Potential of controlled traffic farming with automatic guidance on an organic farm in the Netherlands

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Abstract

Some organic farms in the Netherlands use RTK-DGPS guidance of machinery over fixed traffic lanes to achieve non-trafficked cropping zones with optimum soil structure. These lanes are not yet used for harvesting and primary tillage. The potential of such a seasonal controlled traffic farming (SCTF) system was evaluated. In an on-farm field experiment in green pea, spinach, onions and carrots, SCTF with traffic lanes at 3.15-m centres was compared with conventional random traffic farming (RTF) using low ground pressures in spring from 2002 till 2005. Compared with RTF, the topsoil structure in the SCTF system improved, also in terms of lower spatial variability, for the crops sown on the flat but not for carrot grown on ridges. Crop yields increased significantly in green pea, spinach and planted onion but not in carrot and sown onion. SCTF resulted in a reduction of N_2O emissions by 20-50%, and reduced CH_4 emissions by a factor 2-12 when compared with RTF. SCTF was economically feasible for hypothetical 50-ha and 200-ha organic farms. An important advantage of SCTF over RTF is the increase in number of days that field operations can be executed.

Keywords: Controlled Traffic Farming, Organic, Nitrous oxide

Introduction

Controlled traffic farming (CTF) is a way of growing crops with adapted mechanisation, such that all field traffic is supported on permanent lanes and crop growth is on non-trafficked, wide beds (Taylor, 1983; 1994). The main objective of CTF is to obtain optimum soil conditions, both for crop growth and for tyres. The economics of CTF on farms with crops that can be combine-harvested were reviewed by Chamen *et al*. (1994). In their study, they concluded that, in order to justify the use of the zero-traffic systems, yield increases and larger scale farms (400 - 500 ha) would be needed. Several years of controlled traffic research in the Netherlands using modified conventional tractors with a wheel span of 3 m showed that CTF gave yield increases of up to 10% (Lamers et al., 1986). At that time, CTF was not an economically attractive option for arable farming in the Netherlands where crop rotations usually included root crops (Vermeulen & Klooster, 1992). The interest in CTF in the Netherlands was renewed when precise machinery guidance became available, based on real time kinematic differential global positioning system (RTK-DGPS). The first application was in organic farming, where optimal soil structure is considered essential to obtain reasonable yields and where high-value vegetable crops are usually part of the rotation. Because harvesting and primary tillage are not adapted to controlled traffic, mainly due to unfavourable economics, the system being studied here was called seasonal controlled traffic farming (SCTF). The research presented in this paper was carried out on an organic farm that adopted SCTF in 1999. The objective was to evaluate the potential of a SCTF system in practise.

Materials and methods

The potential of SCTF was evaluated in a field experiment with the crops green pea, spinach, onions and carrots. Topsoil condition, crop growth, farm profits and environmental impacts in a SCTF system were compared with those in a conventional random-traffic (RTF) system, in which low ground pressures were used in spring.

<u>Traffic systems</u>

The SCTF machinery was automatically guided over fixed traffic lanes using tractor guidance based on RTK-DGPS with a precision of about 2 cm. This precision was checked and confirmed from year tot year by using buried markers. For some operations vision was used to guide the machinery, using marker lines or crop rows that were previously laid out with RTK-DGPS. The distance between the traffic lanes was 3.15 m, which allowed 15 cm extra width of the traffic lanes in crops with standard distances of 50 and 75 cm between plant rows (Figure 1). Crops which would normally be sown on 25 and 12.5 cm distance were sown at a closer distance of 24 and 10.8 cm, respectively, to maintain the number of crop rows in the field while providing 53 and 44 cm wide traffic lanes, respectively. The main tractor was a 140 kW four wheel drive, fitted with 30-cm wide rubber tracks to increase tractor stability and to avoid lateral slippage under wet field conditions (Figure 2). The traffic lanes were used for seedbed preparation, sowing/planting, liquid manure application in spring and for mechanical weed control. The working width was 6.30 m for most operations but the 75-cm wide ridges for carrots were made with 3 m wide equipment (Figure 1). In autumn, after random traffic during harvest, the fields were conventionally ploughed to a depth of about 17 cm to alleviate soil compaction.
The RTF system was based on a tractor with wide tyres at about 0.5 bar pressure for seedbed preparation and sowing in green pea, spinach and onions. For ridging, sowing and weeding in carrots, a tractor with narrow tyres fitting between the ridges (track width 1.50 m) was used. For some operations, such as the application of manure in

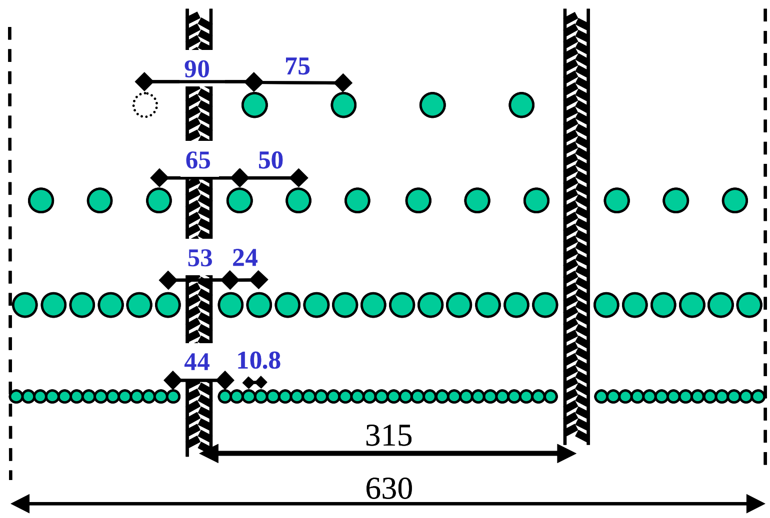

Figure 1. Lay-out of traffic lanes and crop rows in the SCTF system (distances in cm).

Figure 2. Wide-span tractor with rubber tracks and RTK-DGPS guidance.

spring, the RTF field operation was performed with SCTF equipment, but the RTF treatment was simulated by making an extra pass over the field with a tractor with relevant tyre sizes and wheel loads. In that case, the controlled traffic wheel ruts were excluded from subsequent measurements. The timing of operations was equal for SCTF and RTF so that differences found can be ascribed to differences in soil condition.

Site and soil characteristics

The experiment at Langeweg in the Netherlands, was situated on a 200 ha organic farm with a variety of arable and vegetable crops. The topsoil (0 - 20 cm depth) classified as a loam according to particle size distribution (USDA classification). Analytical data of the five fields involved in the experiment are presented in Table 1.

Experimental design

In the first year of the experiment (2002) only green pea was grown and only on field K1. In each of the successive years (2003, 2004 and 2005), three fields were selected on the farm and these grew onion, carrot and spinach in turn (Table 2). On each field, SCTF and RTF were compared in a randomized block design with 4 blocks. The plots were 6.30 m wide and 80 m long.

Table 1. Analytical data based on the topsoil of the fields used in the experiment.

Field	Particle size distribution (%, w/w) [1]					$CaCO_3$	Organic matter
	<2 µm	2-16 µm	16-50 µm	50-150 µm	<150 µm	(%,w/w)	(%,w/w)
K1	24.7	14.1	18.5	40.1	2.6	5.5	4.3
B8	18.5	13.8	23.1	43.3	1.4	8.6	4.0
B10	24.8	15.1	22.2	36.9	1.4	7.8	4.7
K2	19.7	21.2	19.1	39.2	1.0	5.4	4.5
K3	23.2	18.0	21.5	36.3	0.9	6.0	5.0

[1] % of mineral parts

Table 2. Location of the crops in the years of the experiment.

Crop	Year			
	2002	2003	2004	2005
Green pea	K1	-	-	-
Onion	-	K1 (sown)	K3 (sown)	B8 (planted)
Carrot	-	B8	K1	K3
Spinach	-	B10	K2	K1

Soil structure measurements

For crops grown on the flat, soil structure was characterised by measurement of the air-filled porosity at -10 kPa soil water matric pressure according to Kuipers (1961). The soil was sampled in 2.5 – 7.5 cm and 10 – 15 cm depth layers early in the growing season (May-June). In all sampling, on each plot and in each depth layer, 8 cores of 100 cm^3 were taken at random in the growing area, excluding the traffic lanes. At the same time as the soil sampling, penetration resistance was measured by taking 10 penetrations per plot, using an Eijkelkamp electronic penetrometer (cone top angle 60 degrees; base area 1.0 cm^2). Reported is the penetration resistance in the 0 – 30 cm depth layer. On the carrot fields with ridge culture, soil structure was only characterised by the mean weight diameter (MWD) of the aggregates.

Crop measurements

The green pea yield was determined by manual harvesting of subplots with an area of 10 m^2. The quality was established by measuring the hardness of the peas.
The spinach yield was determined both by hand and machine harvest. By hand, the spinach was cut about 3 cm above the soil surface. Yield subplots for SCTF were 6.3 m wide (full working width) and 1 m long. Yield subplots of RTF had a similar area, but were selected such that the subplot had a wheel rut pattern typical for conventional random traffic. Fresh yield, dry matter yield and nutrient content were determined. The harvester-yield was determined (in 2004 and 2005) on subplots 3 m wide (working width of the harvester) and 20 m long, by collecting and weighing the fresh spinach in wooden boxes once for each plot.
The onion yield was determined from subplots with an area of 10 m^2. The onions were dug out by hand, dried on the field for several hours and weighed. After two months, the sown onions (2003 and 2004) were weighed again and the quality was characterized by the yield fractions in various size classes and by the fraction of bad onions. For the planted onions destined for the fresh market (2005), quality measurements were not carried out. The reported yields relate to onions with a diameter larger than 40 mm.
The carrot yield was determined from subplots 3 m (4 rows) wide and 3 m long. After harvest, the carrots were kept in cool storage for about 6 weeks. Thereafter, the product was washed and the total yield was measured. The quality was characterized by the yield fractions in various thickness classes and by the marketable fraction of carrots.

Measurements in relation to the nitrogen balance

During cropping, plant-available nitrogen loss can be attributed to leaching and denitrification, but also to immobilization. The total plant-available nitrogen loss, defined as nitrogen deficit, was measured on field K1, where comparison of RTF and SCTF was completed for 4 years in succession. The N-balance at the start and at the end of the cropping period was determined from the measured amount of mineral nitrogen in the soil (0-60 cm depth), estimation of N-mineralization and uptake by the crop. Mineralization was estimated by measuring N-min in the soil also on fallow plots. The uptake by the crop was estimated from the dry matter yield and plant analysis. From the data, the N-deficit during cropping was calculated. The available N-min in the soil, measured at the end of the cropping period is an indication for the potential loss of nitrogen by leaching during the winter.

Measurement of the emissions of N_2O and CH_4

Gas exchange (N_2O, CH_4) between the soil surface and the atmosphere was measured in 2004 and 2005. Closed flux chambers (3.5 m^2 surface area, 1.5 m^3 volume) were used, either placed on top of the soil (Figure 3a) or on permanently installed wooden frames inserted 5-10 cm into the soil (Figure 3b). Each chamber was equipped with a battery-driven axial flow fan to ensure proper mixing of gases in the chamber. An estimate of leakage over the measurement period was obtained by measuring the rate of decay of a known amount of injected tracer gas (SF_6) as described by Mosquera *et al.* (2002). Gas samples were collected in 30 ml syringes 0, 20 and 40 min after the start of the measurements. The gas samples were the same day analyzed *in situ* by using a gas chromatograph equipped with an electron capture detector (ECD) for N_2O and SF_6, and a flame ionization detector (FID) for CH_4. A paired one-tailed t-test was applied to study the significance ($p \leq 0.05$) of the differences measured between treatments RTF and SCTF (Weiss, 1999).

Assumptions for economic assessment

The economics of SCTF and RTF were compared for hypothetical organic farms with 50 and 200 ha land, and a crop rotation including (sown) onion, spring wheat, green beans and pea, potatoes, spinach and carrot. For the 50 and 200 ha RTF farms, standard machinery fleets were assumed, typical for such farms. The 50 ha SCTF farm was assumed to use no RTK-DGPS system and to have standardized track width and working width of 3.15 m for all machinery. Some of the assumptions for the 200 ha SCTF farm were a track width of 3.15 m, a predominant working width of 6.30 m, the use of narrow rubber tracks and the use of RTK-DGPS machinery guidance. Having selected farm sizes, crops and machinery, the crop yield increase necessary to justify the use of SCTF machinery was calculated.

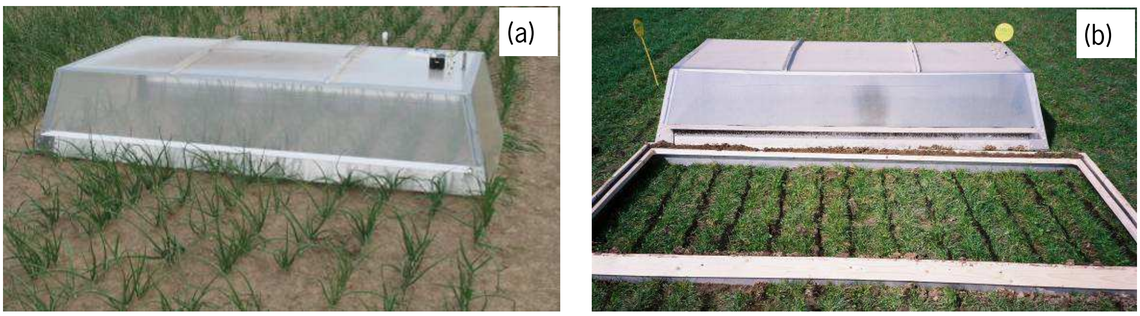

Figure 3. Flux chamber on top of the soil (a) and on permanently installed frames (b)

Results

<u>Topsoil structure</u>

The air-filled porosity at -10 kPa soil water matric pressure (ϕ_{a1}) in the topsoil, averaged per crop, is presented in Table 3. The data were analysed using the residual maximum likelihood (REML) procedure of Genstat (Payne et al., 1993). At both depths, ϕ_{a1} was significantly ($P<0.01$) increased in the SCTF system, compared with the RTF system. ϕ_{a1} decreased clearly with sampling depth. The spatial variability, expressed as the coefficient of variation, was lower in the SCTF system compared with the RTF system. The penetration resistance in the top 30 cm of the soil, averaged per crop, was lower for SCTF than for RTF for all crops, but only significant for pea and spinach (Figure 4). The overall average MWD of the soil aggregates in the carrot ridges was 8.4 mm for SCTF and 9.6 mm for RTF. This difference was not significant.

<u>Crop responses</u>

The yield in the SCTF system was significantly increased ($P<0.05$) compared with the RTF system in green pea in 2002, in spinach in 2004 and in planted onion in 2005. Yields were not different for carrot and sown onion (Table 4). Based on mechanical harvesting, the SCTF system yielded significantly more spinach than the RTF system in both 2004 and 2005. Differences in crop quality between systems were not significant.

<u>Nitrogen balance</u>

The N-balance was not significantly different between the traffic systems (Table 5).

Table 3. Average (ϕ_{a1}) and coefficient of variation (*cv*) of the air-filled porosity at -10 kPa soil water matric pressure per crop, depth layer and farming system.

	2.5-7.5 cm depth				10-15 cm depth			
	RTF		SCTF		RTF		SCTF	
	ϕ_{a1}	*cv*	ϕ_{a1}	*cv*	ϕ_{a1}	*cv*	ϕ_{a1}	*cv*
Pea	0.166	0.29	0.216	0.20	0.130	0.41	0.156	0.32
Spinach	0.154	0.31	0.192	0.27	0.107	0.51	0.146	0.47
Onion	0.159	0.25	0.195	0.21	0.092	0.46	0.117	0.38

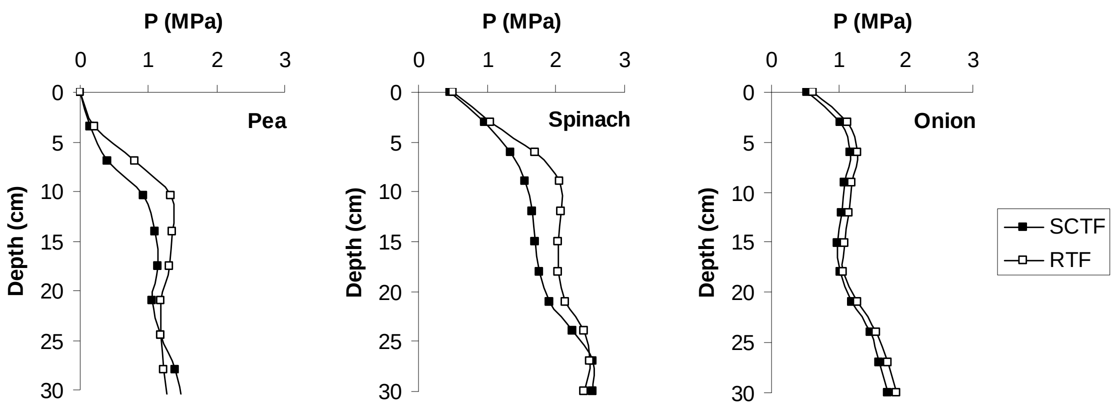

Figure 4. Soil penetration resistance (P) in the 0-30 cm depth layer for random traffic (RTF) and seasonal controlled traffic (SCTF), averaged per crop.

Table 4. Relative crop yield (RTF = 100), for harvesting by hand and by machine[1].

Crop	2002	2003	2004	2005
Green pea	131*			
Onion		100	98	110*
Carrot		93	104	102
Spinach		107	115* (135)*	102 (112)*

[1] For spinach and in 2004 and 2005 only, in parenthesis.
* Yield increases compared with RTF significant at $P<0.05$

Table 5. Estimated N-deficit and amount of N-min in the soil at end of cropping.

Year	Crop	Estimated N-deficit (kg/ha)		N-min at end of cropping (kg/ha)	
		RTF	SCTF	RTF	SCTF
2002	pea [1]	-107	-165	37	31
2003	onion	43	46	103	81
2004	carrot	0	-11	38	34
2005	spinach	0	9	28	27

[1] accumulation of N because of leguminous crop (nitrogen fixation).

Emissions of N_2O and CH_4

All sites were net sources for N_2O, with values ranging from 0 to 50 mg m^{-2} day^{-1}. The average coefficient of variation varied between 25 and 35%, with maximum values of up to 80% for individual measurements. Soil compaction markedly influenced N_2O emissions from all sites (figure 5). Application of the SCTF system resulted in a significant ($p < 0.05$) decrease of N_2O emissions by 20-50%.

Fluxes of CH_4 varied between –3 and 3 mg m^{-2} day^{-1} and showed a large within-site variation. The average coefficient of variation for the daily means ranged between 30 and 100%, although values as high as 600% were found for individual measurements. Application of the SCTF system resulted in a significant ($p < 0.05$) increase in CH_4 uptake by a factor 2-12 in the fields cultivated with onion (field K3) and carrot (field K1), compared to the RTF system (figure 5). At the other two field locations, a net CH_4 source (RTF system) was transformed into a net CH_4 sink (SCTF system).

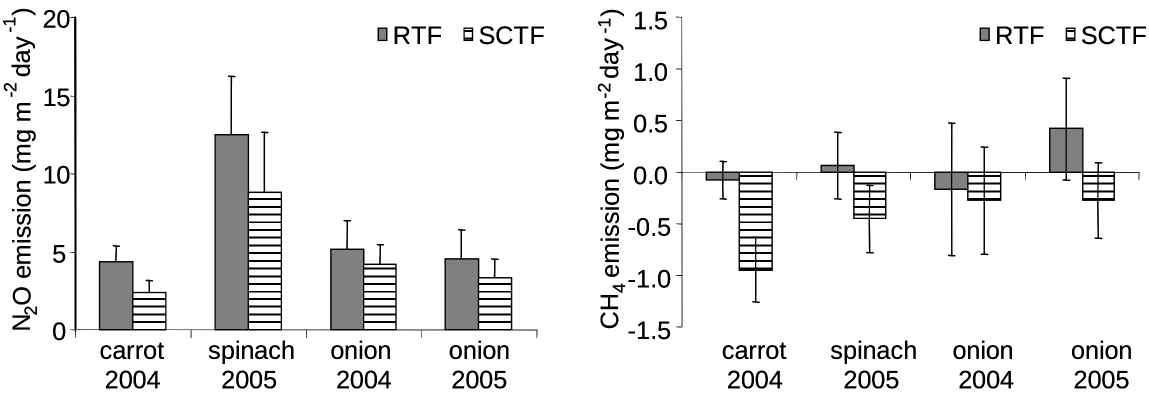

Figure 5. N_2O and CH_4 fluxes as a function of soil compaction for different crops.

Technical assessment of the guidance system

The 2-cm precision of the RTK-DGPS guidance system, mounted on the tractor, was accurate enough to trace back the permanent traffic lanes from year tot year. In the first two years, RTK-DGPS was also used to make the headland turns automatically, which resulted in sinusoidal deviations of more than 2 cm from the target line in the first 20 meters after the turn. In later years the automatic turning feature was not used and the tractor was steered close and parallel to the target line by hand, resulting in accurate guidance from the start of the run onwards. The guidance system was used succesfully for spring tillage, for marking a line for the manure applicator, for sowing and planting and for ridge building. It was felt that the guidance system was not yet reliable and accurate enough to perform mechanical weeding with sweeps at close distance to the plant rows. This operation was still performed by hand steering.

Economic assessment of SCTF

Compared with RTF, more investment in machinery is required for SCTF. Based on the cost of machinery needed on 50 ha and 200 ha organic farms for both systems, it was estimated that compared with RTF, SCTF is more profitable when the average crop yield increases by more than 1.6% in the case of a 50 ha farm and by more than 2.2% in the case of a 200 ha farm.

Discussion

The relatively low carrot yield in SCTF in 2003 is likely to have been caused by a difference in applied weeding method between systems. The mechanically harvested spinach in SCTF yielded considerably more than in RTF, both in 2004 and 2005. This effect was much stronger than for the hand cut spinach. The more level soil in SCTF, compared with RTF, may have caused this because the straight cutter bar of the harvester cannot follow micro-undulations in the terrain. The hand harvest gives the best estimate of the dry matter production of the crop and, therefore, nutrient uptake. The harvester yield is more meaningful for economic assessment of the farming systems. Averaged over all crops and years the yield increase was about 6% based on manual harvest and 10% based on machine harvest.

The SCTF system showed no advantage in terms of losses of plant available nitrogen due to leaching, de-nitrification or immobilization during the cropping period. Also, the available N-min at the end of the season was not different between the systems and, therefore, leaching losses in the winter are expected to be the same. Due to uncertainty about the amount of immobilization, the total losses of nitrogen to the environment cannot be exactly calculated. However, as leaching in winter is the most important source of loss, the difference in nitrogen losses to the environment between the RTF and SCTF systems is expected to be limited.

The lower emissions of N_2O and CH_4 found for SCTF, compared with RTF, agree with the information reviewed in Mosquera *et al.* (2005), and suggest the possibility of using controlled traffic farming to control and reduce N_2O and CH_4 emissions from agricultural soils.

Compared with RTF, SCTF was economically feasible on hypothetical 50-ha and 200-ha farms for average yield increases of 1.6% or 2.2 %, respectively. As the results suggest an average yield increase of 6-10%, SCTF is considered economically feasible.

It was observed that more workable days for field operations were available in SCTF compared with RTF. This effect is consistent with the results reported by Vermeulen & Klooster (1992). The increased timeliness of operations may be very important in organic farming as the number of field operations is greater than in conventional farming. Also, correct timing is essential for successful mechanical weed control. The workability effect of SCTF may further improve its feasibility.

Conclusions

Compared with RTF, the topsoil structure in the SCTF system improved physically and in terms of lower spatial variability for the crops sown on the flat but not for carrot grown on ridges. Crop yields increased significantly in green pea in 2002, in spinach in 2004 and in planted onion in 2005, while no differences were observed in carrot and sown onion. The available N-min at the end of the season was not different between the systems and, therefore, leaching losses in winter are expected to be the same. SCTF resulted in a reduction of N_2O emissions by 20-50%, and reduced CH_4 emissions by a factor 2-12 when compared with RTF. SCTF was economically feasible for hypothetical 50-ha and 200-ha organic farms. The RTK-DGPS guidance system was succesfully used to trace back the permanent traffic lanes, and to perform spring tillage, manure application, sowing and planting, but was considered te be not yet reliable and accurate enough to perform mechanical weeding with sweeps. Perhaps the most important advantage of SCTF over RTF is the increase in number of days that field operations can be executed, which further increases its potential for practical application.

Acknowledgements

We gratefully acknowledge the support and cooperation of J.A. Korteweg, C.F.A. van Beek, the Ministry of Agriculture, Nature and Food Quality and Senternovem.

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