SEEDLING DYNAMICS AND SUBSEQUENT PRODUCTION OF ANNUAL <u>MEDICAGO</u> SPP. AS AFFECTED BY PASTURE UTILIZATION, SEEDBED PREPARATION AND SOIL TYPE.

by

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DECLARATION

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

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ABSTRACT

In spite of numerous benefits of incorporating annual legumes in a rotation system, only 20% of a potential 1,7 million hectare in the western and southern Cape region of South Africa is currently under medics (annual *Medicago* spp.). Poor regeneration and persistence of annual medics is one of the major problems deterring farmers from incorporating medics in their crop rotations.

In this study, which consists of several experiments, various aspects were investigated. These included the effect of digestion of medic seeds by sheep on the recovery thereof; the effect of tillage methods used during seedbed preparation for wheat on the wheat yield and subsequent regeneration and production of medics; and the effect of soil type, planting depth and seeding rate on the establishment and dry mass production of different medic cultivars. A field study was conducted over two years to quantify the relationship between sward density of regenerated medic pastures and seasonal dry mass and seed production.

In the first experiment pod and seed characteristics of different sub-species as well as the effect of digestion by sheep on seed recovery were investigated. Although the *M. truncatula* cultivars produced larger pods, *M. polymorpha* and *M. littoralis* cultivars had higher seed to pod ratios's. Smaller seed size and higher hardseededness of cv. Santiago in addition to the high seed percentage of this cultivar had resulted in significant higher seed recovery percentages after ingestion.

In the second experiment the effect of different tillage systems on the placement of medic seed reserves in the soil profile and subsequent regeneration was studied. Tine implements, regardless the depth of cultivation, maintained more medic seed reserves in the topsoil in comparison with disc and mouldboard ploughing. Deeper tine (150 mm) cultivations however, were required to

maintain high wheat yields.

When establishment of different medic species in coarse sand, loamy sand and sandy loam soils and at different planting depths were investigated, significant differences between soil types were found. Lighter textured soils resulted in higher establishment percentages and dry mass production. Regardless of soil type 10 mm was found to be the optimum planting depth. Deeper planting depths resulted in poor establishment and subsequent dry mass production. When seed was left on the soil surface, results for all parameters tested were inferior to all other planting depths.

Due to the poor results obtained with deeper (>30 mm) planting depths, the cumulative strength of seedlings obtained from higher seeding rates on the negative effect of planting depth was studied. Increasing sward populations to more than 2000 to 3000 plants m^{-2} however, resulted in self thinning due to interplant competition, especially in soil types that tend to form surface crusts. In general, plant size was more affected by sward densities compared to planting depth.

Seasonal production of the different *Medicago* species / cultivars was significantly influenced by sward density. Early dry mass production correlated with increased sward density but differences decreased towards the end of the growing season due to higher rates of dry mass production obtained from the lower sward densities. In general, differences in seed production obtained from the different sward densities at the end of the growing season were small. Except for the 78 plants m^{-2} treatment, all the sward densities produced enough seed to ensure successful regeneration after a cereal crop.

Although management of ley farming systems is complex, it became clear that if good management is practised, crop rotations with medics and cereals could be successfully implemented in the western and southern Cape areas of South Africa.

UITTREKSEL

Ten spyte van die verskeie voordele wat die insluiting van eenjarige peulgewasse in wisselboustelsels inhou, is slegs 20% van 'n potensieële 1,7 miljoen hektaar in die Wes- en Suidkaap tans onder medics (eenjarige *Medicago* spp.). Swak hervestiging en produksie van eenjarige medics is een van die hoof oorsake wat boere weerhou om medics in hul wisselboustelsels in te sluit.

Hierdie studie het uit verskeie eksperimente bestaan. Faktore soos die verteerbaarheid van medicsade en die deurvloei daarvan deur die spysverteringskanaal van skape; die effek van bewerkingsmetodes wat gebruik word vir saadbedvoorbereiding op die opbrengs van koring en daaropvolgende hervestiging en produksie van medics; asook die effek van grondtipe, saaidiepte en saaidigtheid op die vestiging en droëmateriaal produksie van verskillende medic kultivars is ondersoek. Om die verwantskap tussen plantestand van hervestigde medicweidings en seisoenale droëmateriaal- en saadproduksie te kwantifiseer, is 'n veldstudie oor twee jaar uitgevoer.

In die eerste eksperiment is die peul- en saadeienskappe van verskillende subspesies asook die effek van verteerbaarheid en die deurvloei daarvan deur skape se spysverteringskanaal ondersoek. Alhoewel *M. truncatula* kultivars groter peule gehad het, het *M. polymorpha* en *M. littoralis* kultivars hoër saad tot peul verhoudings gehad. Die kleiner sade en hoër hardskaligheid van kultivar Santiago, tesame met die hoë saadpersentasie het tot hoër saad herwinnings persentasies na inname en deurvloei deur die spysverteringskanaal gelei.

In die tweede eksperiment is die effek van verskillende bewerkingsmetodes op die plasing van medic saad reserwes in die grondprofiel en daaropvolgende hervestiging bestudeer. Tand implemente, ongeag die diepte van bewerking, het meer medic saad reserwes in die bogrond gelaat as skottel- en skaarploeg bewerkings. Dieper tand bewerkings (150 mm) word egter benodig

om hoë koring opbrengste te verseker.

In die eksperiment waar die vestiging van verskillende medic spesies in growwe sand, leem sand en sanderige leem gronde by verskillende saaidieptes ondersoek is, is betekenisvolle verskille tussen grondtipes gevind. Ligter gronde het hoër vestigingspersentasies en droëmateriaal produksies gelewer. Die optimale saaidiepte in alle grondtipes was 10 mm. Dieper saaidieptes het swak vestiging en laer droëmateriaal produksie veroorsaak. Waar saad op die grondoppervlakte gelaat is, is die swakste resultate verkry.

As gevolg van die swak resultate wat met dieper (>30 mm) saaidieptes verkry is, is die gesamentlike krag van saailinge verkrygbaar deur hoër saaidigthede op die negatiewe effek van plantdiepte bestudeer. Verhoogde plantestande bo 2000 tot 3000 plante m^{-2} het egter tot self uitdunning as gevolg van interplant kompetisie gelei. Hierdie tendens is versterk deur grondtipes wat tot toeslaan geneig is. In die algemeen is plantgrootte meer deur plantestand as saaidiepte beïnvloed.

Seisoenale produksie van die verskillende *Medicago* spesies / kultivars is beduidend deur plantestand beïnvloed. Aanvanklike droëmateriaal produksie was in ooreenstemming met verhoogde plantestand dighthede, maar verskille het gaandeweg gedurende die groeiseisoen verminder as gevolg van die hoër tempo van droëmateriaal produksie wat by die laer plantestande verkry is. Saadproduksie aan die einde van die groeiseisoen het min verskil. Behalwe vir die laagste plantestand (78 plante m^{-2}), het al die plantestande voldoende saad geproduseer om suksesvol te hervestig na 'n kleingraan siklus.

Alhoewel die bestuur van wisselboustelsels wat peulgewasrusoeste insluit baie kompleks is, het hierdie navorsing getoon dat sodanige stelsels wel suksesvol in die Wes- en Suidkaap gebiede van Suid Afrika toegepas kan word.

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"Courage for each challenge, strenght to do what's right,
wisdom in life's choices, love to make life bright,
hope to keep you reaching, faith to see you through,
blessings in abundance... may God give these to you".
Prayer - Anon

CONTENTS

Layout and style used for chapters 2 to 6 in this thesis are in accordance with the requirements of the Field Crops Research journal. This thesis represents a compilation of manuscripts where each chapter is an individual entity and some redundancy between chapters has, therefore, been unavoidable.

CHAPTER 1

INTRODUCTION

Although some annual *Medicago* species (*M. polymorpha*, *M. minima*, *M. laciniata* and *M. arabica*) are well naturalised in southern Africa (Wassermann, 1974), *M. truncatula* and *M. orbicularis* were the first to be experimentally evaluated in South Africa at Elsenburg during 1949 (Sim, 1958). It was only after Australian successes however, that commercial cultivars were re-introduced for production from Australia during 1966 (Wassermann, 1979).

In spite of the numerous benefits of incorporating annual legumes in a rotation system like the improvement of soil fertility, fixation of nitrogen, control of problem weeds, etc., only 20% of the 1.7 million hectare suitable for medic production is currently under medics. A field survey done by Carter et al. (1988) indicated insufficient seed reserves and unfavourable distribution of these seed reserves in the soil profile as important factors responsible for the poor regeneration and persistence of medics in the western and southern Cape. Poor regeneration and persistence of annual medics was also identified as one of the major problems deterring farmers from incorporating medics in a ley farming system.

During summer months the diet of sheep grazing medic pasture could consist of 70% medic pods (Brownlee and Denney, 1985). Thorn et al. (1988) found that 5 sheep ha^{-1} could remove as much as 260 kg seed ha^{-1} during the summer months (late October to early May). Summer utilization of medic pastures by sheep could therefore seriously limit the seed reserves available in medic cereal rotation systems. Utilization of medic pods by sheep and the potential regeneration of medics after summer grazing could also be affected by differences between medic cultivars.

Planting depth, or the distribution of seed in the soil profile during seedbed preparation for cereals in rotational systems, can be critical in ensuring a successful medic pasture (Abd El-Moneim and Cocks, 1986; Carter and Challis, 1987; Cocks, 1992). Although the germination of medic seeds and emergence of seedlings is negatively affected by increasing seeding depths (Carter and Challis, 1987), little is known in regard to the effect of methods of tillage used in South Africa on seed distribution and possible interactions between planting depth and soil type.

Evans et al. (1992) found that early winter production could seriously limit stocking rate due to limited feed sources during that time. In general sward densities of 400 to 500 plants m^{-2} are needed for successful sustainable medic cereal rotation systems under Mediterranean conditions in Australia (Carter and Lake, 1985; Carter, 1987; Jones and Carter, 1989). In weedy situations Puckridge and French (1983) found that 1000 to 2000 plants m^{-2} may be needed to compete effectively against weeds.

In order to decide on optimal sward densities for South African conditions, data on seasonal production obtained from a range of different medic sward densities and the relationship between plants established or regenerated and subsequent dry mass production during the season and seed production at the end of the season is needed.

The aim of the study was therefore to investigate the effect of summer utilization of pods as a factor which could lead to a depletion of seed reserves, the effect of tillage practises on the placement of medic seed reserves in the soil, the effect of planting depth and soil type on the establishment and subsequent production of medics and the seasonal dry mass and seed production obtained from different sward densities to create a better understanding of the dynamics of a sustainable medic cereal rotation system.

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CHAPTER 2

A COMPARISON OF POD AND SEED CHARACTERISTICS, NUTRITIVE VALUE, DIGESTIBILITY AND SEED SURVIVAL IN CULTIVARS FROM DIFFERENT *MEDICAGO* SPECIES FED TO SHEEP.

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Abstract

This study was conducted to compare pod and seed characteristics, nutritive value, digestibility and seed survival of intact medic pods after ingestion by sheep. Different diets comprising the intact pods of six cultivars of the medic species that are most widely sown in South Africa, i.e. cvv.: Paraggio, Parabinga, Sephi and Cyprus (*Medicago truncatula*), Santiago (*M. polymorpha*) and Harbinger AR (*M. littoralis*) were randomly allocated to 30 South African Mutton Merino wethers. Representative feed and faeces samples were collected daily and analysed for dry matter (DM), organic matter (OM) and crude protein (CP). Acid detergent fibre (ADF) and neutral detergent fibre (NDF) were also determined and apparent digestibility coefficients were subsequently calculated for DM, OM and CP. Pod and seed characteristics, i.e. pod and seed mass, seed to pod ratio, number of seeds per pod, hardseededness and seed recovered after ingestion, were determined.

M. truncatula cultivars had the highest pod mass (71 - 91 mg) followed by *M. littoralis* (27 mg) and *M. polymorpha* (23 mg). The better seed:pod ratio of *M. polymorpha* (34%) and *M. littoralis* (30%), in comparison to the *M. truncatula* cultivars (18 - 28%), were associated with significant ($P \leq 0.05$) differences in the number of seeds per 100 g pods. This higher seed content of *M. littoralis* and *M. polymorpha* was also expressed in higher crude protein, digestible protein and digestible organic matter contents in pods. *M. polymorpha* had the highest (95%) and *M. littoralis* the lowest level of hardseededness (86%).

M. polymorpha (23%) was superior to the other cultivars in terms of seed recovered after ingestion by sheep, followed by *M. littoralis* (9%) and *M. truncatula* cultivars (4%). This study showed that *M. polymorpha* (cv Santiago) is best suited for utilization by sheep during the summer months when medic pods are the major component of the their diet.

Keywords: *M. littoralis*, *M. polymorpha*, *M. truncatula*, Seed recovery, Summer grazing.

1. Introduction

The value of legumes, not only as a high quality fodder crop but also for the fixation of nitrogen and the improvement of soil structure, is well known. Although the annual *Medicago* spp originate from the Mediterranean regions, *M. polymorpha*, *M. minima*, *M. laciniata* and *M. arabica* are well naturalised in southern Africa (Wassermann, 1974). According to Sim (1958), *M. truncatula* and *M. orbicularis* were the first annual *Medicago* spp. to be evaluated at Elsenburg during 1949. Commercial cultivars from Australia were re-introduced into South Africa during 1966 (Wassermann, 1979).

In the south-western Winter Rainfall Region, where over 500 000 ha of dryland pastures are grown, medics are one of the major pasture legumes and are used in short term rotations with wheat and barley. In the western Cape or also know as the Swartland region (south of the 32° latitude and west of the 20° longitude) with its pronounced winter rainfall pattern, medics form the primary pasture in rotation with wheat, being planted over an area of approximately 100 000 ha. Another 190 000 ha low to medium and 243 000 ha medium to high potential soils is areas where annual medics may play an important role in future depending on produce prices and input costs.

Due to seasonal changes and variations in the soil types, different mixtures of annual medic cultivars are recommended in practice. This raised the question of what cultivars are best suited not only environmentally but also for utilisation by sheep. Utilisation by sheep also affects the amount of seed available to replenish the seed reserve in the soil, which is of the utmost importance for regeneration after a crop rotation.

This study was conducted to identify differences that could have a possible effect on the utilization of medic pods by sheep and the potential regeneration of medics after summer grazing.

2. Material and methods

2.1 Digestion trial

Thirty South African Mutton Merino wethers with a mean live mass of 53 kg were used as experimental animals. The wethers were randomly allocated to the six different diets representing the intact pods of the six medic cultivars, i.e. *M. truncatula* cvv. Paraggio, Parabinga, Sephi and Cyprus, *M. polymorpha* cv. Santiago and *M. littoralis* cv. Harbinger AR. The wethers were subjected to a 20-day trial period comprising a 12-day adaptation period, and an eight-day collection period during which faeces were collected. During the first four days of the adaptation period, medic pods were fed at 500 g day^{-1} and supplemented with 200 g of lucerne/oat hay (50:50) which was gradually reduced. During the collection period the animals were fed pods at 500 g sheep^{-1}day^{-1} in two equal portions at 08:00 and 13:00 hours and had free access to water at all times.

Representative feed and faeces samples were taken daily and pooled for analysis. Dry matter (DM), organic matter (OM) and crude protein (CP) contents of feed and faeces samples were determined (AOAC, 1985). Acid detergent fibre (ADF) and neutral detergent fibre (NDF) were determined as described by Van Soest (1963) and Van Soest and Wine (1967). Apparent digestibility coefficients were subsequently calculated for DM, OM and CP.

2.2 Seed characteristics and recovery rate

Pods of the six medic cultivars were collected at Langgewens experimental station near Moorreesburg. Three replications of a thousand pods of each medic cultivar were weighed; the seed was extracted by rubbing, then counted and weighed to determine pod and seed characteristics and the number of pods and seeds offered to sheep.

Representative faeces sub samples were collected daily during the collection period, pooled and stored in a cooler at 2^0C. At the end of the collection period samples were dried and 3 replicates of 100 g sub samples from each animal were rubbed to release seeds in the faeces. Seeds were counted and a germination test was done by putting 3 replicates of 100 seeds in petri dishes in a growth cabinet at 20^0C. A similar germination test was done with scarified seed to determine viability. Differences in germination between scarified and unscarified seed were used as an indicator of hardseededness.

Differences between medic cultivars in seed characteristics, digestibility and proportion of seeds recovered were tested for statistical significance by analysis of variance. The effects of seed size, pod size, seeds per 1g pods and degree of seed hardness on seeds recovered (survival) were obtained by regression analysis. The procedures used were described by Snedecor and Cochran (1980).

3. Results

3.1 Pod and seed characteristics

The pod and seed characteristics of six different medic cultivars are presented in Table 1.

Table 1. Pod and seed characteristics of 6 different medic cultivars.

Cultivars	Pod mass (mg)		Seed mass (mg)		seed:pod ratio(%)		Seeds per pod		Seeds per 100 g pods	
M truncatula										
Paraggio	83.5	b*	4.1	a	21.4	c	4.4	bc	5294	b
Parabinga	87.0	ab	3.2	b	18.1	c	5.0	ab	5747	b
Sephi	90.8	a	4.2	a	27.1	b	5.9	a	6437	b
Cyprus	70.9	c	3.9	a	28.5	b	5.3	ab	7454	b
M polymorpha										
Santiago	23.0	d	2.6	bc	34.3	a	3.0	d	13321	a
M littoralis										
Harbinger AR	26.6	d	2.4	c	30.3	ab	3.6	cd	13652	a
Mean	63.6		3.4		26.6		4.5		8651	
LSD ($P \leq 0,05$)	4.6		0.6		5.6		1.3		4592	
($P \leq 0,01$)	6.4		0.9		7.8		1.8		6438	

* Values followed by the same letter do not differ significantly at $P \leq 0,05$.

There were significant differences in pod mass between the *M. truncatula* cultivars with Sephi having the largest pods (Table 1). The *M. polymorpha* cv. Santiago and *M. littoralis* cv. Harbinger AR pods were less than one third of the size of the *M. truncatula* pods. Sephi had the heaviest pods and seeds, as well as the highest number of seeds per pod. However, there was no fixed relationship as Cyprus had a relatively high seed mass and number of seeds per pod, yet a relatively low pod mass. Overall the *M. truncatula* cultivars had the highest seed mass, followed by *M. polymorpha* and *M. littoralis*. Although seed masses reported were lower than masses reported by Oram (1990), the trend was the same.

3.2 Nutritive Value

Nutritive value of the different medic cultivars is presented in Table 2.

Table 2. Nutritive value of pods of different medic cultivars (% of DM)

Cultivars	DM	OM	CP	ADF	NDF	Acid insoluble lignin
M truncatula						
Paraggio	94.7	95.4	14.2	46.5	70.7	10.8
Parabinga	94.6	95.8	14.2	53.4	73.7	12.3
Sephi	94.7	96.2	16.7	45.3	67.9	11.0
Cyprus	95.6	95.9	17.7	45.5	66.2	11.8
M polymorpha						
Santiago	96.1	95.4	23.3	34.6	58.7	8.6
M littoralis						
Harbinger AR	95.4	94.8	19.2	46.4	64.2	13.1
Mean	95.2	95.6	17.6	45.3	66.9	11.3

The CP content of the *M. truncatula* cultivars and *M. littoralis* cv. Harbinger AR varied between 14% and 19%, which was within the range of the normal values (15 - 20%)(Elsenburg Feed Databank, 1992) for the *M. truncatula* cv Jemalong. The CP content of the *M. polymorpha* cv Santiago (23%) was higher, while the ADF (35%) and NDF (59%) contents were lower than the mean value for the *M. truncatula* cultivars (ADF = 47.7 ± 3.3% and NDF = 69.6 ± 2.8%). There was a highly significant relationship between percentage seed and CP content of the pods ($Y = 2.997 + 0.547X$; $r = 0.94$; $P \le 0.01$).

The fibre fractions of Harbinger AR were in the same range as those of the *M. truncatula* cultivars. The CP percentage and fibre fractions of the medic cultivars (except the CP percentage of Santiago) were lower than the values found by Denney et al. (1979) for the *M. truncatula* cultivar Jemalong (23,8 g CP, 85,5 g NDF and 77,5 g ADF per 100 g OM).

3.3 Digestibility

Significant differences in the digestibility of DM, OM and CP were found between cultivars (Table 3). Parabinga had the lowest OM digestibility which differed significantly from that of all the other cultivars except Paraggio, which was also significantly lower than Santiago and Harbinger AR. The DOM and TDN contents of the cultivars were in the same order. Harbinger AR had the highest CP digestibility and differed significantly from all the cultivars except Sephi, while Sephi had a significantly higher CP digestibility than Paraggio and Parabinga. Parabinga also had a significantly lower CP digestibility than Cyprus.

Table 3. Digestibility of pods of six medic cultivars fed to wethers (mean ± SE). Total digestible nutrients calculated from the equation (Engels, 1966): Total digestible nutrients = 0.8 x Digestible organic matter + 15.35

Parameter measured (mean ± SE)	Cultivars						LSD ($P \leq 0.05$)	Level of significance (P)
	Paraggio	Parabinga	Sephi	Cyprus	Santiago	Harbinger AR		
Apparent digestibility of:								
DM, %	35.1 ± 0.6	31.0 ± 1.7	38.3 ± 2.4	37.2 ± 1.0	38.1 ± 3.5	42.3 ± 0.8	5.8	0.04
OM, %	35.6 ± 0.6	32.2 ± 1.5	39.6 ± 2.2	38.2 ± 1.3	41.6 ± 3.2	43.2 ± 0.9	5.5	0.01
CP, %	61.5 ± 0.8	60.0 ± 0.9	68.5 ± 1.5	66.3 ± 1.6	63.4 ± 3.3	72.9 ± 0.9	3.5	0.001
Digestible organic matter, %	34.0 ± 0.6	30.8 ± 1.4	38.0 ± 2.2	36.7 ± 1.2	39.7 ± 3.1	41.0 ± 0.9	5.3	0.01
Total digestible nutrients, %	42.5 ± 0.5	40.0 ± 1.2	45.8 ± 1.7	44.7 ± 1.0	47.1 ± 2.5	48.1 ± 0.7	4.2	0.01
Digestible protein, %	8.7 ± 0.1	8.5 ± 0.1	11.5 ± 0.2	11.7 ± 0.3	14.7 ± 0.8	14.0 ± 0.2	1.1	0.001

3.4 Ingestion, excretion and seed recovery

Table 4. The number of seeds recovered after passing through the intestine of sheep.

Cultivars	Ingested per day	Per 1g dry faeces	Excreted per day	% Recovered	% Germination
M truncatula					
Paraggio	23913 b	3.2 c	924 c	3.9 c	12.3 a
Parabinga	22089 b	3.0 c	835 c	3.5 c	6.6 bc
Sephi	29055 b	4.0 c	1108 c	3.8 c	10.3 ab
Cyprus	29058 b	7.2 c	1680 c	6.1 bc	14.1 a
M polymorpha					
Santiago	53731 a	47.9 a	11824 a	22.6 a	5.3 c
M littoralis					
Harbinger AR	55993 a	22.4 b	4789 b	8.8 b	13.8 a
Mean	35640	14.6	3527	8.1	10.4
LSD ($P \leq 0,05$)	10869	6.5	1794	4.8	4.3
($P \leq 0,01$)	14728	8.8	2431	6.4	5.7

There were no significant differences within species regarding the ingestion, excretion and recovery of seed (Table 4). Animals receiving Santiago and Harbinger AR pods ingested approximately twice as much seed (53 730 and 55 992 seeds respectively) as animals receiving *M. truncatula* pods (26 028 seeds on average). However, animals eating *M. polymorpha* cv. Santiago pods excreted significantly larger amounts of seed than any of the other cultivars involved.

There were no significant differences between the *M. truncatula* cultivars in percentage seed recovered after ingestion by sheep. There were, however, significant differences between *Medicago* species, with Santiago (*M. polymorpha*) being the highest at 22.6%, while the percentage seed recovered from Harbinger AR was also significantly higher than the amounts recovered from the *M.*

truncatula cultivars (Paraggio, Parabinga and Sephi).

Although most of the seed ingested were digested, the passage through the intestine of sheep did not affect the viability of excreted seed as there were no significant differences between cultivars and all six cultivars germinated well (>99%) when the seed were scarified (Data not shown). Germination data (unscarified) of seed excreted by wethers show that, with the exception of Parabinga, there were no significant differences between Harbinger AR (*M. littoralis*) and the *M. truncatula* cultivars (Table 4). Santiago (*M polymorpha*) showed the lowest percentage of germination (5.3%) and therefore the highest level of hardseededness (94.7%).

3.5 Effect of pod and seed characteristics on seed recovered

Table 5. Effect of pod and seed characteristics on the seed survival after ingestion of medic pods by sheep.

Pod and seed characteristics	Regression	r	Prob. level
Hardseededness	$Y = 2.2x10^{-10} X^{5.36}$	0.31	0.55
Seed size	$Y = 78.61 X^{-2.11}$	-0.71	0.11
Pod size	$Y = 427.69 X^{-1.05}$	-0.92	<0.01
Seeds per 1g pods	$Y = 4.1x10^{-3} X^{1.66}$	0.89	<0.01

Although seed survival is the result of more than one characteristic (Table 5) pod size and number of seeds per 1g pods showed the highest correlation (r=-0.92 and r=0.89 respectively) with seed survival.

4. Discussion

Apart from the supply of high quality winter pasture (6-10 t dry matter $ha^{-1}year^{-1}$)(Van Heerden and Wassermann, 1977; Silsbury et al., 1979), the supply of residues and pods, which are well utilized by sheep during the relatively dry summer/autumn months, adds to the popularity of medics (Wassermann, 1980).

Seed mass defines the amount of reserves available to support growth of the plants from germination to appearance above the soil surface. Medics are very sensitive to depth of sowing or placement of seed reserves in a rotation system as percentage emergence of seedlings decrease from about 80% at 1 cm to about 5% at 5 cm depth in loam soil (Carter and Challis, 1987). However, the smaller the seed, the higher the number of seed and attendant recovery of seed after ingestion and digestion by sheep, and thus an increase of seed reserves in the soil (Thomson et al., 1990). Factors such as hardseededness however also affect the recovery of seed after ingestion (Cocks, 1988). The *M. polymorpha* cv. Santiago (23 mg/pod) and the *M. littoralis* cv. Harbinger AR (26 mg/pod) pods were more than three times smaller than the *M. truncatula* pods (83 mg/pod), but had a high number of seeds per pod and therefore a good seed:pod ratio, with Santiago the highest (34%).

The percentage of seed from pods is important as it may affect the seed production of cultivars and the seed reserves available for regeneration, as well as the nutritive value of the residues utilized by sheep (Tonnet and Snudden, 1974). Although Santiago has a low seed mass and number of seeds per pod, it had the highest percentage seed from total pod weight. There was a highly significant relationship between percentage seed and CP content of the pods ($Y=2.997+0.547X$; $r=0.94$; $P\leq0.01$). Within the *M. truncatula* cultivars, Sephi and Cyprus had significantly higher percentage seed than Paraggio and Parabinga. However, it is important to remember that compensation might occur according to the environmental conditions from one year to another. Proportion of seed may well be high, but number of pods per unit area may be lower. Therefore, the ultimate measures are seed weight per unit area and seed number per unit area in the pasture.

Santiago and Harbinger AR had the highest digestible protein content, which is related to the higher CP content of these cultivars, as well as the higher digestibility of Harbinger AR. Parabinga and Paraggio had the lowest digestible protein content due to a lower CP content as well as a lower digestibility.

The lowest digestibility coefficients were recorded with Paraggio, while Harbinger AR on the other hand, was the highest. The OMD of the *M. truncatula* cultivars evaluated in this study was only slightly lower than the value for Jemalong (44%) found by Brand et al. (1991), but higher than the value (24%) found by Denney et al. (1979). The differences between this study and the value found by Denney et al. (1979) might be related to lower fibre fractions found in this study. The CP digestibility of pods was in the same order as the values found by Denney et al. (1979) and Valizadeh et al. (1992).

Data representing the ingestion, excretion and recovery of seed (Table 4) show that there was a direct relation between the number of seed per 100g of pod (Table 1) and the amount of seed ingested per day as well as between the number of seed per 1 g dry faeces and the number of seed excreted per day.

Although animals receiving Santiago ingested twice as much seed as animals receiving *M. truncatula* cultivars and about the same amount of seed as animals receiving Harbinger AR, they excreted more than ten times as much seed as animals receiving *M. truncatula* cultivars and approximately 2.5 times as much as those receiving Harbinger AR. This could be attributed to the significant higher hardseededness (94.7%) of Santiago compared to the rest of the cultivars (88%). The higher number of seeds recovered from Harbinger AR compared to the *M. truncatula* cultivars shows, however, that smaller seed size further promotes passage through the intestine of sheep. However, the percentage seed recovered from the six different cultivars was not significantly affected by seed size ($P = 0.11$; $r = -0.71$) or hardseededness ($P = 0.55$; $r = 0.31$), while the number of seeds per 1 g pods ($P < 0.01$; $r = 0.89$) and pod size ($P < 0.01$;

r = -0.92) significantly affected the percentage of seed recovered after ingestion. These effects, although interesting, must be seen in relation to the fact that the means of only six cultivars were used in the analysis.

According to Carter (1980), there is a linear decline over time in seed throughput per sheep per day and mean seed weight when pods are utilized by sheep during the summer months. The recovery of most pasture legume seed is less than 5% after passage through the intestine of sheep and is frequently less than 3% as in the case of *M. truncatula* (Valizadeh et al., 1992). Even with only 2% passage of barrel medic seed, sheep can still excrete approximately 6 000 seeds sheep^{-1} day^{-1} (Carter and Lake, 1985). However, care must be taken to avoid excessive grazing in summer and autumn to ensure that there is adequate seed to replenish the seed reserves in the soil, which will ensure good regeneration and a dense pasture in the following season as well as persistence through cropping rotation.

It appears that the larger the seed, the lower the proportion of seed surviving ingestion and digestion by sheep and therefore higher the depletion of seed reserves in the soil. According to Squella and Carter (1992) it is more likely that mastication would cause damage to larger than smaller seed and therefore it would also led to less seeds surviving ingestion by sheep.

5. Conclusions

It was clear from the study that for most of the measurements there were no significant differences between *M. truncatula* cultivars, but significant differences between cultivars of different species.

It appeared that hardseededness, small seeds and the amount of seed ingested had an effect on seed recovered after ingestion by sheep. Santiago had the highest recovery rate of 23% compared to 4% on average for the *M. truncatula* cultivars. Therefore, because of the high recovery rate of Santiago, it will be less susceptible to overgrazing during summer months and therefore depletion of seed reserves in the long term.

This paper provides benchmark information that could assist in interpreting observations of differences in persistence and regeneration of medics following grazing by sheep.

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CHAPTER 3

THE INFLUENCE OF SOIL TILLAGE ON THE DISTRIBUTION OF MEDIC SEEDS IN THE SOIL, REGENERATION OF MEDICS AND WHEAT YIELDS IN A MEDIC WHEAT ROTATION.

(Published in Field Crops Research 1998 55:175-181)

Abstract

The ability of tillage systems to maintain sufficient seed reserves (200 kg ha^{-1}) in the topsoil (0-50 mm) without decreasing the yields of the successive wheat crop is one of the major factors determining the success of medics in ley farming systems with wheat (*Triticum aestivum* L.). The effect of six methods of tillage commonly used in medic and cereal farming in the southern Cape, i.e. fieldspan (light spring-tooth cultivator; 50 mm), shallow scarifier (50 mm), deep scarifier (150 mm), shallow disc plough (50 mm), deep disc plough (150-200 mm) and mouldboard plough (250 mm), on the distribution of the medic seed reserves in the soil profile and yields of successive wheat crops were investigated. Results revealed that tine implements, regardless the depth of cultivation, maintained more seed in the topsoil, compared to the shallow disc-, deep- disc and mouldboard ploughing. Seed reserves in the topsoil correlated with the regeneration and growth of the following medic pastures. In 1990 wheat yields did not differ significantly between tillage treatments and an average yield of 1.5 t ha^{-1} was obtained. In 1992 the highest wheat yields were obtained with deep scarifier and to a lesser extend disc and mouldboard ploughing. This study illustrated that although shallow tine cultivations favours the regeneration of medics, deeper tine cultivations (obtained with the deep scarifier treatment) may be needed to ensure high wheat yields.

Keywords: Ley farming, *Medicago* spp., Soil tillage, Wheat yields.

1. Introduction

The beneficial effects of legume crops on soil fertility are well known and cropping systems where cereals are rotated with annual medic pastures are therefore employed in the Mediterranean climatic areas of South Africa. However, only approximately 20% of the large area suitable for medic pastures in the western and southern Cape is currently used for this purpose. The poor regeneration and therefore the poor persistence of annual medics is one of the major problems deterring farmers from incorporating medics in ley farming systems. Insufficient reserves and unfavourable distribution of seeds within the soil profile after being rotated with a wheat crop are regarded as important factors responsible for poor regeneration and persistence of medics (Carter et al., 1988).

Annual medics have small seeds, varying from 4.5 mg for *M. truncatula* cv Paraggio to 2.6 mg for *M. polymorpha* cv Santiago (Oram, 1990; Kotzé et al., 1995). The depth of sowing, or the distribution of seed in the soil profile during seedbed preparation for cereals in rotational systems, are therefore critical in ensuring a successful medic pasture (Abd El-Moneim and Cocks, 1986; Cocks, 1992). Sowing depths of 10 to 15 mm are regarded as optimum. Carter and Challis (1987) found that by increasing the sowing depth from 10 to 50 mm in a heavy loam soil, emergence of medic seedlings was reduced from 80 to 5%. Tine implements and shallow cultivations which ensure more crop residue on or in the surface layers of the soil during tillage (Mannering et al., 1975) may improve medic swards, but may reduce the yield of crops when compared to deep mouldboard and disc tillage (Hargrove and Hardcastle, 1984).

The objective of this study was to evaluate different methods of tillage in terms of their effect on the distribution of medic seed, pasture establishment and yield of wheat in a medic-wheat crop rotation.

2. Material and methods

The experiment was conducted at Tygerhoek Experimental Farm (Lat 34°08'S; Long 19°54'E; 168 m asl) near Riviersonderend in the southern Cape. The rainfall received during the experimental period is presented in Fig. 1.

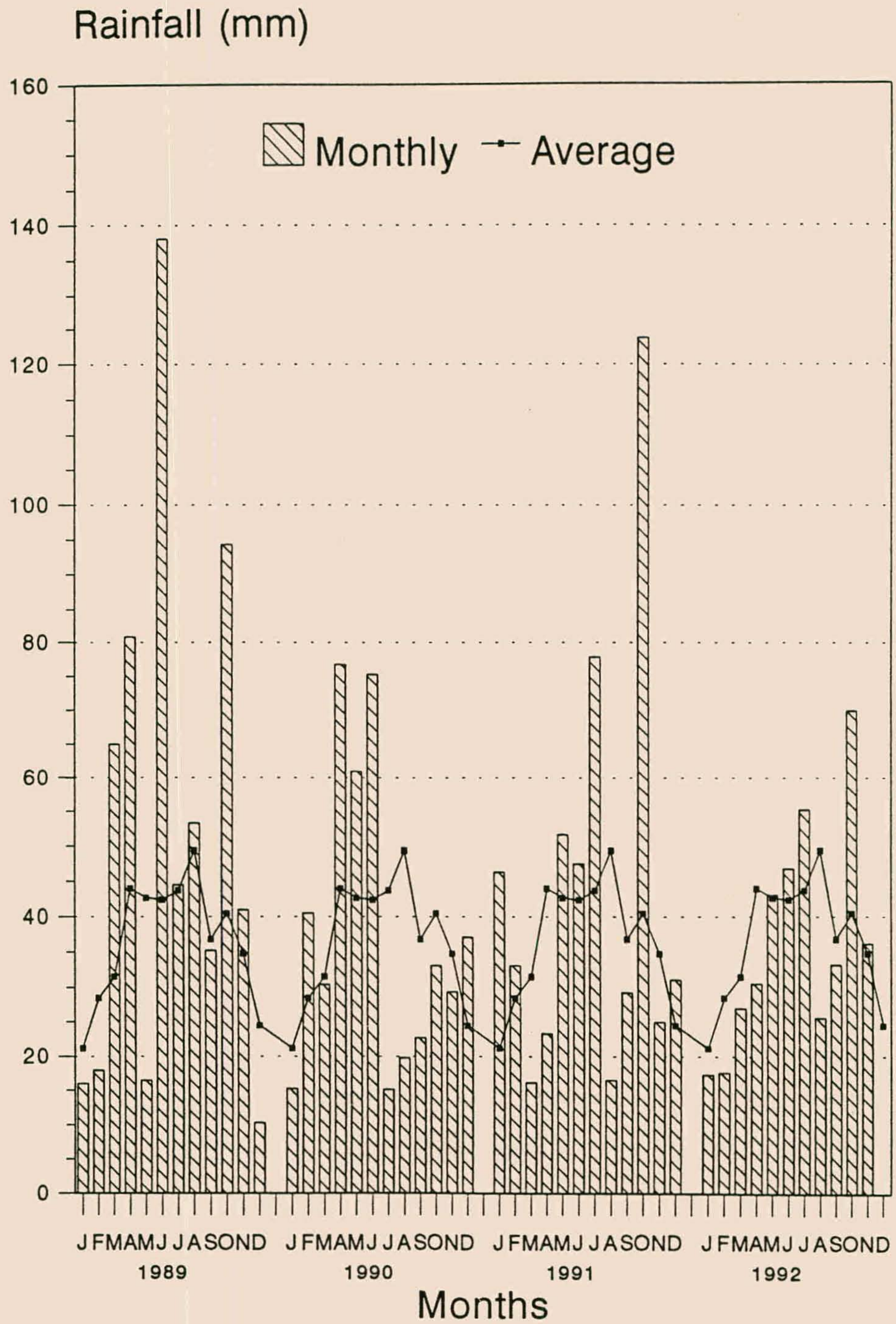

Figure 1. The monthly and longterm average rainfall distribution at Tygerhoek Experimental Farm.

A 1 ha paddock with a history of cereal crops which had never had any medics before was identified and sown on 20 April 1989 with a mixture of *M. truncatula* cv's Paraggio and Parabinga, two widely used medic cultivars, at a seeding rate of 6 kg ha^{-1} respectively. The Glenrosa loam soil (MacVicar et al., 1977) (pH(KCl) = 5.7, P(citric acid method) = 38 ppm, K = 114 ppm, 17% clay, 33% silt, 32% fine sand, 6% medium sand and 12% coarse sand) was classified as a Lithic Haploxeralf (Soil Survey Staff, 1975).

The medic pasture of 1989 was followed by wheat in 1990. In 1991, the soil were left undisturbed to allow the medics to regenerate. This was followed by a second wheat crop in 1992 and a volunteer medic pasture in 1993. During the growing season, the medics were grazed and grass weeds were chemically controlled with fluazifop-P-butyl to maximise seed production. Controlled grazing with a small flock of 20 Merino wethers for certain periods were used to prevent the medics from becoming to lush during the vegetative stage and to remove excess pasture residues during the summer months to enable seedbed preparation for the following wheat crop.

The experiment was laid out in the middle of the 1 ha paddock as a randomised block with six blocks and six treatments per block. To allow the use of farm implements for tillage treatments, plot sizes were 5 x 20 m. The treatments comprised six methods of tillage (Table 1) commonly used in medic and cereal farming in the southern Cape. These were used in preparation of the soil prior to sowing of the wheat crops in 1990 and 1992. All tillage treatments were applied at seeding time after weeds and volunteer medics were killed with a diquat-paraquat mixture applied as a nonselective herbicide. Wheat (cv Palmiet) was sown on 14 June 1990 and 11 May 1992 at 120 kg ha^{-1}. No fertilizer was used in 1990 while 60 kg N ha^{-1} was applied at seeding in 1992.

Table 1. Different tillage methods used for wheat production

Tillage implement	Depth (mm)	Method of sowing
Fieldspan[a]	50	Tine drill[b]
Shallow scarifier[c]	50	Tine drill
Deep scarifier	150	Tine drill
Shallow disc plough	50	Tine drill
Deep disc plough	150	Tine drill
Mouldboard plough	250	Tine drill

[a] An Australian made light, spring-tooth field cultivator.
[b] Seeding machine where seed is placed behind tilling tines.
[c] An Australian made tine cultivator of medium to heavy weight equipped with wide duckfeet.

In 1990, prior to tillage 50 quadrants of 0.25 m^2 each were sampled to determine the mass of pods present on the soil surface. At the end of the pasture year in 1991, medic pods were sampled again in five quadrants of 0.25 m^2 each per tillage plot. Pods were threshed to determine seed production. After tillage, the distribution of medic pods and seed in the profile was determined, using steel cylinders of 117 mm in diameter to remove soil cores from depths of 0-50 and 50-150 mm in 1990. In 1992 samples were taken at 0-25, 25-50 and 50-150 mm depths. Pods and seed were recovered from the soil by putting the soil samples into a saturated KCl solution (Carter et al., 1977). Due to density differences, all organic material floated, which made it easy to select the medic pods and seed.

In 1991 and 1993, medic plants were counted in five 0.05 m^2 areas per tillage plot at the end of May when most of the seed had germinated. To determine wheat yields, the borders was first harvested and then strips of 1.3 x 20 m were mechanically harvested from each plot with a Wintersteiger combine.

Data were analysed using analyses of variance and significant differences between means and were determined using least significance difference (P=0.05) as described by Snedecor and Cochran (1980).

3. Results and discussion

3.1. Seed recoverage and distribution in the soil profile

Determinations of the seed mass, before tillage treatments were applied in 1990, showed an average of 549 kg seed ha^{-1} on the soil surface. After tillage, the seed mass recovered from the 0-150 mm soil profile varied between 730 kg ha^{-1} where a deep scarifier cultivation was applied to 180 kg ha^{-1} after mouldboard ploughing (Fig. 2a).

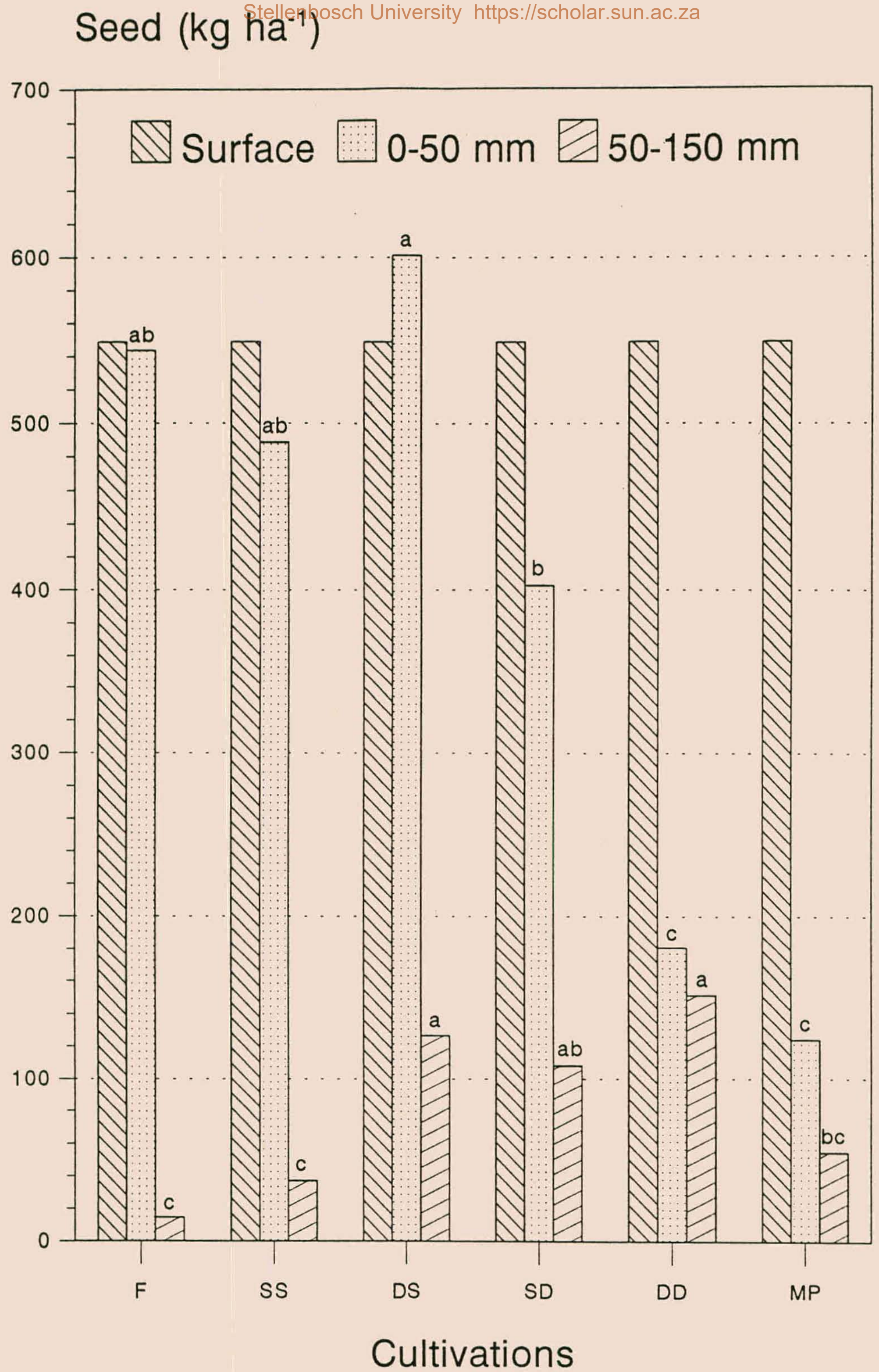

Figure 2a. Medic seed mass on the surface prior to tillage and its distribution in the soil profile at Tygerhoek in 1990 after different cultivations (F, fieldspan; SS, shallow scarifier; DS, deep scarifier; SD, shallow disc plough; DD, deep disc plough; and MP, mouldboard plough). (Values followed by the same character do not differ significantly among cultivation techniques at $P \leq 0.05$).

In the deep disc- and mouldboard-plough treatments, 40 and 68% respectively of the seed initially present on the soil surface were not recovered and presumably had been placed deeper than 150 mm.

The greater seed mass found after tillage with both the fieldspan and deep scarifier treatments indicated that a considerable amount of seed was already buried before tillage. This was probably due to the soil disturbance brought about by the hooves of the grazing sheep. No significant differences were found among seed masses recovered from the topsoil (0-50 mm) of the tine treatments (fieldspan and scarifier) regardless the depth of cultivation. Deep cultivation with tine implements could therefore be used to eliminate soil compaction without any detrimental effect on the distribution of the medic seed reserves in the soil profile. Although it was difficult to control the exact tillage depth with the shallow disc, that treatment also resulted in a large quantity (approximately 80%) of the seed in the 0-50 mm layer.

With deep disc (150 mm depth) and mouldboard ploughing, significantly less seed were recovered from the 0-50 mm profile. After deep disc tillage, less than 33% of the seed mass that was on the surface before tillage was found within the top 50 mm of the profile. This depth is regarded as the maximum seeding depth for medics (Carter and Challis, 1987). With deep mouldboard ploughing, this amount dropped to less than 23%. These results are similar to those of Carter et al. (1988) who found that only 15% of medic seed was in the top 50 mm of soil after deep mouldboard ploughing, compared with 90% after a scarifier cultivation.

In 1991, seed was determined in the 0-25, 25-50 and 50-150 mm depths (Fig. 2b) because of the large effect of seeding depth on regeneration reported by Carter and Challis (1987) and Crawford and Nankivell (1989).

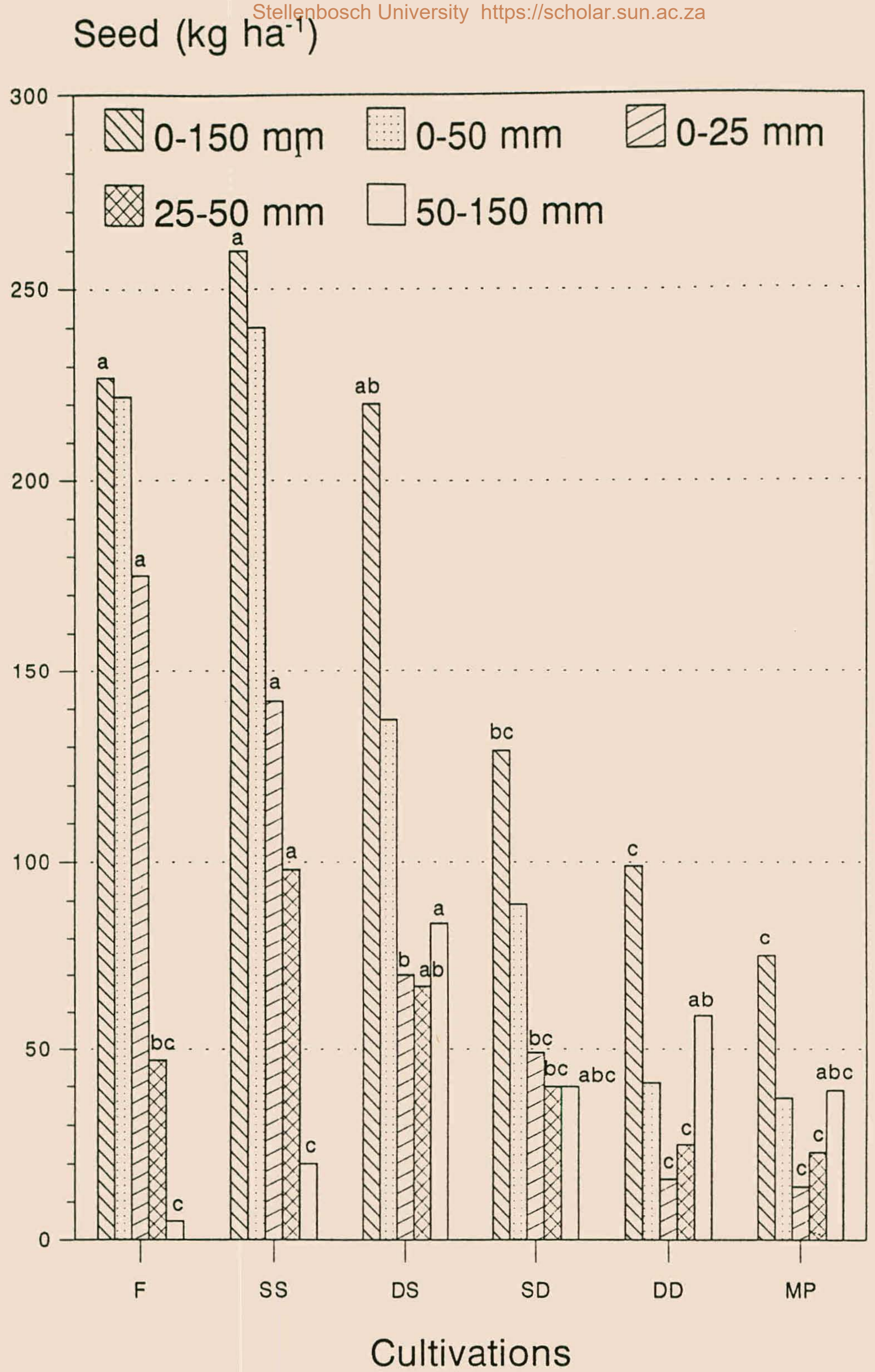

Figure 2b. Medic seed distribution in the soil profile at Tygerhoek in 1992 after different cultivations (F, fieldspan; SS, shallow scarifier; DS, deep scarifier; SD, shallow disc plough; DD, deep disc plough; and MP, mouldboard plough). (Values followed by the same character do not differ significantly among cultivation techniques at P≤ 0.05).

From Fig. 2b it is clear that seed mass recovered in 1992 was considerably less for all treatments than in 1990. This is somewhat surprising as one would expect greater seed mass due to the additional pods and seeds produced during the second pasture crop in 1991, but Crawford and Nankivell (1989) also reported seed losses of more than 50% in rotation experiments. This smaller seed mass in 1992 may be the result of too intensive grazing in the summer or poor seed production due to low rainfall during August 1991 (Fig. 1). In general however, the distribution of seed in the soil profile in 1992 confirmed the results of 1990, where tine tillage resulted in the largest and deep disc and mouldboard ploughing in the smallest seed mass in the topsoil (0-50 mm). The distribution in the 0-50 mm soil layer however, reflected the depth of tine cultivations. With shallow (50 mm) fieldspan and scarifier tillage, most of the seed was recovered from the 0-25 mm soil layer, but with the deep (150 mm) scarifier treatment the seed was more evenly distributed in the 0-150 mm soil profile.

According to Carter (1987) and Brahim and Smith (1993), seed reserves of 200 kg ha^{-1} are considered adequate to regenerate a productive medic pasture. From Fig. 2b it is clear that this requirement was, with the exception of deep disc and mouldboard ploughing, easily met by all tillage treatments in 1990, but in 1992 only shallow (50 mm) tine tillage satisfied this requirement.

3.2. Medic regeneration and seed production

The effect of the tillage treatments on the regeneration of the medics after wheat crops in 1990 and 1992 is presented in Fig. 3.

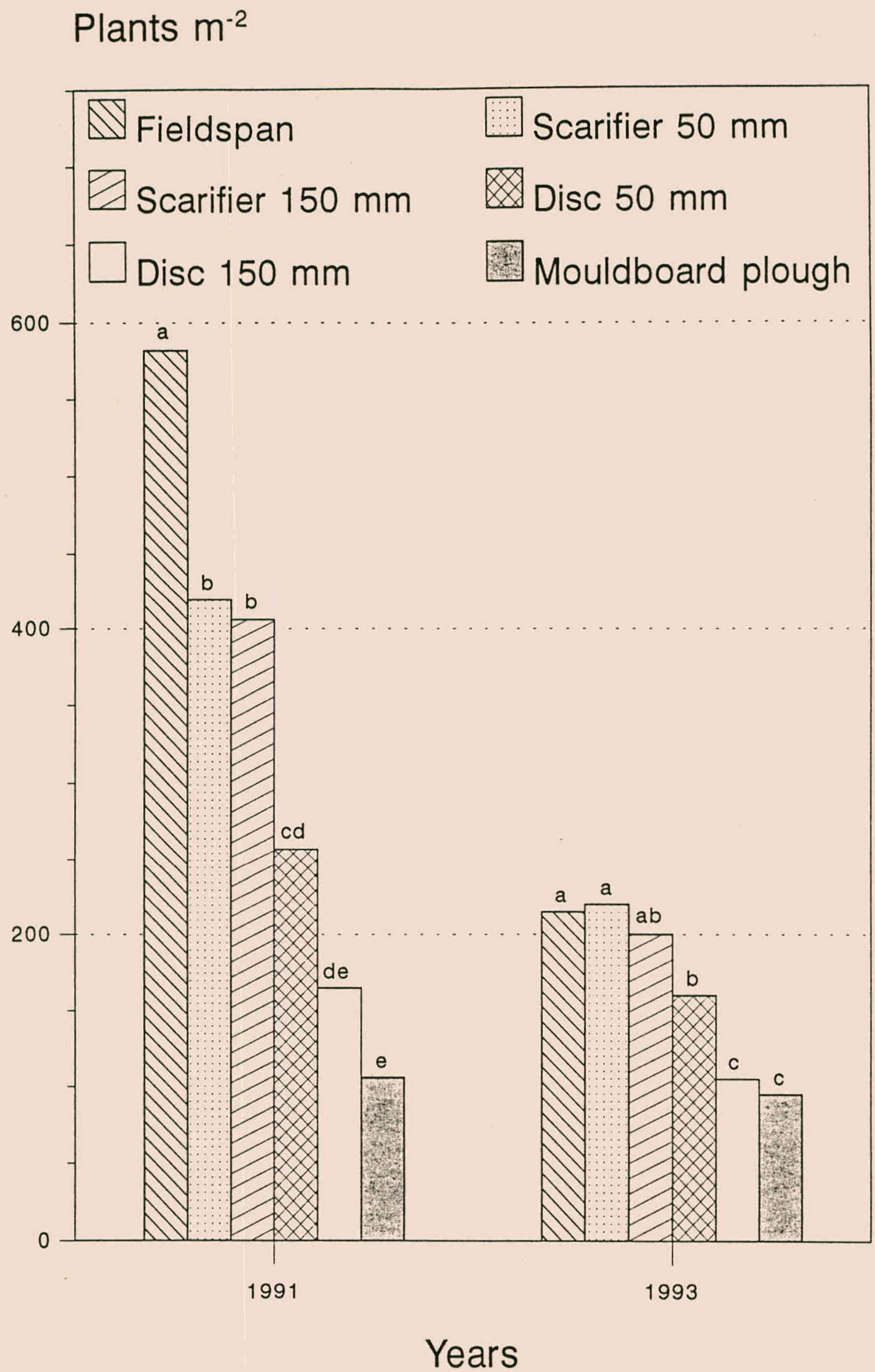

Figure 3. The influence of different cultivations on the number of medic seedlings regenerated during 1991 and 1993 at Tygerhoek (values within a year followed by the same character do not differ significantly at P≤ 0.05).

It is clear that the fieldspan cultivation favoured regeneration of medics in 1991, resulting in significant more seedlings than other tillage treatments. The depth of the scarifier treatments did not affect the number of seedlings regenerated, which was significantly larger than with disc and mouldboard plough treatments. No significant differences were found between shallow and deep disc treatments, while the mouldboard plough cultivation resulted in smallest number of seedlings.

Table 2. The correlation of medic seed reserves in the topsoil after different methods of tillage, on regeneration of medics the following year (X = seed reserves in topsoil kg ha^{-1} and Y = medic seedlings regenerated plants m^{-2})

Seed reserves in topsoil	Regression	r	Prob. Level
1990 (0-50 mm)	$Y = 1.15\ X^{0.942}$	0.96	0.0029
1992 (0-25 mm)	$Y = 41.83\ X^{0.336}$	0.98	0.0009
1992 (25-50 mm)	$Y = 16.36\ X^{0.599}$	0.91	0.0106
1992 (0-50 mm)	$Y = 20.36\ X^{0.445}$	0.98	0.0004

From Table 2 it is clear that there was a highly significant correlation between seed reserves in the topsoil (0-50 mm) and medic regeneration. Although the seedling numbers were less in 1991 than in 1993, fieldspan and shallow (50 mm) scarifier treatments still resulted in the largest seedling populations, and deep (150 mm) disc and mouldboard ploughing in the smallest (Fig. 3). In contrast to 1991, no differences were found between the fieldspan and scarifier treatments. In general lower plant populations in 1993 correlated with the smaller seed mass found in the soil after the tillage treatments were applied for wheat productions in 1992.

Pod and seed production at the end of 1991 (Fig. 4) revealed the same trend as the number of medic seedlings (Fig. 3).

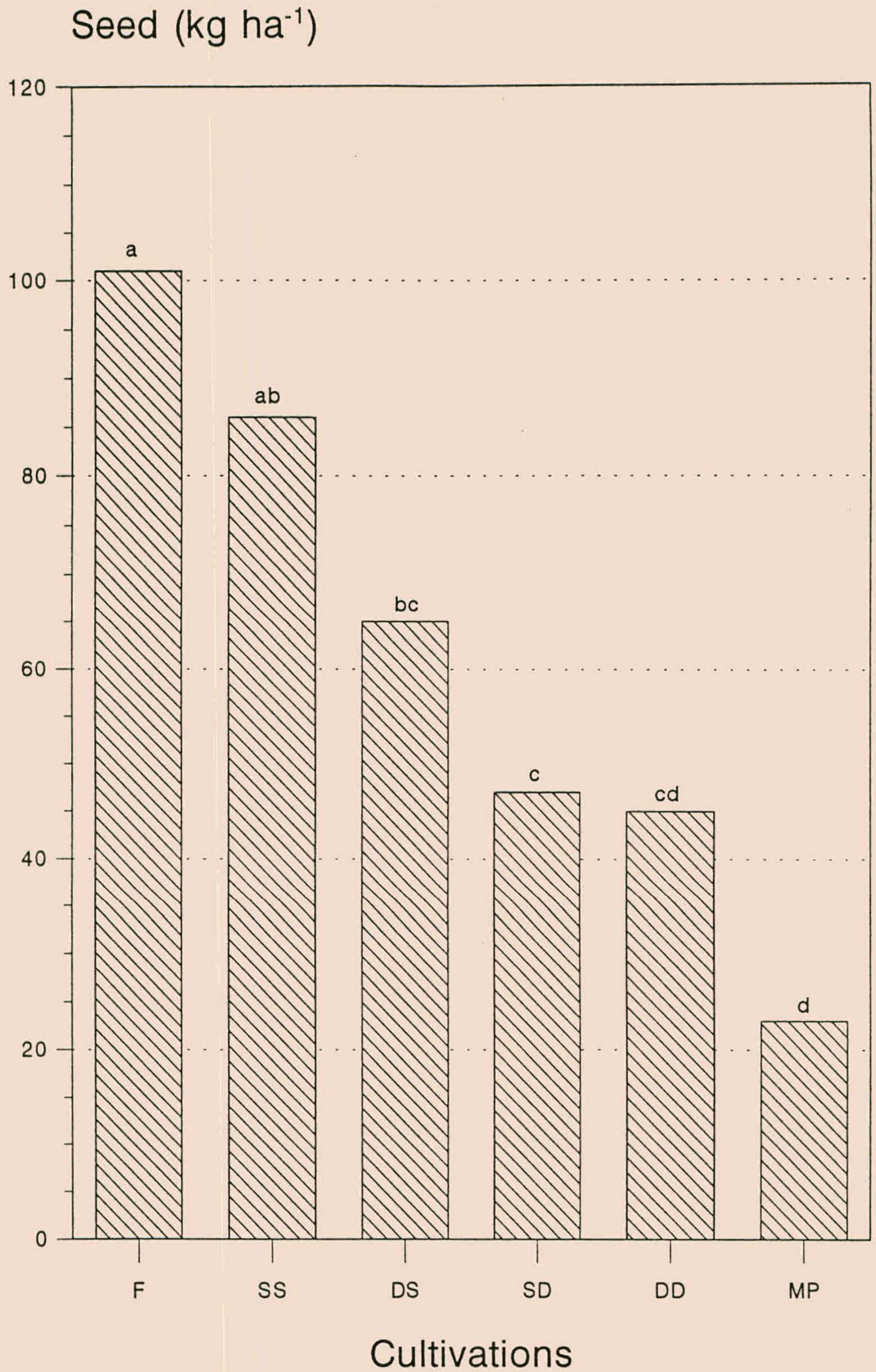

Figure 4. The influence of different cultivations (F, fieldspan; SS, shallow scarifier; DS, deep scarifier; SD, shallow disc plough; DD, deep disc plough; and MP, mouldboard plough) on the seed production of volunteer medics during 1991 at Tygerhoek (values followed by the same character do not differ significantly at P≤ 0.05).

The fieldspan treatment resulted in the largest and mouldboard ploughing in the smallest seed production. No significant differences were found between the two scarifier treatments, but the tine cultivations produced almost twice as much seed as the disc and mouldboard plough treatments. Although it is acknowledged that many other factors, such as grazing management, influence seed production, these results clearly revealed that tined cultivations, which leave more seed in the 0-50 mm soil profile, favours the regeneration and seed production of medics after wheat.

3.3. Wheat yield

As advantages of a medic rotation are also reflected in the following wheat crop, the profitability of a medic/wheat rotation often depends on the wheat yields obtained. The wheat yields obtained in 1990 and 1992 are depicted in Fig. 5.

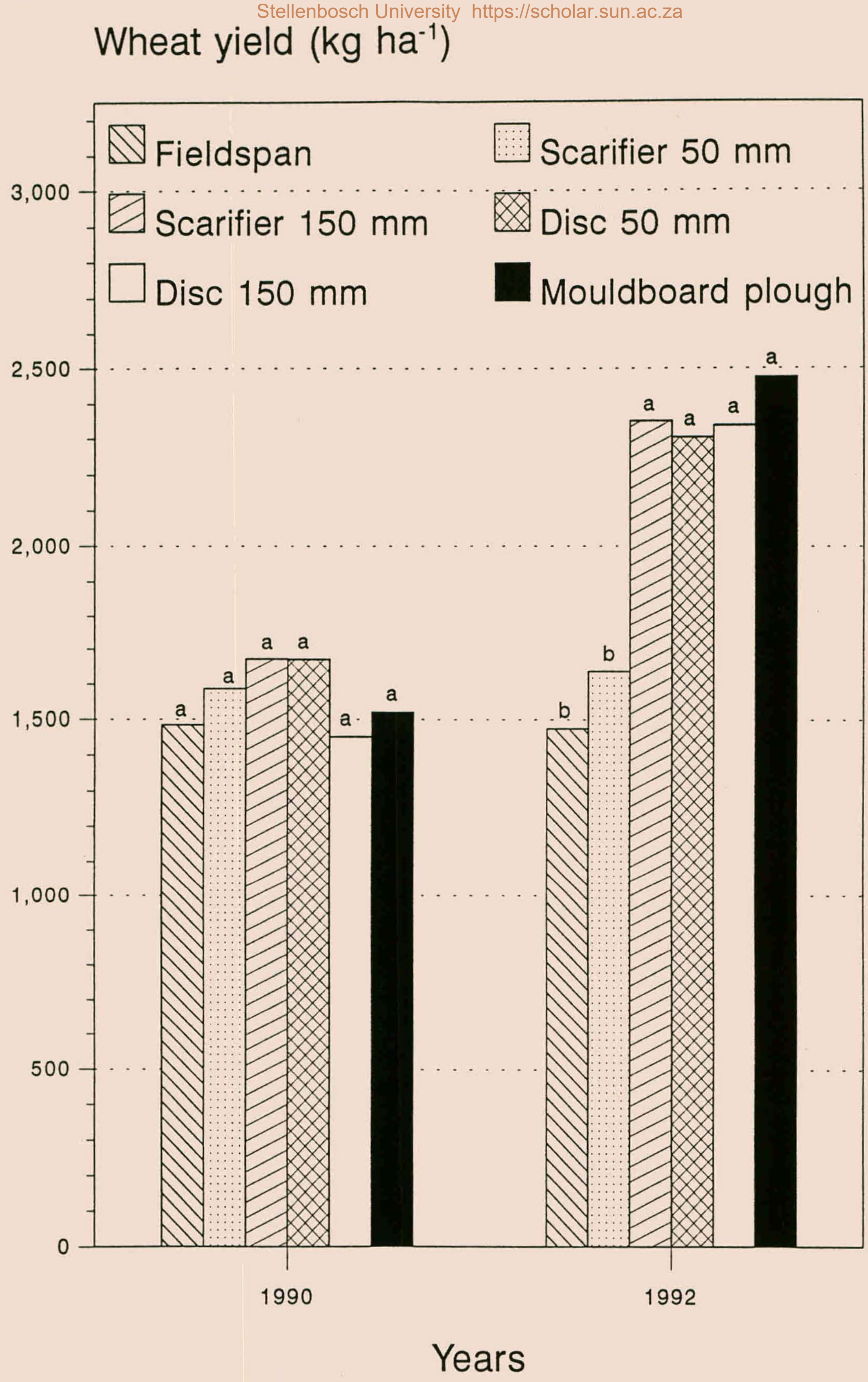

Figure 5. The influence of tillage methods on wheat yield obtained during 1990 and 1992 in a medic-wheat rotation system at Tygerhoek (values within a year followed by the same character do not differ significantly at P≤ 0.05).

In 1990, when the wheat was sown fairly late in the season without any nitrogen fertilizer and after only 1 year of medic pasture, yields were generally low and did not differ significantly between tillage treatments. This result indicated that the time of sowing, the low rainfall during July to September 1991 (Fig. 1) and the absence of nitrogen fertilizer had more effect on yield than did different methods of tillage.

In 1992, yields obtained with the fieldspan and shallow scarifier (50 mm) treatments were almost as low as in 1990 in spite of earlier sowing, more favourable rains and the application of 60 kg N ha^{-1} (Fig. 5). During this year, the more aggressive tillage treatments (scarifier 150 mm, disc and mouldboard plough) yielded considerably more than in 1990. Yields obtained with these treatments were also significantly larger than those obtained with the fieldspan and shallow scarifier treatments. Greater nitrogen mineralization (Agenbag and Maree, 1989), better root growth (Agenbag and Maree, 1991) and/or more effective weed control (Cussons, 1975) are possible advantages of deep scarifier, disc- and mouldboard plough tillage. Yields obtained with deep (150 mm) scarifier treatments were not significantly different from those obtained with disc or mouldboard ploughing. Although shallow tine cultivations favour medic regeneration, these results indicate that more aggressive deep tine cultivation may be needed to ensure high wheat yields.

4. Conclusions

This study revealed that the distribution of the medic seed in the soil profile had a major effect on the regeneration and productivity of medic pastures in a medic/wheat rotation. Regeneration was improved when most medic seeds were distributed in the 0-50 mm layer of the soil profile, using tine implements for seedbed preparation for the following wheat crop. Shallow tine tillage may result in lower wheat yields, however. Therefore tine implements that cultivate soil to a depth of at least 150 mm, while keeping most of the medic seed in the 0-50 mm layer appear best for medic/wheat rotations. Such tillage will also suffice for adequate root development, weed control and for mixing of lime and fertilizers into the soil.

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CHAPTER 4

MEDIC SEEDLING DYNAMICS AND EARLY PRODUCTION: 1. EFFECT OF SOIL TYPE, PLANTING DEPTH AND CULTIVARS.

Abstract

Regeneration and establishment problems are important issues to be understood in increasing efficiency of medic/cereal ley farming systems in the western and southern Cape areas of South Africa. Three annual *Medicago* cultivars i.e. *M. truncatula* cv Paraggio, *M. polymorpha* cv Santiago and *M. littoralis* cv Harbinger AR, were planted in 3 different soil types (coarse sand, loamy sand and sandy loam) at 6 different depths, namely 0, 10, 20, 30, 40 and 50 mm, respectively. Seedling establishment was measured in terms of days to emergence, rate of emergence and percentage emerged while early production was monitored by determining dry mass production 21 and 48 days after planting.

No clear evidence in regard to certain cultivars performing better than others in specific soil types was found for the different soil types investigated. Although Harbinger AR showed the best establishment percentages, Santiago produced the highest dry mass at both harvests. Similarly, the hard setting loamy sand soil type showed inferior qualities when compared to the coarse sand and sandy loam soil types. The best results however were obtained on the sandy loam soil. The 10 mm planting depth treatment resulted in the quickest emergence and highest establishment, with subsequent higher dry mass production per plant at both harvests. Increased planting depth from 10 to 50 mm had a negative effect on the days to emergence, rate of emergence and percentage plants emerged. This lead to low early dry mass production.

Keywords: Seedling dynamics; Planting depth; Soil type; *Medicago*

spp; Early production

1. Introduction

Annual *Medicago* spp (medics) in rotation with cereals is one of the most successful rotation systems used in the western and southern Cape (south of 32^0 latitude and west of 20^0 longitude) areas of South Africa. Although the distribution of medic seed reserves in the soil (especially the top 5 cm of the soil layer) is considered to be the most important factor for successful medic regeneration (Abd El-Moneim and Cocks, 1986; Carter et al., 1988; Thorn et al., 1988; Cocks, 1992; Kotzé et al., 1998) differences between soil types exist (Andrew and Hely, 1960; Carter and Challis, 1987; White and Robson, 1989; Little et al., 1992). The formation of hard soil crusts decrease seedling emergence and lead to uneven emergence and establishment.

Carter and Challis (1987) reported decreases from 80% to 5% in percentage of plants established when planting depth was increased from 10 to 50 mm while Carter et al. (1988) and Kotzé et al. (1998) found that implements that resulted in the deeper placement of medic seed reserves in the soil during tillage, similarly reduced the number of plants established during regeneration.

Furthermore, quick establishment and early production is of vital importance if a late break of the season is experienced. Not only does it provide early grazing for the livestock, but it also helps suppress weeds in the pasture. Evans, et al. (1992) found that early winter growth was the most limiting factor in determining stocking rates on pastures.

The objective of this study was to determine the effect of cultivars, soil type and planting depth on the establishment and early production of medic pastures.

2. Material and methods

The experiment was conducted under irrigation in a polycarbonate tunnel where the average minimum and maximum temperatures during the experimental period were 9.6 and 22.9 ^{0}C and minimum and maximum relative humidities were 53.0 and 92.9%, respectively.

The most commonly used cultivars in the western and southern Cape within the different *Medicago* spp were planted; namely *M. truncatula* cv Paraggio, *M. polymorpha* cv Santiago and *M. littoralis* cv Harbinger AR. Six different planting depths, namely 0, 10, 20, 30, 40 and 50 mm, were used.

Representative soils from the main production areas were used in this study. These soils were classified (Alexander and Middleton, 1952) as a loamy sand and sandy loam and were compared to a coarse sand. Physical and chemical properties of the different soil types used in the experiment are presented in Table 1.

Table 1. Soil physical and chemical characteristics of the three soil types used in the experiment.

Soil characteristics	Soil types		
	Coarse sand	Loamy sand	Sandy loam
% Silt	0.0	8.0	10.0
% Clay	2.0	6.0	16.0
% Coarse sand	43.92	17.34	10.22
% Medium sand	41.12	13.92	23.16
% Fine sand	12.96	54.74	40.62
pH(KCl)	6.2	5.5	5.5
Conductivity (ohms)	2780	1740	2440
P mg kg^{-1} (Citric acid)	23	27	49
K mg kg^{-1} (Citric acid)	41	100	76

Although the total sand content increased from 74 to 86 and 98% accordingly, the loamy sand had the highest percentage of fine sand.

Ten seeds of each of the 3 different cultivars (commercial seed) were planted at 6 different depths in pots (150 mm in diameter and 160 mm deep) filled with one of the 3 different soil types respectively. Seeds were not inoculated with the respective *rhizobium* strains as a balanced liquid nutrient and water mixture was applied 3 times a day to keep the soil at optimum germination conditions. All treatments were replicated three times.

Number of plants per pot were recorded daily for 21 days to determine differences in emergence and establishment. These data are presented as days to emergence, rate of emergence and percentage emerged. Days to emergence represent the number of days before the first seedlings emerged. The rate of emergence is the gradient measured in plants per day and was calculated by dividing the final number of seedlings with the number of days recorded from the first seedling emerged till the final counting. The percentage emerged represent the total number of seedlings established after 21 days relative to the amount of seeds that were sown.

After 21 days the seedlings in each pot were visually rated and then thinned out leaving two representative plants per pot. One of the seedlings was then harvested and the remaining plant was harvested 48 days after planting to determine early production. Plants were cut at the soil surface to determine dry mass production per plant.

Data were analysed using analysis of variance (ANOVA). Where data did not had a normal distribution, it was submitted to a logarithmic transformation ($\ln(x + 0.5)$). Student's least significant differences (LSD) were calculated at $P = 0.05$ to compare treatment means as described by Snedecor and Cochran (1980).

3. Results and discussion

From Table 2 it is clear that all factors had highly significant effects on the different parameters measured. Where significant interactions occurred, only data from these interactions will be presented and discussed.

Table 2. Analysis of variance (ANOVA) for the different parameters measured.

Source	DF	Days to emergence		Rate of emergence		% emerged		Dry mass (21 days)		Log Dry mass (48 days)	
		MS	Pr>F	MS	Pr>F	MS	Pr>F	MS	Pr>F	MS	Pr>F
Block	2	61.93	0.0182	0.15	0.6182	6.06	0.2472	0.00001	0.3662	0.02	0.2930
Soiltype (S)	2	179.11	0.0001	1.73	0.0055	23.57	0.0053	0.00027	0.0001	1.44	0.0001
Depth (D)	5	516.04	0.0001	1.32	0.0017	57.48	0.0001	0.00058	0.0001	0.31	0.0001
Cultivar (C)	2	95.01	0.0024	3.98	0.0001	169.24	0.0001	0.00005	0.0149	0.17	0.0005
S x D	10	13.32	0.5406	0.70	0.0216	3.20	0.6783	0.00005	0.0001	0.05	0.0144
S x C	4	26.39	0.1398	0.20	0.6400	6.98	0.1714	0.00003	0.0294	0.01	0.6127
D x C	10	38.50	0.0076	0.38	0.3092	6.82	0.1180	0.00002	0.0800	0.04	0.0347
S x D x C	20	12.07	0.6957	0.36	0.3234	2.29	0.9446	0.00001	0.6980	0.02	0.7144
Error	106	14.89		0.32		4.27		0.00001		0.02	

3.1 Seedling emergence

3.1.1. Days to emergence

Depth of sowing and soil type were the most dominant factors influencing the number of days to emergence (Table 2).

Table 3. The influence of soil type on the number of days to emergence.

Soil type	Days to emergence
Sandy Loam	8.65 a*
Coarse Sand	9.74 a
Loamy Sand	12.20 b
LSD (P = 0.05)	1.47

* Values followed by the same letter do not differ significantly at the 5% level.

The loamy sand soil caused a significant delay in emergence of approximately 3 and 4 days compared to the coarse sand and sandy loam soils respectively (Table 3). As a result of the higher fine sand fraction it appeared that the loamy sand was a more hard setting soil and prone to surface crusting which could have led to the delay in emergence. This data supports the findings of White and Robson (1989) who reported a delay of 5 days between the emergence of seedlings in crust forming soil compared to one not prone to crusting. Under field conditions the optimum time for germination and emergence will be during the wet, moist conditions during and just after a rainy period. The delay in emergence under field conditions could therefore further enhance the chance of encountering hard crusts.

Table 4. The influence of cultivars and planting depth on the number of days to emergence.

Planting depth	Days to emergence		
	Paraggio	Santiago	Harbinger AR
0 mm	16.22 fg*	21.33 h	13.22 ef
10 mm	6.33 a	5.67 a	5.33 a
20 mm	6.56 a	7.11 ab	5.89 a
30 mm	8.33 abcd	7.89 abc	7.89 abc
40 mm	8.89 abcd	10.33 bcde	11.33 cde
50 mm	11.78 de	17.89 gh	11.56 de
LSD (P = 0.05)	3.60		

* Values followed by the same letter do not differ significantly at the 5% level.

Although the data showed slight differences between the cultivars (Table 4) a similar trend namely a steady increase in the number of days to emergence from 10 to 30 mm planting depth followed by a dramatic increase to 40 and 50 mm planting depth respectively was found. However, the 0 mm planting depth needed the highest number of days to emergence. From Table 4 it was clear that the optimum planting depth was 10 mm. Although the days to emergence increased according to planting depth, no significant differences were found between 10 to 30 mm. The delay in number of days to emergence however, increased almost two and three fold compared to the optimum depth when planting depth was increased to 40 and 50 mm. This results supported the emergence data reported by Carter and Challis (1987).

3.1.2 Rate of emergence

Despite the differences between the average seed sizes of the different cultivars, Harbinger AR (2.4 mg $seed^{-1}$), Paraggio (4.1 mg $seed^{-1}$) and Santiago (2.6 mg $seed^{-1}$) (Oram, 1990; Kotzé, et al., 1995) no relation between the rate of emergence and seed size was found (Table 5).

Table 5. The influence of different cultivars on the rate of emergence.

Cultivars	Plants day^{-1}
Harbinger AR	0.82 a*
Paraggio	0.49 b
Santiago	0.28 b
LSD (P = 0.05)	0.21

* Values followed by the same letter do not differ significantly at the 5% level.

In this study Harbinger AR showed a significantly higher rate of emergence compared to the other cultivars tested.

Table 6. The influence of soil type and planting depth on the rate of emergence.

Planting depth	Plants day^{-1}		
	Coarse sand	Loamy sand	Sandy loam
0 mm	0.23 de	0.41 cde	0.23 de
10 mm	0.74 bcd	0.39 cde	1.34 a
20 mm	0.59 cd	0.58 cde	0.43 cde
30 mm	0.76 bc	0.22 de	1.23 ab
40 mm	0.71 bcd	0.25 cde	0.47 cde
50 mm	0.43 cde	0.11 e	0.34 cde
LSD (P = 0.05)	0.53		

* Values followed by the same letter do not differ significantly at the 5% level.

The rate of emergence for different planting depths showed the same tendency as days to emergence (Table 6). The highest rate of emergence was obtained at the 10 mm planting depth with severe reductions in rate of emergence when planting depth was increased to 40 and 50 mm. In general the 0 mm planting depth proved to be the slowest.

Significant differences between soil types were also found. A reduction of 45 and 71% occurred when the rate of emergence from the coarse sand and loamy sand soils, respectively, were compared to the sandy loam soil at 10 mm planting depth.

3.1.3 Percentage emerged

Table 7. The influence of different cultivars on the total number of plants established after 21 days.

Cultivars	% emerged
Harbinger AR	66.11 a*
Paraggio	47.04 b
Santiago	30.74 c
LSD (P = 0.05)	7.89

* Values followed by the same letter do not differ significantly at the 5% level.

Percentage seedlings emerged at 21 days after planting differ significantly between cultivars (Table 7). Although the three different cultivars represent different species, the limited number of cultivars tested make it impossible to draw any conclusion in regard to different species. According to Bounejmate et al. (1992) *M. truncatula* is well adapted on the heavier soils whilst *M. polymorpha* is almost ubiquitous to all soil types. The relative poor performance of Santiago in this experiment may be the result of poor quality seed.

Table 8. The influence of soil type on the total number of plants established after 21 days.

Soil type	% emerged
Sandy loam	55.19 a*
Coarse sand	46.48 b
Loamy sand	42.22 b
LSD (P = 0.05)	7.89

* Values followed by the same letter do not differ significantly at the 5% level.

From Table 8 it is clear that the highest percentage of seedlings emerged was obtained in the sandy loam soil followed by the coarse sand and the loamy sand. This data supported the reduction in emergence of between 57 and 90% found when seed was planted at an optimum depth in soil that had no surface crust compared to a hard setting soil (White and Robson, 1989). Although no visual crusting was observed in the coarse sand, the poor moisture retention abilities of this soil may have a negative effect on the number of seedlings emerged.

Table 9. The influence of depth of planting on total number of plants established after 21 days.

Planting depth	% emerged
0 mm	29.26 c*
10 mm	61.11 a
20 mm	60.37 a
30 mm	58.15 ab
40 mm	47.78 b
50 mm	31.11 c
LSD (P = 0.05)	11.16

* Values followed by the same letter do not differ significantly at the 5% level.

The combined effect of the differences in the initial time to emerge (Table 4) and rate of emergence (Table 6) between the planting depths, is best illustrated by the percentage of seedlings that eventually emerged (Table 9). The optimum planting depth again proved to be between 10 and 30 mm with significant reductions in percentage seedlings emerged when seeds were planted at 40, 50 and 0 mm respectively. The results obtained with the 10 to 50 mm planting depth range confirmed the trends observed by Carter and Challis (1987). The treatment where the seed was left on the soil surface however, was inferior to all other treatments in this experiment. Lodge (1991) also reported reductions of between 45 to 73% in numbers of plants established under field conditions when surface broadcasting and drilled as different methods of planting were compared.

3.2 Dry mass (DM) production

To measure early DM production, plants were harvested 21 and 48 days after sowing or approximately 2 and 6 weeks after emergence. At the first harvest, significant interactions between soil type and depth of planting, as well as soil type and cultivars were found.

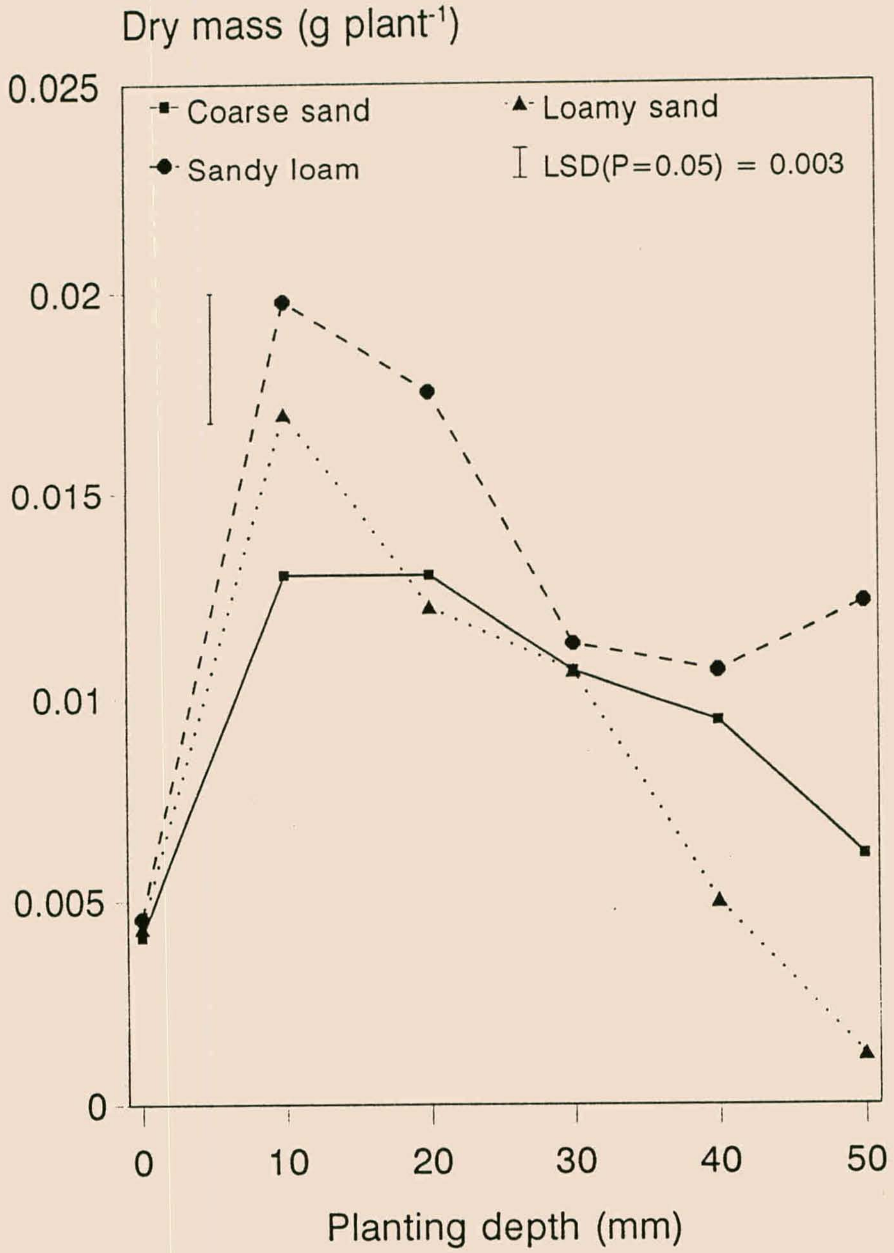

Figure 1. The influence of different soil types and planting depth on the dry mass production 21 days after planting.

DM production increased with 400%, 425% and 325% when planting depth was increased from 0 to 10 mm in the sandy loam, loamy sand and coarse sand respectively (Fig. 1). Although the percentage reduction varied between the different soil types, DM production decreased significantly as planting depth were increased from 10 to 50 mm. In the loamy sand an almost linear reduction in DM production occurred from the 10 to 50 mm planting depth with the result that the DM production obtained from the 50 mm depth being only 6% of that obtained at 10 mm depth. This data confirmed visual observations and support the findings of White and Robson (1989) that plants that emerged 5 to 10 days later (Table 3 and 4) appeared stressed and weakened, being small and pale yellow in colour.

In the coarse sand DM production decreased less dramatically with DM production obtained at 50 mm planting depth being 46% of that obtained with the 10 mm planting depth. In general the DM production obtained from the sandy loam were higher than those obtained in the coarse sand and loamy sand.

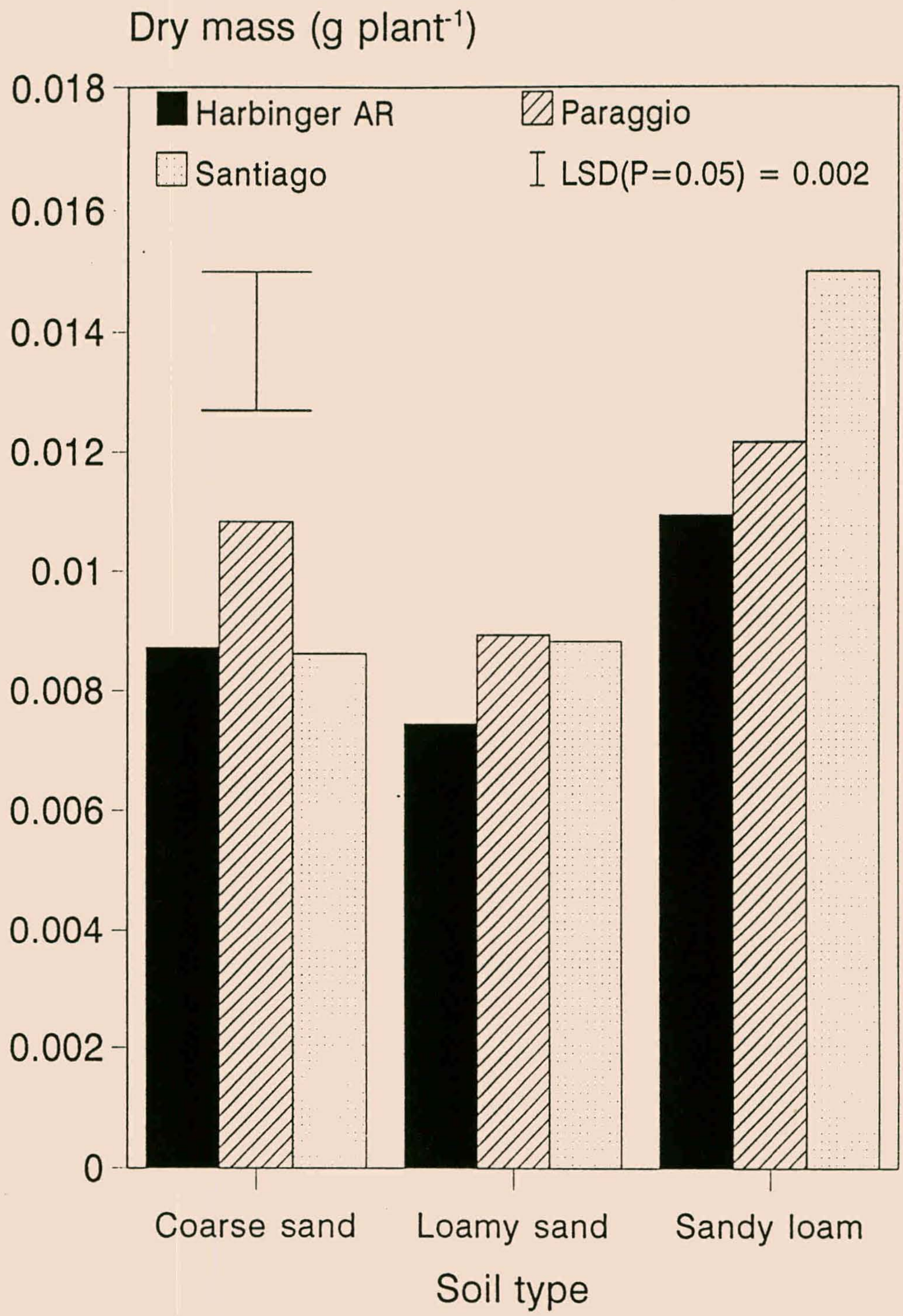

Figure 2. The influence of different cultivars and soil types on the dry mass production 21 days after planting.

From Fig. 2 it became clear that all cultivars showed the highest DM production on sandy loam with Santiago being the highest producer. However, no significant differences between the cultivars on the loamy sand and coarse sand soil types were found.

To obtain a normal distribution, data from the final harvest (48 days after planting) was submitted to a log transformation. Significant interactions between soil type and planting depth as well as cultivars and planting depth, were again obtained.

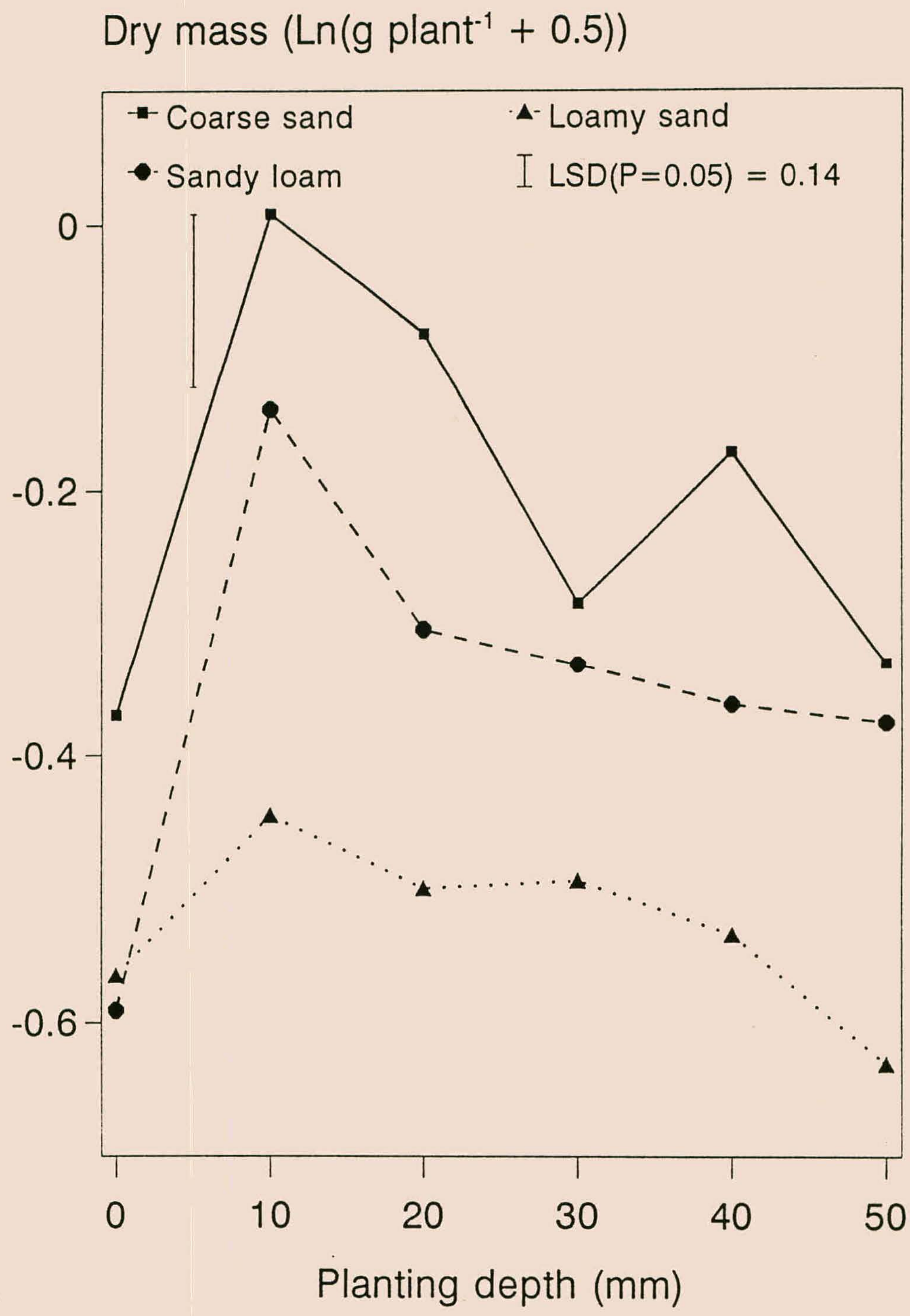

Figure 3. The influence of different soil types and planting depth on the dry mass production 48 days after planting.

In general dry mass production at 48 days after planting showed the same trend as the earlier harvest, namely a sharp increase when planting depth increased from 0 to 10 mm followed by a decline in DM production when planting depth were increased to 50 mm (Fig. 3). Dry mass produced on different soil types also differed significantly. Plants grown in the coarse sand produced significant higher yields than plants in the sandy loam which in turn produced significant more dry mass than plants in the loamy sand.

The DM production at 48 days after planting for the different cultivars planted at different depths show similar trends to that found for soil types (Fig. 4).

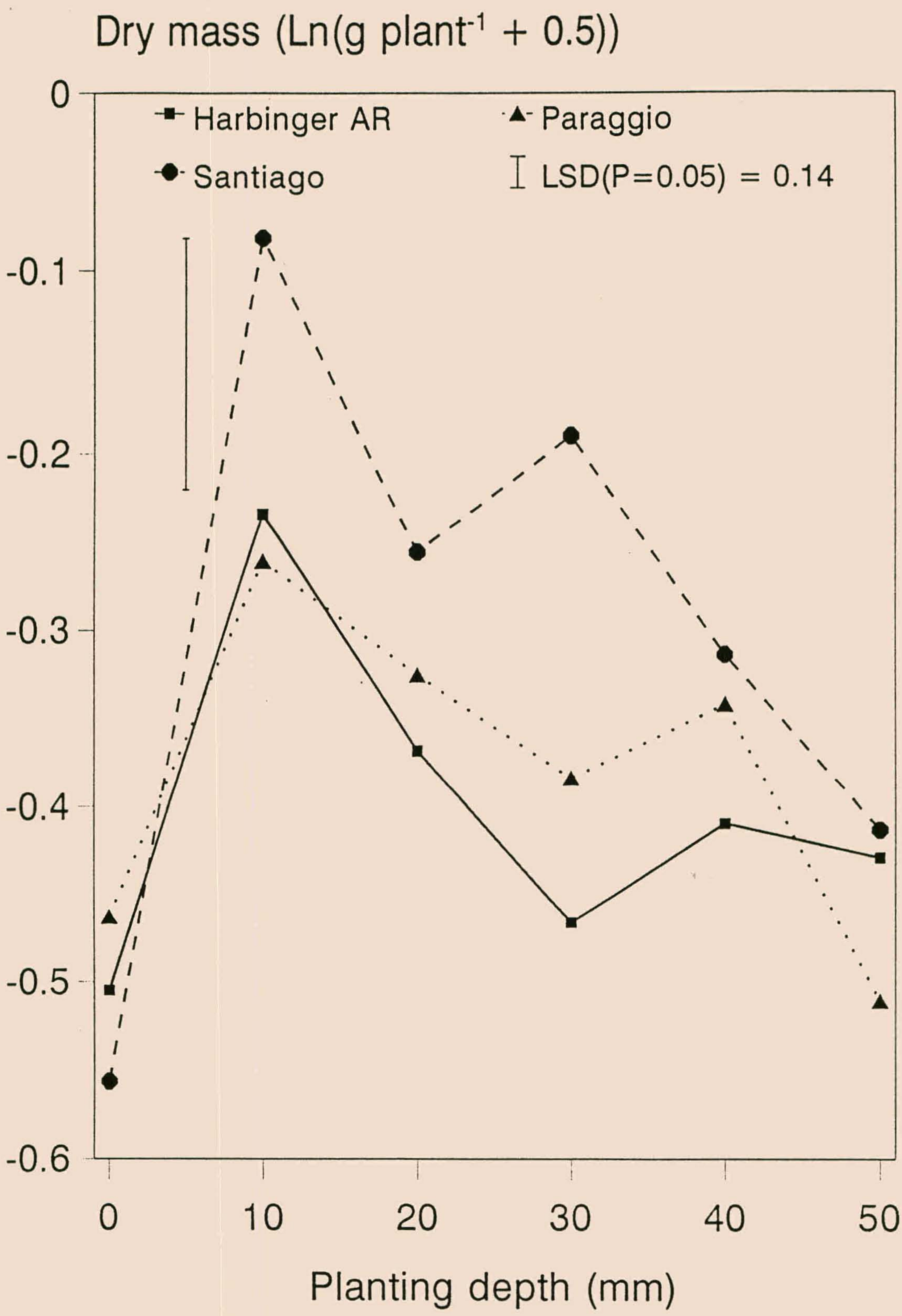

Figure 4. The influence of different cultivars and planting depth on the dry mass production 48 days after planting.

Santiago produced significant more DM at 10 and 30 mm planting depth compared to Paraggio and Harbinger AR. Although the average seed size of Paraggio is considerable larger than those of Santiago and Harbinger AR (Oram, 1990; Kotzé, et al., 1995), no significant differences between Paraggio and Harbinger AR at any planting depth were obtained. It therefore appeared that in this study seed size had no effect on establishment and DM production, supporting the findings of Collins et al. (1983) and Evans et al. (1992).

4. Conclusions

Although it is reported that different *Medicago* species are adapted to different soil types under field conditions (Andrew and Hely, 1960; Little et al., 1992) no clear evidence for this interaction were found for the different species, varieties and soil types investigated. However, the data clearly showed that there was significant differences in the performance of all the medics tested on the different soil types investigated. The sandy loam soil showed superior qualities throughout the experiment with the shortest period to emergence, highest rate of emergence and finally the highest percentage plants emerged which lead to the highest dry mass production per plant obtained at 21 after planting at 10 mm planting depth. The coarse sand soil however, showed superior dry mass production at 48 days after planting. Santiago produced significant more dry mass per plant than other species and varieties at both harvests.

Planting depth had a significant effect on all the parameters measured. The optimum planting depth throughout the experiment was 10 mm. Further increased planting depths lead to a delay in emergence, a decline in rate of emergence and percentage emerged and subsequent lower DM production per plant. The worst results throughout the experiment were obtained when medic seeds were left on the soil surface (0 mm planting depth treatment).

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CHAPTER 5

MEDIC SEEDLING DYNAMICS AND EARLY PRODUCTION: 2. EFFECT OF SOIL TYPE, PLANTING DEPTH AND SEEDING RATE.

Abstract

The negative effect of increased planting depth on medic establishment and early production is well documented. The hypothesis that increased seeding rates could alleviate these negative effects due to the cumulative strength of seedlings was tested during this study. The experiments were conducted on two soil types, namely a loamy sand and a coarse sand. Seed of *Medicago truncatula* cv Paraggio at seeding rates of 10, 20, 40, 80, 160, 320, 640 and 1280 kg ha^{-1} were each sown at six different planting depths, namely, 0, 10, 20, 30, 40 and 50 mm respectively. Seedlings were counted 21 days after planting to determine percentage establishment and plots were harvested 48 days after planting to determine dry mass production.

Planting depths of 10 mm resulted in the fastest emergence and establishment, with subsequent higher dry mass production per plant as well as dry mass yields per hectare. Leaving medic seed on the soil surface (0 mm planting depth) resulted in the lowest percentage of plants emerged in both soil types. Percentages of plants established were significantly reduced by increasing planting depths from 10 to 50 mm on loamy sand but not on coarse sand.

Although plants per m^2 increased significantly at high seeding rates, the percentages of plants established decreased due to severe interplant competition.

Total dry mass production reached a maximum at seeding rates of 320 and 640 kg ha^{-1} in the loamy sand. On the coarse sand an almost linear increase in total dry mass production were obtained with increasing seeding rates. Dry mass production per plant, however, decreased with increasing seeding rates in both soil types due to interplant competition.

Keywords: Seedling dynamics; Planting depth; Seeding rate; Soil type; *Medicago* spp; Establishment; Dry mass production

1. Introduction

In the western and southern Cape of South Africa (south of 32^0 latitude and west of 20^0 longitude) an estimated 500 000 ha of dryland pastures are grown. Self regenerating annual medics are one of the major pasture legumes used in short rotations with cereals like wheat and barley. Cultivations during these crop rotations however, result in the placement of the medic seed reserves at different levels in the soil profile (Quigley et al., 1987; Heida and Jones, 1988; Crawford and Nankivell, 1989). This was confirmed by local studies done by Carter et al. (1988) and Kotze et al. (1998) who found that only 15-20% of medic seed remained in the top 50 mm of soil after deep mouldboard ploughing compared to more than 90% when tine implements such as scarifiers were used in rotation systems.

The importance of adequate medic seed reserves in the topsoil (0-50mm) for successful regeneration is well documented (Carter and Challis, 1987; Heida and Jones, 1988; Cocks, 1992; Kotzé et al., 1998). Results from Carter and Challis (1987) however, revealed significant differences in establishment obtained from different planting depths in both sandy and heavier clay soils. Differences in performance of medics on different soil types were also reported by Andrew and Hely (1960), White and Robson (1989), Bounejmate et al. (1992), Little et al. (1992) and Kotzé and Agenbag (chapter 4).

Quick establishment and early production is of vital importance especially if a late break of the season is experienced. Heavy demands for nutrients during the last trimester of pregnancy and early lactation by ewes coincide with the establishment and early productive phase of medic pastures. Therefore early production is critical in alleviating pressure from both the pasture and animals. Evans et al. (1992) found that seedling density accounted for 45 to 73% of the variation in winter production and that especially in cool environments winter production limits stocking rates.

The objective of this study was to determine the effect of planting depth and seeding rate on the establishment and early production of medics on two different soil types. The hypothesis that higher seeding rates could lead to cumulative strength which will enhance emergence when planting depth increase, was tested.

2. Material and methods

The experiment was conducted in a polycarbonate tunnel where the average minimum and maximum temperature during the 48 day experimental period were 8.8 and 28.1^{0}C and minimum and maximum relative humidity 40.2 and 70.3% repectively. The effect of six different planting depths (0, 10, 20, 30, 40 and 50 mm) and eight seeding rates on the establishment and early production of medics were investigated on two soil types. The different seeding rate treatments were equivalent to 10, 20, 40, 80, 160, 320, 640 and 1280 kg seed ha^{-1}. Commercial seed of one of the most commonly used cultivars in the western and southern Cape area, *M. truncatula* cv Paraggio, was used during the experiment.

Characteristics of the different soil types used in the experiment are presented in Table 1.

Table 1. Soil physical characteristics of the two soil types used in the experiments.

Soil characteristics	Soil types	
	Coarse sand	Loamy sand
% Silt	0.0	8.0
% Clay	2.0	6.0
% Coarse sand	43.92	17.34
% Medium sand	41.12	13.92
% Fine sand	12.96	54.74

In an earlier study Kotzé and Agenbag (chapter 4) found poor establishment on a loamy sand compared to a coarse sand. Due to these large differences it was decided not to include soil type as a treatment in this study but to conduct seperate experiments on the loamy sand and coarse sand. This was done to prevent third order interactions which make the interpretation and discussions of results very difficult. From Table 1 it is clear that although both clay and silt content were less in the coarse sand than in the loamy sand, the largest differences between soil types were found in the coarse sand and fine sand fractions. This caused the loamy sand soil to be hard setting and poorly aerated.

A 6 x 8 factorial design (six planting depths x eight seeding rates) with three replications was used. The experiments were laid out as randomized blocks and conducted in large trays (0.9 x 0.5 m) filled with the different soil types to a depth of 0.3 metre. Each tray was divided into smaller plots (100 x 150 mm) for each treatment. To achieve the specific planting depths the soil was excavated to the required depths where after the seed mass representing the different seeding rates were evenly spread onto the soil. Excavated soil was returned and all plots irrigated to bring soil moisture to field water capacity (FWC). Soil moisture was kept at FWC throughout the experimental period by irrigating the soil three times a day.

After planting, emerged seedlings were counted daily for a period of 21 days. At 48 days after planting (approximately 6 weeks after emergence) all plants were cut at the soil surface level, dried for 48 hours at 80 ^{0}C and weighed to determine dry mass.

Analysis of variance (ANOVA) was used to test for treatment differences. Where data did not show a normal distribution, a square root transformation was done to obtain a normal distribution. Student's least significant differences (LSD) were calculated at P = 0.05 to compare treatment means as described by Snedecor and Cochran (1980). Where significant interactions occurred, only data from the interaction are presented and discussed.

3. Results and discussion

3.1. Establishment

3.1.1. Loamy sand

Percentage seedlings emerged and plants m^{-2} were significantly affected by both planting depth and seeding rate (Table 2).

Table 2. Analysis of variance (ANOVA) for the different parameters measured on the loamy sand.

Source	DF	Plants m^{-2}		% Seedlings emerged		Dry mass (kg ha^{-1})		Dry mass (sqrt) (kg ha^{-1})		Dry mass (g $plant^{-1}$)	
		MS ($x10^3$)	Pr>F	MS	Pr>F	MS	Pr>F	MS	Pr>F	MS	Pr>F
Block	2	2305.74	0.0939	2563.56	0.0030	232900.6	0.1999	176.46	0.0142	0.00113	0.1010
Depth (D)	5	18268.01	0.0001	5206.19	0.0001	3358715.6	0.0001	798.61	0.0001	0.00129	0.0255
Seeding Rate (R)	7	65826.49	0.0001	5136.23	0.0001	5180690.3	0.0001	1909.94	0.0001	0.00151	0.0049
D x R	35	6340.34	0.0001	332.69	0.7692	818055.5	0.0001	136.01	0.0001	0.00050	0.4209
Error	94	950.59		415.82		142216.9		39.65		0.00048	

Percentage seedlings emerged increased significantly when planting depth increased from 0 to 10 mm (Table 3). Further increases in planting depth, however, resulted in significant decreases in the percentage seedlings emerged.

Table 3. The influence of planting depth on the percentage of seedlings emerged on the loamy sand soil type.

Planting depth	% Seedlings emerged
0 mm	35.1 d*
10 mm	77.0 a
20 mm	55.6 bc
30 mm	56.0 b
40 mm	44.3 cd
50 mm	42.8 d
LSD (P=0.05)	11.7

* Values followed by the same letter do not differ significantly at the 5% level.

With increasing seeding rates, no significant differences in percentage seedlings emerged were found between 10 and 80 kg ha^{-1} (Table 4). Higher seeding rates however, resulted in a significant decline in the percentage seedlings emerged. The lowest percentage seedlings emerged was found with the highest seeding rate (1280 kg ha^{-1}), clearly indicating the effect of competition on the emergence of seedlings and supported the findings of Silsbury et al. (1979), Puckridge and French (1983) and Abd El-Moneim and Cocks (1986).

Table 4. The influence of seeding rate on the percentage of seedlings emerged on the loamy sand soil type.

Seeding rate (kg ha^{-1})	% Seedlings emerged
10	67.7 a*
20	69.6 a
40	63.9 ab
80	59.6 ab
160	53.2 bc
320	40.2 cd
640	38.7 d
1280	21.6 e
LSD (P=0.05)	13.5

* Values followed by the same letter do not differ significantly at the 5% level.

In spite of the above mentioned effect of competition on percentage seedlings emerged, plants m^{-2} generally increased with increasing seeding rates (Table 5).

Table 5. The influence of seeding rate (R) and planting depth (D) on plant populations (plants m^{-2}) on the loamy sand.

Seeding Rate (kg ha^{-1})	Seeds m^{-2}	Planting depth (mm)						Mean
		0	10	20	30	40	50	
10	181	67	178	111	156	89	133	122
20	362	178	378	267	222	244	222	252
40	724	267	578	489	511	556	377	463
80	1448	467	1067	1089	1067	822	667	863
160	2896	1111	2022	1756	1756	1356	1244	1541
320	5791	1422	3867	2578	2867	1400	1822	2326
640	11582	3600	8533	4511	4267	2711	3267	4482
1280	23164	7400	11511	5289	2178	2200	1422	5000
Mean	5769	1814	3517	2011	1628	1172	1144	
LSD D (P=0.05) = 558.8								
LSD R (P=0.05) = 645.3								
LSD D x R (P=0.05) = 1584.2								

In general the highest number of plants m^{-2} were found at a planting depth of 10 mm, with less plants at both shallower and deeper planting depths. Plants m^{-2} however, showed a significant interaction between planting depth and seeding rate. At low seeding rates, the lowest number of plants m^{-2} were found where the seed was left on the soil surface. This data supported the results of Carter and Challis (1987) and Kotzé and Agenbag (chapter 4).

In contrast to this, the lowest number of plants m^{-2} at the higher seeding rates (640 - 1280 kg ha^{-1}) were found at the deepest planting depth. Due to large differences in plants m^{-2} with different seeding rates, no significant differences between different planting depths were found at low seeding rates. Silsbury et al. (1979), Prioul and Silsbury (1982) and Kotzé and Agenbag (chapter 4) also found a thinning effect due to competition at high seeding rates.

Although plants m^{-2} decreased for all seeding rates with increasing planting depths between 10 and 40 mm, the declining tendency became smaller with increasing seeding rates between 10 and 80 kg ha^{-1}. With higher seeding rates, the effect however increases again. These tendency indicated that the cummulative strength of more seedlings at higher seeding rates initially helped to overcome the negative effect of deeper planting depths on seedling emergence. This was however not the case at high seeding rates, because the hard setting loamy sand formed clods at deeper planting depths which forced the seedlings to grow through the cracks. This phenomenon increases physical interplant competition and reduces seedling survival at high seeding rates. Puckridge and French (1983) reported that medic seedlings compete vigorously if plant densities exceeded 1000 - 2000 plants m^{-2}. In our study such plant densities at optimum planting depths (10 mm) were reached at seeding densities of 80 - 160 kg ha^{-1}, which also marked the turning point for the above mentioned phenomenon.

3.1.2. Coarse Sand

A significant interaction between planting depth and seeding rate existed for both plants m^{-2} and percentage seedlings emerged (Table 6).

Table 6. Analysis of variance (ANOVA) for the different parameters measured on the coarse sand.

Source	DF	Plants m^{-2}		% Seedlings emerged		Dry mass ($kg\ ha^{-1}$)		Dry mass (sqrt) ($kg\ ha^{-1}$)		Dry mass ($g\ plant^{-1}$)	
		MS ($x10^3$)	Pr>F	MS	Pr>F	MS	Pr>F	MS	Pr>F	MS	Pr>F
Block	2	8.43	0.9493	39.26	0.6359	1226237	0.0019	229.16	0.0001	0.00285	0.0018
Depth (D)	5	109310.02	0.0001	33703.2	0.0001	14844588	0.0001	4709.2	0.0001	0.00857	0.0001
Seeding Rate (R)	7	687256.09	0.0001	400.76	0.0002	41400139	0.0001	6039.9	0.0001	0.00657	0.0001
D x R	35	26792.74	0.0001	153.16	0.0153	1610347	0.0001	141.67	0.0001	0.00165	0.0001
Error	94	161.87		86.29		182625		18.49		0.00042	

With the exception of the 0 mm planting depth, much higher percentage seedlings emerged and plants m^{-2} were found in the case of the coarse sand compared to the loamy sand (Table 7 and 8).

Table 7. The influence of seeding rate (R) and planting depth (D) on the percentage of seedlings emerged on the coarse sand.

Seeding Rate ($kg\ ha^{-1}$)	Planting depth						
	0 mm	10 mm	20 mm	30 mm	40 mm	50 mm	Mean
10	0	98.4	86.1	98.4	110.7	110.7	84.1
20	0	92.1	104.4	98.2	92.1	110.5	82.9
40	0	82.9	101.3	82.9	85.9	98.2	75.2
80	0	93.6	82.9	90.5	93.6	90.5	75.2
160	3.1	86.7	91.3	85.2	86.0	66.0	69.7
320	1.9	90.6	95.2	86.0	92.5	89.0	75.9
640	1.9	97.7	92.3	92.5	99.4	99.2	80.5
1280	1.4	96.8	93.8	85.3	91.9	89.0	76.4
Mean	1.0	92.4	93.4	89.9	94.0	94.1	
LSD D (P=0.05) = 5.3							
LSD R (P=0.05) = 6.1							
LSD D x R (P=0.05) = 15.1							

Where the seed were left on the soil surface (0 mm planting depth), the percentage seedlings emerged for all seeding rates were well below 4%. This is probably due to the poor water holding capacity and resultant quick drying of these soil and confirmed the importance of good contact between seed and moist layers of the soil as reported by Thorn et al. (1988) and Lodge (1991). With planting depths between 10 and 50 mm, the percentage seedlings emerged were generally high. At low seeding rates percentage figures even exceeded 100%. This was due to the fact that the number of seeds sown were not counted but calculated from the seedmass sown and mean weight of individual seeds. In contrast to the loamy sand, percentage seedlings emerged did not decrease significantly with high seeding rates.

Increasing planting depths between 10 and 50 mm also did not affect the percentage seedling that emerged. Plants still managed to emerge at deeper planting depths, due to the porosity of this soil type. These data supported the results obtained in different soil types as reported by Carter and Challis (1987) and Kotzé and Agenbag (chapter 4).

No significant differences were found between the plant populations at low seeding rates (10 to 40 kg ha^{-1}). Each increase in seeding rate thereafter resulted in significant more plants established. These increasing tendency followed the exponential increase in seeding rates (Table 8).

Table 8. The influence of seeding rate (R) and planting depth (D) on plant populations (plants m^{-2}) on the coarse sand.

Seeding Rate (kg ha^{-1})	Seeds m^{-2}	Planting depth						
		0 mm	10 mm	20 mm	30 mm	40 mm	50 mm	Mean
10	181	0	178	156	178	200	200	152
20	362	0	333	378	356	333	400	300
40	724	0	600	733	600	622	711	544
80	1448	0	1356	1200	1311	1356	1311	1089
160	2896	89	2511	2644	2466	2489	1911	2018
320	5791	111	5244	5511	4978	5356	5156	4393
640	11582	222	11311	10689	10711	11511	11489	9322
1280	23164	333	22422	21733	19755	21289	20622	17692
Mean	5769	94	5494	5381	5044	5395	5225	
LSD D (P=0.05) = 230.6								
LSD R (P=0.05) = 266.3								
LSD D x R (P=0.05) = 653.7								

The negative effect of increased planting depth on the number of plants established was only evident at the highest seeding rate of 1280 kg ha^{-1}. The very high plant densities found at high seeding rates and the absence of a decrease in plants m^{-2} at the lower seeding rates with deeper planting depths supported our conclusion that formation of clods was the main limiting factor for seedling emergence with deeper planting depths in the loamy sand.

3.2. Dry mass (DM) production

3.2.1 Loamy Sand

Total dry mass (DM) production (Table 9) showed a significant interaction between seeding rate and planting depth (Table 2).

Table 9. The influence of seeding rate (R) and planting depth (D) on dry mass (DM) production (kg ha^{-1}) on the loamy sand.

Seeding Rate (kg ha^{-1})	Planting depth						
	0 mm	10 mm	20 mm	30 mm	40 mm	50 mm	Mean
10	34.4	117.8	37.8	108.9	37.8	44.5	63.5
20	93.4	251.1	86.7	140.0	117.1	128.9	136.2
40	160.0	428.9	177.8	273.4	220.0	257.8	253.0
80	291.1	733.3	522.2	573.4	400.0	295.6	469.3
160	528.9	1120.0	753.3	791.1	351.1	486.7	671.9
320	862.2	1913.3	1226.6	937.8	344.4	631.1	985.9
640	1675.5	2828.9	1048.9	860.0	893.3	835.6	1357.0
1280	3131.1	3320.0	948.9	464.5	471.1	237.8	1428.9
Mean	847.1	1339.2	600.3	518.6	354.4	364.8	
LSD D (P=0.05) = 216.2							
LSD R (P=0.05) = 249.6							
LSD D x R (P=0.05) = 612.7							

To obtain a normal distribution the data was submitted to a square root transformation.

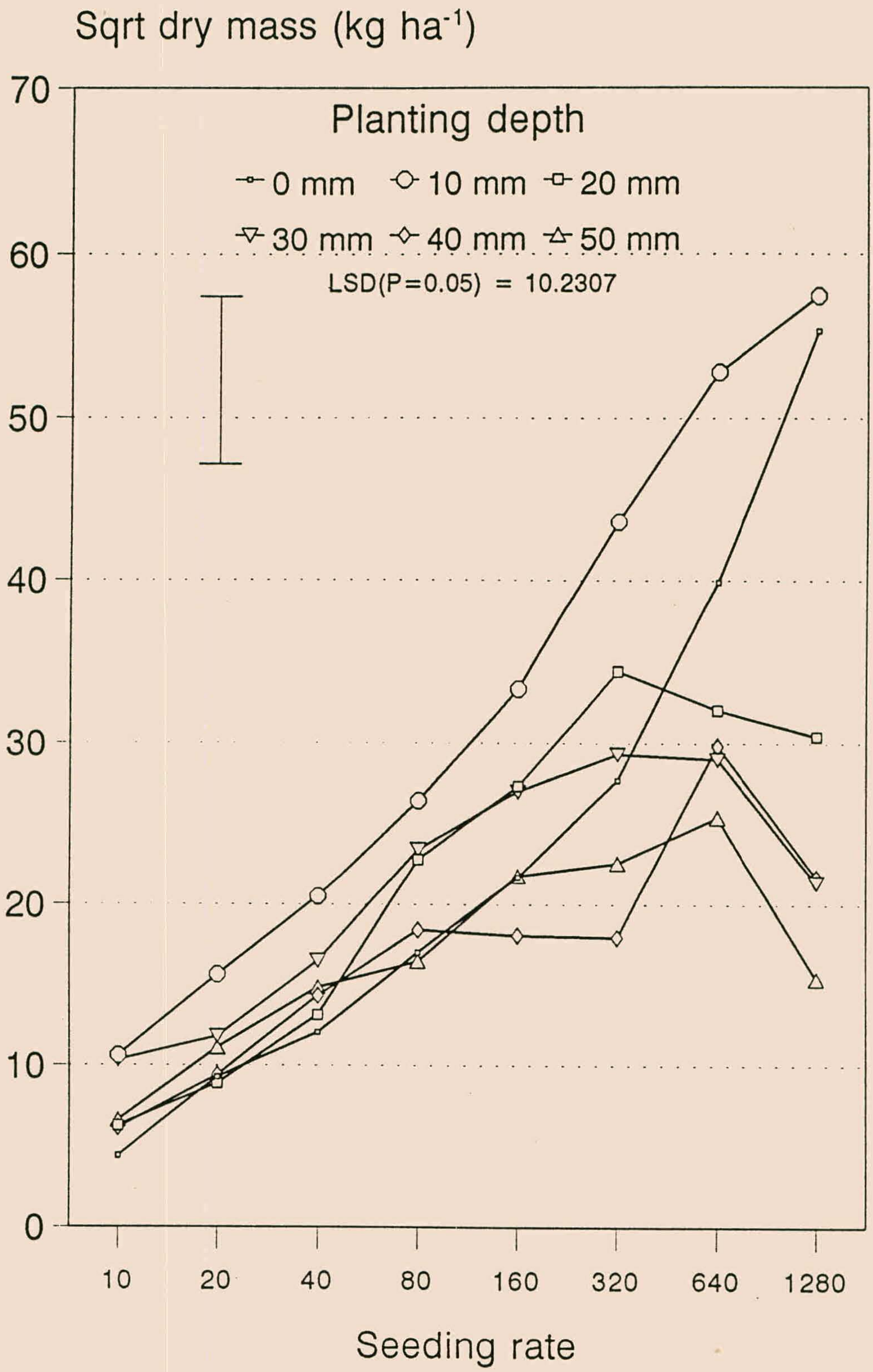

Figure 1. The influence of planting depth and seeding rate on the dry mass production 48 days after planting on a loamy sand soil type (Sqrt = square root).

Dry mass production obtained 48 days after planting were similar to that reported by Ababneh et al. (1990). The 10 mm planting depth treatment resulted in the highest DM production at 48 days after planting at all seeding rates (Table 9 and Fig. 1). Total DM production at 10 mm planting depth increased almost exponentially with increasing seeding rates between 10 and 160 kg ha^{-1}. Due to sharp increases in plants m^{-2} with higher seeding rates, DM production at this planting depth also showed exponential increases between seeding rates of 160 and 640 kg ha^{-1}, but started to level off at DM productions of approximately 3000 kg ha^{-1} with further increases in seeding rate. This supports the findings of Silsbury et al. (1979) and Prioul and Silsbury (1982) who reported an exponential increase in growth rate until DM productions of 2000 to 3500 kg ha^{-1} are reached.

At the 20, 30, 40 and 50 mm planting depths the highest DM productions of 900 - 1200 kg ha^{-1} were obtained at seeding rates between 320 to 640 kg ha^{-1}. These DM productions correlated with the highest number of plants being recorded at 30, 40 and 50 mm planting depths (Table 5). DM production however, was also affected by DM production per plant. Both planting depth and seeding rate had a significant effect on dry matter production per plant in this study (Table 10 and 11).

Table 10. The influence of seeding rate on the dry mass (DM) production per plant on the loamy sand.

Seeding rate (kg ha^{-1})	g $plant^{-1}$
10	0.046 ab*
20	0.051 a
40	0.054 a
80	0.053 a
160	0.041 abc
320	0.040 abc
640	0.028 c
1280	0.034 bc
LSD (P=0.05)	0.0145

* Values followed by the same letter do not differ significantly at the 5% level.

No significant differences were found for increasing seeding rates between 10 and 320 kg ha^{-2}. DM production per plant for these seeding rates varied between 0.04 and 0.054 g $plant^{-1}$ which correlated with earlier results by Kotzé and Agenbag (chapter 4) on loamy sand. The high seeding rates (640 and 1280 kg ha^{-1}) resulted in significantly smaller plants with mean values of 0.028 and 0.034 g $plant^{-1}$ respectively which clearly illustrated the effect of competition at the high seeding rates. This supports earlier findings by Muyekho et al. (1993) who reported significant reductions in production with higher seeding rates.

Table 11. The influence of planting depth on the dry mass (DM) production per plant on the loamy sand.

Planting depth	g $plant^{-1}$
0 mm	0.047 ab*
10 mm	0.055 a
20 mm	0.036 b
30 mm	0.046 ab
40 mm	0.036 b
50 mm	0.039 b
LSD (P=0.05)	0.0126

* Values followed by the same letter do not differ significantly at the 5% level.

The delay in emergence of seedlings observed with deep planting depths resulted in visible stressed plants. This observation was confirmed by the low production per plant with deep planting depths (Table 11). With the exception of the 30 mm planting depth, DM production per plant at the optimum planting depth of 10 mm, was significantly higher than DM production per plant for all planting depths between 20 and 50 mm. This tendency supported earlier findings of White and Robson (1989) and Kotzé and Agenbag (chapter 4). Kotzé and Agenbag (chapter 4) reported DM production per plant at 50 mm planting depth being only 6% of that obtained at 10 mm planting depth in hard setting soils.

3.2.2. Coarse Sand

Dry mass (DM) production (kg ha^{-1} and g $plant^{-1}$) on coarse sand (Table 12) was significantly affected by both seeding rate and planting depth, but the results also showed a significant interaction between seeding rate and planting depth for both parameters (Table 6).

Table 12. The influence of seeding rate (R) and planting depth (D) on dry mass (DM) production (kg ha^{-1}) on the coarse sand.

Seeding Rate (kg ha^{-1})	Planting depth						Mean
	0 mm	10 mm	20 mm	30 mm	40 mm	50 mm	
10	0.0	200.0	160.0	162.2	171.1	193.3	147.8
20	0.0	368.9	388.9	275.5	233.3	315.6	263.7
40	0.0	660.0	731.1	548.9	537.8	580.0	509.6
80	0.0	1297.8	1106.7	1137.8	1048.9	920.0	918.5
160	84.4	2064.4	1973.3	1635.6	1551.1	1380.0	1448.1
320	106.7	3100.0	2675.5	2760.0	2148.9	2793.3	2264.1
640	160.0	4160.0	4042.2	3831.1	3368.9	3284.4	3141.1
1280	217.8	5828.9	5624.5	4971.1	5240.0	4391.1	4378.9
Mean	71.1	2210.0	2087.8	1915.3	1787.5	1732.2	
LSD D (P=0.05) = 244.9							
LSD R (P=0.05) = 282.8							
LSD D x R (P=0.05) = 694.4							

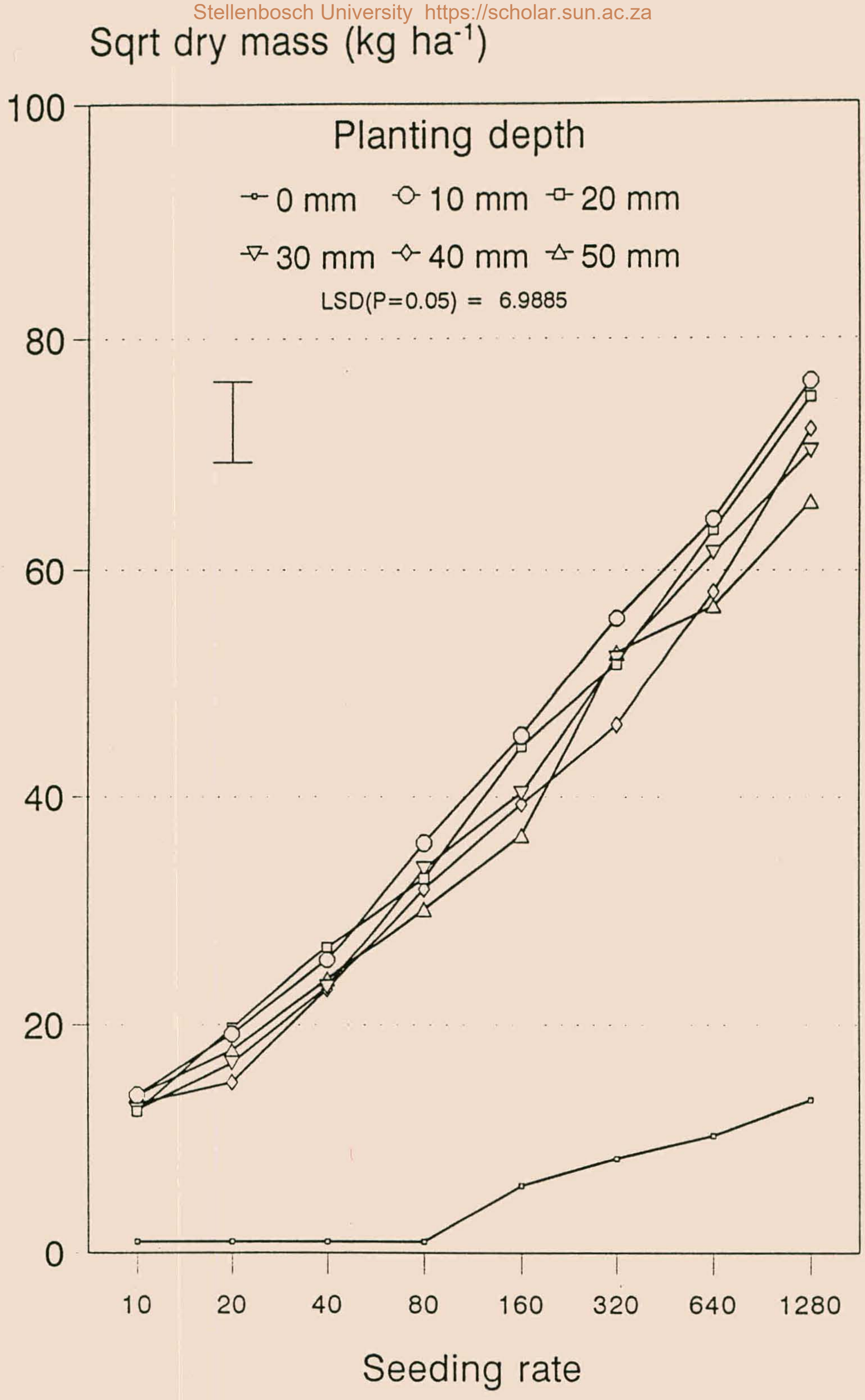

Figure 2. The influence of planting depth and seeding rate on the dry mass production 48 days after planting on a coarse sand soil type (Sqrt = square root).

From Table 12 and Fig. 2 it is clear that DM production (kg ha^{-1}) increased with increasing seeding rates at all planting depths, as also found by Ababneh et al. (1990). DM production, however, showed a declining trend with increasing planting depths between 10 and 50 mm for all seeding rates (Table 12). In general, the highest DM production was obtained at the optimum planting depth of 10 mm for all seeding rates.

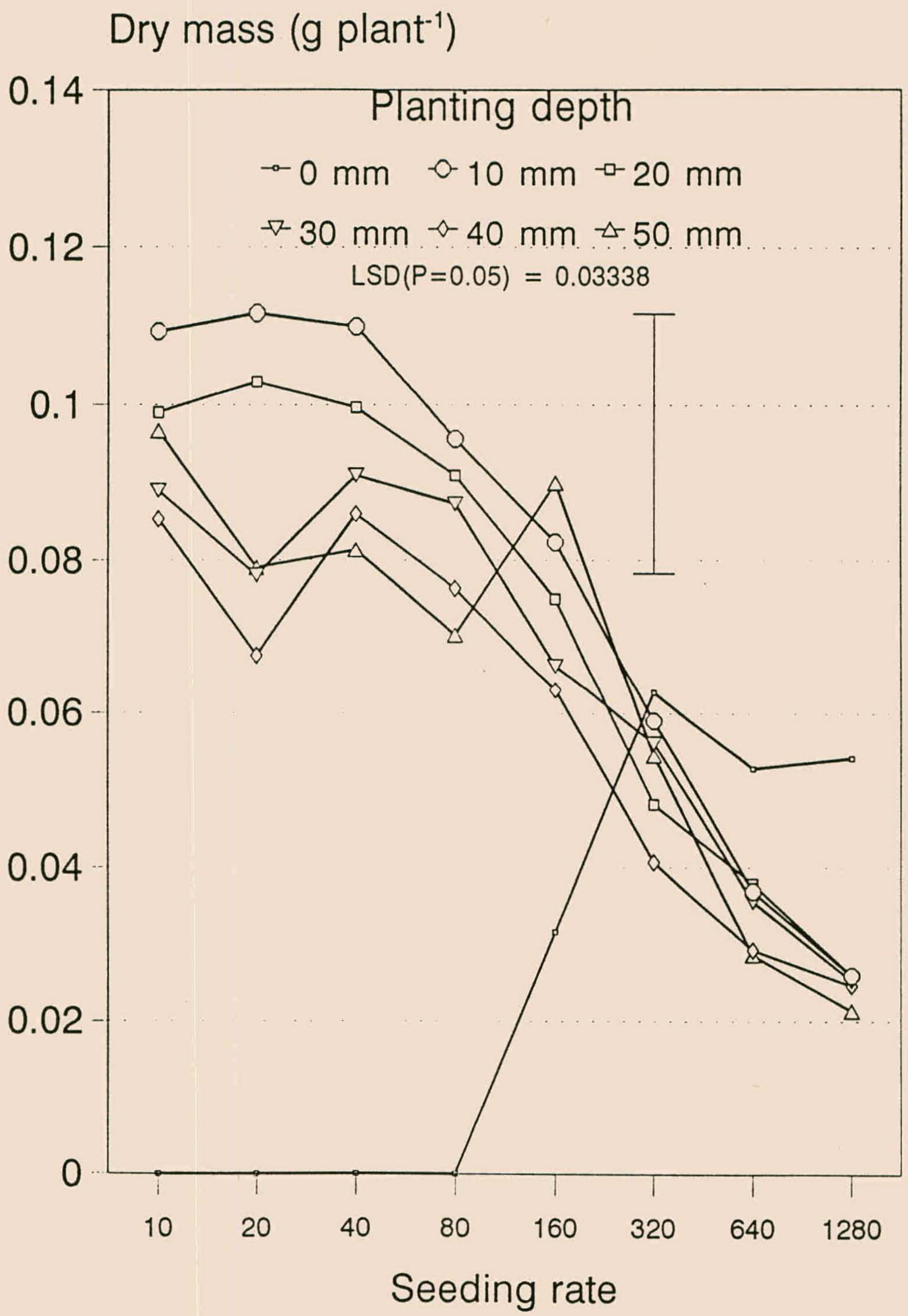

Figure 3. The influence of planting depth and seeding rate on the dry mass production per plant 48 days after planting on a coarse sand soil type.

From Fig. 2 it is clear that although seeding rates and therefore also plant numbers increased exponentially (Table 8) the production curves obtained were almost linear. This implies that production per plant must have declined with increasing seeding rates (Fig. 3). As clearly illustrated at the lower seeding rates, production per plant decreased as planting depth increased from 10 to 50 mm. There was a simultaneous negative effect on production per plant (plant size) as seeding rate increased above 40 kg ha^{-1}. Plants resulting from rates below 40 kg ha^{-1} were significantly larger (approximately 0.08 to 0.11 g $plant^{-1}$) than plants from the higher seeding rates, such as 640 and 1280 kg ha^{-1} (0.02 to 0.04 g $plant^{-1}$). It is clear that production per plant at the lower seeding rates was mostly effected by planting depth which agrees with the earlier findings of Kotzé and Agenbag (chapter 4) who reported reductions of 46% when planting depth was increased from 10 to 50 mm. However with higher seeding rates, the differences between the 10 and 50 mm planting depth treatments became smaller. From Fig. 3 it is clear that there was virtual no difference in DM production per plant at the 1280 kg ha^{-1} treatment between the 10 and 50 mm planting depths. Yet as seeding rates increased above 40 kg ha^{-1} a dramatic reduction in plant size was evident.

4. Conclusions

Although it was not the aim of the experiment to compare different soils, obvious differences between the two soil types were evident.

Seeds sown in soils like the loamy sand in our study, that tend to form surface crusts, were sensitive to planting depths. In such soils increasing planting depth from 10 to 50 mm resulted in percentage of plants emerged at 21 days after planting being reduced from 77 to 43%. However, seeding rate was by far the most dominant factor that affected the establishment of seedlings. Percentage of plants emerged after 21 days were reduced from approximately 70% at 20 kg ha^{-1} to 39 and 22% at 640 and 1280 kg ha^{-1} respectively. It appeared that weaker plants resulting from the delay in emergence at deeper planting depths were more susceptible to competition due to higher seeding rates causing the poor establishment obtained in the loamy sand.

In general DM production correlates with the number of plants established. The highest DM production at 48 days after planting for different seeding rates were obtained at 10 mm planting depth which correlate with the number of seedlings established. However, when total dry mass production were expressed as production per plant (g plant^{-1}) it became clear that deeper planting depths resulted in smaller plants. Similarly the competition created at higher seeding rates caused smaller plants. Plant size were reduced by 44% when comparing plants obtained from 10 and 1280 kg ha^{-1} seeding rates.

In the coarse sand much higher establishment percentages were obtained for the 10 to 50 mm range of planting depths varying between 100 and 80%. Early DM production showed the same tendency than the plant numbers. However, a significant interaction between planting depth and seeding rate became evident when plant size was investigated. At the low seeding rates (10 to 40 kg ha^{-1}) deeper planting depths caused plants to be 27% smaller than plants obtained from the optimum planting depth of 10 mm. The competition caused by the high seeding rates (640 and 1280 kg ha^{-1} treatments) were the most dominant factor that affected plant size as a reduction of almost 80% was obtained when plants from the 640 to 1280 kg ha^{-1} range were compared to plants obtained at the 10 to 40 kg ha^{-1} range.

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CHAPTER 6

THE INFLUENCE OF SWARD DENSITY ON THE SEASONAL PRODUCTION OF FOUR ANNUAL *MEDICAGO* CULTIVARS

Abstract

Annual medics play an important role not only as a rotation crop with wheat, but also as the major feed source for livestock in the western and southern Cape areas of South Africa. The objective of this study was to investigate the effect of different sward densities on the seasonal dry matter production of the most commonly used cultivar of different annual *Medicago* species, namely *M. truncatula* cv Paraggio, *M. polymorpha* cv Santiago, *M. sphaerocarpos* cv Orion and *M. littoralis* cv Harbinger AR, used in the area. Different seeding rates were used to obtain sward densities of 78, 156, 312, 625, 1250, 2500 and 5000 plants m^{-2}. Trials were conducted at Welgevallen experimental farm in Stellenbosch during the 1994 and 1995 seasons. Establishment data, dry matter production (monitored during the season at regular intervals) and pod and seed production data were collected. Although plant numbers and therefore sward density increased with increased seeding rate in both seasons, the percentage of plants established declined with the result that the targeted sward densities were not obtained for most cultivars at the highest seeding rates. Increasing sward densities resulted in significant higher dry mass productions, especially early in the season. Rate of dry mass production during the growing season was however lower for the high sward densities compared to low sward densities which resulted in the narrowing of differences in total dry mass production by the end of the season. Except for the lowest sward density treatment no significant differences in seed production was obtained from the different swards. Higher sward densities resulted in higher pod and seed production but differences in the seed to pod ratio for different cultivars caused significant

differences between cultivars.

Keywords: Dry matter production, Seeding rate, Sward density, *Medicago* species, Medic cultivars.

1. Introduction

Annual medics are the most popular pasture component used in short rotation ley farming systems in the western and southern Cape areas of South Africa. Seasonal dry matter production of medics is therefore very important as insufficient early winter production could limit stocking rates (Evans, et al., 1992) at a time of the year when other sources of grazing are very limited. Early winter also coincides with the last trimester of pregnant ewes or early lactation, when feed requirements are at their highest.

Plant density at regeneration significantly influence subsequent dry matter production. Brownlee and Scott (1974) found positive correlations between pod mass before regeneration and subsequent dry mass production of the pasture as well as between plant density and pod production. They regarded 250 plants m^{-2} as a minimum prerequisite for a productive medic pasture. In weedy situations, Puckridge and French (1983) found that 1000 to 2000 plants m^{-2} were needed to be competitive against weeds. Very high plant densities may however cause self thinning due to competition (Silsbury, et al., 1979; Prioul and Silsbury, 1982; Kotzé and Agenbag, chapter 5). In general, seed reserves of 200 kg ha^{-1} and sward densities of 400 to 500 plants m^{-2} will be sufficient for sustainable medic cereal rotation systems (Carter and Lake, 1985; Carter, 1987; Jones and Carter, 1989).

Although various factors such as grazing management (Chaichi and Carter, 1993; Kotzé, et al., 1995), rainfall and temperature regimes (Ababneh, et al., 1990b) affected dry mass production, this study was conducted to quantify seasonal dry mass production which can be expected from different sward densities of different medic cultivars/species most commonly used in the western and southern Cape wheat producing areas of South Africa.

2. Material and methods

The trials were conducted during 1994 and 1995 at Welgevallen experimental farm (33°54'S, 18°52'E) on a clay loam soil described as an Oakleaf soil type (MacVicar, et al., 1977). A representative soil sample which was analysed indicated a satisfactory pH(KCl) of 5.6, as well as high phosphorus (161 mg kg^{-1}) and potassium (119 mg·kg^{-1}) content. As a result of this no fertilizer was applied.

The rainfall for the experimental period (Table 1), showed a typical winter rainfall with total annual precipitation of about 700 mm which is regarded as the longterm average for the experimental site.

Table 1. Monthly rainfall received during 1994 and 1995 at the experimental site.

Months	Rainfall (mm)	
	1994	1995
January	42.8	17.1
February	3.3	7.8
March	15.9	12.8
April	58.6	22.5
May	47.4	95.1
June	278.9	136.6
July	96.0	146.8
August	39.0	123.6
September	45.0	24.8
October	27.5	89.3
November	13.2	12.2
December	16.0	51.3
Total annual rainfall	683.6	739.9

Cultivars of the four most commonly used *Medicago* species namely *M. truncatula* cv Paraggio, *M. polymorpha* cv Santiago, *M. sphaerocarpos* cv Orion and *M. littoralis* cv Harbinger AR were sown at seven different seeding rates to obtain sward populations of 78, 156, 312, 625, 1250, 2500 and 5000 plants m^{-2}.

Before planting, each of the cultivars was inoculated with the recommended *Rhizobium meliloti* strain. Plot size was 5 x 1.2 m and 3 replications were used. To ensure an even distribution of the seed, seed was sown shallow (10-30mm deep) with an eight row cone seeder on a well prepared, weed free seedbed after a rainy period on 17 May and 18 May during 1994 and 1995 respectively. Grass weeds were controlled with a selective herbicide about 6 weeks after sowing. To obtain the required sward densities, 1000 seed weight of the different cultivars were determined in both years and were used to calculate required seed mass per plot. Twenty percent extra seed was sown to allow for establishment losses. Cultivars were sown at equivalent of the following seeding rates (Table 2):

Table 2. Seeding rate (kg ha^{-1}) of different cultivars sown to obtain required sward densities

a) 1994

Sward density (plants m^{-2})	Paraggio	Santiago	Orion	Harbinger AR
78	5.81	5.23	5.46	2.31
156	11.63	10.46	10.92	4.63
312	23.25	20.92	21.84	9.25
625	46.57	41.91	43.75	18.54
1250	93.15	83.82	87.51	37.08
2500	186.30	167.64	175.02	74.16
5000	372.60	335.28	350.04	148.32

b) 1995.

Sward density (plants m^{-2})	Paraggio	Santiago	Orion	Harbinger AR
78	6.31	4.72	6.45	2.33
156	12.63	9.44	12.90	4.65
312	25.25	18.88	25.80	9.31
625	50.59	37.82	51.68	18.64
1250	101.18	75.64	103.35	37.29
2500	202.35	151.29	206.70	74.58
5000	404.70	302.58	413.40	149.16

Plant populations were determined by counting four sub-plots of 25 x 25 cm per plot 20 days after planting. Broadleaf weeds were counted 90 days after planting during 1994 when differences between treatments became obvious. Dry mass production was measured by cutting 0.25 m^2 samples from each plot every two to three weeks during the season. Pod production was determined at the end of the season, when all plant material was dry, by collecting all the pods within a 0.25 m^2 area from each plot. After pod mass was determined, the samples were threshed to determine seed mass as well as seed to pod ratios.

Data was subjected to an analysis of variance (ANOVA). To fit regressions between treatments and dry mass production, dry mass production data was submitted to a logarithmic transformation ($\ln(y) = a + bx$). Student's least significant differences (LSD) were calculated at $P = 0.05$ to compare treatment means as described by Snedecor and Cochran (1980).

3. Results and discussions

Where significant interactions occurred between treatments only data from such interactions will be presented and discussed.

3.1 Sward dynamics

The statistical analysis of the sward population characteristics for 1994 and 1995 is summarised in Table 3.

Table 3. Analysis of variance (ANOVA) for the sward population characteristics during (a) 1994 and (b) 1995.

(a)

Source	DF	Medic plants m^{-2}		% Plants established		Weed plants m^{-2}	
		MS	Pr>F	MS	Pr>F	MS	Pr>F
Block	2	130328.2	0.0077	143.2	0.7440	116281.3	0.0001
Cultivar (C)	3	462904.4	0.0001	2416.1	0.0041	52092.4	0.0039
Sward density (S)	6	13123915.7	0.0001	1562.9	0.0090	965717.8	0.0001
C x S	18	137694.8	0.0001	283.0	0.8915	15036.5	0.1477
Error	52	24077.7		481.4		10327.4	

(b)

Source	DF	Medic plants m^{-2}		% Plants established	
		MS	Pr>F	MS	Pr>F
Block	2	184114.4	0.0027	2342.6	0.0001
Cultivar (C)	3	553636.3	0.0001	7611.8	0.0001
Sward density (S)	6	16708419.2	0.0001	786.8	0.0042
C x S	18	177087.3	0.0001	142.2	0.8325
Error	52	27668.2		215.4	

Although significant interactions between cultivar and sward density occurred for plants established in both 1994 (Table 3a) and 1995 (Table 3b), sward density dominated the number of plants m^{-2} in both years as can be seen in differences between mean sum of squares (MS) of various factors.

Table 4. Number of plants established (plants m^{-2}) during (a) 1994 and (b) 1995 as influenced by different cultivars and targeted sward density.

(a)

Sward density (plants m^{-2})	Paraggio	Santiago	Orion	Harbinger AR	Mean
78	75 mno*	65 no	76 lmno	49 o	66
156	151 lmno	153 klmno	173 klmno	141 lmno	154
312	331 ijkl	326 ijklm	316 ijklmn	228 jklmno	300
625	649 gh	515 hi	464 hij	408 hijk	509
1250	1330 f	1130 f	1138 f	796 g	1099
2500	2446 c	1990 d	2332 c	1728 e	2124
5000	3422 a	3551 a	2334 c	2824 b	3033
Mean	1201	1104	976	882	
LSD (P=0.05) = 255					

(b)

Sward density (plants m^{-2})	Paraggio	Santiago	Orion	Harbinger AR	Mean
78	57 kl	79 kl	73 kl	49 l	65
156	144 kl	180 jkl	183 jkl	92 kl	150
312	236 jkl	305 ijkl	316 ijkl	241 jkl	275
625	448 hij	549 hi	620 h	325 ijk	486
1250	1042 g	1288 fg	1272 fg	617 h	1055
2500	1769 e	2106 d	2252 d	1461 f	1897
5000	3091 b	3987 a	4096 a	2661 c	3459
Mean	970	1213	1259	778	
LSD (P=0.05) = 273					

* Values followed by the same letter within each year do not differ significantly at the 5% level.

Plants m^{-2} increased significantly with increasing sward densities, but the target of 5000 plants m^{-2} was not obtained with any of the cultivars (Table 4). Higher sward density treatments of 2500 and 5000 plants m^{-2} in fact had a negative effect on the percentage of plants established (Table 5).

Table 5. The effect of sward density on the percentage of plants established during 1994 and 1995.

Sward density (plants m^{-2})	1994	1995
78	85.0 a*	82.9 b
156	99.2 a	95.9 a
312	96.3 a	88.0 ab
625	82.9 a	77.7 bc
1250	87.6 a	84.4 ab
2500	87.9 a	77.8 bc
5000	62.7 b	68.0 c
LSD (P=0.05)	18.5	12.2

* Values followed by the same letter do not differ significantly at the 5% level.

During both seasons the 5000 plants m^{-2} sward density treatment resulted in the lowest percentage of plants established, namely 63 and 68% during 1994 and 1995, respectively. These results supported the findings of Silsbury, et al. (1979), Prioul and Silsbury (1982), and Kotzé and Agenbag (chapter 5) who reported significant reductions in percentage plants established with sward populations in excess of 2000 plants m^{-2}.

Table 6. The effect of different cultivars on the percentage of plants established during 1994 and 1995.

Cultivars	1994	1995
Paraggio	95.5 a*	75.6 b
Santiago	89.1 a	97.3 a
Orion	89.7 a	99.2 a
Harbinger AR	70.4 b	59.0 c
LSD (P=0.05)	13.96	9.2

* Values followed by the same letter do not differ significantly at the 5% level.

From Table 6 it is clear that in comparison with the other cultivars Harbinger AR resulted in a significant lower percentage of plants established during both seasons. This might be due to the significant smaller seedlings obtained with Harbinger AR compared to the other cultivars tested (Kotzé and Agenbag, chapter 4).

All plots showed broadleaf weed infestations during the 1994 season. Although not one of the objectives of the experiment, weed numbers were counted. These data showed significant lower numbers of weeds with increasing medic populations (Table 7).

Table 7. The effect of sward density on the weed numbers (plants m^{-2}) present during 1994.

Sward density (plants m^{-2})	Weeds
78	778 a*
156	444 b
312	317 c
625	177 d
1250	19 e
2500	4 e
5000	5 e
LSD (P=0.05)	85

* Values followed by the same letter do not differ significantly

at the 5% level.

The higher sward densities, therefore, not only resulted in self thinning as shown in Table 5, but also suppressed the weeds effectively. Puckridge and French (1983) also found that sward densities of 1000 to 2000 plants m^{-2} were sufficient to compete effectively against weeds.

Table 8. The effect of different cultivars on the weed numbers (plants m^{-2}) present during 1994.

Cultivars	Weeds
Paraggio	228.2 b*
Santiago	225.5 b
Orion	346.7 a
Harbinger AR	248.0 b
LSD (P=0.05)	64.7

* Values followed by the same letter do not differ significantly at the 5% level.

Our results however showed that numbers of weed plants in the plots of cultivar Orion were significant higher in comparison with the other cultivars which might indicate that this cultivar is less competitive against weeds (Table 8).

3.2. Dry mass production

The statistical analysis of the seasonal dry mass production obtained during 1994 and 1995 is summarised in Tables 9 and 10.

Table 9. Analysis of variance (ANOVA) for the seasonal (days after planting) dry matter production obtained during 1994.

Source	DF	21 days		40 days		57 days		76 days	
		MS	Pr>F	MS	Pr>F	MS	Pr>F	MS	Pr>F
Block	2	1067	0.0002	36439	0.0001	62877	0.0173	418577	0.0228
Cultivar (C)	3	8569	0.0001	154104	0.0001	429614	0.0001	664077	0.0009
Sward density (S)	6	21110	0.0001	520380	0.0001	1688363	0.0001	6099790	0.0001
C x S	18	1602	0.0001	22945	0.0001	37811	0.0034	67238	0.8373
Error	52	102		2694		14273		102702	

Source	DF	93 days		111 days		127 days	
		MS	Pr>F	MS	Pr>F	MS	Pr>F
Block	2	265672	0.2667	759928	0.7083	4948773	0.2415
Cultivar (C)	3	1276062	0.0008	3320229	0.2217	13784514	0.0117
Sward density (S)	6	7881250	0.0001	14537213	0.0001	33163440	0.0001
C x S	18	201254	0.4474	2613950	0.3020	3996811	0.3123
Error	52	195830		2188361		3380888	

Table 10. Analysis of variance (ANOVA) for the seasonal (days after planting) dry matter production obtained during 1995.

Source	DF	21 days		35 days		49 days		63 days		77 days	
		MS	Pr>F	MS	Pr>F	MS	Pr>F	MS	Pr>F	MS	Pr>F
Block	2	1356	0.0046	2501	0.3255	13095	0.3462	101561	0.1738	265879	0.3735
Cultivar (C)	3	14664	0.0001	103755	0.0001	562777	0.0001	1614209	0.0001	4116371	0.0001
Sward density(S)	6	39011	0.0001	347175	0.0001	1399440	0.0001	4250601	0.0001	7667473	0.0001
C x S	18	4071	0.0001	22304	0.0001	94446	0.0001	182083	0.0005	457551	0.0653
Error	52	226		2181		12095		56114		264726	

Source	DF	91 days		106 days		121 days		138 days	
		MS	Pr>F	MS	Pr>F	MS	Pr>F	MS	Pr>F
Block	2	805199	0.0906	493991	0.5054	671434	0.6882	1028816	0.6328
Cultivar (C)	3	12386175	0.0001	35890759	0.0001	22320993	0.0001	44634232	0.0001
Sward density(S)	6	13075969	0.0001	18821227	0.0001	12378411	0.0001	16243646	0.0001
C x S	18	714035	0.0131	1565492	0.0160	1899793	0.4109	2616793	0.3155
Error	52	319456		713417		1783903		2228295	

It is clear that in both years a significant interaction between sward density and cultivars existed in early season. As the season progressed however, the interaction became insignificant with only sward density and cultivar treatments remaining significant.

When data was submitted to a logarithmic transformation and regression curves were fitted, analysis of variance for both the intercept and gradient showed significant differences within sward densities and cultivars in 1994 while significant interactions between sward densities and cultivars were found for these parameters in 1995 (Table 11).

Table 11. Analysis of variance (ANOVA) for the dry mass production regressions ($\ln(y) = a + bx$) during 1994 and 1995.

Source	DF	1994				1995			
		Intercept		Gradient		Intercept		Gradient	
		MS	Pr>F	MS($x10^{-3}$)	Pr>F	MS	Pr>F	MS($x10^{-3}$)	Pr>F
Block	2	4.8917	0.0001	0.4881	0.0001	0.0937	0.6196	0.0020	0.9060
Cultivar (C)	3	10.0129	0.0001	0.8770	0.0001	7.2608	0.0001	0.1935	0.0001
Sward density (S)	6	29.5421	0.0001	1.1281	0.0001	29.8220	0.0001	1.0859	0.0001
C x S	18	0.3056	0.2673	0.0419	0.2295	0.6729	0.0002	0.0785	0.0001
Error	52	0.2463		0.000032		0.1939		0.0204	

It is clear from Tables 9 and 10 that sward density dominated the dry mass production obtained especially during the first 90 days after planting which confirms findings of Evans, et al. (1992) that seedling density accounted for up to 73% of variation in dry mass production during winter months.

Although initial dry mass productions were the highest for high sward densities, differences in dry mass production decreased towards the end of the season (Fig. 1 and Table 12)

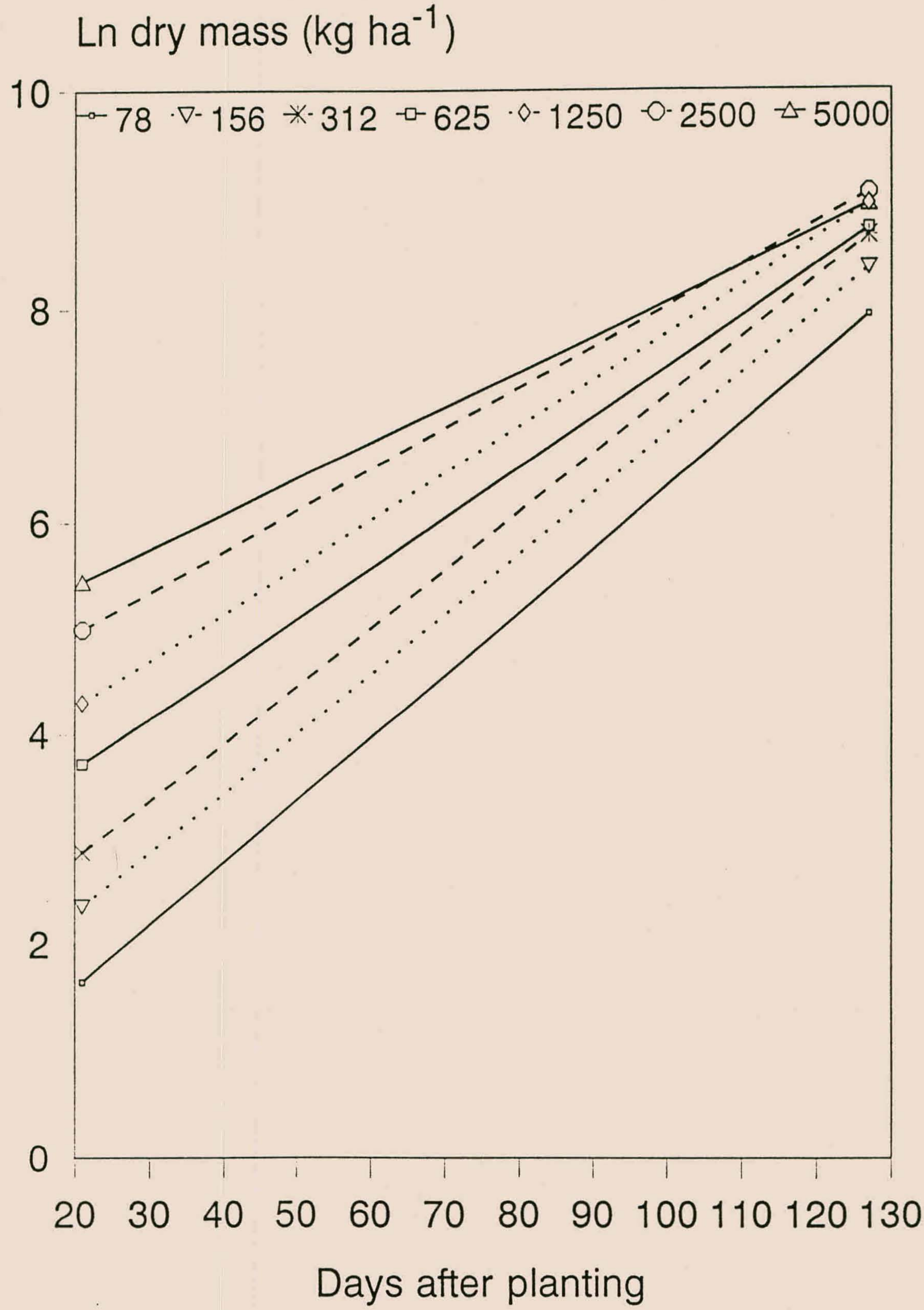

Figure 1. The effect of sward density (plants m^{-2}) on the seasonal dry mass production obtained during 1994 at Welgevallen.

From Table 12 it is clear that the gradients of regressions for dry mass production decreases with increasing sward densities. The largest gradients were thus found for sward densities of 78 to 312 plants m^{-2} and the smallest gradient for 5000 plants m^{-2}.

Table 12. The effect of sward density on the dry mass production regressions (ln(y) = a + bx) fitted on the 1994 data.

Sward density (plants m^{-2})	Intercept (a)	Gradient (b)	R-square
78	0.4038 g	0.0594 a	0.86
156	1.1658 f	0.0567 a	0.88
312	1.7227 e	0.0547 a	0.87
625	2.7269 d	0.0473 b	0.86
1250	3.3868 c	0.0439 b	0.86
2500	4.1956 b	0.0383 c	0.84
5000	4.7562 a	0.0331 d	0.83
LSD (P=0.05)	0.4174	0.0048	

* Values followed by the same letter do not differ significantly at the 5% level.

Dry mass production therefore significantly increased with increasing sward densities at the start of the season. Thereafter, rate of production was highest at the 78 to 312 plants m^{-2} treatments and declined as sward density increased. Silsbury et al. (1979) and Prioul and Silsbury (1982) reported exponential growth until dry mass productions of 2000 to 3500 kg ha^{-1} are reached, followed by a constant crop growth rate and a declining growth rate which coincide with seed production and plant maturation. Consequently, dry mass levels of 2000 to 3500 kg ha^{-1} were reached at earlier stages during the growing season which resulted in lower gradients for the dry mass production regressions fitted for the higher sward densities. The range of total dry mass production at the end of the season in this study (from 1,5 to 6 t ha^{-1} at 78 and 5000 plants m^{-2} respectively), were similar to yields obtained by Taylor et al. (1979), Puckridge and French (1983), Alston and Puckridge (1986), Clarkson et al. (1987), Ababneh et al. (1990a), Cocks (1990) and

Mason and Rowland (1992).

When comparing different cultivars it became clear that Paraggio showed the highest dry mass production at the beginning of the season, followed by Orion which produced significant more dry mass than Santiago. Harbinger AR on the other hand showed the lowest early season dry mass production (Table 13).

Table 13. Dry mass production regressions (ln(y) = a + bx) of the different cultivars obtained from the 1994 data.

Cultivars	Intercept (a)	Gradient (b)	R-square
Paraggio	3.3176 a	0.0421 c	0.67
Santiago	2.4194 c	0.0508 b	0.75
Orion	2.8856 b	0.0423 c	0.65
Harbinger AR	1.6406 d	0.0562 a	0.78
LSD (P=0.05)	0.3158	0.0036	

* Values followed by the same letter do not differ significantly at the 5% level.

Regressions for dry mass production however, showed the largest gradient for Harbinger AR during the season followed by Santiago, Orion and Paraggio (Fig. 2). Strong interplant competition which is associated with dry mass productions in excess of 2000 kg ha^{-1} (Silsbury et al., 1979; Prioul and Silsbury, 1982) must therefore have set in earlier in the case of Paraggio, allowing Harbinger AR and Santiago to narrow the difference in production towards the end of the season.

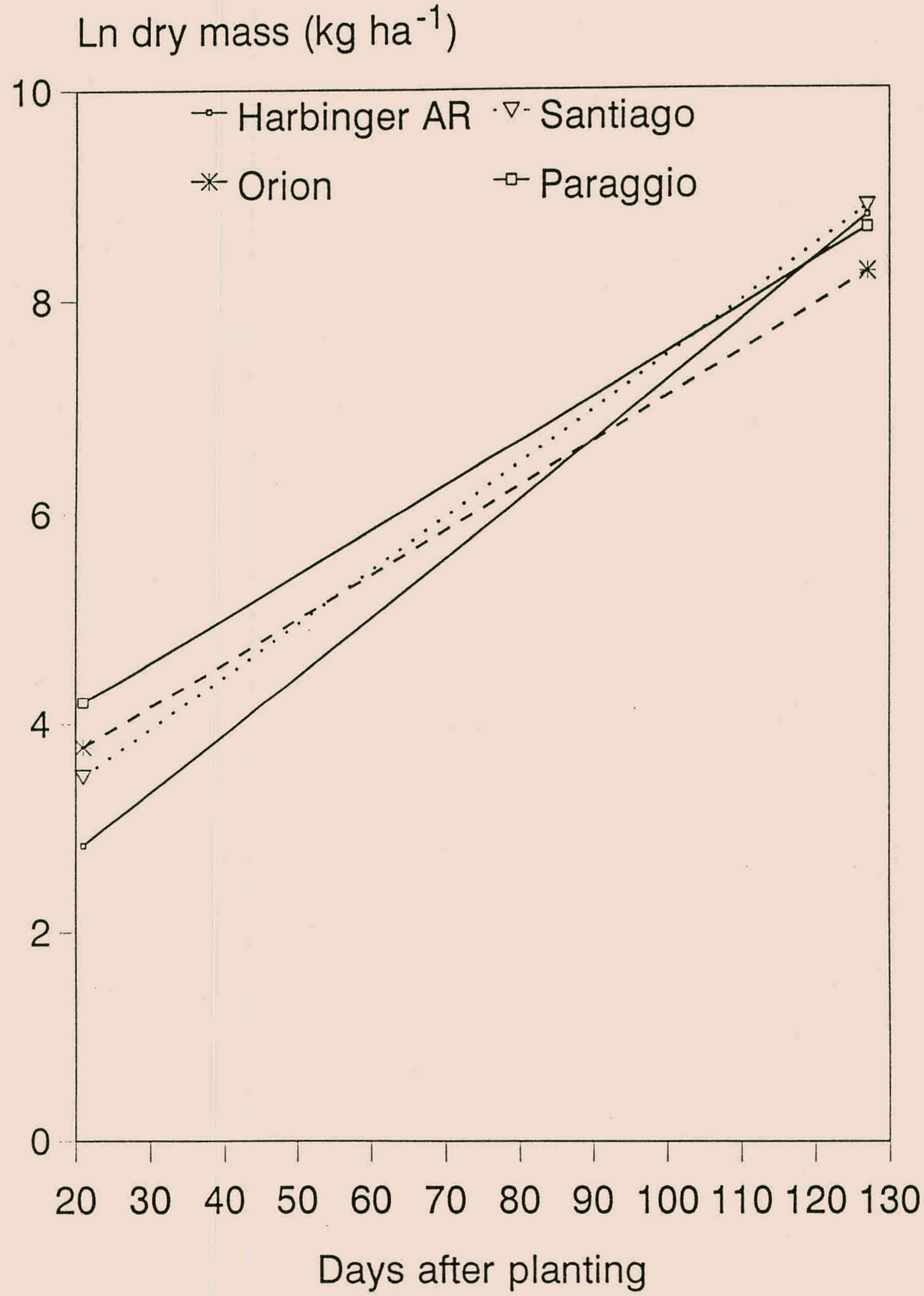

Figure 2. The influence of different medic cultivars on the seasonal dry mass production obtained during 1994 at Welgevallen.

During the 1995 season a significant interaction (Table 11) between sward density and cultivars existed (Fig. 3). When dry mass production for each of the four cultivars was compared with results of 1994, similar trends were found but production was higher due to a higher rainfall during the latter part of the season (Table 1) resulting in a slightly longer growing season.

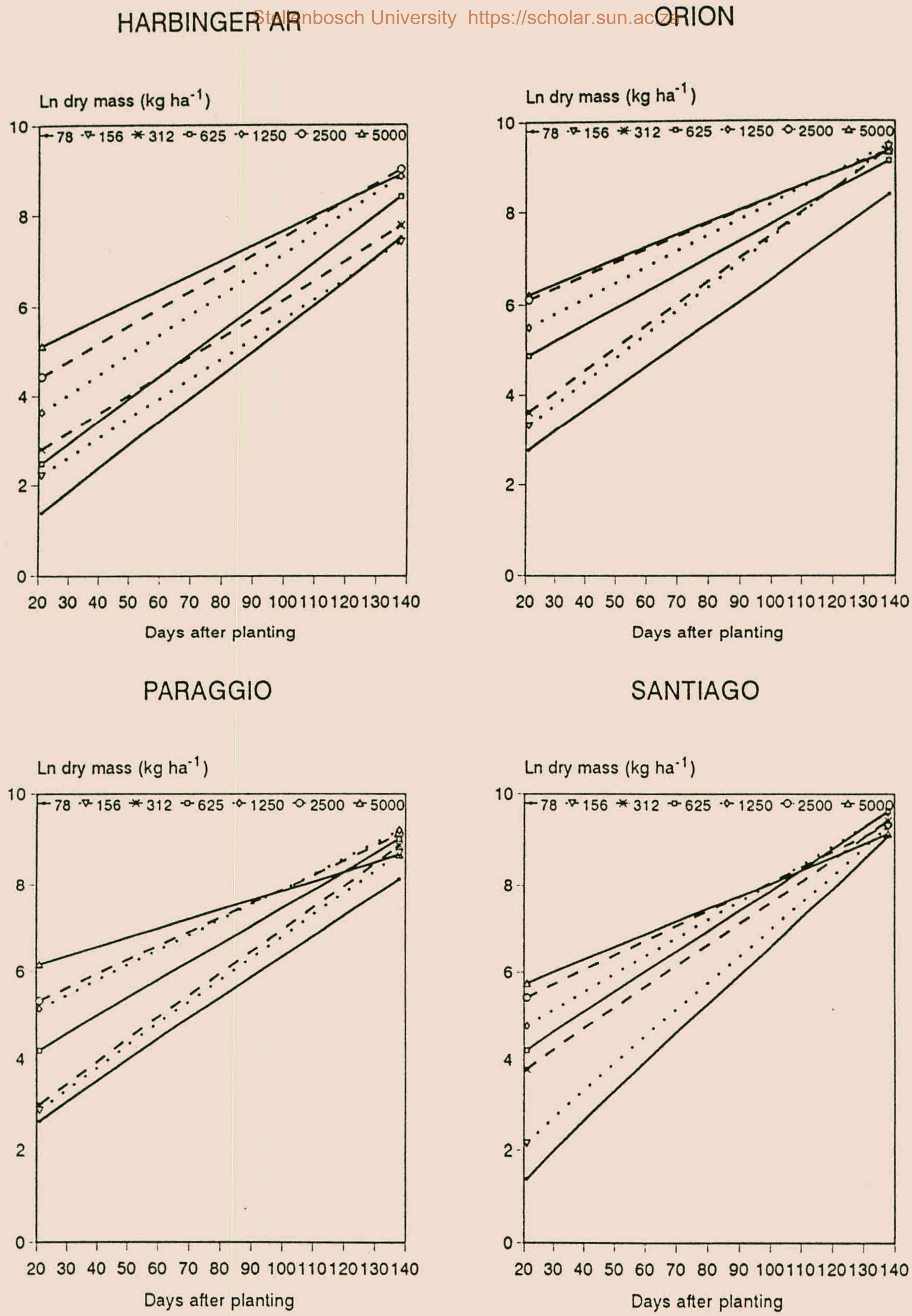

Figure 3. The effect of sward density (plants m^{-2}) on the seasonal dry matter production of different medic cultivars obtained during 1995 at Welgevallen.

Initial dry mass production (Table 14 and Fig. 3) of all four cultivars increased significantly with increasing sward densities in 1995.

Table 14. The effect of sward density on the dry mass production regressions (ln(y) = a + bx) of the different cultivars obtained from the 1995 data.

Cultivar/ Sward density	Intercept (a)	Gradient (b)	R-square
Paraggio			
78	1.6225 klm	0.0472 bcd	0.90
156	1.7990 kl	0.0500 bcd	0.91
312	1.9242 jk	0.0503 bc	0.95
625	3.1224 gh	0.0427 defg	0.91
1250	4.4040 cd	0.0348 hijk	0.88
2500	4.6445 bc	0.0324 ijkl	0.87
5000	5.7078 a	0.0214 m	0.71
Santiago			
78	0.0013 o	0.0658 a	0.91
156	0.8676 mn	0.0610 a	0.95
312	2.7817 hi	0.0480 bcde	0.87
625	3.2395 fgh	0.0463 bcdef	0.87
1250	3.8896 def	0.0413 efh	0.88
2500	4.7199 bc	0.0334 ijkl	0.84
5000	5.1325 ab	0.0289 jkl	0.82
Orion			
78	1.7457 kl	0.0480 bcde	0.89
156	2.1924 ijk	0.0524 b	0.90
312	2.5765 hij	0.0492 bcd	0.90
625	4.1007 cde	0.0363 ghij	0.71
1250	4.7782 bc	0.0340 hijkl	0.83
2500	5.5332 a	0.0276 jklm	0.81
5000	5.6633 a	0.0264 lm	0.91
Harbinger AR			
78	0.2868 no	0.0523 b	0.89
156	1.2711 lm	0.0445 cdef	0.83
312	1.8904 kl	0.0426 def	0.86
625	1.4000 klm	0.0507 bc	0.84
1250	2.6878 hi	0.0446 cdef	0.89
2500	3.6084 efg	0.0391 fghi	0.90
5000	4.4385 bcd	0.0323 ijkl	0.833
LSD (P=0.05)	0.7226	0.0074	

* Values followed by the same letter do not differ significantly at the 5% level.

In general, rate of subsequent dry mass production, as illustrated by the regression gradients (Table 14), decreased with increasing sward densities for all cultivars and confirm trends observed for 1994. Although sward density was the dominant factor affecting dry mass production during the season, minor cultivar differences existed. For cultivar Harbinger AR, decreases in regression gradients with increasing sward densities were much smaller than for cultivar Santiago and to a lesser extend also, for cultivars Paraggio and Orion (Fig. 3). These cultivar differences were however too small to draw any conclusions.

3.3. Pod and seed production

Analysis of variance for pod and seed production showed significant differences between sward density and cultivars in both years (Table 15a and 15b). Seed mass as a percentage of pod mass (percentage seed) on the other hand were only affected by cultivars in both years.

Table 15. Analysis of variance (ANOVA) for the pod and seed production during (a) 1994 and (b) 1995.

(a)

Source	DF	Pods		Seed		% Seed	
		MS	Pr>F	MS	Pr>F	MS	Pr>F
Block	2	232749	0.5663	30725	0.6565	18.49	0.6806
Cultivar (C)	3	5041652	0.0001	606547	0.0001	251.73	0.0030
Sward density (S)	6	1728301	0.0014	338240	0.0007	104.65	0.0583
C x S	18	288723	0.7823	48855	0.8196	35.37	0.7536
Error	52	404892		72429		47.72	

(b)

Source	DF	Pods		Seed		% Seed	
		MS	Pr>F	MS	Pr>F	MS	Pr>F
Block	2	3757989	0.0005	356228	0.0009	15.98	0.0397
Cultivar (C)	3	4924446	0.0001	261137	0.0015	1157.21	0.0001
Sward density (S)	6	2034110	0.0006	165574	0.0035	8.52	0.1111
C x S	18	712266	0.0741	63014	0.1568	7.85	0.0724
Error	52	423825		44030		4.65	

Pod and seed production increased with increasing sward densities in both years (Table 16). All treatments produced more than 150 to 200 kg of seed ha^{-1} which are considered as the minimum seed mass required for successful medic regeneration (Carter and Lake, 1985; Cocks, 1992). If considered that 5 sheep ha^{-1} could eat 260 kg ha^{-1} of seed from October to early May (Thorn, et al., 1988), it became clear that the lowest sward density of 78 plants m^{-2} did not produced enough seed for a sustainable medic pasture if it is used for summer grazing by five or more sheep ha^{-1}.

Table 16. The effect of sward density on the pod and seed mass (kg ha^{-1}) production during 1994 and 1995.

Sward density (plants m^{-2})	1994		1995	
	Pods	Seed	Pods	Seed
78	1057.9 d*	279.3 d	1034.9 b	282.9 b
156	1459.2 cd	443.4 cd	1807.1 a	531.0 a
312	1686.8 bc	527.5 bc	1873.9 a	537.0 a
625	1830.1 abc	470.7 cd	2122.7 a	584.3 a
1250	1978.6 abc	595.9 abc	2168.2 a	617.0 a
2500	2069.2 ab	717.8 ab	1805.3 a	522.8 a
5000	2239.0 a	805.9 a	2298.9 a	655.7 a
LSD (P=0.05)	528.0	223.3	540.2	174.1

* Values followed by the same letter do not differ significantly at the 5% level.

In contrast to 1994, in 1995 pod and seed production did not increased significantly for sward densities between 156 and 5000 plants m^{-2}. The same tendency applied for sward densities between 1250 and 5000 plants m^{-2} in 1994. These results supported the findings of Muyekho et al. (1993) that high sward densities could have a negative effect on seed production.

In 1994 Orion produced significantly less pods and seed when compared to the other cultivars (Table 17). In 1995 Paraggio and Santiago produced significantly more seed ha^{-1} in comparison with Orion and Harbinger AR. The same tendency was shown for the percentage of seed mass produced from the different cultivars in both years. Santiago had the highest percentage of seed from pods (35 to 38%), followed by Harbinger (30%), Paraggio (25 to 28%) and Orion (21 to 26%) supporting the earlier findings of Kotzé et al. (1995).

Table 17. Pod and seed production (kg ha^{-1}) obtained from different cultivars during 1994 and 1995.

Cultivars	1994			1995		
	Pods	Seed	% Seed	Pods	Seed	% Seed
Paraggio	2181.6 a*	641.7 a	28.7 bc	2396.6 a	611.2 a	24.7 c
Santiago	1850.8 a	645.3 a	34.6 a	1645.5 b	635.4 a	38.5 a
Orion	1003.4 b	275.7 b	26.4 c	2149.9 a	467.7 b	21.2 d
Harbinger AR	1899.4 a	591.4 a	30.9 ab	1309.4 b	406.0 b	30.2 b
LSD (P=0.05)	399.2	168.8	4.3	408.4	131.6	1.4

* Values followed by the same letter do not differ significantly at the 5% level.

4. Conclusions

From the study it became clear that the higher sward densities resulted in lower percentage of plants established, but these swards were more competitive resulting in effective weed suppression during 1994.

Seasonal dry matter production was significantly influenced by sward density during both years, especially for the first 90 days after planting. High sward densities led to significant higher dry mass production early in the season, but subsequent rates of production (gradients) were the highest at low sward densities. Due to this, differences in total dry mass production diminished towards the end of the season.

Dry mass production at the beginning of the growing season for Paraggio was the highest followed by Orion, Santiago and Harbinger AR. As for sward densities, subsequent rate of production over the season showed the reversed order.

Although a positive correlation between sward density and pod and seed production were found, differences were small by the end of the season. During 1995 no significant differences in seed production (average of 575 kg ha^{-1}) were found between 156 and 5000 plants m^{-2}. Seed production at the lowest sward density (78 plants m^{-2}) was only approximately 50% of the above mentioned average. Seed production at sward densities of 78 plants m^{-2} will therefore not be sufficient to ensure a sustainable medic cereal rotation system if grazed by five or more sheep ha^{-1} during the summer months.

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CHAPTER 7

SUMMARY AND CONCLUSIONS

The numerous benefits (improved soil fertility, nitrogen fixation, less fungicidal diseases, improved control of problem weeds and more stable cereal yields) of a medic cereal rotation system is well known. In spite of similar climatic conditions between the Mediterranean areas of South Africa and Australia such rotation systems are at present applied to only 20% of the potential area of the western and southern Cape. Poor regeneration and persistence of medics after the cropping phase is one of the major factors deterring farmers from incorporating medics in crop rotation systems. This may be the result of various factors such as the availability of viable seed reserves and the distribution thereof in the soil profile.

In this study, which consists of several experiments, the influence of various aspects such as the effect of digestion of medic seeds by sheep on the recovery thereof; the effect of tillage methods used during seedbed preparation for wheat on the wheat yield and subsequent regeneration and production of medics; and the effect of soil type, planting depth and seeding rate on the establishment and dry mass production of different medic cultivars were investigated. To quantify the relationship between sward density of regenerated medic pastures and seasonal dry mass and seed production, a field study was conducted over two years to determine the effect of sward density on dry mass production during the season and eventual seed production at the end of the season.

In the first experiment pod and seed characteristics of different sub-species as well as the effect of digestion by sheep on seed recovery were investigated. This study showed that *M. truncatula* cultivars had the largest pods, followed by *M. littoralis* and *M. polymorpha*. In contrast to the larger pods however, *M. polymorpha* and *M. littoralis* showed significant higher seed to pod ratio's when compared to the *M. truncatula* cultivars. This higher seed content was also expressed in higher crude protein, digestible protein and digestible organic matter.

From the results it became clear that hardseededness, seed size and the amount of seed ingested had affected seed recovery after ingestion by sheep. Santiago (*M. polymorpha*) had significant higher recovery rate compared to Harbinger AR (*M. littoralis*) and cultivars of *M. truncatula*. Therefore cultivars like Santiago (*M. polymorpha*) will be less susceptible to over utilization during the summer months which will result in depletion of seed reserves and poor regeneration in the long term.

In the second experiment the effect of different tillage systems on the placement of medic seed reserves in the soil profile and subsequent regeneration was studied. The results showed that tine implements, regardless the depth of cultivation, maintained significantly more seed in the topsoil (0-50 mm) than disc and mouldboard ploughing. Shallow tine cultivations (0-50 mm) however, could result in lower wheat yields. Seedbed preparations for wheat with tine implements that cultivate soil to a depth of 150 mm proved to be more sustainable regarding seed placement, medic regeneration, medic dry mass production and wheat yields in this study.

When establishment of different medic species in coarse sand, loamy sand and sandy loam soils and at different planting depths were investigated, significant differences between soil types were found. The best results in regard to time to emergence, percentage plants emerged and dry mass production at 21 and 48 days after planting were obtained in the sandy loam soil. The optimum planting depth was found to be 10 mm. Deeper planting depths resulted in a delay in emergence, decline in rate and percentage emerged and subsequent lower dry mass production, especially in the hard setting loamy sand. When seed was left on the soil surface, results for all parameters measured were inferior to all other seeding depths tested. In contrast to the general believe that Harbinger AR is best suited to sandy soils, results showed no evidence of certain cultivars/species performing better on specific soil types. In general best dry mass productions on all soil types tested were obtained with Santiago.

Due to the poor results obtained with deeper planting depths, the cummulative strength of seedlings obtained from higher seeding rates on the negative effect of planting depth was studied. Soils like the loamy sand that tend to form surface crusts however, remained sensitive towards planting depth. In these soil increased seeding densities above 2000 to 3000 seeds m^{-2} resulted in self thinning due to interplant competition. It appeared that the weaker plants resulting from the deeper planting depths were more susceptible to competition arising from high seeding densities. In the loamy sand, the effect was exaggerated due to clods that formed at deeper planting depths which forced seedlings to grow around clods through the cracks.

In this experiment, highest dry mass production at 48 days after planting was still obtained at 10 mm planting depth. At deeper planting depths highest dry mass production was obtained at seeding rates of 320 to 640 kg ha^{-1} which correlated with the highest number of plants established.

In the sandy soil, dry mass production per plant showed a significant interaction between planting depth and seeding rate. At low seeding rates (10 to 40 kg ha^{-1}) deeper planting depths caused a decline in plant size (production per plant). Plant size at the high seeding rates of 640 and 1280 kg ha^{-1} were significantly reduced, but at these high plant populations, planting depth had little effect on production per plant.

Seasonal production of the different *Medicago* species / cultivars was significantly influenced by sward density. Initial dry mass production increased significantly with increased sward populations, but higher rates of production obtained from the lower sward densities during the season, caused proportional differences in production to narrow towards the end of the season. Although the seed production obtained from the 78 plants m^{-2} treatment was only 50% of that of the higher sward densities, enough seed was still produced to ensure successful regeneration after a cereal cropping rotation, provided that grazing was properly managed.

It can be concluded that although differences between dry mass production diminished towards the end of the season due to inter-plant competition in dense swards, dense swards will result in significant higher dry mass productions early in the season when pasture availability is very limited in the western and southern Cape. From COMBUD (1998) figures it appear that the gross margins per ha from 3 ewes per ha^{-1} and monocultural wheat production with conventional tillage practises, compare favourable. As sward density was the dominant factor affecting seasonal dry mass production most, the effect thereof on the dry mass productions obtained and dry mass requirements of different stocking rates are illustrated in Table 1.

Table 1. The influence of sward density (plants m^{-2}) on the seasonal dry mass production (kg ha^{-1}) of medics at Welgevallen during a) 1994 and b) 1995 as well as the dry mass requirements of different stocking rates.

a)

Sward density	Days after planting							Pod (kg ha^{-1})	Seed (kg ha^{-1})
	21	40	57	76	93	111	127		
78	5	15	74	351	624	**1453**	**1564**	1057	279
156	10	35	130	469	813	2219	3010	1459	443
312	11	59	212	707	**1207**	2377	3228	1686	527
625	27	124	370	**1231**	1519	3213	4537	1830	470
1250	50	261	585	1441	2041	4208	5043	1978	595
2500	84	374	**937**	1971	2740	4337	6283	2069	717
5000	122	**604**	1041	2241	2598	4217	6081	2239	805
1 ewe ha^{-1}	68	130	185	247	302	361	413	171	52
3 ewes ha^{-1}	**205**	**390**	**556**	**741**	**907**	**1082**	**1238**	513	156
5 ewes ha^{-1}	341	650	926	1235	1511	1804	2063	855	260

b).

Sward density	Days after planting									Pod (kg ha^{-1})	Seed (kg ha^{-1})
	21	35	49	63	77	91	106	121	138		
78	6	16	50	122	321	560	**1565**	**1196**	**2946**	1034	282
156	9	27	70	243	587	**1027**	2309	2394	4221	1807	531
312	16	36	172	360	**957**	1463	2546	2579	4782	1873	537
625	35	94	308	**731**	1189	2013	3625	3429	5286	2122	584
1250	61	185	**587**	1129	2009	2986	4525	4123	5909	2168	617
2500	103	295	763	1431	2169	3082	4719	3488	6271	1805	522
5000	164	**475**	891	1605	2400	2952	4475	3763	5687	2296	655
1 ewe ha^{-1}	68	114	159	205	250	295	345	393	449	171	52
3 ewes ha^{-1}	**205**	**341**	**478**	**614**	**751**	**887**	**1034**	**1180**	**1346**	513	156
5 ewes ha^{-1}	341	569	796	1024	1251	1479	1723	1966	2243	855	260

As regenerating medics will germinate earlier (mid April) than the medics sown in mid May in this study, one can assume that early production will be significantly higher. Therefore the targeted 2500 plants m^{-2} treatment which resulted in 2000 plants m^{-2}, will most probable meet the requirements of 3 ewes ha^{-1} at 35-40 days after planting. To ensure the establishment of 2000 plants m^{-2}, at least 150 kg germinable seed per ha distributed in the 10 to 30 mm soil profile will be needed. Seeds placed on the soil surface or deeper than 30 mm will result in poor regeneration and consequent lower dry mass production, especially if the soil is prone to crusting. From this study it is evident that in order to ensure the placement of medic seed reserves in the 10-30 mm soil profile, seedbed preparation for the cereal crops should be done by tine implements. Although deep ploughing with a mouldboard plough may result in higher cereal yields, it will result in decreased regeneration of medics. It is also important to remember that if medic pastures are grazed during summer months, care must be taken to ensure that at least 200 kg seed ha^{-1} are left on the field to ensure good regeneration. Due to a better recovery rate after utilization by sheep from *M. polymorpha* cultivars like Santiago, seed reserves removed by grazing will be less critical for this cultivar.

If low sward populations exist however, the data clearly show that such paddocks could be transformed into productive pastures with the correct management. The objective in such situations would be to maximize seed production at the end of the season and to minimize summer utilization in order to ensure sufficient seed reserves for future regeneration.

In general however, 400-500 plants m^{-2} and 200 kg seed ha^{-1} of seed reserves in the topsoil are regarded as two important prerequisites for productive medic pastures (Carter and Lake, 1985; Carter, 1987; Jones and Carter, 1989; Cocks, 1992). A schematic representation of important guidelines of a medic rotation system is presented in Fig. 1.

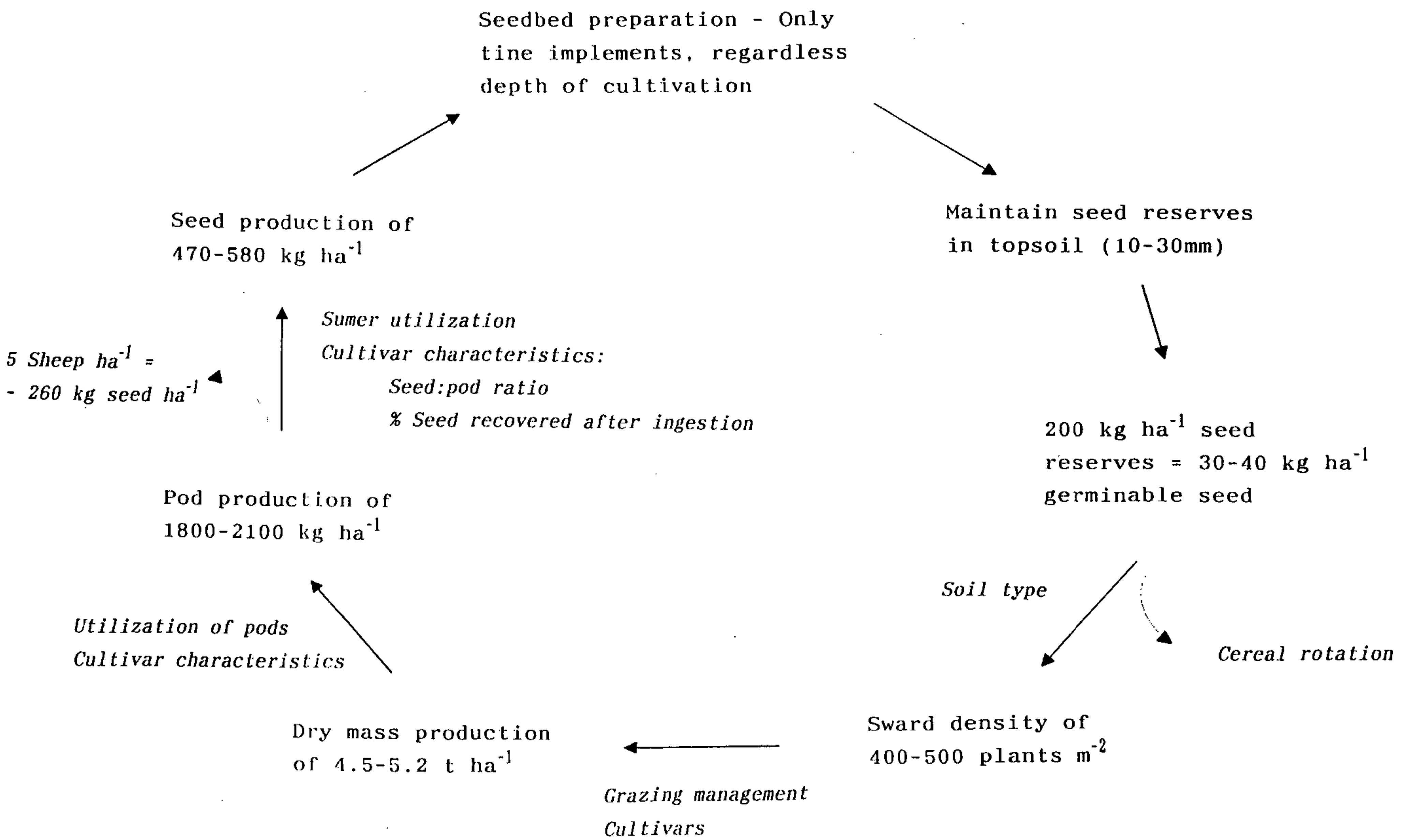

Figure 1. Schematic representation of important guidelines for sustainable medic rotation systems

From Fig. 1 it is clear that only tine implements, regardless depth of cultivation, should be used in seedbed preparation of cereal crops. This will ensure the distribution of medic seed reserves in the topsoil (prefrable in the 10-30mm zone). Seed reserves of 200 kg seed ha^{-1} will result in 30-40 kg of germinable seed per ha which resulted in 400-500 medic plants m^{-2} in our study. The effect of soil type on establishment percentages as reported earlier should be noticed. The targeted 625 plants m^{-2} resulted in 500 plants m^{-2} which produced 4,5 and 5,3 t ha^{-1} of dry mass at the end of the season in 1994 and 1995 respectively. Pod production of 1800-2100 kg ha^{-1} can be expected from such swards which will result in 470-580 kg seed ha^{-1} according to our study. Although cultivar differences in seed to pod ratio's and recovery after ingestion and level of summer utilization of pods by animals will influence the eventual amount of seed to supplement seed reserves, this will ensure successful regeneration of the pasture after the cereal crop.

Therefore it is clear that if good management is practised, medic cereal rotation systems could be successfully implemented in the western and southern Cape areas of South Africa.

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