HELIA, **23**, Nr. 32, p.p. 1-18, (2000) UDC 633.854.78:631.582

EFFECTS OF CROP ROTATION ON SOIL CHEMICAL CONDITIONS AND SUNFLOWER, SOYBEAN AND MAIZE PRODUCTION

Ungaro, M.R.G.[1*], Dechen, S.C.F.[2*], Quaggio, J.A.[2*], Nnabude, P.C.[3], Gallo, P.B.[4]

[1] *Instituto Agronômico, CEGRAN, Caixa Postal 28, CEP 13001-970, Campinas, SP, Brazil*
[2] *Instituto Agronômico, Centro de Solos e Recursos Agroambientais, Brazil*
[3] *Nnamdi Azikiwe Federal Univesity, Anambra State, Nigeria*
[4] *Instituto Agronômico, Estação Experimental de Agronomia de Mococa, Brazil*

Received: February 04, 1999
Accepted: May 24, 2000

SUMMARY

A study was conducted in Mococa, State of São Paulo, Brazil, from 1981 to 1989, to evaluate sunflower as a dry season option, mainly after short-season soybean and maize and to study the effects of crop rotational management systems on soil chemical conditions and the yields and agronomic parameters of sunflower, soybean and maize. The treatments were: (a) Continuous sunflower grown in the wet and dry seasons (Cont. SFw/SFd); (b) Continuous succession soybean/dry season sunflower (Cont. S/SFd); (c) Continuous maize (Cont. M); (d) Rotation maize followed by soybean/dry season sunflower (M-S/SFd); (e) Rotation maize followed by wet season sunflower/green manure (M-SFw/GM); (f) Rotation maize followed by wet season sunflower/dry season sunflower (M-SFw/SFd). The results show that sunflower improves phosphorus availability in the upper soil layers and increases soil acidification; continuous S/SFd accumulates more K at all soil depths; there is a positive influence of the leguminous crop on sunflower grain and dry matter yield; for the São Paulo State conditions, maize grain yield in rotational treatments performs 30% higher than continuous maize, soybean grain and dry matter yield of the succession soybean/sunflower, even in continuous cropping, maintain the same productivity levels than in rotational treatments; rotational treatments has no influence in sunflower head diameter.

Key words: **crop rotation, chemical conditions, grain yields, *Helianthus annuus* L., *Glycine max* L., *Zea mays* L., *Mucuna aterrima* Piper and Tracy**

---

* With research grant from National Council of Scientific and Technological Development (CNPq).

INTRODUCTION

Crop rotation and biological diversity have long been cornerstones of successful and traditional agricultural production systems (Francis and Clegg, 1990). The attention and interest given to the system in past decades was diminished by the introduction of inorganic fertilizers. However, environmental considerations and high cost of inorganic fertilizers are becoming limiting factors in sustainable crop production. Crop rotation as a soil management system provides a suitable alternative as an environmentally sound agricultural production as minimum and no tillage systems.

Several studies have shown that crop rotations with or without legumes enhance soil productivity. However, there is general agreement that legumes contribute nitrogen to a succeeding crop (Heichel, 1987; Power, 1989). Maize yield increases of 16 to 17 percent have been reported under maize grown after soybean compared with continuous maize (Higgs *et al.*, 1976; Randall, 1981; Hesterman *et al.*, 1986) while Dechen *et al.* (1990) reported up to 30 percent increase under maize/green manure followed by peanuts. Improved grain legumes after cereals (Roder *et al.*, 1989) as well as high yields under rotations of non-leguminous crops (Robinson, 1966; Adams *et al.*, 1970; Turner *et al.*, 1972) have been reported.

Other benefits of crop rotation include improvement in soil organic matter (Mannan, 1962), increased microbial mass and water infiltration into the soil (Roder *et al.*, 1988; Adams *et al.*, 1970). Research has also shown that crop rotation is effective in the control of insect pests, plant pathogens, nematodes and weeds. This is accomplished by breaking the reproductive cycles of these species because different pests are generally found on or with different crops. Rotation of summer annuals with winter annuals, perennial crops with annual crops, legumes with cereals, long-season with short season crops, and in the tropics wet-season with dry-season have been advocated as part of integrated pest management (Francis and Clegg, 1990).

At the end of 70' in Brazil, farmers started to growth sunflower as a dry season option, mainly after short-season soybean and maize. The research had no experience about these succession crops or even about the continuous cultivation of sunflower in tropical conditions. The objective of the present research was to evaluate the effects of long-term crop rotation systems on soil chemical conditions and yield of wet and dry season sunflower, soybean and maize.

MATERIAL AND METHODS

The experiment was set up on an Alfisol at an experimental farm of Instituto Agronômico (IAC), in Mococa, State of São Paulo, Brazil, at 47°01' west longitude and 21°28' south latitude, at 662 m above sea level, from 1981 to 1989 over an area maintained uncultivated during ten years. According to Köppen classification

(Köppen, 1936), the climate is AW, with a warm and wet season from October to March, with 1,182 mm of an annual precipitation of 1,465 mm and mean temperature between 23°C and 25°C. A dry season occurs from April to September, with mean temperature between 19°C and 23°C and total precipitation of 283 mm (Pedro Júnior *et al.*, 1997). Figure 1 shows the average hydric balance from 1983 to 1989 and Figure 2 the ten-days hydric balance of 1985.

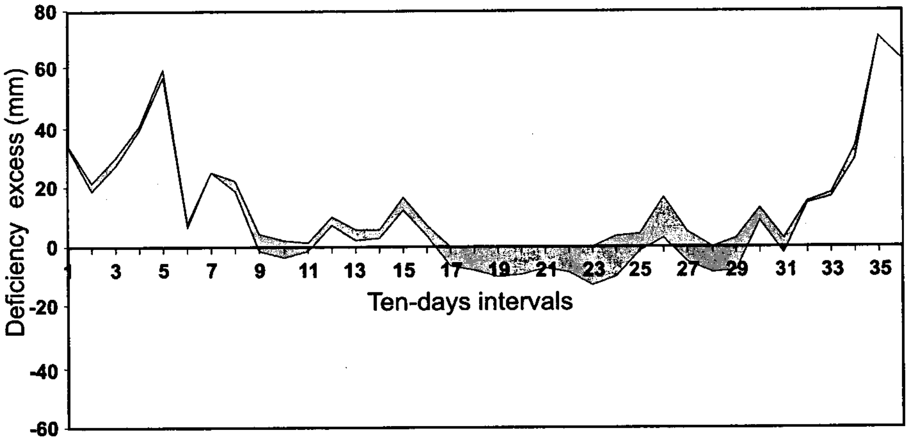

Figure 1: Average ten-day hydric balance for 1983 to 1989.

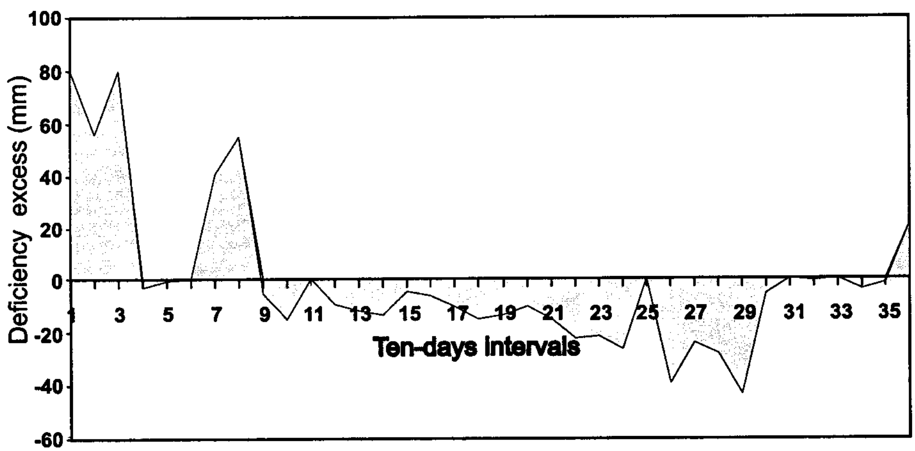

Figure 2: Ten-day hydric balance of 1985.

The effect of different rotation systems, including sunflower (*Helianthus annuus* L.), maize (*Zea mays* L.), soybean (*Glycine max* L.) and green manure

(*Mucuna aterrima* Piper and Tracy) were studied in a long-term field experiment using a randomized complete block design with four replications.

The treatments were as follow:

a. Continuous sunflower grown in the wet and dry seasons (Cont. SFw/SFd);
b. Continuous succession soybean/dry season sunflower (Cont. S/SFd);
c. Continuous maize (Cont. M);
d. Rotation maize followed by soybean/dry season sunflower (M-S/SFd);
e. Rotation maize followed by wet season sunflower/green manure (M-SFw/GM);
f. Rotation maize followed by wet season sunflower/dry season sunflower (M-SFw/SFd).

In order to avoid seasonal climatic variation, the rotation treatments were replicated, as shown in Table 1. The results of the measured variables were the average of the two replications.

Table 1: Rotation treatments during the experimental phases

Treatment	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89
Cont. SFw/SFd	SFw/SFd	SFw/SFd	SFw/SFd	SFw/SFd	SFw/SFd	SFw/SFd	SFw/SFd	M
Cont. S/SFd	S/SFd	S/SFd	S/SFd	S/SFd	S/SFd	S/SFd	S/SFd	M
Cont. M	M	M	M	M	M	M	M	M
S/SFd-M	S/SFd	M	S/SFd	M	S/SFd	M	S/SFd	M
M–S/SFd	M	S/SFd	M	S/SFd	M	S/SFd	M	M
SFw/GM–M	SFw/Gm	M	SFw/Gm	M	SFw/Gm	M	SFw/Gm	M
M–SFw/GM	M	SFw/Gm	M	SFw/Gm	M	SFw/Gm	M	M
SFw/SFd–M	SFw/SFd	M	SFw/SFd	M	SFw/SFd	M	SFw/SFd	M
M–SFw/SFd	M	SFw/SFd	M	SFw/SFd	M	SFw/SFd	M	M

For the wet season cultivation (October sowing) conventional tillage system with plowing and disking with preceding culture residues incorporation was adopted. In the dry season crop, a disk harrowing with only half mineral supplement of those of wet season crop was used.

For sunflower, maize and green manure was used a 100 cm spacing between rows while for soybean 60 cm spacing was adopted (Campinas, 1972).

The NPK rate 20-18-50 was used for sunflower before sowing, and 40 kg ha^{-1} of N 40 days after emergence. Dry season sunflower received only half NPK rate. Soybean received 0-27-24; for maize it was 10-27-12 at sowing and 40 kg ha^{-1} of N 35 days after emergence. No fertilization was used for green manure crop. The soil chemical analysis at the onset of the experiment, for the 0-20 cm depth, was characterized by pH 5.2; organic matter content of ca. 21 g kg^{-1}; K content of 0.16 cmol dm^{-3}; P content of 10.7 mg kg^{-1}; Ca content of 1.5 cmol kg^{-1}; Mg content of 0.6 cmol kg^{-1}; Al content of 0.3 cmol kg^{-1}.

In the second and fifth year of crop rotation, the soil of each plot was sampled for chemical evaluation at 0-20 cm, 20-30 cm and 30-40 cm depths. The soil chemical analyses were made according to the methods proposed by Raij and Quaggio (1983). Due to the data in the second year, lime was applied in order to reach 70% of base saturation in all plots.

After each crop, grain yield and total dry matter production were recorded at harvest on a 30 m^2 sampling area in each plot. For wet season sunflower plant height and head diameter were also recorded, and for dry season sunflower, only plant height was recorded. For green manure total dry matter was evaluated.

Soil and agricultural parameters were analyzed as a randomized design using analysis of variance and F-test procedure. Comparisons among class means were made by Least Significant Difference according to Duncan's test (Snedecor and Cochran, 1976), when F-test was significant at 0.05 level. In order to be able to compare the data from one year to another, all treatments were installed each year, as shown in Table 1. Is not possible to compare yields from different crops at the same year not even from the same crop in different years. This is true for any other data in this research. During the discussion of the data, the comparisons between years were done only taking in account absolute values. For the statistical analysis, the results of the measured variables in the rotation treatments were averaged over the two replications.

RESULTS AND DISCUSSION

1. CROP ROTATION AND SOIL PROPERTIES

1.1. Effects on soil organic matter, phosphorus-resin and exchangeable potassium

Results of soil nutrient concentration of organic matter (OM), phosphorus-resin (P) and exchangeable potassium (K) in two (1982/83) and five (1985/86) years in the rotation are presented in Table 2.

The lowest OM concentration found in treatment M-S/SFd at 0-20 cm depth (Table 2) cannot be considered as a result of treatment because the rotational experiment was in the first year of installation. In the fifth year those differences disappeared. The OM rate did not increase as a consequence of crop rotation, as related by Mannan (1962). Not even the continuous treatments showed a markedly decrease in OM concentration.

The average P at the depth 0-20 cm increased from 10.7 mg kg^{-1} at the onset of the experiment (Table 2), to 18.7 mg kg^{-1} five years later. This must have resulted in part from the annual P dressing which was applied in all the treatments. It also supported the report on sunflower research (Koide, 1985; Thompson, 1987) which showed that P nutrition is complex in plants that are able to form symbiotic relationship with vesicular-arbuscular mycorrhizae (VAM) which enhances P acquisition from the soil. Its poor mobility accounted for the high concentration at the depth 0-20 cm. The soil analysis did after the first year of the experiment showed

Table 2: Effects of crop rotation on soil OM, P and K

	Treatment	OM, g/kg			P, mg/kg			K, cmol/dm^3		
	1982/1983									
	Treatment	0-20 cm	20-30 cm	30-40 cm	0-20 cm	20-30 cm	30-40 cm	0-20 cm	20-30 cm	30-40 cm
1	Cont. SFw/SFd	20.2 a	19.0 a	13.5	15.0	9.1	5.7	0.24 ab	0.22 a	0.15
2	Cont. S/SFd	19.7 a	17.2 ab	12.3	13.0	9.7	4.5	0.18 bc	0.17abc	0.16
3	Cont. M	21.0 a	18.2 ab	12.8	10.7	9,0	5.2	0.16 c	0.13 c	0.12
4	M - S/SFd	17.5 b	16.2 b	12.5	12.1	10.6	5,0	0.17 c	0.15 c	0.12
5	M - SFw/GM	19.4 a	16.6 ab	13.4	13.7	10.1	4.9	0.18 bc	0.16 bc	0.14
6	M - SFw/SFd	21.2 a	18.2 ab	13.5	14.1	11.0	4.6	0.27 a	0.21 ab	0.15
	CV (%)	6.2	9.0	14.8	21.8	32.6	21.3	19.0	19.3	20.1
	Mean	19.8	17.6	13.0	13.1	9.9	5.0	0.2	0.17	0.14
	1985/1986									
	Treatment	0-20 cm	20-30 cm	30-40 cm	0-20 cm	20-30 cm	30-40 cm	0-20 cm	20-30 cm	30-40 cm
1	Cont. SFw/SFd	18.8	17.0	10.3	22.2 a	14.7 a	4.2	0.16 c	0.14 bc	0.95 b
2	Cont. S/SFd	18.8	16.8	11.3	25.5 a	16.2 a	6.5	0.24 a	0.22 a	0.16 a
3	Cont. M	19.5	16.0	9.3	12.5 b	7.7 d	4.0	0.17 b	0.16 bc	0.12 b
4	M - S/SFd	18.0	16.8	9.9	21.6 a	12.0 b	4.4	0.21 b	0.17 b	0.10 b
5	M - SFw/GM	18.4	15.8	8.9	16.1 d	9.9 c	4.2	0.14 c	0.12 c	0.10 b
6	M - SFw/SFd	19.6	16.9	10.0	14.2 b	8.6 cd	4.0	0.1c b	0.12 c	0.09 b
	CV (%)	5.8	6.7	14.9	19.4	10.7	33.0	12.9	16.2	20.8
	Mean	18.8	16.5	9.9	18.7	11.54	4.56	0.18	0.16	0.11

no statistical difference between treatments (Table 2). Five years later in the rotation (Table 2), the soil P accumulation of 25.5 mg dm^{-3} at the depth 0-20 cm, 16.2 mg dm^{-3} at the depth 20-30 cm in treatment cont. S/SFd was statistically superior to the other treatments and similar to the cont. SFw/SFd in all depths and to treatment M-S/SFd at the depth 0-20 cm. The least P accumulation in all depths was in treatment cont. M. These results showed that sunflower improves P availability in the upper layers, despite receiving less P fertilizer rates than the other crops and about 75% of the P in the aerial parts of the plants are exported by the seeds.

Changes in soil K after two and five years in the rotation were similar to those of P (increased) at 0-20 cm and 20-30 cm depths for treatment cont. S/SFd. The K content diminished in treatments cont. SFw/SFd, M-SFw/GM and M-SFw/SFd in the three depths which pointed out the high K requirement of sunflower, as it received more K fertilizing rates than the other crops. Sunflower needs three times more K than maize, and two times more than soybean (Khera, 1990). Nevertheless, almost 85% of K returns to soil after seed harvest (Kovačević, 1985). At all depths treatment cont. S/SFd exceeded the rest (Table 2) while treatment cont. M maintained K reserve. The highest K concentrations of 0.24, 0.21 and 0.16 at the depths 0-20 cm, 20-30 cm and 30-40 cm, respectively, were obtained in treatment cont. S/SFd. These were closely followed by the average of treatments M-S/SFd at the depths 0-20 cm and 20-30 cm. The average K reserve in the top soil (depth 0-20 cm) declined from 0.20 cmol dm^{-3} in 1982/83 to 0.18 cmol dm^{-3} in 1985/86 (Tables 3 and 4). The rest of the treatments had K values significantly lower than those above. In the second year of the rotational treatments the plots with cont. SFw/SFd and M-SFw/SFd showed a higher level of K rate.

1.2. Effects of rotation on soil pH, H+Al and cation exchangeable capacity

The results of the changes in soil pH, H+Al and cation exchangeable capacity (CEC) due to different rotational managements are presented in Tables 5 and 6. In the second year of the rotation (Table 3), treatment cont. M maintained the highest pH at the three depths considered, as discussed earlier by Adams *et al.* (1970). This was significantly higher than the pH in treatments cont. SFw/SFd and cont. S/SFd, at all depths. The effect was maintained up to the fifth year of the rotation with significantly higher values over all treatments and depths. As can be seen in Tables 5 and 6, sunflower causes soil acidification, because in all treatments involving sunflower there was an increase in the H+Al content.

The H+Al concentrations of 2.72 cmol kg^{-1}, 2.55 cmol kg^{-1} and 2.71 cmol kg^{-1} at the depth 0-20 cm, 20-30 and 30-40 cm, respectively, under treatment cont. SFw/SFd (Table 3) were significantly higher than the values under treatment cont. M at the corresponding depths. Table 3 also showed that compared with the rest of the treatments, cont. M maintained the lowest concentration of H+Al in the fifth year of the rotation, for all depths.

Table 3: Effects of rotation on soil pH, H + Al and CEC

	Treatment	pH			H + Al (cmol/kg)			K (cmol/kg)		
		0-20 cm	20-30 cm	30-40 cm	0-20 cm	20-30 cm	30-40 cm	0-20 cm	20-30 cm	30-40 cm
	1982/1983									
1	Cont. SFw/SFd	5.03 c	5.08 b	4.90 b	2.73 a	2.55 a	2.71 a	5.98 ab	5.53	5.33
2	Cont. S/SFd	5.20 bc	5.15 c	5.10 b	2.48 ab	2.50 ab	2.50 a	6.60 a	5.63	5.65
3	Cont. M	5.48 a	5.45 a	5.50 a	2.15 b	2.15 b	2.20 a	5.70 ab	6.28	5.6
4	M - S/SFd	5.25 abc	5.29 ab	5.01 b	2.36 b	2.29 ab	2.71 a	5.75 b	6.00	5.41
5	M - SFw/GM	5.24 abc	5.25 ab	5.02 b	2.34 b	2.31 ab	2.60 a	5.76 b	5.65	5.01
6	M - SFw/SFd	5.33 ab	5.33 ab	5.00 b	2.24 b	2.30 ab	2.69 a	5.76 b	5.76	5.1
	CV (%)	3.0	3.0	3.5	8.9	9.4	21.0	8.0	13.6	17.2
	M	5.25	5.26	5.09	2.38	2.35	2.51	5.92	5.35	5.42
	1985/1986									
1	Cont. SFw/SFd	4.73 b	4.68 b	4.73 ab	3.03 a	3.10 a	2.88 b	5.83 a	5.93 a	5.15 ab
2	Cont. S/SFd	4.75 b	4.75 b	4.85 ab	2.98 a	3.05 a	2.72 ab	5.60 a	5.68 a	5.13 ab
3	Cont. M	5.05 a	5.10 a	5.05 a	2.50 b	2.48 b	2.38 b	5.63 a	5.63 a	4.68 b
4	M - S/SFd	4.79 b	4.76 b	4.63 b	2.91 a	2.94 a	2.98 a	5.63 a	5.49 a	5.05 ab
5	M - SFw/GM	4.66 b	4.74 b	4.66 b	2.81 a	2.95 a	2.86 a	5.74 a	5.56 a	4.94 ab
6	M - SFw/SFd	4.90 ab	4.74 b	4.61 b	2.80 a	2.98 a	3.03 a	5.80 a	5.93 a	5.19 a
	CV (%)	2.4	2.7	4.3	6	7.5	10	4.6	4.8	6.1
	M	4.85	4.79	4.75	2.84	2.91	2.81	5.7	5.66	5.02

Table 4: Effects of rotation on soil Ca, Mg and BS

		1982/1983								
		Ca (cmol/kg)			Mg (cmol/kg)			BS (%)		
	Treatment	0-20 cm	20-30 cm	30-40 cm	0-20 cm	20-30 cm	30-40 cm	0-20 cm	20-30 cm	30-40 cm
1	Cont. SFw/SFd	1.90 b	1.65 a	1.63 b	1.13 a	1.10 a	1.23 a	54.00 b	54.00 b	49.00 b
2	Cont. S/SFd	2.53 a	1.88 a	1.93 ab	1.43 a	1.08 a	1.05 a	62.25 a	55.50 ab	55.50 ab
3	Cont. M	2.20 ab	2.65 a	2.15 a	1.20 a	1.33 a	1.13 a	62.00 a	64.25 a	60.50 a
4	M - S/SFd	2.04 ab	2.34 a	1.63 b	1.19 a	1.24 a	0.95 a	58.38 a	60.00 ab	49.63 b
5	M - SFw/GM	2.05 ab	1.96 a	1.66 ab	1.20 a	1.21 a	0.95 a	59.38 a	58.88 ab	51.38 b
6	M - SFw/SFd	2.01 ab	1.95 a	1.61 b	1.25 a	1.30 a	0.99 a	61.13 a	59.75 ab	50.50 b
	CV (%)	16.1	29.8	17.8	14.5	19.5	22.4	6.9	9.7	9.8
	Mean	2.12	2.07	1.77	1.23	1.21	1.05	59.52	58.73	52.75
		1985/1986								
	Treatment	0-20 cm	20-30 cm	30-40 cm	0-20 cm	20-30 cm	30-40 cm	0-20 cm	20-30 cm	30-40 cm
1	Cont. SFw/SFd	1.65 b	1.65 ab	1.30 b	0.98 ab	1.03 ab	0.88 a	48.0 cd	47.3 b	44.3 ab
2	Cont. S/SFd	1.65 b	1.60 ab	1.45 ab	0.75 c	0.80 c	0.78 a	46.5 d	46.0 b	46.8 ab
3	Cont. M	1.90 a	1.90 a	1.55 a	1.05 a	1.08 a	0.63 a	55.8 a	56.2 a	49.0 a
4	M - S/SFd	1.64 b	1.51 b	1.23 b	0.88 bc	0.86 bc	0.73 a	48.1 cd	46.6 b	41.2 b
5	M - SFw/GM	1.79 ab	1.60 ab	1.25 b	0.99 ab	0.90 abc	0.73 a	50.75 bc	47.0 b	42.1 b
6	M - SFw/SFd	1.83 ab	1.61 ab	1.29 b	1.05 a	0.98 abc	0.78 a	51.63 b	47.7 b	42.0 b
	CV (%)	8.6	11.2	11	9.3	13.4	20.6	4.1	7.5	9.3
	Mean	1.74	1.65	1.34	0.95	0.94	0.75	50.13	48.48	44.23

The CEC was highest (6.60 cmol dm^{-3}) under treatment cont. S/SFd at depth 0-20 cm (Table 3), with the exception of treatment cont. SFw/SFd. At the depths 20-30 cm and 30-40 cm, no significant changes in CEC occurred among the different rotational treatments. In the fifth year of the rotation, changes in CEC among the different treatments were not significant, except for the 30-40 cm depth.

1.3. Effects of rotation on Ca, Mg and base saturation

Table 4 shows that Ca level increased in the second year of the rotation due to liming. In the second year there was a significative difference between cont. SFw/SFd and cont. S/SFd. Absolute values were however higher under cont. M at the 20-30 cm depth and became significantly higher than rotational treatments at the depth 30-40 cm, wich was maintained up to the fifth year of the rotation.

Changes in Mg level were not significant at the three depths considered in the second year of the rotation (Table 4). In the fifth year of the rotation, Mg level under cont. M significantly exceeded those of M–S/SFd and cont. S/SFd at the depths 0-20 cm and 20-30 cm, but these differences disappeared at the depth 30-40 cm.

In the second year of the rotation the treatment cont. SFw/SFd showed the lowest base saturation (BS) in all depths (Table 4). In 1985/86, BS was highest in treatment cont. M in all depths. Significant differences however occurred at the depths 0-20 cm and 20-30 cm between cont. M and the other treatments. At the depth 30-40 cm, although cont. M showed the highest value, it was not statistically different from cont. SFw/SFd and cont. S/SFd. As a rule, BS decreased in all treatments from the beginning of the experiment to the end of it.

Table 5: Plant height of wet and dry season sunflower, head diameter of wet season sunflower, dry matter yield of dry and wet season sunflower and soybean

Agronomic parameter	Cont. SFw/SFd	M-SFw/GM	M-SFw/SFd	Cont. S/SFd	M-S/SFd
Plant height of wet season sunflower, cm	245 a	242 a	233 b	-	-
Plant height of dry season sunflower, cm	165 bc	-	162 c	169 ab	174 a
Head diameter of wet season sunflower, cm	17.1 a	17.5 a	16.7 a	-	-
Dry matter yield of wet season sunflower, kg ha^{-1}	13,422 b	15,135 a	13,457 b	-	-
Dry matter yield of dry season sunflower, kg ha^{-1}	10,323 bc	-	9,915 c	12,395 a	11,494 ab
Dry matter yield of soybean, kg ha^{-1}	-	-	-	3,678 a	3,872 a

Means followed by the same letter in the line are not significant by Duncan's test at 0.05 level.

2. CROP ROTATION AND AGRONOMIC PARAMETERS

2.1. Seasonal variations in final height and head diameter of wet and dry season sunflower

Both final height of wet and dry season sunflower presented, as expected, seasonal fluctuations under different rotational managements. Table 5 shows that average final height in M–SFw/SFd was however significantly inferior to cont. SFw/SFd and M–SFw/GM both in wet and dry season. The dry season sunflower treatments which included soybean showed higher final height, probably as a consequence of an addition as biological N fixation. As expected, dry season sunflower showed smaller height than wet season sunflower.

Significant seasonal fluctuations in the head diameter of the wet season sunflower was also recorded in the rotational treatments. Differences in average head diameter among the four treatments were not significant.

2.2. Seasonal variations in dry matter yields of sunflower and soybeans

Like plant height and head diameter significant seasonal variations in dry matter yield of wet and dry season sunflower were observed.

In the wet season sunflower the M–SFw/GM rotational treatment with an average dry matter yield of 15,135 kg ha^{-1}performed significantly better than the rest of the treatments (Table 5), as also observed for other crops like maize and peanuts (Dechen *et al.*, 1990).

For dry season sunflower the average dry matter yield among the various treatments was highest (12,394 kg ha^{-1}) in cont. S/SFd and was significantly greater ($p<0.05$) than yields in cont. SFw/SFd and M-SFw/SFd. Dry matter yields of dry season sunflower followed the same pattern of plant height: those that included soybeans showed higher yields.

Soybeans dry matter yield (Table 5) showed no differences in the average for the two treatments.

3. CROP ROTATION AND GRAIN YIELDS OF SUNFLOWER, SOYBEANS AND MAIZE

3.1. Changes in grain yield of wet season sunflower

Figure 3 shows that seasonal fluctuation in wet season sunflower grain yield was common among all treatments. According to the obtained results only in the third rotational cycle, differences appeared between continuous sunflower and rotation involving green manure and maize (M-SFw/GM).

Average yield over the six years under the three treatments ranged from 1,048 kg ha^{-1} in cont. SFw/SFd to 1,258 kg ha^{-1} in M-SFw/GM. This showed highly significant yield increase ($p<0.01$) in M-SFw/GM over cont. SFw/SFd. The poor performance under cont. SFw/SFd relative to other rotational managements highlighted the dangers of continuous cropping which has been associated with high pest and disease incidence as well as reduced yield.

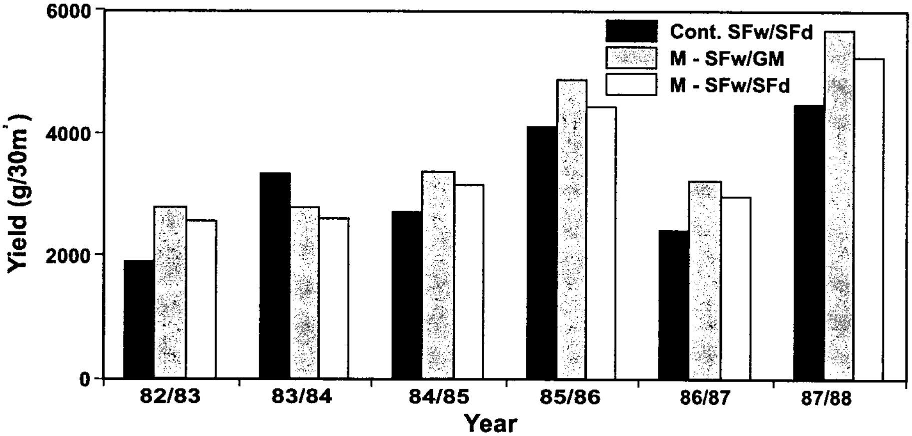

Figure 3: Grain yield of wet season sunflower in different treatments.

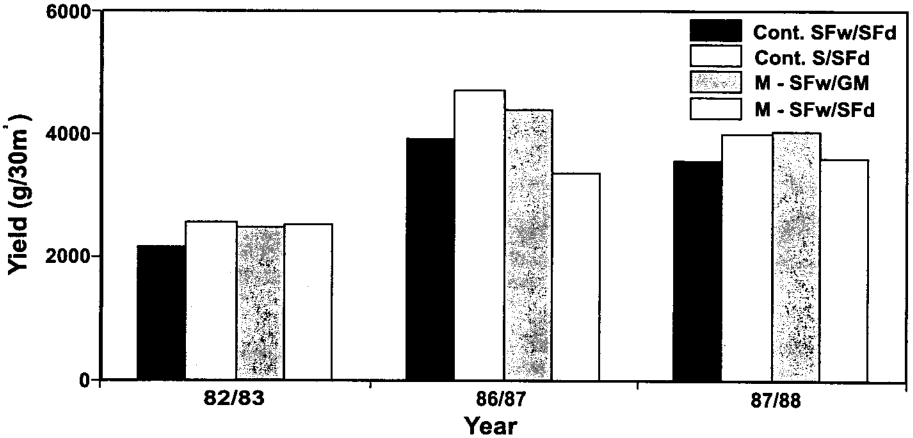

Figure 4: Grain yield of dry season sunflower in different treatments.

3.2. Changes in grain yield of dry season sunflower

Seasonal changes in dry season sunflower under different rotational managements were recorded for three years (Figure 4). In some years excess of drought was responsible for sunflower failure like 1985 (Figure 2). Maximum yields were obtained in 1986/87 in all the treatments except M-SFw/SFd which gave maximum yield in 1987/88.

Average yield differences among the treatments were also significant in the order cont. S/SFd ≥ M-S/SFd ≥ cont. SFw/SFd = M-SFw/SFd. The improved yield under rotation in combination with soybean should be noted. Even though the S/SFd was continuous, the alternate cropping of soybean and sunflower in the dry and wet seasons respectively probably interrupted the pest/disease host persistence in continuous mono-crops. Nitrogen fixation under soybeans which is known to vary from 57 to 94 kg ha^{-1} yr^{-1} (Evans and Barber, 1977) must have made significant contributions to the grain production under the two rotational managements.

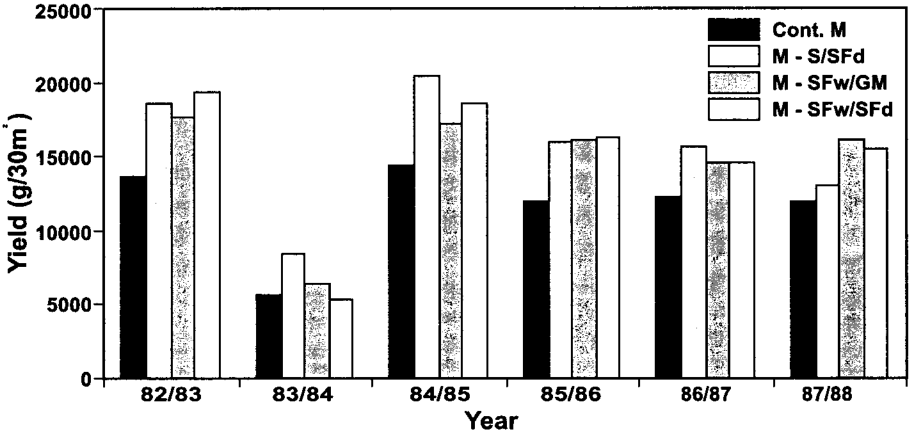

Figure 5: Maize grain yield in different treatments.

3.3. Changes in maize grain yield

Results in Figure 5 show that maximum yields were obtained in all treatments in 1982/83 and 1984/85 growing seasons. Significant yield reductions were recorded in all treatments in 1983/84 season. Yields were generally lower in the later years of the rotation in all treatments.

A comparison of the average grain yields among various treatments showed that yield under cont. M (3,875 kg ha^{-1}) was significantly inferior ($p<0.05$) to those obtained under the other rotational treatments. The results are in agreement with similar studies on crop rotation in which maize yields were increased by 16 to 17 percent when grown after soybeans compared with continuous maize (Robinson, 1966; Higgs *et al.*, 1976; Randall, 1981 and Hesterman *et al.*, 1986). Dechen *et al.* (1990) found differences of 30% like in the present research.

Grain yield in the three rotational treatments was in the order M–S/SFd > M–SFw/SFd > M–SFw/GM but these differences were not significant.

3.4. Changes in soybean grain yield

In the case of soybean grain yield (Figure 6) the succession with sunflower, sometimes adopted by soybean growers, was sufficient to maintain the productivity levels in comparison with rotational treatments.

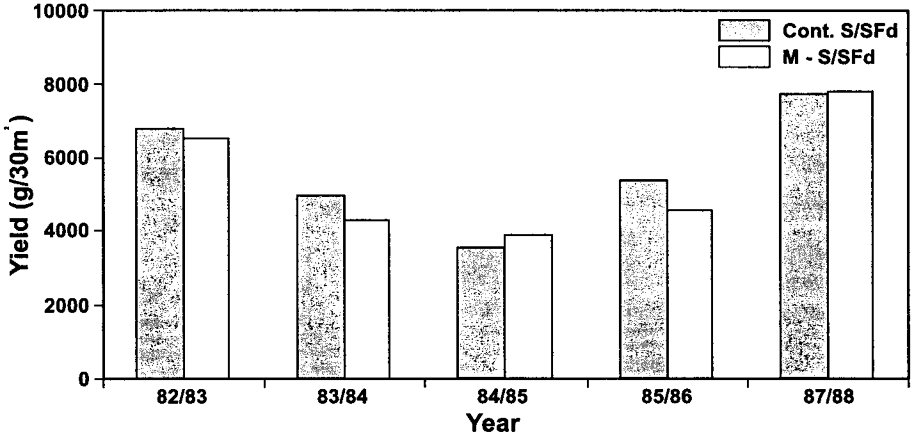

Figure 6: Soybean grain yield in different treatments.

Although no significant difference occurred in yields under the two rotational treatments, the grain yield in terms of absolute values was higher in cont. S/SFd. This was consistent with the results for dry season sunflower under the same rotational management. The intervention of maize in the rotation during which no N fixation occurred left the M-S/SFd at a disadvantage relative to cont. S/SFd.

CONCLUSIONS

- Sunflower improves phosphorus availability in the upper soil layers.
- Continuous S/SFd accumulates more K at all soil depths.
- Sunflower increases soil acidification.
- There is a positive influence of the leguminous crop over sunflower grain and dry matter yield.
- For the São Paulo State conditions, maize grain yield in rotational treatments performs 30% higher than continuous maize.
- Soybean grain and dry matter yield in the succession soybean/sunflower, even in continuous cropping, maintain the same productivity levels as in rotational treatments.
- Rotational treatments have no influence on sunflower head diameter.

ACKNOWLEDGEMENTS

We are thankful to Dr. Teresa Cuélar and Carlos Colombo for the Spanish and French summaries translations, and to Dr. Marcelo B. P. Camargo for the climatic data.

REFERENCES

Adams, W.E., Morris, H.D. and Dawson, R.N., 1970. Effects of cropping systems and nitrogen levels on corn (*Zea mays*) yields in the southern Piedmont Region. Agronomy Journal, 62: 655-659.

Campinas, 1972. Secretaria da Agricultura do Estado de São Paulo. Coordenadoria da Pesquisa Agropecuária. Instituto Agronômico. Instruções agrícolas para o Estado de São Paulo. Campinas, Instituto Agronômico, p. 310, (Boletim 200).

Dechen, S.C.F., Vieira, S.R., Lombardi Neto, F., Castro, O.M., Quaggio, J.A. and De Maria, I.C. Physical characterization of a Dark-Red Latosol under crop rotation with peanut and maize. In: Unger, P.W., Sneed, T.V., Jordan, W.R. and Jensen, R., eds. Challenges in dryland agriculture: a global perspective. Amarillo, 1990. International Conference on Dryland Farming, August 15-19, 1988, Amarillo/Bushland, Texa, USA, Proceedings, pp. 581-583.

Evans, H.J. and Barber, L.E., 1977. Biological nitrogen fixation for food and fibre production. Science, 197: 322-339.

Francis, C.A. and Clegg, M.D., 1990. Crop rotations in sustainable production systems. In: Edwards, C.A., Lal, R., Madden, P., Miller, R.H. and House, G., eds. Sustainable Agricultural Systems. SCWS, Ankeny, Iowa, USA, pp. 107-120.

Heichel, G.H., 1987. Legumes as a source of nitrogen in conservation tillage systems. In: Power, J.F., ed. The Role of Legumes in Conservation Tillage Systems. SCSA, Ankeny, Iowa, USA, pp. 29-34.

Hesterman, O.B., Shaeffer, C.C., Barnes, D.K., Leuschen, W.E. and Ford, J.H., 1986. *Alfalfa* dry matter and N production and fertilizer response in legume-corn rotations. Agronomy Journal, 78: 19-23.

Higgs, R.L., Paulson, W.H., Pendleton, J.W., Peterson, A.E., Jackobs, J.A. and Shrader, W.D., 1976. Crop rotations and nitrogen: crop sequence comparisons on soils of the driftless area of south-western Wisconsin, 1967-1974. Madison, Research Division of College of Agriculture and Life Science, University of Wisconsin, (Madison Research Bulletin R2761).

Khera, M.S., 1990. Strategy for use of potassium in Indian agriculture. Soil Fertility and Fertilizer Use, 4: 69-93.

Koide, R., 1985. The nature of growth depressions in sunflower caused by vesicular-arbuscular mycorrhizal infection. New Phytopatology, 99: 449-462.

Köppen, W., 1936. Das geographische system der climate. Verl. Gebr. Borntraeger, Berlin.

Kovačević, M., 1985. La dinamique d'absortion et des redistribution des macro and oligo elements de l'hybride NS-H-27 RM. In: International Sunflower Conference, 11, Mar del Plata, 1995, Proceedings. Vol. 1, p. 276.

Mannan, M.A., 1962. Organic matter, nitrogen and carbon: nitrogen ratio of soils as affected by crops and cropping systems. Soil Science, 93: 83-86.

Pedro Júnior, M.J., Mello, M.H.A., Pezzopane, J.R.M. and Moraes, A.V.C., 1997. Caracterização agroclimática: Estação Experimental de Mococa (Microbacia). Campinas, Instituto Agronômico, p. 22 (Boletim técnico, 159).

Power, J.F., 1989. Legumes and crop rotations. In: Francis, C.A., Flora, C. and King, L., eds. Sustainable agriculture in temperate zones. New York, John Wiley and Sons, p. 284.

Raij, B. van and Quaggio, J.A., 1983. Métodos de análise de solo para fins de fertilidade. Campinas, Instituto Agronômico, p. 31 (Boletim técnico, 81).

Randall, G.W., 1981. Rotation nitrogen study. Waseu, 1980, St. Paul, Department of Soil Science, University of Minnesota, pp. 115-116. (Soil Series 109, Agricultural Experiment Station, Miscellaneous Publication, 2).

Robinson, R.G., 1966. Sunflower-soybean and grain sorghum-soybean rotations versus monoculture. Agronomy Journal, 58: 475-477.

Roder, W., Mason, S.C., Clegg, M.D. and Kneip, K.R., 1988. Plant and microbial responses to sorghum-soybean cropping systems and fertility management. Soil Science Society of America Journal, 52: 200-208.

Roder, W., Mason, S.C., Clegg, M.D. and Kneip, K.R., 1989. Yield-soil water relationships in sorghum-soybean cropping systems with different fertiliser regimes. Agronomy Journal, 81: 300-308.

Snedecor, G.W. and Cochran, W.G., 1976. Statistical Methods. 6 edition, The Iowa University Press, Ames, Iowa, p. 593.

Thompson, J.P., 1987. Decline of vesicular-arbuscular mycorrhizae in long fallow disorder of field crops and its expression in P deficiency of sunflower. Australian Journal of Agricultural Research, 38: 847-867.

Turner, J.H., Smith, E.G., Garber, R.H., Williams, W.A. and Yamada, H., 1972. Influence of certain rotations on cotton production in the San Joaquin Valley. Agronomy Journal, 64: 543-546.

EFECTOS DE SISTEMAS DE ROTACIÓN EN LAS CONDICIONES QUÍMICAS DEL SUELO Y PRODUCCIÓN DE GIRASOL, SOYA Y MAIZ

RESUMEN

Se hizo una investigación en Mococa, en el Estado de São Paulo, Brasil, de 1981 a 1989, para evaluar el girasol como opción de otoño-invierno, principalmente después del ciclo corto de soja y maíz, además se estudiaron los efectos de sistemas de rotación según las condiciones químicas del suelo, producción de semillas y fitomasa y parámetros agronómicos de girasol, soja y maíz. Los tratamientos fueron los siguientes: (a) Sucesión continua de crecimiento de girasol en las estaciones húmedas y secas (Cont. SFw/SFd); (b) Sucesión continua de soja/girasol durante sequía (Cont. SF/SFw); (c) Crecimiento continuo de maíz (Cont. M); (d) Rotación de maíz seguido por soja/girasol durante sequía (M-S/SFd); (e) Rotación de maíz seguido por girasol durante la estación húmeda/abono verde (M-SFw/GM); (f) Rotación de maíz seguido por girasol durante la estación seca/estación húmeda (M-SFw/SFd). Los resultados mostraron que el girasol mejora la disponibilidad del fósforo en las capas más superficiales del suelo y aumenta la acidez; el tratamiento S/SFd continuo, acumula más K en todas las capas del suelo; existe una influencia positiva del abono verde sobre las producciones de semillas y fitomasa en el girasol; para las condiciones del Estado de São Paulo, la producción de semillas de maíz en los tratamientos de rotación produce 30% más que el maíz continuo; la producción de semillas y fitomasa de soja en sucesión soja/girasol, mismo siendo continua, no respondió diferentemente de los tratamientos en rotación.

EFFETS DES SYSTÈMES DE ROTATION DE CULTURES DANS LES CONDITIONS CHIMIQUES DE SOL ET DANS LE RENDEMENT DU TOURNESOL, DU SOJA ET DU MAIS

RÉSUMÉ

Cette étude a été conduite a Mococa, Etat de São Paulo, Brésil, de 1981 a 1989, pour évaluer le tournesol comme une option pour la saison sèche, surtout après les cultures du mais et du soja de cycle court. L'étude a vérifié aussi les effets des systèmes de rotation de cultures dans les conditions chimiques de sol, dans le rendement de grains et de phytomasse du tournesol, du soja et du mais. Les traitements ont employés les suivantes cultures: a) Tournesol dans les saisons sèches et humides in continuum (Cont. SFw/SFd); b) soja suivi par le tournesol de saison sèche in continuum (Cont. S/SFd); c) Mais seul in continuum (Cont. M); d) Mais suivi par le soja dans le saison humide et le tournesol de saison sèche (M-S/SFd); e) Mais suivi par le tournesol de saison humide et le culture vertes dans la saison sèche (M-SFw/GM); f) Mais suivi par le tournesol de saison humide et le tournesol de saison sèche (M-SFw/SFd). Les résultats montrent que le tournesol augmente la disponibilité de phosphore dans les couches superficielles du sol et augmente l'acidification du sol; des continuum S/SFd accumule du potasse dans toutes les profondeurs du sol; il y a une positive influence des legumineuses (cultures vertes) sur la production de graines et de matières séches; le mais en rotation avec d'autres cultures comparé avec le mais seul a donné une augmentation de rendement d'ordre de 30%, le rendement de graines et de matière verte du soja n'a pas augmenté dans le système soja suivi par le tournesol (S/SFd).