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SUSTAINABLE CROP PRODUCTION ON AEOLIAN SANDY SEMI-ARID SOILS IN SOUTH AFRICA

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ABSTRACT

Large areas of the soils under rainfed crop production in the semi-arid climatic regions of Southern Africa are of aeolian origin with a sandy texture. These soils are prone to wind erosion, soil compaction and drought, which hamper sustainable crop production. Field experiments were conducted over three years in which 3 tillage practices were combined with 3 cropping practices. The tillage practices were: i) conventional mouldboard ploughing, ii) stubble mulch tillage, both in combination with deep ripping and controlled traffic, and iii) no-tillage with chemical weed control. Every tillage practice was combined with three cropping practices *viz.* i) continuous maize, ii) wheat with a 5-month fallow, and (iii) maize and wheat in rotation allowing a 10- month fallow. It was found that continuously grown maize and wheat with conventional tillage gave the highest rainfall use efficiency. Conventionally grown maize and wheat in rotation with a longer fallow gave the highest yields, whereas no-tillage with continuous maize and wheat gave the lowest yields. The yields on stubble mulching were lower than those on conventional tillage.

Key Words: **Maize, tillage practice, soil texture, rainfall use efficiency, wheat yields**

RÉSUMÉ

De larges surfaces de sols sous production de cultures alimentées par précipitations dans les régions climatiques semi-désertiques de l'Afrique Australe sont d'origines éolienne avec une texture sabloneuse. Ces sols sont facilement érodables par le vent,leur compacité et la secheresse handicapent la production viable de cultures. Des expériences en champs ont été entreprisent sur une période de trois ans durant lesquelles 3 séquences de labourages ont été combinés à 3 séquences de cultures. Les séquences de labourages étaient i) le labourage à versoir conventionnel et ii) le labourage à fumier de chaume, tous les deux en combinaison avec sillonage profond et une circulation controlée, et iii) non-labourage avec controle chimique des herbes sauvages. Chaque séquence de labourage était combiné avec une séquence de culture c'est à dire i)du maïs sans interruption et ii) du blé avec une jachère de 5 mois et iii)du maïs et du blé en rotation permettant une jachère de 10 mois. L'on a trouvé que le maïs produit sans interruption et le blé avec un labourage conventionnel fournissaient l'utilisation la plus efficasse des précipitations. Le maïs produit conventionnelement et le blé produit en rotation, avec une jachère plus longue, avaient le plus grand rendement alors que le maïs et le blé produit sans interrution par le non-labourage avaient le plus faible rendement. Les rendements par fumier à chaume étaient plus faibles que ceux obtenus par labourage conventionnel.

Mots Clés: **Maïs, séquences de labourages,texture du sol, efficacité des précipitations, rendements de blé**

INTRODUCTION

Large areas of Southern Africa are covered by aeolian sand deposits with a silt with clay content lower than 10%. The natural vegetation on these soils is savanna grassveld with shrubs. In South Africa alone, about 1.5 million ha. of these soils are cultivated for rainfed crop production. The main crops are maize *(Zea mays* L.), wheat *(Triticum aestivum L.)* and groundnut *(Arachis hypogaea* L.), with conventional mouldboard plowing and seedbed preparation with tine cultivators as the main tillage practice. This practice has led to severe wind erosion and the formation of tillage induced compacted layers just below the plough layer at 0.25 m. The subsoil compaction results in shallow rooting and consequent inefficient utilization of plant available water and nutrients in these deep soils, which have an average rooting depth of 2 m (Bennie, 1991). The low average annual rainfall of 450 to 550 mm and high annual evaporation of 2000 to 2500 mm result in severe crop water stress in most seasons. The introduction of stubble mulching as a conservation tillage practice against wind erosion resulted in epidemic plant disease problems like cob rot *(Diplodia zea)* in maize and root rot *(Gaeumannomyces graminis)* in wheat. Cook (1990) reported cases where root diseases increased resulting from the adoption of stubble mulching tillage practices.

It was argued that the sustainability of crop production on these sandy soils could be improved with the introduction of the following measures to solve or alleviate the effect of the detrimental factors. The protection of the soil surface by a plant residue mulch of preferably standing stubble, effectively reduces the wind speed and erosion. Recent reviews by Linger (1990) and Prasad and Power (1991) discussed the advantages and disadvantages of conservation tillage. There is agreement that a mulch of plant residue on the soil surface reduces soil erosion. Subsoil compaction can be alleviated by deep ripping and controlling implement wheel traffic to fixed parallel lanes (Taylor, 1983; Bennie and Botha, 1986). The damaging effect of mid-season droughts and more severe seasonal droughts on crop yields can be alleviated by allowing a longer fallow period between harvesting of the previous crop and the planting of the next crop. This practice allows storage of more rainfall in the soil, which buffers the crop against drought during the growing season. Several measures for improving the efficiency of rainfall on dryland crop production, including longer fallow periods, were discussed by Venkateswarlu (1987) and Mugah and Steward (1986), Steiner *et al.*, (1988), Steward and Steiner (1990). The risk of crop damage by plant diseases associated with stubble mulching can be reduced by planting, in rotation, crops that are not attacked by the same diseases.

The objective of this study was to test these possibilities of increasing the sustainability of crop production on sandy soils.

MATERIALS AND METHODS

Soils. The parent material of the soil is aeolian deposits. The texture is fine sand with a clay content of 6% in the topsoil, increasing to 16% at a depth of 1 m and 22% at a depth of 1.8 m. A dense clay layer occurs at a depth of 1.8 m which retards water percolation. A shallow perched water table can develop in wet years. The structure is apedal and the colour yellow brown.

The soil is classified as a Clovelly Soil Form Mooilaagte Family (Soil Classification Working Group, 1991) or Plinthic Quartzipsamments (Soil Survey Staff, 1992). The plant available water capacity increases from 80 mm m^{-1} in the topsoil to 120 mm m^{-1} at 1.8 m. The well rounded and poorly graded particle size distribution allows the soil to yield under low pressures and under gravity during wet conditions, forming high strength layers that retard, and in severe conditions, prevent root elongation. The high permeability of the sandy topsoil and flat topography result in little or no runoff during heavy rains.

Treatments. The treatments consisted of 3 tillage practices combined with 3 cropping practices to give a total of 9 treatments that were randomized in blocks and each block was replicated twice. The tillage practices were: i) conventional mouldboard ploughing plus deep ripping as primary tillage operations and a rodweeder on a controlled wheel traffic system for secondary weed control and seedbed preparation, ii) stubble mulch tillage with deep ripping as a primary tillage operation and a rodweeder on a controlled wheel traffic system for secondary weed control and seedbed preparation, and iii) no-tillage with chemical weed control. All of these tillage practices were combined with the following cropping practices: i) continuous maize in an annual monoculture system with a 5-month fallow period, ii) continuous wheat in an annual monoculture system with a 5-month fallow period, and iii) maize and wheat crop rotation with one summer maize and one winter wheat crop every 3 years on the same plot allowing for a 10- to 12-month fallow period. Three plots of this treatment in different phases were needed in the experiment to enable comparison of short with long fallow wheat and maize every season.

Maize (cv. PNR 6479) was planted in 2 m rows at a population of 17,000 plants per hectare in mid-November each year, and harvested in June the next year. Fertilizer N and P were applied at 35 kg N and 15 kg P ha^{-1}. Wheat (cv. Tugela) was planted in 0.5 m rows at a seeding density of 25 kg seed ha^{-1}. Fertilizer was applied at 25 kg N and 12.5 kg P ha^{-1}. The wheat was planted in May and harvested in November the same year.

Measurements. The soil water content was measured with a neutron probe using access tubes installed in each plot to a depth of 3 m. Readings were taken at 0.3 m depth intervals every 2 weeks during the growing season, and every 4 weeks during the fallow period. Rainfall was measured using gauges. Total dry matter was harvested at the end of the season and measured.

The efficiency with which rainfall was converted to crop production, measured as rainfall use efficiency (RUE, kg seed ha^{-1} mm^{-1}), was calculated using the equation:

$$RUE = \frac{Y}{Rf + R_{gs} - AW}, \text{ where}$$

Y = seed yield (kg ha^{-1});
R_f = rainfall from harvesting to planting during the fallow period (mm);
R_{gs} = rainfall from planting till harvesting during the growing season (mm);
AW= change in profile water content (mm) between harvesting of the previous crop and harvesting of the present crop over a depth of 1.2 m, increase (+) and decrease (-).

Low RUE values indicate high evaporation and/or percolation losses during the fallow period

TABLE 1: Mean maize seed yields (kg ha^{-1}) under different tillage practice and fallow length (5, 10 months)

Year	Conventional		Stubble mulch		No-tillage		$LSD_{0.05}$
	5	10	5	10	5	10	
1990-91	1625	2450	792	1661	532	1984	1888
1991-92	1171	1481	805	1134	712	546	628
1992-93	2898	3699	2732	3277	1803	2989	1568
Average	1898	2543	1443	2024	1016	1840	
	2220		1733		1428		

TABLE 2: Mean wheat seed yields (kg ha^{-1}) under different tillage practices and fallow length (5, 10 months)

Year	Conventional		Stubble mulch		No-tillage		$LSD_{0.05}$
	5	10	5	10	5	10	
1990	1047	1685	1226	1534	585	990	734
1991	2451	2458	1873	2184	1828	2362	376
1992	611	1036	592	944	583	649	n.s.
Average	1370	1726	1230	1554	999	1334	
	1548		1392		1166		

or a poor rainfall distribution during the growing season resulting in crop damage by drought.

RESULTS AND DISCUSSION

The results reported in this paper are for the three years 1990 to 1993.

Seed yield. The seed yields for maize and wheat for the different tillage practices and lengths of fallow are presented in Tables 1 and 2. Maize yield varied between seasons due to large differences in total seasonal rainfall and rainfall distribution during the growing season. Total rainfall during the growing season was 499 mm (poorly distributed, late onset), 77 mm (well distributed) and 165 (well distributed) for the 1990-91, 1991-92 and 1992-93 seasons, respectively. The relatively high rainfall during the 1990-91 growing season fell too late to make a significant contribution to the crop yield, and 1991-92 was a very dry season. In all the years significantly better yields were obtained with conventional tillage with a long fallow period compared to no-tillage with continuous maize which gave the lowest yields. The conventional tillage practice outyielded the conservation stubble mulch tillage in all the years by an average of 28% for both the 5- and 10-month fallow periods and no-tillage by about 55%. A crop rotation system with a longer fallow period increased the maize yields by between 34 and 40% for conventional and stubble mulching and up to 80% for notillage.

Wheat production is almost solely dependant on stored water with very little rainfall during the winter growing season. The yield differences and responses to the treatments are similar to those for maize. Conventional tillage gave the highest and no-tillage the lowest yields.

Rainfall use efficiency (RUE). The RUE of summer crops is mainly determined by the rainfall distribution and varied much between seasons as can be seen from Table 3 for maize. The RUE for wheat is presented in Table 4. Conventional tillage practices gave the highest RUE and no-tillage the lowest for both maize and wheat. As expected, the shorter 5-month fallow period with a smaller possibility of evaporation and percolation losses resulted in higher RUE values during the dry

TABLE 3. Mean rain use efficiency (RUE, kg seed ha^{-1} mm^{-1}) for maize tillage practices and fallow length (5, 10 months)

Year	R_{gs}	R_f		Conventional				Stubble mulch				No-tillage			
		5	10	5		10		5		10		5		10	
				AW	RUE	AW	RUE	AW	RUE	AW	RUE	AW	RUE	AW	RUE
1990-91	499	67	81	+10	2.92	+35	2.90	+5	1.41	+33	1.96	+8	0.95	+33	2.34
1991-92	77	116	626	-49	4.84	+24	2.18	-48	3.34	+23	1.67	-9	3.52	+9	0.79
1992-93	165	129	198	+9	10.17	-4	10.08	+16	9.83	-13	8.72	0	6.13	-1	8.21
Average					5.98		5.05		4.86		4.12		3.53		3.78

R_{gs} = rainfall from planting to harvest. R_f = rainfall from harvest to next planting.
AW = difference in profile water content (mm) over 1.2 meter depth at harvest of previous and present crops.

TABLE 4. Mean rain use efficiency (RUE kg seed ha^{-1} mm^{-1}) for wheat tillage practices and fallow length (5, 10 months)

Year	R_g	R_f		Conventional				Stubble mulch				No-tillage			
		5	10	5		10		5		10		5		10	
				AW	RUE	AW	RUE	AW	RUE	AW	RUE	AW	RUE	AW	RUE
1990	56	331	379	-32	2.50	-106	3.11	-27	2.96	-114	2.79	-32	1.40	-65	2.48
1991	149	56	541	+24	13.54	-35	3.39	+38	11.22	-19	3.08	+33	10.63	-39	3.24
1992	129	124	193	+12	2.54	-31	2.93	+14	2.48	-15	2.80	+20	2.50	+9	2.07
Average					6.19		3.14		5.55		2.89		4.01		2.60

R_g = rainfall from planting to harvest. R_f = rainfall from harvest to next planting.
AW = difference in profile water content (mm) over 1.2 meter depth at harvest of previous and present crops.

1991-92 maize and wet 1992 wheat seasons.

These results emphasize the contradiction between conservation practices and economic realities. Conventional tillage practices, especially when combined with a longer fallow period, have the highest risk for wind erosion but it gives the highest yields. No-tillage in a monoculture situation is not economically feasible on these soils, and cannot therefore be recommended to farmers, but is a possibility in a crop rotation system. The reason why stubble mulching gave lower yields than conventional tillage needs further investigation but it was, from visual observations, very effective in preventing wind erosion. Longer fallow periods increased yields although the yield increases were not statistically significant. Little emphasis can be placed on the absence of statistical differences in these experiments because only two replications were used. This benefit must be compared to the fact that only two crops can be grown in three years with this long fallow practice.

CONCLUSIONS

Lower wheat and maize yields are obtained with the conservation tillage practices compared to conventional tillage. There is therefore no yield or financial incentive for farmers to adopt conservation tillage practices.

Seed yields were improved with a crop rotation programme of maize and wheat allowing for longer fallow periods and a small risk for crop diseases. There is therefore a need for more disease resistant varieties of crops to increase the sustainability of crop production with conservation tillage practices.

Stubble mulch tillage combined with deep ripping, controlled wheel traffic and a crop rotation system on deep sandy soils, with a clay content lower than 10% and a high wind erosion and soil compaction susceptibility, is sustainable in terms of soil and water conservation but will be less economical than conventional tillage practices in a monoculture or crop rotation system.

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