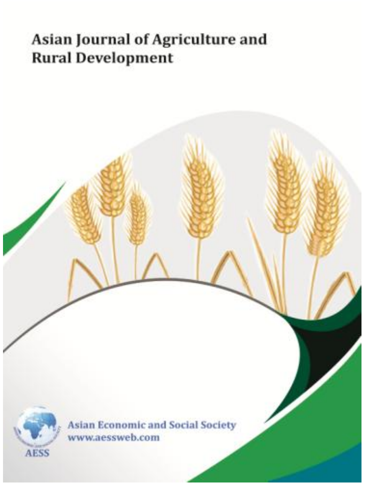
Publisher: Asian Economic and Social Society
ISSN (P): 2304-1455, ISSN (E): 2224-4433
Volume 2 No. 4 December 2012.



Effects of Long Term Cropping Systems on Soil Chemical Properties

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Citation: U. Mazarura and C. Chisango (2012) “Effects of Long Term Cropping Systems on Soil Chemical Properties”, Asian Journal of Agriculture and Rural Development, Vol. 2, No. 4, pp. 632 – 640.

Asian Journal of Agriculture and Rural Development, 2(4), pp. 632-640.

Effects of Long Term Cropping Systems on Soil Chemical Properties

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Abstract

In this study we examined the impact on soil C, total soil N and available P of six rotations namely: long season tobacco cultivar 'KM10' grown continuously (ContKM10), medium season tobacco cultivar 'RK8' grown continuously (ContRK8), grass-grass-grass-KM10 (G-G-G-KM10), grass-grass-grass-RK8 (G-G-G-RK8), KM10-Crotalaria juncea (KM10-Cr) and RK8-Crotalaria juncea (RK8-Cr). The experiment was established in 1990 under irrigation on a sandy loam soil at Kutsaga Research Station, Zimbabwe. Soil samples were taken from 0- to 15-cm deep, after each season. After 9 years, tobacco-grass rotations showed higher soil C than monocropping, regardless of variety. The monocropping systems, ContKM10 and ContRK8, did not differ from KM10-Cr and RK8-Cr respectively showing that when crop intensity is maintained soil C will be reduced regardless of a winter C. juncea green manure in a sandy loam soil. After 9 years, soil N was greatest in the G-G-G-KM10 rotation. Available P was lower in the grass (G-G-G-KM10, G-G-G-RK8) relative to the other rotations regardless of variety. Available P accumulated in monocropping systems (ContRK8, ContKM10) and was consistently lower in the grass-tobacco rotations. This indicated an accumulation of P in the case of monocropping systems because of continuous inorganic fertiliser input. The results reaffirmed the deleterious effect of monocropping and suggested the need for diverse rotations.

Keywords: Crotalaria, soil carbon, nitrogen, phosphorous, rotations, grass

Introduction

Crop sequencing is widely known to have a major influence on such soil chemical properties as organic C content, pH, available P, K, Ca and Mg as well as N supply and transformations (Wilson et al., 1982). Generally, crop rotations increase soil C (Varvel, 1994; Drury et al., 1998) and N (Varvel, 1994) more than a monoculture or fallow. For example, Aref and Wander (1998) reported that organic matter content was least in a maize (*Zea mays* L.) monoculture, intermediate in a maize-oat (*Avena sativa* L.) rotation and largest in a maize-oat-hay rotation.

In the very long term, however, tillage, intensive cropping or continuous monocropping (Drury et al.,1998; Varvel, 1994; Kätterer, et al. 2008; Salvo et al. 2010) decrease soil organic C compared to natural untilled areas. No-till (Al-Kaisi et al., 2005) and organic systems (Nautiyal et al. 2010) have been shown to increase soil C and N content compared to conventional farming. Green manures (Al-Kaisi et al., 2005) and grasses (Salvo et al. 2010; Eriksen et al. 2008) can increase soil C and/or N.

Soil N can be high in crop rotations, especially when legumes are included (Bruulsema and Cristie, 1987; Harris and Hesterman, 1990; Arshad et al., 1998) and leaching is reduced. The contribution of a legume as a source of N could be as much as 120 kg N/ha (Ebelhar et al. 1984; Hargrove, 1986). Leaching of NO_3-N is

usually lower in crop rotations than in continuous cropping (Anderson et al. 1997; Arshad et al. 1998; Simmelsgaard, 1998).
Legumes can also have a positive influence on available P by altering the rhizosphere (Wilson et al. 1982).

The three-year grass-tobacco (*Nicotina tabacum* L.) rotation (G-G-G-T) is a standard cropping system in most tobacco farms in Southern Africa. However, despite that this rotation is accepted as sustainable, particularly with regard to its effect on nematodes and soil chemical properties, farmers find it uneconomical especially when they have invested in a very costly irrigation system. Such farmers resort to growing continuous tobacco (ContKM10 or ContRK8) for even more than 20 years. Hence, the overall objective of this study was to find the long term effects of growing irrigated tobacco continuously with or without a green manure crop on soil chemical properties compared to tobacco rotated with a grass ley. These effects were compared using two varieties that differed significantly in growth habits: a high leaf numbered variety, KM10 and a moderate leaf numbered variety, RK8.

Materials and Methods

Site description and experimental design

This experiment was carried out under irrigation on a sandy loam soil (72.8% sand, 8.8% silt and 18.4% clay) at Kutsaga Research Station (17º 55' S, 31º 08'E ; Altitude 1480m above sea level, Average annual rainfall 882 mm, and distribution given in Table 1), Zimbabwe from 1990. Before 1990 the research area had been planted to tobacco followed by five years of *Chloris gayana cv.* Katambora Rhodes grass. Tobacco variety KM10 was grown as a uniformity crop in the plots in 1990 and the actual year of first rotation was 1991. This paper is confined to the period 1994 to 2000 (4th year of rotation to the 10th year of rotation respectively). After the year 2000, the rotation was changed and those changes and their effects are the subject of another publication. The experiment was laid out as four randomized complete blocks consisting of six treatments, replicated once in each block, namely: Continuous long season tobacco variety Kutsaga Mammoth 10 (ContKM10), KM10 followed by *Crotalaria juncea* (KM10-Cr), Continuous short season tobacco variety RK8 (ContRK8), RK8 followed by *Crotalaria juncea* (RK8-Cr), KM10 after three years of *Chloris gayana* cv. Katambora Rhodes grass (G-G-G-KM10), and RK8 after three years of *Chloris gayana* cv. Katambora

Rhodes grass (G-G-G-RK8). KM10 is a high yielding, high leaf numbered (23) variety, while RK8 is moderately yielding and moderate leaf numbered (18-19) variety. The treatment layout was such that every component of a rotation was included in each block in every year. This enabled yearly analysis of variance (ANOVA) to explain direct effects of a treatment or component in every year and cycle analyses to explain residual or cumulative effects after the end of a complete cycle of the rotation (4 y and 9 y for the longest G-G-G-KM10 or RK8 rotations). Analyses after several complete cycles would reveal limiting effects; rotational effects after cycles have stabilized. Our best estimate of this was at the end of the 1998/99 season and contrasts at this point might reveal interesting patterns in addition to the trends. Each plot was 4.8 m wide and 17.92 m long. The main comparison was on the continuous tobacco after grass rotations and the respective continuous rotations. After the year 2000 the continuous tobacco rotation with *C. juncea* was changed to continuous tobacco with winter wheat and data from 2001 will be reported elsewhere.

Table 1: Monthly and Seasonal Rainfall Totals in mm from 1990 to 2000

Year	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total
1990/91	0.4	0.7	68	128.2	183.3	79.7	46	0	506.3
1991/92	6.2	29.8	96.4	171.3	42.6	12.2	142.8	79.7	581.0
1992/93	0.0	7.6	80.2	186.2	212.1	195.4	61.7	89.6	832-8
1993/94	6.6	15.2	92.9	178.2	222.7	167.2	45	1.6	729.4

1994/95	0.0	87.7	46.5	129.3	156.8	52.2	5.4	9.4	487.3
1995/96	0.0	20.8	40.5	217.4	300.3	146.4	98.9	5.9	830.2
1996/97	0.5	5.1	79.1	149.9	254.9	172.6	102.3	34.9	799.3
1997/98	70.2	43.6	104.4	53.3	326.5	41.8	214.2	1	855.0
1998/99	0.0	13.2	117.6	268.6	415.9	217.3	261.1	10.5	1304.2
1999/00	0.0	57.0	83.3	119	334.2	145.8	220.7	77.6	1037.6

Irrigation and Cultural Practice

Irrigation water was applied by sprinkler at 50% available soil moisture depletion, estimated using the evaporation pan method. The land was ploughed and disced according to standard practice. Tobacco was grown on 0.2 m high ridges, 1.2 m apart in the inter-row, and 0.56 m apart in the intra-row. The *C. juncea* was seeded at 50 kg/ ha with rainfall or irrigation and was incorporated just before flowering which was approximately 3 months after seeding. *Chloris gayana* cv. Katambora Rhodes grass was seeded at 12 kg/ha and also incorporated early (April-May) during the year preceding the tobacco crop.

Fertilisation

The tobacco crop received a basic application of 600 kg/ha compound fertiliser (36 kg N; 102 kg P_2O_5;80 kg K_2O) and the land was pre-irrigated before planting at the beginning of September each year. Mechanical and chemical weed control methods were employed to keep the tobacco crop weed-free. The herbicide Metolachlor 960 EC was applied at 2.3 L/ha product within 7 days of transplanting and settled in with 12 mm of irrigation. Topdressing applications of 100 kg N/ha and 10 kg N/ha as ammonium nitrate (AN, 0-34-0) were applied to RK8 at 3-4 weeks after planting and at topping, respectively, while KM10 received just the initial topdressing at 3-4 weeks after planting as is standard practice. The fertiliser was applied by dollop placement 10 cm from the plant and 5 cm deep. Lime was only applied as and when needed to correct pH to 5.5 ($CaCl_2$).

Soil Sampling and Analyses

Soil sampling was done at the end of each growing season. The soil samples were collected from the top 15 cm from each plot. Soil pH was measured in a supernatant suspension of 1: 5 soil: 0.01 M $CaCl_2$) solution using a glass electrode (Page *et al*., 1982). Soil organic C was determined using the Walkley and Black wet digestion method (Walkley and Black, 1934). Total soil N was determined using the standard Kjeldahl digestion and distillation technique. The soil was digested with sulphuric acid and selenium catalyst, and distilled with zinc and Sodium hydroxide. After distillation total N was determined by titration with hydrochloric acid using Tashiro indicator (Chemistry and Soil Research Institute of Zimbabwe, unpublished). Available soil P was extracted using an anion-exchange resin method which utilizes Dowex 21K in the chloride form and involves leaching of phosphate with NaOH followed by HCl. Available P in solution was determined calorimetrically by the ammonium molybdate stannous chloride method (Sparling et al., 1985).

Statistical Analysis

ANOVA was done after each season and at the end of the two cycles using SAS software Version 6. Selected treatments were further compared using orthogonal contrasts of the following; ContKM10 vs. G-G-G-KM10, KM10-Cr vs. G-G-G-KM10, ContKM10 vs. KM10-Cr, ContRK8 vs. G-G-RK8, RK8-Cr vs. G-G-G-RK8, and Cont RK8 vs. RK8-Cr.

Results and Discussion

Soil Carbon

The direct effects of each treatment component for each year shown by a plot of the soil C over time indicated that G-G-G-KM10 and G-G-G-RK8 consistently had higher soil C relative to ContRK8, ContKM10, RK8-Cr and KM10-Cr (Fig 1). In essence ContRK8 and ContKM10 did not differ from RK8-Cr and KM10-Cr respectively. The cumulative rotation effect (Table 2) confirmed the above trends showing that at 9 y tobacco-grass rotations, G-G-G-

KM10 and G-G-G-RK8, had significantly (P<0.0001) higher soil C than the continuous monocultures, ContKM10 and ContRK8, regardless of variety. The respective continuous rotations, ContKM10 and ContiRK8, did not differ from KM10 Cr and RK8-Cr, respectively howing that when crop intensity is maintained, soil C will be reduced regardless of a winter *C. juncea* green manure. KM10-Cr was significantly lower than G-G-G KM10 (P<0.0002) while RK8-Cr was significantly lower than G-G-G-RK8 (P<0.004). A change in soil C from the initial values taken in 1990 relative to values at 9 yr indicated a decreasing trend with continuous tobacco and virtually unchanged values for the grass rotations (Table 2).

Regardless of the variety, the grass rotation, in general, improved soil C or maintained it above the continuous rotation with or without *C. juncea*. This result from the grass rotation was anticipated since the grass ley was incorporated into the soil. Similar results have been reported by other workers (Drury et al. 1998; Kätterer et al. 2008; Al-Kaisi et al., 2005; Salvo et al. 2010). Kätterer et al. (2008) consistently showed that conversion of grassland to arable land was associated with a drop in Soil C stock while conversion from arable to grassland always improved soil C stock. The contribution of the green manure was below anticipated levels. It is possible that since the green manure was incorporated after only 3 months it was easily mineralised because of a low C: N ratio leading to higher loss of soil C. Daimon et al. (1995) showed that the C: N ratio of *C. juncea* even after 120 days after sowing was only 23:5. Silva et al. (2007) and Mtambanengwe and Mapfumo (2006) reported a quick mineralization of *C. juncea* with the onset of rains. In a long term trial, Gerzabek et al. (1997) showed that the green manure was able only to maintain soil C over a long period, showing no significant rise with time.

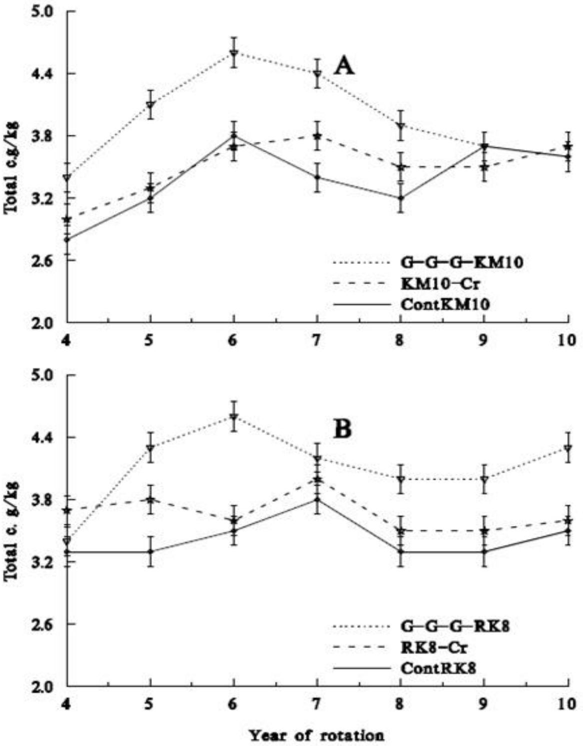

Fig. 1: Total c response to rotation treatments ContKM10, KM10-Cr and G-G-G-KM10 (A); and treatments ContRK8, RK8-Cr and G-G-G-RK8 (B). Vertical bars are standard errors of the difference between means

Table 2: Overall Means Over Eight Years and Contrasts Comparing Soil C and Total N amongst the Rotations

Rotation	Soil C Initial g/kg	Soil C 9-yr g/kg	ΔSoil C	Total N Initial μg/g	Total N 9-yr μg/g	ΔTotal N
ContKM10	3.8	3.4	-0.4	440.3	343.3	-97.0
ContRK8	4.1	3.4	-0.7	457.0	391.7	-65.3
KM10-Cr	3.9	3.5	-0.4	424.3	383.3	-41.0
RK8-Cr	4.1	3.7	-0.4	441.0	404.2	-36.8
G-G-G-KM10	3.7	4.0	0.3	423.0	430.8	7.8
G-G-G-RK8	3.9	4.1	0.2	456.0	430.0	-26.0
Contrasts						
ContKM10 vs. G-G-G-KM10		***			***	
KM10-Cr vs. G-G-G-KM10		***			***	
ContKM10 vs. KM10-Cr		ns			**	
ContRK8 vs. G-G-G-RK8		***			**	
RK8-Cr vs. G-G-G-RK8		**			ns	
Cont RK8, vs. RK8-Cr		ns			ns	

***P < 0.001, **P<0.01, *P<0.05, ns=not significant

Total soil nitrogen

The direct effects of each treatment component for each year shown by a plot of total soil N Over time showed significant higher values for G-G-G-KM10 relative to ContKM10 and were only higher than KM10-Cr in year 4, 5, 8 and 10 while KM10-Cr was higher than ContKM10 in years 4, 6, 9 and 10 but tended to be higher consistently (Fig 2). Similarly, G-G-G-RK8 had consistently higher soil N than ContRK8 but only higher than RK8-Cr in yr 5, 8 and lower in yr 10. RK8-Cr was significantly higher than ContRK8 in years 6 and 10 but consistently tended to be higher. The cumulative rotation effect at the 9th year (Table 2) showed differences in the order G-G-G-KM10>KM10-Cr>ContKM10 (P<0.01). With regard to RK8, G-G-G-RK8 was greater than ContRK8 (P<0.0087) but marginally greater than RK8-Cr (p<0.076) while RK8-Cr was equal to ContRK8. A change in total N from the initial value at the start of the rotation compared with values at 9 yr indicated a decreasing trend greatest in the continuous rotations and least with G-G-G-RK8 and virtually unchanged values with G-G-G-KM10 (Table 2). The initial values themselves were not significantly different between treatments.

An increase in soil N due to grass rotations relative to continuous cropping was also reported by Al Kaisi et al. (2005). The increased soil N (ContKM10 vs. KM10-Cr) as a result of the green manure was anticipated as also reported by other workers (Silva et al. 2007 and Mtambanengwe and Mapfumo, 2006). In this experiment continuous fertilization slightly masked the deleterious effect of monocultures on soil chemical properties. The grass was better than the green manure perhaps because it had a higher soil C and reduced leaching. Reduced leaching under pasture periods relative to soil after disturbance by ploughing were found by Berntsen et al. (2006). Mtambanengwe and Mapfumo, (2006) also observed high leaching loses with *C. juncea* in sand soils.

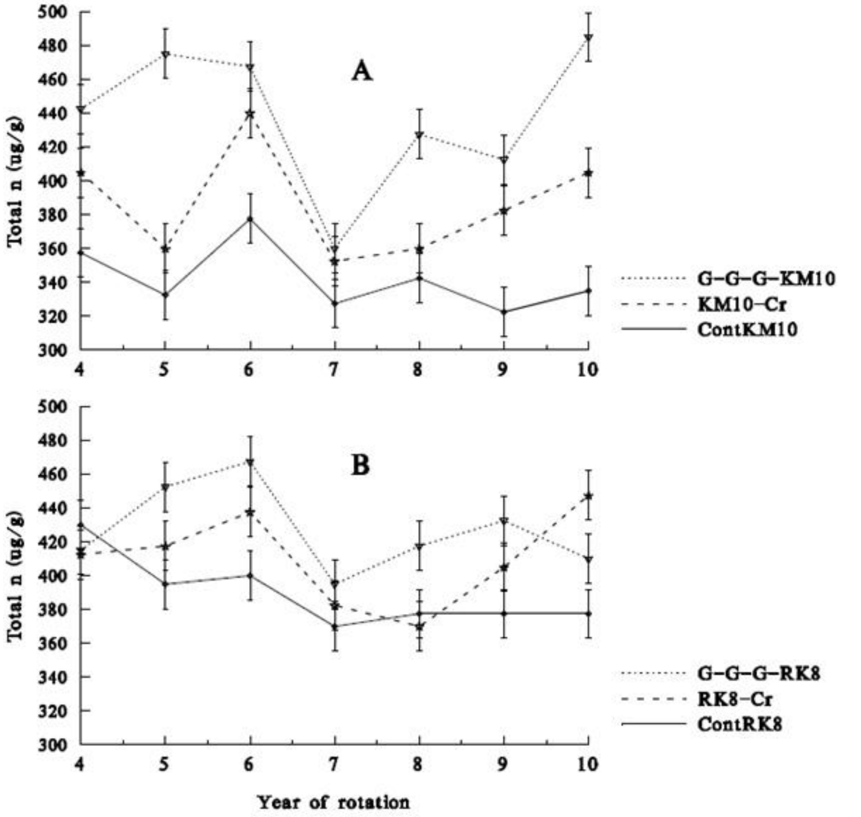

Fig. 2: Total N response to rotation treatments ContKM10, KM10-Cr and G-G-G-KM10 (A); and treatments ContRK8, RK8-Cr and G-G-G-RK8 (B). Vertical bars are standard errors of the difference between means

Available phosphorus

The direct effects of each treatment component on available P for each year shown by a plot of available P over the years was consistently higher for the ContRK8, ContKM10, KM10-Cr, and RK8-Cr rotations than the G-G-G KM10 or G-G-G-RK8 rotations (Fig 3). The cumulative rotation effect at 9 y (Table 3) showed significantly ($P<0.0001$) lower soil available P in the grass (G-G-G-KM10, G-G-G-RK8) relative to the other rotations regardless of variety. Generally, the continuous rotation (ContiKM10) did not differ from the rotations with *C. juncea* (KM19-Cr) while RK8-Cr was lower than ContRK8. In general, the results showed available P accumulation in continuous monoculture (ContRK8, ContKM10) and consistently lower values in the G-G-G-RK8 and G-G-G-KM10 rotations. A change in available P relative to the initial value at the start of the rotation indicated an accumulationof P greater in the case of the monocultures and least with the grass rotations (Table 3). The initial values themselves were not significantly different between treatments.

The fact that the continuous rotations received 102kgP/ha annually must largely account for the observed higher P in these monocultures relative to the grass rotations which received the P only once in four years. Other workers have shown such accumulation under long term continuous inorganic P fertilization (Dodd and Mallarino, 2005; Bowman and Halvoson, 1997; Bunemann et al. 2006). The role of the green manure in supplying P was not evident in this work although Wilson et al. (1982) reported an increase in available P linked to legumes. Silva et al. (2007) also found *Crotalaria juncea* to have no effect on P in a six year trial.

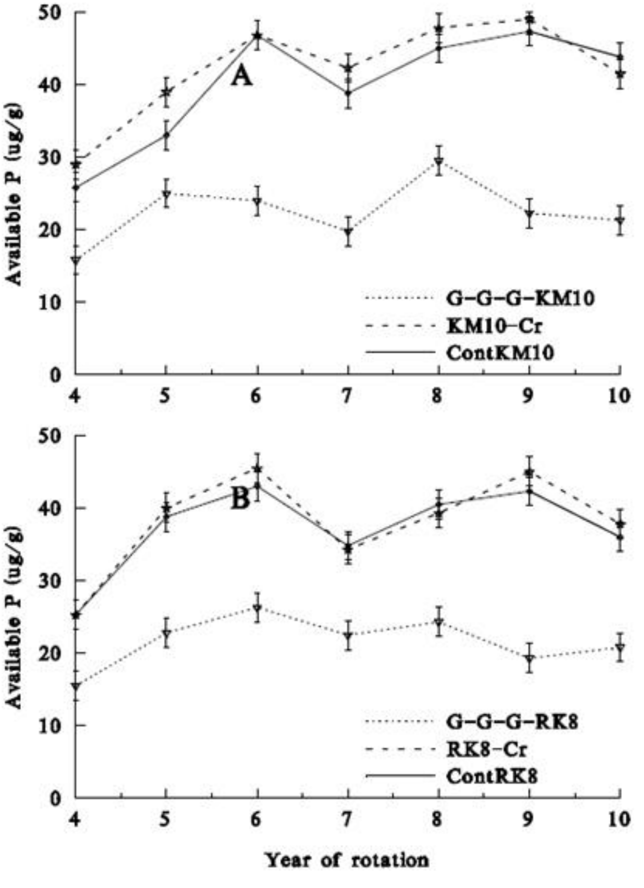

Fig. 3: Available P response to rotation treatments ContKM10, KM10-Cr and G-G-G-KM10 (A); and treatments ContRK8, RK8-Cr and G-G-G-RK8 (B). Vertical bars are standard errors of the difference between means

Table 3: Overall Means Over Eight Years and Contrasts Comparing Soil Available P_2O_5 (Ug/G) Amongst the Rotations

Rotation	**Available P_2O_5 Initial µg/g**	**Available P_2O_5 9-yr µg/g**	**Δ P_2O_5**
ContKM10	21.2	39.4	18.2
ContRK8	21.7	42.3	20.6
KM10-Cr	21.3	37.4	16.1
RK8-Cr	21.8	38.2	16.4
G-G-G-KM10	20.0	22.7	2.7

G-G-G-RK8	21.0	21.8	0.8
Contrasts			
ContKM10 vs. G-G-G-KM10		***	
KM10-Cr vs. G-G-G-KM10		***	
ContKM10 vs. KM10-Cr		ns	
ContRK8 vs. G-G-G-RK8		***	
RK8-Cr vs. G-G-G-RK8		***	
Cont RK8, vs. RK8-Cr		*	

***P < 0.0001, **P<0.001, *P<0.05, ns=not significant

Conclusions

In general, this experiment shows that despite the need by farmers to maximise returns from installation of an irrigation system, monocultures are soil degrading, particularly so in sandy soils and it is imperative that a more economical and sustainable rotation be sought as an alternative. Additionally, although the traditional grass rotation seemed to, at best, maintain soil C and N, a more diverse rotation should, perhaps, be considered so as to optimise the availability of these nutrients.

Further study inclusive of more diverse cropping systems as well as monitoring such parameters as green house gas emission, soil microbial activity, nutrient leaching, soil physical properties would allow us to evaluate soil quality as well as effects on the environment.

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