha)	248
Fertiliser operation 2nd split (mechanical 2 row)	206
Total	**2956**

Table 4. Cost of harvest and haulage operation for the conventional farming system.

Operation	R/ton
Cut and Windrow	11.00
Bell loader	7.06
Tractor trailer in-field haul-outs	14.48
Trans-loading	9.44
Road Haulage	26.75
Total	**68.73**

Table 5. Cost of the harvesting and haulage operations for the controlled traffic farming system.

Operation	R/ton
Cut and windrow	11.00
Side-slewing loader	6.35
Auto-steer for the loader	0.46
Tractor trailer in-field haul-outs	14.48
Auto-steer for the haul-outs	1.39
Trans-loading	9.44
Road haulage	26.75
Total	**69.87**

Financial analysis

The different farming systems were compared in economic terms using a capital budgeting approach recommended by Wynne and Gilmour (2010). Tax and debt/equity complications are excluded from the comparative analysis. Wynne and Gilmour (2010) proposed that, "the national prime lending rate be used as a proxy for the grower's annual discount rate (which is termed the nominal annual discount rate r_n; i.e. before inflation is accounted for)". A producer related inflation factor (i) is then used to adjust the nominal annual discount rate (r_n) to a real annual discount rate (r_r) as illustrated below, whereby future values (FVs) are expressed in 'today's' nominal values (i.e. FV_n before inflation is accounted for):

$$\text{Present Value (PV)} = \frac{FV_n}{(1+r_r)^n} \qquad \text{where} \qquad (1+r_r) = \frac{(1+r_n)}{(1+i)}$$

Although the Net Present Value (NPV) (i.e. the sum of all future cash-flows expressed as today's nominal value) is a measure of wealth creation, a direct comparison of NPVs is not valid where different projects have unequal lives as is the case for this analysis. Nevertheless, if the NPVs are converted to an equivalent series of equal annual cash-flows over the life of a project, named the Annuity Equivalent (AE) and it is assumed that the project will be repeated, the AEs can be compared in order to rank and compare projects (Barry *et al*., 2000).

Wynne and Gilmour (2010) also recommend using the Modified Internal Rate of Return (MIRR) to compare projects of unequal lives. The MIRR is determined by, "calculating the terminal value of each of the future cash-flows using a known real discount rate and then solving for the discount rate that equates the present value of the combined terminal values with the initial capital investment". According to Wynne and Gilmour (2010) the assumption that reinvestment is at the cost of capital or real national prime lending rate (r_r) is valid in the calculation of MIRR for sugarcane farming enterprises, i.e. positive and negative cash-flows are compounded using the same discount rate. The higher the MIRR above the real prime lending rate (r_r), the greater the wealth creation relative to a risk free investment at the bank (Wynne and Gilmour, 2010).

Results

Cash-flow analyses of the three farming systems are shown in Tables 6, 7 and 8. For these initial analyses it was assumed that:

- yield declined at a rate of 6% per year from the plant crop
- the annual inflation rate was 6%
- the annual prime interest rate was 10%.

Although a yield decline rate of 6% may be a conservative yield decline rate (cf Hoekstra, 1976), the highest AE was realised with the farming system which had the fewest ratoons. The CTF 3R system had an AE of R14 730, followed by the CTF 7R system, which had an AE of R13 013, with the CF system having the lowest AE of R10 558. The MIRR for the CTF 3R system was highest at 57%, indicating that investment in this system would yield the greatest rate of increase in wealth compared to the CTF 7R system, which had a MIRR of 36%, and the CF system which had a MIRR of 30%.

Table 6. Cash-flow analysis of the conventional farming system (CF).

Annual real discount rate (r_r) =				**3.8%**										
Yield Decline Rate =				**6.00%**										
Period Years =					0	1	2	3	4	5	6	7	8	9
Cut Age					0	14	12	11	11	11	11	11	11	11
t/ha/mth					0.0	10.0	9.4	8.8	8.3	7.8	7.3	6.9	6.5	6.1
t/ha					0.0	140.0	112.8	97.2	91.4	85.9	80.7	75.9	71.3	67.1
RV %					0.0	13.0	12.6	12.2	12.2	12.2	12.2	12.2	12.2	12.2
t RV					0.0	18.2	14.2	11.8	11.1	10.5	9.8	9.3	8.7	8.2
		Rate	Unit	R/Unit										
Expenses														
Land Preparation														
		Table 2	ha	4146.00	4146.00									
Fertilizers														
	N	150	kg	9.75	1462.50	1462.50	1462.50	1462.50	1462.50	1462.50	1462.50	1462.50	1462.50	0.00
	P	60	kg	15.37	922.11	922.11	922.11	922.11	922.11	922.11	922.11	922.11	922.11	0.00
	K	150	kg	8.65	1297.50	1297.50	1297.50	1297.50	1297.50	1297.50	1297.50	1297.50	1297.50	0.00
	Labour	2	man days	72.60	145.20	145.20	145.20	145.20	145.20	145.20	145.20	145.20	145.20	0.00
Chemicals														
	Pre-	1	mix	302.50	302.50	302.50	302.50	302.50	302.50	302.50	302.50	302.50	302.50	0.00
	Post-	1	mix	246.84	246.84	246.84	246.84	246.84	246.84	246.84	246.84	246.84	246.84	0.00
	Labour/hoe	7		72.60	508.20	508.20	508.20	508.20	508.20	508.20	508.20	508.20	508.20	0.00
Seedcane														
		10	t	320.00	3200.00									
Irrigation														
	water	833	m3/mth	0.12	0.00	1399.44	1199.52	1099.56	1099.56	1099.56	1099.56	1099.56	1099.56	1099.56
	power	833	m3/mth	0.21	0.00	2449.02	2099.16	1924.23	1924.23	1924.23	1924.23	1924.23	1924.23	1924.23
Harvest & Transport														
		Table 4	t	68.73	0.00	9622.20	7752.74	6680.28	6279.46	5902.70	5548.53	5215.62	4902.69	4608.52
Income														
Yield														
	RV		t	2260.00										
	Revenue		ha		0.00	41226.92	32146.42	26776.91	25170.30	23660.08	22240.48	20906.05	19651.69	18472.58
Undiscounted nominal cash Flows					-12230.85	22871.41	16210.15	12188.00	10982.20	9848.75	8783.31	7781.79	6840.37	10840.27
Modified IRR (MIRR)					29.80%									
Net Present Value (NPV)					R 79,220.58									
Annuity Equivalent (AE)					R 10,557.73									

Table 7. Cash-flow analysis of the controlled traffic plus seven ratoon crop farming system (CTF 7R).

Annual real discount rate (r_r) =				**3.8%**										
Yield Decline Rate =				**6.00%**										
Period Years =					0	1	2	3	4	5	6	7	8	9
Cut Age					0	0	13	13	13	13	13	13	13	13
t/ha/mth					0.0	0.0	10.0	9.4	8.8	8.3	7.8	7.3	6.9	6.5
t/ha					0.0	0.0	130.0	122.2	114.9	108.0	101.5	95.4	89.7	84.3
RV %					0.0	0.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
t RV					0.0	0.0	16.9	15.9	15.0	14.1	13.2	12.4	11.7	11.0
		Rate	Unit	R/Unit										
Expenses														
Land Preparation & Planting														
	Operations	Table 3	ha	Table 3	898.00	2058.00								
	Seed	50	ha	18.00	900.00									
Fertilizers														
	N	150	kg	9.75		731.25	1462.50	1462.50	1462.50	1462.50	1462.50	1462.50	1462.50	0.00
	P	60	kg	15.37	922.11	0.00	922.11	922.11	922.11	922.11	922.11	922.11	922.11	0.00
	K	150	kg	8.65	1297.50	0.00	1297.50	1297.50	1297.50	1297.50	1297.50	1297.50	1297.50	0.00
	Labour	2	man days	72.60	145.20	72.60	145.20	145.20	145.20	145.20	145.20	145.20	145.20	0.00
Chemicals														
	Pre-	8	8l	336.00	336.00	336.00								
	Post-	1	mix	246.84			246.84	246.84	246.84	246.84	246.84	246.84	246.84	0.00
	Boom	1	ha	74.00	74.00	74.00	74.00	74.00	74.00	74.00	74.00	74.00	74.00	0.00
	Pre-	1	mix	302.50			302.50	302.50	302.50	302.50	302.50	302.50	302.50	0.00
	Labour	2		72.60			145.20	145.20	145.20	145.20	145.20	145.20	145.20	0.00
Seedcane														
		5.5	t	320.00		1760.00								
Irrigation														
	water	833	m3/mth	0.12		0.00	1299.48	1299.48	1299.48	1299.48	1299.48	1299.48	1299.48	1299.48
	power	833	m3/mth	0.21		0.00	2274.09	2274.09	2274.09	2274.09	2274.09	2274.09	2274.09	2274.09
Harvest & Transport														
		Table 5	t	69.87			9083.10	8538.11	8025.83	7544.28	7091.62	6666.12	6266.16	5890.19
Income														
Yield														
	RV		t	2260.00	0.00	0.00								
	Revenue		ha		0.00	0.00	38282.14	35985.21	33826.10	31796.53	29888.74	28095.42	26409.69	24825.11
Undiscounted nominal cash Flows					-4572.81	-5031.85	21029.62	19277.68	17630.86	16082.84	14627.70	13259.88	11974.12	15361.35
Modified IRR (MIRR)					35.98%									
Net Present Value (NPV)					R 97,643.18									
Annuity Equivalent (AE)					R 13,012.91									

Table 8. Cash-flow analysis of the controlled traffic plus three ratoon crop farming system (CTF 3R).

Annual real discount rate (r) =				3.8%						
Yield Decline Rate =				6.00%						
Period Years =					0	1	2	3	4	5
Cut Age					0	0	14	14	14	14
t/ha/mth					0.0	0.0	10.0	9.4	8.8	8.3
t/ha					0.0	0.0	140.0	131.6	123.7	116.3
RV %					0.0	0.0	13.0	13.0	13.0	13.0
t RV					0.0	0.0	18.2	17.1	16.1	15.2
		Rate	Unit	R/Unit						
Expenses										
Land Preparation										
	Operations	Table 3	ha	Table 3	898.00	2058.00				
	Seed	50	ha	18.00	900.00					
Fertilizers										
	N	150	kg	9.75		731.25	1462.50	1462.50	1462.50	0.00
	P	60	kg	15.37	922.11	0.00	922.11	922.11	922.11	0.00
	K	150	kg	8.65	1297.50	0.00	1297.50	1297.50	1297.50	0.00
	Labour	2	man days	72.60	145.20	72.60	145.20	145.20	145.20	0.00
Chemicals										
	Pre-	8	l	336.00	336.00	336.00				
	Post-	1	mix	246.84			246.84	246.84	246.84	0.00
	Boom	1	ha	74.00	74.00	74.00	74.00	74.00	74.00	0.00
	Pre-	1	mix	302.50			302.50	302.50	302.50	0.00
	Labour	2		72.60			145.20	145.20	145.20	0.00
Seedcane										
		5.5	t	320.00		1760.00				
Irrigation										
	water	833	m3/mth	0.12		0.00	1399.44	1399.44	1399.44	1399.44
	power	833	m3/mth	0.21		0.00	2449.02	2449.02	2449.02	2449.02
Harvest & Transport										
		Table 5	t	69.87			9781.80	9194.89	8643.20	8124.61
Income										
Yield										
	RV		t	2260.00	0.00	0.00				
	Revenue		ha		0.00	0.00	41226.92	38753.30	36428.11	34242.42
Undiscounted nominal cash Flows					-4572.81	-5031.85	23000.81	21114.11	19340.60	22269.35
Modified IRR (MIRR)					57.33%					
Net Present Value (NPV)					R 65,947.22					
Annuity Equivalent (AE)					R 14,730.40					

A move to the CTF 3R system is likely to have many other benefits which have not thus far been included in the analysis. These include:

- better soil health due to the frequent inclusion of a rotation crop;
- better root growth due to better soil health and reduced compaction;
- greater plant available water and more effective rainfall and irrigation due to less compaction, increased infiltration rates and better root growth;
- improved nutrient uptake efficiency due to better root growth;
- reduced pest pressure. Reduced pest pressure is likely because the crop should suffer less stress with a healthier root system and more favourable soil biota and a field will be without cane for a larger proportion of time. Furthermore, the pollen in the flowers of a break crop such as sunn hemp has been reported to increase the density of pest predators (Magdoff and van Es, 2000), which could help to control the borer *Eldana saccharina*.

Planting cane in the late summer/early autumn period is good practice for reducing potential damage due to thrips (Keeping *et al*., 2008);

- reduced disease pressure. With replanting taking place in rotation with a break crop after only three ratoons, smut and RSD are unlikely to pose a significant threat, especially if clean seedcane is used when replanting. Clean seedcane can be obtained, for example, via meristem tissue culture (Snyman *et al*., 2008). Nixon and Simmonds (2004) reported a reduction in disease levels, particularly ratoon stunting disease (*Leifsonia xyli xyli*), and smut (*Ustilago scitaminea*) following a green manure break crop;
- a higher stalk population, which is likely because controlled trafficking should result in less stool damage and there should be reduced pest and disease pressure;
- a potential motivation to release high yielding varieties that have been withheld previously because of low resistance to pests and/or diseases. Provided a CTF 3R farming system is widely adopted in a region and reduced pest and disease pressure has been observed, the release of high yielding varieties which are more susceptible to pest and disease damage could be considered.

Agronomic benefits of green manures or break crops have been widely corroborated by research results reported in the literature (e.g. Garside *et al*., 2001; Nixon, 1992; Umrit *et al*., 2009). Thus, it is very likely that the plant crop yields in the CTF 3R system would be at least 20% higher than in a CF system. Garside *et al*. (2001) reported yield increases ranging from 15 to 25% following a break crop, Nixon (1992) reported yield benefits of up to 54% following a break crop and Umrit *et al*. (2009) recorded yield increases of 15 to 40% in the plant crop.

Swinford and Boevey (1984) reported yield losses due to compaction damage of 18 to 32%. Thus, plant crop benefits associated with a green manure crop are unlikely to continue into the ratoon crops while there is still compaction damage. However, in cases where

- compaction damage is minimised with controlled trafficking,
- soil health is improved by having frequent green manure or break crops, and
- pest and disease pressures are reduced,

ratoon crop yields are likely to decline at a lower rate under a CTF 3R system. Furthermore, with less runoff, better root colonisation and therefore more effective rainfall and irrigation, a potential saving in irrigation water should be possible.

The financial analysis of a CTF 3R system, assuming a 20% yield increase in the plant crop, a 3% yield decline rate and a 5% saving in irrigation water, is given in Table 9. Although the magnitude of these particular assumptions can be debated, they represent a scenario of integrated benefits based on a combination of research evidence and systematic rationale. At a yield decline rate of 6%, the AE of the CTF 3R system with the likely yield benefits (CTF 3R+YI) is nearly double the AE of the traditional CF system and the MIRR has more than doubled.

In a sensitivity analysis the AEs for various rates of yield decline, namely, 0, 3, 6 and 9% and the various farming system options were determined. The results of this sensitivity analysis are shown in Figure 5. The profitability indicated by the AE was lowest under all rates of yield decline in the CF system. The AE of the CTF 7R system was only higher than the AE of the CTF 3R system assuming no yield benefit in the CTF 3R system and a 0% rate of yield decline. For yield decline rates of 3% or more, a move to a CTF 3R system, even assuming no relative yield benefits, was most profitable. When typical yield decline rates and likely yield benefits were included in the analysis, a move to a CTF 3R system, i.e. CTF 3R+YI, was shown to nearly double profitability compared to the CF system.

A water use productivity (WUP) index, defined as the total RV yield per crop cycle (plant plus all ratoon crops) divided by the total water use per cycle, was determined for the various farming systems. The gains in WUP relative to the CF system are shown in Figure 6 for the various yield decline rates.

Table 9. Cash-flow analysis of the controlled traffic plus three ratoon crop farming system assuming a 20% yield increase in the plant crop, a 5% saving in irrigation and a 3% yield decline rate (CTF 3R+YI).

Annual real discount rate (r_r) =				**3.8%**						
Yield Decline Rate =				**3.00%**						
Period Years =					0	1	2	3	4	5
Cut Age					0	0	14	14	14	14
t/ha/mth					0.0	0.0	12.0	11.6	11.3	11.0
t/ha					0.0	0.0	168.0	163.0	158.1	153.3
RV %					0.0	0.0	13.0	13.0	13.0	13.0
t RV					0.0	0.0	21.9	21.2	20.6	20.0
		Rate	Unit	R/Unit						
Expenses										
Land Preparation										
	Operations	Table 3	ha	Table 3	898.00	2058.00				
	Seed	50	ha	18.00	900.00					
Fertilizers										
	N	150	kg	9.75		731.25	1462.50	1462.50	1462.50	0.00
	P	60	kg	15.37	922.11	0.00	922.11	922.11	922.11	0.00
	K	150	kg	8.65	1297.50	0.00	1297.50	1297.50	1297.50	0.00
	Labour	2	man days	72.60	145.20	72.60	145.20	145.20	145.20	0.00
Chemicals										
	Pre-	8	l	336.00	336.00	336.00				
	Post-	1	mix	246.84			246.84	246.84	246.84	0.00
	Boom	1	ha	74.00	74.00	74.00	74.00	74.00	74.00	0.00
	Pre-	1	mix	302.50			302.50	302.50	302.50	0.00
	Labour	2		72.60			145.20	145.20	145.20	0.00
Seedcane										
		5.5	t	320.00		1760.00				
Irrigation										
	water	791	m3/mth	0.12		0.00	1328.88	1328.88	1328.88	1328.88
	power	791	m3/mth	0.21		0.00	2325.54	2325.54	2325.54	2325.54
Harvest & Transport										
		Table 5	t	69.87			11738.16	11386.02	11044.43	10713.10
Income										
Yield										
	RV		t	2260.00	0.00	0.00				
	Revenue		ha		0.00	0.00	49472.30	47988.13	46548.49	45152.04
Undiscounted nominal cash Flows					-4572.81	-5031.85	29483.88	28351.85	27253.79	30784.51
Modified IRR (MIRR)					67.06%					
Net Present Value (NPV)					R 92,318.93					
Annuity Equivalent (AE)					R 20,620.96					

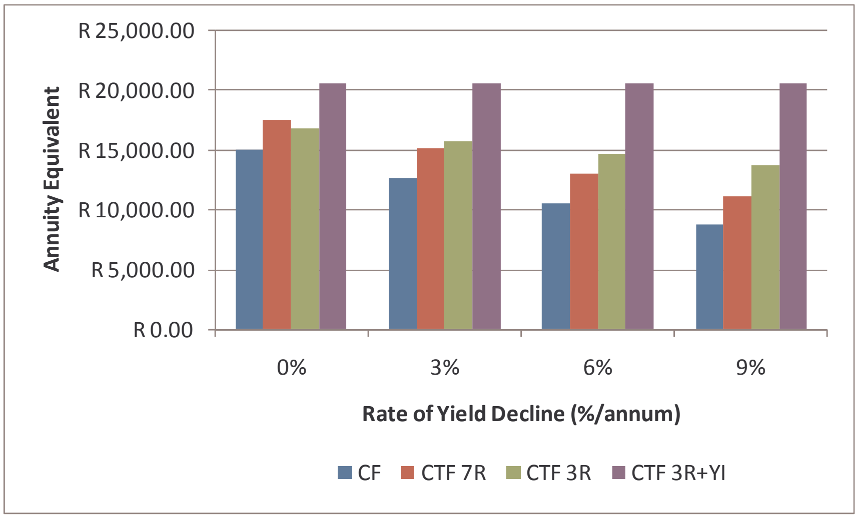

Figure 5. Comparison of the Annuity Equivalents (AE) for the conventional farming system (CF), the controlled traffic plus seven ratoons system (CTF 7R), the controlled traffic plus three ratoons system (CTF 3R) and the controlled traffic plus three ratoon system assuming a 20% yield increase in the plant crop, a 3% yield decline rate and a 5% saving in irrigation water (CTF 3R+YI).

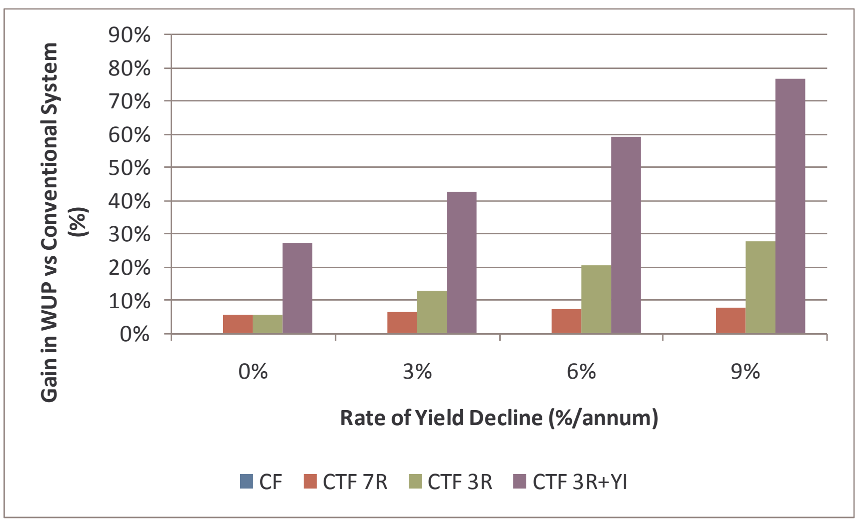

Figure 6. Comparison of the gains in Water Use Productivity (WUP) relative to the conventional farming system (CF), for the controlled traffic plus seven ratoons system (CTF 7R), the controlled traffic plus three ratoons system (CTF 3R) and the controlled traffic plus three ratoon system assuming a 20% yield increase in the plant crop, a 3% yield decline rate and a 5% saving in irrigation water (CTF 3R+YI).

The gains in WUP for the CTF 3R farming system were substantial, even when no irrigation water savings were assumed. Where yield improvements and water savings of only 5% were included in the analysis, a gain in WUP of nearly 80% was indicated over a CF system with a yield decline rate of 9%.

Discussion and Conclusions

The objective of this research was to analyse a controlled traffic zero-till farming system, (CTF) which includes:

- reduced re-establishment costs;
- changed cutting sequences which result in cane harvested at a more optimal age, i.e. 14 months old versus 11 months old;
- fewer ratoon numbers, i.e. three compared to eight or more;
- the incorporation of frequent break crops such as sunn hemp versus less frequent winter fallows.

CTF systems are facilitated by technologies such as GPS guided auto-steer systems, direct drill seed and cane planters, and side slewing loaders, together with a well-planned harvesting and replanting schedule. The harvesting and replanting schedule which allows cane to be harvested at an older age and higher sucrose content is critical to the success of the CTF systems. The potential benefits of harvesting an older crop could be further enhanced if the cause of reduced specific leaf nitrogen was better understood and addressed.

All the required machines considered necessary for the CTF farming systems described in this analysis are available commercially. The formation of contracting syndicates whereby groups of farmers become shareholders of contracting businesses should ensure expensive machines are well utilised, such that the cost of operations does not exceed levels indicated in this analysis. The formation of such syndicates may, however, prove a challenge to adoption. For large sugarcane estates, effective utilisation of expensive machinery should not be a constraint to adoption.

A rigorous yield, sucrose content, costing and cash-flow analysis, based on published research findings and detailed costing of representative machinery, showed that a CTF system with only three ratoon crops was far more profitable than a conventional farming system involving eight ratoon crops and more intensive and expensive tillage operations. Adoption of a CTF 3R system resulted in profits nearly doubling when the yield benefits reported with break crops and the yield decline rates reported under conventional farming systems were included in the analysis.

Very substantial gains in water use productivity were also shown – nearly an 80% improvement compared to the traditional CF system with a yield decline rate of 9%. Given that many irrigation farms in southern Africa experience frequent water shortages, such large gains in WUP are highly desirable for sustaining cane production with limited water.

Many traditional farming and research challenges, including *E. saccharina*, thrips, smut, RSD, nematodes and weeds are likely to pose far less of a problem where a CTF 3R farming system is widely adopted. This could have implications for breeding programmes. Should the danger posed by pests and diseases be reduced, relatively high yielding varieties which may be less tolerant to pests and diseases could be considered for release. As a result of all these benefits, varieties which have been reported to have 'no legs' when grown in a conventional farming system, are likely to yield better in a CTF 3R farming system.

Researching and adopting controlled traffic zero-till farming systems should be given a very high priority by decision makers in the irrigated sugarcane industry. A CTF 3R system is likely to result in a step change to the productivity of irrigation farms and be better for the environment.

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REFERENCES

Barry, PJ, Ellenger, PN, Hopkin, JA and Baker, CB (2000). *Financial management in agriculture*. Insterstate Pub, Inc., Illinois, USA

Braunack MV and Hurney AP (2000). The position of harvesting traffic does affect yield. *Proc Aust Soc Sug Cane Technol* 22: 126-132.

Garside AL, Bell MJ and Magarey RC (2001). Monoculture yield decline – fact not fiction. *Proc Int Soc Sug Cane Technol* 24: 16-21.

Garside, AL, Robotham, B and Bell, M (2006). Management of the interface between sugarcane cycles in a permanent bed, controlled traffic farming system. Australian Society of Agronomy Conference, 2006. (http://regional.org.au/au/asa/2006/concurrent/systems/4513_garside.htm Accessed: 26 March 2010.)

Hoekstra RG (1976). Analysis of when to plough out a sugarcane field. *Proc S Afr Sug Tech Ass* 41: 103-113.

Inman-Bamber NG (1994). Effect of age and season on components of yield of sugarcane in South Africa. *Proc S Afr Sug Technol Ass* 68: 23-27.

Ismael FM, Seeruttun S, Barbe C and Gaungoo A (2007). Improving cane productivity with dual row planting in Mauritius. *Proc Int Soc Sug Cane Technol* 26: 220-228.

ISSCT (2004). *Agricultural machinery costing method and standards protocol*. ISSCT (www.issct.org/machinerycostingprotocol.htm).

Keeping M, Butterfield M, Leslie G and Rutherford S (2008). Initial measures for management of thrips. The Link 17(3), South African Sugarcane Research Institute, Mount Edgecombe, South Africa.

Meyer JH and van Antwerpen R (2001). Soil degradation as a factor in yield decline in the South African sugar Industry. *Proc Int Soc Sug Cane Technol* 24: 8-15.

Nixon DJ (1992). *The impact of fallowing and green manuring on soil physical properties and the productivity of sugarcane in Swaziland*. PhD thesis, Univ of Reading, UK.

Nixon DJ and Simmonds LP (2004). The impact of fallowing and green manuring on soil conditions and the growth of sugarcane. *Expl Agric* 40: 127-138.

Norris CP, Robotham BG and Bull TA (2000). High density planting as an economic production strategy: (c) A farming system and equipment requirements. *Proc Aust Soc Sug Cane Technol* 22: 113-118.

Magdoff F and van Es H (2000) (Eds). *Building Soils for Better Crops*. Sustainable Agriculture Publications, USA.

Monteith JL (1977). Climate and the efficiency of crop production in Britain. *Philosophical Transactions of the Royal Society B* 281: 277-294.

Singels A (2007). A new approach to implementing computer-based decision support for sugarcane farmers and extension staff. The case of My Canesim. *Proc Int Soc Sug Cane Technol* 26: 211-219.

Snyman SJ, Meyer GM, Banasiak M, NicholsonTL, van Antwerpen T, Naidoo P and Erasmus JD (2008). Micropropagation of sugarcane via Novacane: Preliminary steps in commercial application. *Proc S Afr Sug Technol Ass* 81: 513-516.

Swinford JM and Boevey TMC (1984). The effects of soil compaction due to infield transport on ratoon cane yields and soil physical characteristics. *Proc S Afr Sug Technol Ass* 58: 198-203.

Umrit G, Bholah MA and Kee Kwong KF (2009). Nitrogen benefits of legume green manuring in sugarcane farming systems in Mauritius. *Sugar Tech* 11(1): 12-16.

van Heerden PDR, Donaldson RA, Watt DA and Singels A (2010). Biomass accumulation in sugarcane - unravelling the factors underpinning reduced growth phenomena. *J Exp Botany* (in press).

Wynne AT and Gilmour R (2010). Economic benefits of research: measuring and reporting. *Proc Int Soc Sug Cane Technol* 27 (in press).