COMPARATIVE RESPONSES OF FODDER AND GRAIN TEFF (*ERAGROSTIS TEF* (ZUCC.) TROTTER) CULTIVARS TO SPATIAL, TEMPORAL AND NUTRITIONAL MANAGEMENT

by

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ABSTRACT

Teff has its origin in Ethiopia as grain crop, while in South Africa it is primarily a forage crop for hay and recently as summer grazing pasture. The response of teff herbage and grain production to planting date, growth stage at cutting, seeding rate and N fertilizer application was studied. Previously limited research data were available for teff production in South Africa.

Spring plantings (September to October) are required to maximise total herbage yield with 9.40, 8.48 and 7.64 t DM ha^{-1} recorded for 1996/97, 1997/98 and 1998/99 respectively. Summer plantings (November to December) give maximum herbage yield from the first cut, yielding 4.42, 4.72 and 3.78 t DM ha^{-1} for 1996/97, 1997/98 and 1998/99 respectively. The exact planting date is season dependent. Temperature and rainfall determine the beginning of the growth season regarding favourable conditions for teff germination and growth.

Herbage yield of cut 1 increases with advancement in growth stage at cutting. Cutting at the vegetative and piping stages gives most number of cuts, up to five yielding 7.45 t DM ha^{-1} (1996) while the full flowering stage gives the least (one or two cuts, 4.75 and 7.72 t DM ha^{-1} in 1996 and 1997 respectively). Yield is also affected by environmental conditions influencing germination, biomass accummulation and regrowth after cutting and by lodging. A trade-off results between herbage quantity and quality. Yield increases while quality decreases with advancing phenological stage, resulting in reduced digestibilty and CP and increased fibre content.

Seeding rate differences were manifested primarily in weed infestation level, which varied between cultivars depending on leafiness and associated sward density. Nitrogen application levels gave maximum response between 75 and 150 kg N ha^{-1}, with some cultivar differences. Split N application according to expected yield distribution related to planting date is recommended.

Grain yield response to seeding rate and N fertilization levels could not be established. Heavy grain losses through thunderstorms and wet conditions at grain maturity precluded yield measurements.

Teff yield responses are influenced by daylength, environmental factors, such as temperature and rainfall, and phenological stage at cutting. These variables influence biomass accumulation and regrowth.

PREFACE

This thesis documents research conducted at the University of Natal from September 1996 to December 2001 under the supervision of Professor PL Greenfield assisted by Professor A Cairns, Professor PJ Zacharias, Dr PE Bartholomew.

I declare that the results contained in this thesis are from my own original work except where acknowledged. I also declare that these results have not otherwise been submitted in any form for any degree or diploma to any university.

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SB Kassier

January 2002

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LIST OF CHEMICAL NAMES

Active ingredients and product names of fungicides, insecticides and herbicides mentioned in the thesis

active ingredient	product name
Fungicides	
2-methoxyethyl mercuric chloride	• Ceresan
tridemorph	
Insecticides	
aldrin 40 % WP	withdrawn in 1992 in South Africa
carboryl 85% WP	• Carboryl • Sevin 850 WP
cypermethrin 25% e.c.	• Cypermethryn EC
cypermethrin 5% ULV	
diazinon 60%	
endosulfan 35% e.c.	• Cropchem Endosulfan EC • Endosulfan EC • Thionex 35 EC
endosulfan 25% ULV	• Thiodan ULV
fenitrothion 50% e.c.	
fenitrothion 50% ULV	
lindane 20 % e.c	
lindane dust	
trichlorfon 95%	• Dipterex 95 SP • Trichlorfon 950 SP
Herbicides	
2,4-D (dimethyl amine salt)	• 2,4-D Amine 480 • 2,4-D Amine 480 SL • 2,4-D Amine Soluble
2,4-D (iso-octyl ester)	• 2,4-D Ester 720 • 2,4-D Ester 500 EC • 2,4-D Ester EC
2,4-D 36% + MCPA 31%	•
ametryne + prometryne	• Gesatan 500 FW
bromoxynil + CMPP	• ARD 12131 50%
chlorosulfuron	• All Farmers Chlorosulfuron 750 WP • Colony 750 WP
diclofop-methyl	• Hoelon 36 Ec • Ravenger
dichloprop 620	• 2,4-DP
mecoprop + bromoxynil + ioxynil	• Brittox 50.5%
mecoprop + MCPA	• Bromuron 60%
glyphosate - isopropylammonium	• Glyphosate • Roundup
MCPA (potassium salt)	• MCPA 415 • MCPA 625
MSMA	• MSMA
paraquat dichloride	• Gramoxone • Paraquat SL
4-chloro-2-butynyl-3-chlorocarbanilate	• Barban

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1 INTRODUCTION

Teff is a determinate, obligate, annual C4 grass with the Kranz-type anatomy and high chlorophyl a/b ratios (Kebede *et al.* 1989). Teff has its centre of origin (Tefera *et al.* 1990) and centre of diversity in Ethiopia (Chapman 1992). Teff is thus an indigenous grain of Ethiopia and the single most important cereal crop in that country (Umeta & Faulks 1988). It is the most important cereal in area grown and in cash value (Jones *et al.* 1978). Teff occupies one-third of the area under cereal production which is estimated to be between 2 x 10^6 ha (Mamo & Parsons 1987; Kebede *et al.* 1989) and 1.4 x 10^6 ha (Tefera *et al.* 1992) annually. Teff accounts for one-half of Ethiopia's annual grain production (Skerman & Riveros 1990). In terms of human nutritional contribution teff has been calculated to contain 41g of the 65g of protein contained in the typical daily Ethiopian diet (Jansen *et al.* 1962).

In 1866 the Royal Botanic Gardens at Kew distributed teff seed to India, Australia, the United States of America (USA) and South Africa. In 1916 Burt Davy introduced teff to California, Malawi, Zaire, Sri Lanka, New Zealand, Argentina and again to India and Australia. Sykes in 1911 introduced the crop to Zimbabwe, Mozambique, Kenya, Uganda and Tanzania, while in 1940 Horiutz introduced teff to Palestine (Ketema 1986). From all these introductions teff became an established crop outside Ethiopia only in South Africa. More recently teff has also been grown to some extent in the USA. In South Africa the use has been exclusively for hay production while in the USA[1] teff is planted mainly for grain with some hay production in South Dakota (Twidwell *et al.* 1991).

In 1936 the main gramineous hay crop in South Africa was teff, with a total of 0.14 x 10^6 ha being planted annually (Pole Evans *et al.* 1936). Of the area planted to teff most was planted in the then Transvaal followed by the Orange Free State. Presently the formal seed trade in South Africa sells 1000 tons of teff seed annually (SANSOR 2000). If this seed is sown at an average seeding rate of 15 kg ha^{-1}, then there are estimated to be 67 x 10^3 ha teff planted annually in South Africa. Not all of this area planted would be for hay production as some seed is used for re-vegetation purposes. There is also a fair amount of teff seed traded informally between farmers. Consequently it is difficult to determine the exact extent of teff production in South Africa.

Recently, dairy farmers have started utilizing teff as a grazing pasture for the late summer and early autumn period. This is to fill the gap between successive ryegrass (*Lolium multiflorum*) pastures. This adds a new dimension to teff utilization is South Africa and possibly world-

[1] W. Carlson, The Teff Company, Caldwall Idaho USA

wide, there has been the notion that teff is not suitable for grazing purposes. The success of grazing teff could expand the use of the species substantially, especially in southern hemisphere countries such as Australasia and South America.

2 LITERATURE REVIEW OF *ERAGROSTIS TEF* (ZUCC.) TROTTER (TEFF), A SPECIES DIVERSE IN ADAPTATION AND UTILISATION

2.1 THE ORIGIN OF *ERAGROSTIS TEF* (ZUCC.) TROTTER

The centre of origin (Vavilov 1957 in Engels *et al.* 1991) and the centre of diversity of *Eragrostis tef* (Zucc.) Trotter (teff) is in Ethiopia (Chapman 1992). It is postulated that teff was domesticated during times of food scarcity (Engels *et al.* 1991). According to both Ketema (1986) and Engles *et al.* (1991), the northern Highlands of Ethiopia are the most likely site of domestication. Some information about the time of domestication can be deduced from archaeological records. Teff seeds have been found in the pyramids of Dassur, in Egypt, which were built in 3349 BC (Ketema, 1986). Teff seeds were also found in Jewish ruins dating back to 1400 to 1300 BC (Mengesha 1966). However the exact reason why, when and how teff was domesticated in Ethiopia is unknown (Ketema 1986). From these archaeological discoveries there is no doubt that teff is an ancient crop but its exact origin has been lost in antiquity and can only be postulated.

If teff was domesticated from a wild grass species, the question arises as to what species it was. Some light has been shed on the most likely ancestor of teff by using leaf phenolic chromatography and seed protein electrophoresis. Both processes indicate that *E. pilosa* is the most likely ancestor of *E. tef* (Engles *et al.* 1991). Teff is a tetraploid with a chromosome number of 2n=40, which is the same as *E. pilosa* (Jones 1988).

The origin of the name "teff" is also not entirely clear, although there are two reported possibilities. The name teff may come from either the Amharic word "taffa", meaning "lost" and referring to the small grain size, or from the Arabic word "tahf" which is the name of a similar wild species of *Eragrostis* used in South Arabia in times of food scarcity (Engles *et al.* 1991).

In recent times there has been a lack of consistency in the spelling of the common name for *E. tef*. According to Dr H. Tefera (pers.comm)[1], originally and formally it was spelt "teff" in Ethiopia, although more recently there has been a move towards spelling it as "tef". Outside Ethiopia it is commonly spelt "t'ef". According to W. Carlson (pers.comm)[2], "teff" is more correct, if one considers the original Amharic pronunciation.

The botanical name of teff has also been changed numerous times since the species was first described. In 1775 Zuccagni first gave teff the botanical name *Poa tef* Zucc. In 1781 Jacquin named it

[1] Dr H. Tefera, Alemaya University of Agriculture, Agricultural Research Centre, P.O. Box 32, Debre Zeit, Ethiopia.

Poa abyssinica Jacq., and in 1827 the name was changed to *E. tef* (Jacq.) Link. Then in 1918 Trotter changed the name to *E. tef* Trott. (Alkämper 1973). Subsequently it has been changed to *E. tef* (Zucc.) Trotter.

2.2 TAXONOMY AND GENERAL BOTANICAL DESCRIPTION OF *ERAGROSTIS TEF* (ZUCC.) TROTTER

It is difficult to give one general botanical description for the species *E. tef* since it is morphologically variable. This is the result of the domestication process whereby teff was most likely domesticated from *E. pilosa* beginning at around 3000 BC. In the process farmers all over Ethiopia selected types which suited their particular agro-ecological conditions. They selected types for various climatic conditions that may prevail in different seasons so that they had a choice of types suited to the conditions of a particular season. In addition, Ethiopia itself is a diverse environment. Consequently the species now consists of a vast number of morphologically different types. Therefore the description of the species as a whole is confined to the following:
Eragrostis tef is a tropical to sub-tropical annual C4 grass. The inflorescence is a panicle ranging from very loose to completely contracted (Engels *et al.* 1991). The description according to Gibbs Russel *et al.* (1990) is as follows:
"Annual; loosely tufted (erect); up to 600 mm tall. Leaf blades up to 300 mm long and up to 4 mm wide. Spikelets are from 5.5 – 9.0 mm long and from 1.5 – 2.0 mm wide. Inflorescences are open or contracted and branches are usually more than 40 mm long, flexible and slender, pedicels slender. Spikelets with rachilla persistent and the lemmas and paleas remain intact at maturity. The upper glume is ½ - ⅔ the length of the lemma above in the intact spikelet. Lemmas are 2.0 – 2.7 mm long. The palea keels are scaberulous. There are 3 anthers that are 0.3 – 0.5 mm long. The caryopsis is oblong."

According to Chippendall (1955), the description is as follows:
"An annual, forming scanty tufts. The culms are up to 120 cm high in selected cultivated plants, but often only 20 cm when growing as a weed, glabrous and finely striate. Leaf sheaths are glabrous and somewhat keeled. The collar is distinct and often brownish. Leaf blades are loosely rolled or expanded, usually rather narrow with a setaceous tip. The inflorescence is very large and lax in relation to the size of the plant, the branches are long, filiform and flexible. The lower branches are in a pseudo-whorl or a few clustered together, very rarely single. Spikelets have long flexible pedicels. The glumes are unequal with the lower two, little more than half the length of the upper. The glumes are acute to acuminate. The lemmas have prominent green nerves with the lowest lemma 2 – 3 mm long. The uppermost lemma is distinctly shorter (1.5 – 2.0 mm long). The anthers are 0.3 mm long and

[2] W. Carlson, The Teff Company, P.O. Box A, Caldwall, Idaho 83606, USA

the grains 1 – 1.5 mm long, oblong to ovate-oblong in outline seen in face view. The embryo is more than half as long as the grain." This description seems to be based on plants with an open inflorescence with no coloration.

The taxonomy of teff is as follows (Constanza *et al.* 1979):

Family	Poaceae
Sub-family	Eragrostoideae
Tribe	Eragrosteae
Genus	Eragrostis

However, according to Cheverton & Chapman (1989) the sub-family is Chloridoideae. Hence there is some inconsistency regarding the taxonomic classification.

2.3 THE DIVERSITY OF *ERAGROSTIS TEF* (ZUCC.) TROTTER

2.3.1 Agro-ecological diversity

Agro-ecological diversity refers to the diversity in the environment in which the crop is produced and relates particularly to rainfall, altitude and edaphic conditions. The considerable variation in the Ethiopian environment, both spatially and temporally, has resulted in teff evolving into numerous ecotypes (Cheverton & Chapman 1989). These diverse conditions have given rise to vast genetic diversity, but also diversity in the adaptation of these ecotypes to different agro-ecological conditions.

The rainfall ranges or rainfall data quoted in some of the literature are somewhat ambiguous. It is not always clear whether the given data are annual or seasonal rainfall. If it is seasonal rainfall then the exact time period over which the rainfall occurs is not clear. It could refer to the growing season of the year or to the growing season of that particular crop. The data from this literature do at least give some indication of the rainfall regimes teff is grown in.

The rainfall range of which teff is tolerant is extensive. Teff can be grown in areas with seasonal rainfall ranging from 300 mm, constituting water stress areas, to high rainfall areas receiving 1000 mm (Ketema 1986; Engels *et al.* 1991). Skerman & Riveros (1990) report the rainfall range to be 950 mm to 1500 mm and a maximum of 2500 mm, but also state that teff is highly adapted to marginal rainfall regions. For very fast maturing types as little as 150 mm seasonal rainfall is sufficient for growth (Cheverton & Chapman 1989). These inconsistent reports on the rainfall range to which teff is tolerant could likely be related to the diversity found in the species where authors may have reported with respect to some types and inadvertently not considered the species as a whole. However, it may nonetheless be concluded that teff can grow in regions ranging from semi-arid through to humid, high rainfall areas. This adaptability makes teff suitable for many areas in southern Africa.

The teff ecotypes growing in the lower rainfall regions have useful drought escaping mechanisms and can thus tolerate water stress conditions. Such drought escaping mechanisms include fast growth rate and the ability of the grain to ripen with residual soil water (Cheverton & Chapman 1989; Engels *et al.* 1991; Riley *et al.* 1994; Stallknecht *et al.* 1993; Tefera *et al.* 1992). Such plants mature in 45 to 60 days and consequently have lower water requirements (Tefera *et al.* 1992) than the longer season types. In practical terms in Ethiopia this means that if, towards the end of the rainy season, all other crops have failed due to erratic rainfall, teff can be planted (Cheverton & Chapman 1989) and still produce grain since all the grains that have been pollinated will ripen without further rain (Jones 1988). Consequently teff is a useful rescue or catch crop (Stallknecht *et al.* 1993). These characteristics may have some application in terms of the effects of the El Nino – Southern Ocellation phenomenon.

In the literature various authors state varying altitudinal ranges suitable for growing teff. However, none of them state a latitudinal reference with the altitude range. This makes the stated lower and upper boundaries for teff production somewhat indistinct. In addition these boundaries are to some extent arbitrary since individual plants within a population can usually be found or bred to grow and produce beyond these natural distribution limits. Nonetheless, the altitude ranges give an indication of the environmental parameters to which the species is adapted the species is adapted.

In Ethiopia, which lies between the latitudes 4°N and 18°N, teff grows in a wide altitudinal range, from sea level to above 3000 m above sea level (asl) (Alkämper 1975). Teff is however mostly cultivated from sea level up to 2800 m (Engels *et al.* 1991; Ketema 1986). According to Mersie & Parker (1983) and Tefera *et al.* (1992), teff is cultivated from 300 m to 2800 m asl while Tefera *et al.* (1990) report the altitudinal range to be 300 m to 2500 m for cultivation. According to Skerman & Riveros (1990), teff grows from sea level to 1800 m in Kenya and in Ethiopia. The white seeded types are grown from 1800 m to 2400 m while the brown seeded types are grown above 2400 m. Mersie & Parker (1983) refer to the altitude range 1700m to 2400 m as the most favourable for growing teff while Alkämper (1973) reports teff to grow at an altitude of 3000 m with its distribution restricted by frost above 3000 m. From these various accounts regarding favourable altitude ranges for teff production, it should be possible to grow teff anywhere in South Africa and possibly even in parts of the Lesotho Highlands during the summer season.

Teff is tolerant of a wide range of soil types and the associated edaphic conditions. It is cultivated on soils with various physical and chemical properties (Engels *et al.* 1991). Teff grows on soils ranging from sandy loam through to the heavy clays or vertisols (Cheverton & Chapman 1989; Ketema 1986; Jones 1988; Jutzi *et al.* 1988; Skerman & Riveros 1990; Tefera *et al.* 1992). A common problem on vertisols is waterlogging (Cheverton & Chapman 1989; Jones 1988; Jutzi *et al.* 1988) and teff is tolerant of such anaerobic conditions (Cheverton & Chapman 1989; Engels *et al.* 1991; Jones 1988; Ketema 1986; Mersie & Parker 1983; Riley *et al.* 1994; Skerman & Riveros 1990; Stallknecht *et al.* 1993; Tefera *et al.* 1992). The Ethiopian Highlands, which are termed the "cradle of teff", consist mainly of soils that are prone to waterlogging (Engels *et al.* 1991). Considering that vertisols cover 80 million hectares of Africa (Jutzi *et al.* 1988), it is a very useful attribute which can assist in making such heavy clay, waterlogged areas, which are marginal to much cultivated agriculture, productive to some extent. There seems to be no information available on acid soil tolerance in teff.

It is apparent that teff has the ability to grow under a wide range of agro-ecological conditions and more specifically has the ability to produce in areas with limited agricultural potential. According to Jones (1988) teff also has the ability to produce higher seed yields than other major cereals under adverse conditions, such as moisture stress or waterlogging (Riley *et al.* 1994).

This diversity within the species gives teff adaptation far outside its centre of origin and possibly it may have a useful niche for both forage and cereal production in many parts of the world. This could include, not only African countries, but also Australia, South America and the USA.

2.3.2 Morphological diversity

Morphological diversity will be discussed in terms of the following characteristics, namely seed colour, inflorescence colour, inflorescence type, panicle length, leaf width, culm thickness, maturity period, grain yield per plant and mass per seed.

Seed colour varies from white to yellowish brown to dark brown and various intermediate colours (Engels *et al.* 1991). The very dark brown seeds are often referred to as red (Berhe *et al.* 1989). According to Alkämper (1973) some types have purple seed.

There are certain agro-ecological and growth characteristics, chemical characteristics and price implications associated with seed colour. As already mentioned, in Ethiopia the white-seeded teff is usually grown at the lower altitudes, i.e. up to 2400 m above sea level, and brown-seeded teff at the higher altitudes, i.e. above 2400 m (Skerman & Riveros 1990). Ecotypes with drought-escaping mechanisms characterised by rapid growth rates are mostly brown-seeded types (Tefera *et al.* 1992). In general the brown-seeded teff types produced higher yields under less favourable growing conditions than does the white-seeded teff (Alkämper 1973).

There are some chemical differences associated with seed colour. Mengesha (1966) reports purple seeded teff to be higher in K and Al compared with other seed colours, while the white-seeded teff is slightly higher in Mn. During fermentation, red-seeded teff was found to have lower maltose and maltotriose percentages than white-seeded teff. This is related to the high tannin content, which cereals with red-brown bran layers are known to have. Tannin acts as an inhibitor of α-amylase (Umeta & Faulks 1988). As a general rule the darker the seed colour the richer the flavour. Thus foods produced from white seeds have a blander taste than those from brown seeds (BOSTID 1996).

The price of teff grain is also associated with seed colour, especially in Ethiopia where the white grain commands a higher price on the markets than the brown grain (Alkämper 1973; Cheverton & Chapman 1989). The white grain is the preferred grain in Ethiopia as it produces a very light coloured injera, a traditional bread made from teff (Alkämper 1973; Skerman & Riveros 1990).

Inflorescence colour is variable between ecotypes and is determined by lemma colour (Berhe *et al.* 1989). The inflorescence colour is varied and may be whitish green, olive grey, pink, purple, or various combinations of these colours (Engels *et al.* 1991). Alkämper (1973) categorised the inflorescences into four colours, namely green, yellow, red-brown and purple. Preliminary categorisation done at ARC - Range & Forage Institute[3] showed the colour variations to be light or dark green, red and purple. Lemmas can also be red or purple tipped. Lemma colour is often used as a classification criterion. Berhe *et al.* (1989) found that coloured lemmas are dominant over non-coloured and that lemma colour, seed colour and panicle form are inherited independently. This means that parents with coloured inflorescences can produce white seed and that coloured seed can be produced by inflorescences where coloration is absent. It also means that seed colour and inflorescence colour are not linked to inflorescence type.

Inflorescence type is an important descriptive characteristic and can be categorised into loose/open, semi-compact and compact (Constanza *et al.* 1979). The loose types have spreading panicle branches and are closest to the ancestral type. The compact type has the branches adherent to the main axis throughout panicle development and the branches are therefore upright in relation to the main axis of the panicle. Berhe *et al.* (1989) found panicle type to be determined by duplicate pairs of genes for degree of looseness and for unilateral as opposed to multilateral branching. The following three terms are used to describe the types: "effusum", meaning very loose and multilateral; "contractum", meaning fairly loose and unilateral; and "compactum", referring to compact and multilateral. Tefera *et al.* (1992) state that among the landraces, panicle type and maturity are linked to a certain extent. The late

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[3] ARC - Range & Forage Institute, P.O. Box 1055 Hilton 3245 South Africa

maturing types often have compact panicles and the plants are large whereas the early maturing types have only very loose or open panicles.

According to Tefera *et al.* (1990) cultivars with the panicle forms that are very loose, fairly loose and semi-compact produce higher seed yields than those with the compact panicles. Hence the panicle form can be a useful criterion for selecting for seed yield. However, if this is true, then one has to ask why the compact types were developed i.e. what their usefulness is, considering that they are the furthest removed from the ancestral type i.e. during the domestication process farmers would have positively selected for the compact type.

The panicle length investigated in 35 cultivars by Tefera *et al.* (1990) was on average 412 mm with cv. Burssa producing the shortest panicle of 282 mm and cv. Alba the longest with 563 mm. Tadesse (1993) studied 70 accessions and found the panicle length to vary from 279 mm to 406 mm. Riley *et al.* (1994) found panicle length to vary from 140 mm to 650 mm. The studies of Tefera *et al.* (1990) indicate panicle length to have a genotypic co-efficient of variability. This means that this characteristic may be useful in selection, as the variability is genetically determined and not influenced by environmental conditions.

Leaf width varies from 3 mm to 10 mm (unpublished observations) resulting in variation ranging from very fine leaved to very broad-leaved plants. The finer leaved plants are better adapted for herbage production purposes and particularly for hay production, since their curing rate will be faster than that of the broad leaved types.

Culm thickness ranges from 1.2 mm to 3.1 mm according to Ketema (1986) and Engels *et al.* (1991) and according to Tadesse (1993) from 1.28 mm to 2.05 mm. Riley *et al.* (1994) report culm diameter to be 1.5 mm to 4 mm. In most cases plants have either broad leaves and thick stems or intermediate leaf width and intermediate culms or narrow leaves and thin culms. There are some plants that have fine stems with intermediate leaves or intermediate stems with fine leaves. However in most cases it seems that leaf and stem width are correlated.

There is substantial variation in plant height. Tefera *et al.* (1990) found the variation in 35 cultivars to range from 736 mm to 1227 mm. In comparison Tadesse (1993) found the plant height range to be 713 mm to 937 mm in 70 accessions. Ketema (1986) found plant height to vary from 450 mm to 1500 mm considering the vast variation that exists within the species. The differences the various authors found in plant height no doubt resulted from how many accessions were investigated and what type of accessions they were.

Differences in plant dry weights exist between short and tall plants. Tall plants have a higher dry matter content than short plants. This is probably due to higher lignin and cellulose of the taller plants, which tend to have thicker stems and broader leaves than the shorter plants. In the grain types one of the plant breeding objectives is to reduce plant height and thus improve standability and reproductive ratio (Tefera *et al.* 1992). It does not follow that the herbage types should be as tall as possible for maximum production because the tall types have thick stems and broad leaves, which cure with difficulty. In addition the high lignin content in the tall types will make them less digestible to animals.

The variation in maturity period is reported by Ketema (1986) and Engels *et al.* (1991) to be 60 to 120 days. However Alkämper (1973) reports maturity time to vary from 80 to 210 days. Riley *et al.* (1994) refer to the range of 62 to 123 days and according to Tefera *et al.* (1992) the early types require 45 to 60 days and the later ones 100 to 130 days to maturity. Tefera *et al.* (1990) report a variation from 82 to 113 days in the 35 cultivars studied. Again, the reported variation in maturity period will depend on how many and what ecotypes were studied. These data should also be considered in terms of the planting date. Especially at the higher latitudes where the seasons are more pronounced. It may be that the plants become reproductive more quickly when planted later in the season compared to the beginning of the season. The data do show however that there is considerable variation in the maturity period.

The variation in maturity period allows for considerable choice of teff type to be grown, depending on weather conditions, particular to the season, and the purpose of growing the crop as well as the climatic conditions of the area. The fast growing, short season types may even have applicability in countries at high latitudes where the growing season is very short, such as Canada, the former Soviet Union and northern China (BOSTID 1996).

Grain yield plant^{-1} is only reported by Riley *et al.* (1994) who found it to vary from 4 g to 22 g. Tefera *et al.* (1990) found grain yield plant^{-1} to have a low value of heritability. Consequently it will be difficult to use single plant selection for improved grain yield.

Some variation exists in mass seed^{-1}, which ranges from 0.28 mg to 0.40 mg (Alkämper 1973). The dimensions of the grain are 0.8 – 1.5 mm in length and 0.4 – 0.8 mm in width. This small grain is free threshing (Cheverton & Chapman 1989), which in grasses is only the case in the genus *Eragrostis* and *Sporobolus* (Jones 1988). Free-threshing means the seed falls easily out of the chaffy glumes at maturity. Mass seed^{-1} has a high heritability value and low genotypic co-efficient of variability (Tefera *et al.* 1990). Therefore mass seed^{-1} is a highly heritable trait and can thus be selected for, although the inherent variation is not very high. This unfortunately reduces the usefulness of seed mass for selections.

From the preliminary categorisation of teff accessions at ARC - Range & Forage Institute[4], differences in tiller density were observed between different accessions. However no literature on tillering in teff and how that influences herbage and seed productivity could be found.

The immense variation of teff allows for ample opportunity for the selection of different types of plants, which are suited to various climatic and edaphic conditions. It also means that improvement can be achieved to a large extent through selection processes, and breeding or crossing of types may not necessarily be required in the initial stages of an improvement programme. Crossing of plants is a tedious process, as teff is self pollinating, thus requiring emasculation of the florets. Due to the small floret size, emasculation has to be done under a dissecting microscope (Ketema 1986).

2.4 THE GENETICS OF *ERAGROSTIS TEF* (ZUCC.) TROTTER

Teff has been subject to far less scientific investigation than other major crops and therefore the amount of information available on the genetics of the crop such as the gene action and inheritance patterns is far less compared with what is known about other crops (Bechere 1995). Gupta & Tsuchiya (1991) report cytogenetic information on teff to be lacking. Berhe *et al.* (1989), Gupta & Tsuchiya (1991), Jones *et al.* (1978), Ketema (1986), Mengesha *et al.* (1965), and Tefera *et al.*(1992) have however undertaken some genetic studies over the years.

2.4.1 Cytology and genetics

Teff is a tetraploid with a chromosome number of 2n = 40 (Mengesha *et al.* 1965). According to Engels *et al.* (1991), teff is also an allopolyploid. Teff is sexually propagated and not apomictic. There is a lack of variability in the progeny from a mother plant that came from an open-pollinated nursery, which indicates that teff is self-fertile (Mengesha *et al.* 1965). The following authors also suggest that teff is self-pollinating; Ketema (1986), Tefera *et al.* (1992) and Tadesse (1993).

The small florets open early in the morning (Tefera *et al.* 1992) and only for a very brief period. Tareke (1974) cited by Engels *et al.* (1991) found that the florets open between 06h45 and 07h45. Some cross pollination can occur and thus hybridisation may occur occasionally, giving rise to new types (Jones 1988). Tareke (1974) cited by Engels *et al.* (1991) managed to effect an intra-specific cross by artificial pollination. In order to make crosses at times other than the brief natural pollination

[4] ARC - Range & Forage Institute, P.O. Box 1055 Hilton 3245 South Africa

time early in the morning, the plants have to be kept at low temperatures (4 - 5 °C) or be put into dark conditions which delays the natural pollination time. Artificial hand-pollination requires emasculation of the florets before the anthers dehisce. An anther removed from the donor plant is then squeezed to release the pollen onto the stigma of the emasculated floret (Engels *et al.* 1991).

Genetic information is available for the phenotypic traits lemma colour, seed colour and panicle form. For lemma colour four pairs of genes are involved in the inheritance. Seed colour is controlled by a duplicate pair of genes with a multiple-allelic series at one of the loci. One pair of duplicate genes controls the degree of looseness in the panicle and another controls unilateral and multilateral branching of the inflorescence (Engels *et al.* 1991).

Berhe *et al.* (1989) determined the inheritance of three phenotypic traits in teff, namely lemma colour, seed colour and panicle form. Four different cultivars were used for the research. They were Fesho which has purple lemmas, dark brown seed and a very loose, multilateral panicle; Kay Murri has red lemmas, yellowish white seed and compact multilateral panicles; Bursa which has grey lemmas, greyish white seed and fairly loose unilateral panicles; and Trotteriana which has yellowish white lemmas, medium brown seed and compact multilateral panicles. The results of six crosses done by Berhe *et al.* (1989) showed that at least four gene pairs control lemma colour. One pair determines the presence or absence of basic anthocyanin colour (C, c). Then there are two pairs of duplicate genes (P_1 and P_2, p_1 and p_2). Purple colour is produced in the presence of a dominant in either of the duplicate gene pairs (P_1 or P_2) if there is a dominant gene for basic anthocyanin colour (C). Red lemma colour is produced by p_1 and p_2 in the presence of C. Grey (G) and yellowish white (g) are produced in the absence of C i.e. the gene for basic anthocyanin coloration. The authors detected no maternal effects.

For seed colour inheritance Berhe *et al.* (1989) found duplicate pairs of genes with a multiple allelic series at one of the loci. The duplicate genes showed additive effects for the brown pigment. At one of the duplicate loci there was an allele that differentiated between greyish white and yellowish white seed colour. Again no maternal effects were observed.

Duplicate pairs of genes for degree of looseness and another gene pair for unilateral and multilateral branching controlled panicle form. The three types of panicle form were identified namely "effusum", "contractum" and "compactum"(see 1.3.2). Genes for multilateral branching were dominant over those for unilateral branching. The inheritance of panicle form was independent from that of lemma and seed colours. Again there were no maternal effects (Berhe *et al.* 1989).

2.4.2 Breeding and plant improvement

In Ethiopia improvement of teff through breeding started in the 1950's. The improvement was achieved through pure line selections from landraces. In 1974 Tareke managed to produce intraspecific crosses through artificial pollination (Engels *et al.* 1991).

Seyfu (1983) cited by Ketema (1986) suggests the following method to achieve artificial crosses in teff. "Grow one or two plants in 130 mm diameter pots. Eight to 18 days after anthesis begins in the central or any other tiller, the seed parent plant and the pollen donor must be put into separate light boxes at around 14h00. The boxes must be kept away from direct sunlight and at temperatures below 28 °C. Lower temperatures improve the degree of control over the flowering process. The following day crossing may be done before early afternoon. Crossing is done by taking the donor plant out first. When the florets start to open, the spikelets with open florets must be detached and placed on the inner, moist wall of a vial. The second plant is then taken from the light box and laid horizontally under a binocular microscope. As soon as the florets start to open, the emasculation must begin, before the anthers dehisce. Only the basal florets should be emasculated and the florets on the other spikelets should be removed to serve as identification for the treated flowers. An individual anther from the spikelet in the vial is detached and gently squeezed to release the pollen onto the stigma of the emasculated floret. This is however a cumbersome and time consuming process."

Important objectives for breeding programmes have been identified as breeding for lodging resistance and for high seed yield (Alkämper 1973; Ketema 1986; Riley *et al.* 1994; BOSTID 1996). These authors refer to higher grain yield rather than herbage yield. BOSTID (1996) also includes objectives such as drought tolerance, larger grain size, less shattering and improved seed drying time. For utilisation in South Africa, objectives of breeding programmes are at present aimed at improved herbage production and in that context also standibility.

2.5 THE PHYSIOLOGY OF *ERAGROSTIS TEF* (ZUCC.) TROTTER

The lack of information on the physiology of teff again emphasises the limited research efforts into this species. Some studies have been undertaken and thus there are a few physiological facts available about teff.

According to Kebede *et al.* (1989) teff is classified as a plant with a KRANZ-type anatomical structure and higher chlorophyll a/b ratios. This makes teff a C4 plant. Stallknecht *et al.* (1992) classify teff as intermediate between tropical and temperate.

Kebede *et al.* (1989) studied the photosynthetic response of teff to temperature. Their study investigated dry matter production at 25°C, 35°C and 45°C. They found the highest dry matter production at 35°C. At 35°C the plants also had a higher growth rate than at 25°C. At 45°C the growth rate was lower than at 35°C as a result of high temperature stress. It was found that leaves measured at 35°C had the capacity to support a higher level of photosynthesis than leaves at 25°C or 45°C. For many C4 plants the optimum leaf temperature for carbon exchange rates ranges from 35°C to 45°C. In the study it was found that maximum carbon exchange rate was at the lower end of the range for C4 species. It appeared that biochemical and biophysical processes associated with internal leaf photosynthesis were potentially most active across the temperature range 35°C to 42°C.

There is a need for more research into the physiological responses of teff, especially to environmental stimuli.

2.6 AGRONOMIC REQUIREMENTS OF *ERAGROSTIS TEF* (ZUCC.) TROTTER

The agronomic requirements of teff have also been poorly researched to date, especially in South Africa. There is no information available on the influence of planting dates on production. For sowing and fertiliser rates there are general research data available but no detailed research has been conducted. This includes cutting height and cutting stage influences.

2.6.1 Establishment

Seedbed preparation is very important in the case of teff because of the very small seed size. A fine and firm seedbed is required for even establishment (Du Plooy 1957; Skerman & Riveros 1990; Dickinson *et al.* 1990; Stallknecht *et al.* 1993). The seed can be either drilled or broadcast (Du Plooy 1957; Skerman & Riveros 1990). Trials conducted by Ketema (1993) indicate that planting depth of greater than 20 mm affected plant growth negatively and that plant height was not affected by planting depths of 5 mm to 15 mm. Stallknecht *et al.* (1993) recommend an average planting depth of 12 mm, while Skerman & Riveros (1990) recommend either surface sowing or to a maximum depth of 10 mm.

Sowing rates recommended by Dickinson *et al.* (1990) are 7 to 10 kg ha^{-1} on sandy soils and 12 to 15 kg ha^{-1} on clay soils, while Stallknecht *et al.* (1993) recommend 5 to 8 kg ha^{-1}. Recommendations made by Ketema (1993) in Ethiopia are between 15 to 55 kg ha^{-1}. More specifically 25 to 30 kg ha^{-1} if broadcast by hand, and 15 kg ha^{-1} if broadcast or drilled mechanically. Bechere (1995) recommended 25 kg ha^{-1} on light soils and 30 kg ha^{-1} on black soils.

It must be borne in mind that with the sowing rates stated in the literature, the use for which the crop is established is not specifically mentioned. It will make a difference to the seeding rate whether the crop is planted for hay or for grain production. One can assume that the sowing rates recommended by South African authors are for hay production and authors from other countries, particularly Ethiopia, will refer to a grain crop.

Advised sowing dates for teff in Ethiopia are given as 15 to 21 July on Andosols and 21 to 31 July on Vertisols (Ketema 1993). No recommended sowing dates are given for other countries, particularly southern hemisphere countries.

2.6.2 Fertilization

For South African conditions Dickinson *et al.* (1990) provide some general recommendations. The soil P and K levels should be raised above the thresholds of 15 and 100 mg kg^{-1}, respectively. The analytical method used to determine these thresholds was not mentioned i.e. whether it was Bray or AMBIC. Two dressings of 50 kg N ha^{-1} are recommended on low fertility soils. No nitrogen fertilization recommendations are made for high fertility soils. Fertilizer applications for Ethiopia are given by Bechere (1995). On light soils 40 kg N ha^{-1} and 26 kg P ha^{-1} are recommended and on heavy soils 60 kg N ha^{-1} and 26 kg P ha^{-1}. The blanket recommendation of Ketema (1993) was 32 kg N ha^{-1} and 10 kg P ha^{-1}, while potassium was claimed to be of minor importance.

Recommendation for N application have limited use on a universal scale. It would be necessary determine the response of teff to fertilizer N. The additional problem is that the repsonse to N, which would include fertilizer N and soil in is difficult to quantify as the availability of soil N varies from season to season and from site to site depending on environmental and site conditions.

2.6.3 Production and harvesting

Teff generally requires little care and attention once it has established well (BOSTID 1996). The crop is harvested for grain when the colour of the vegetative plant parts turns green to yellowish or straw coloured. Harvesting before the plants are completely dry helps to reduce seed shattering in the field (Ketema 1986).

2.6.4 Diseases

Teff is relatively disease resistant when compared with other cereals (Stallknecht *et al.* 1993) both pre- and post-harvest, that is both the plant and the grain (Cheverton & Chapman 1989). Ketema (1986) and Mersie & Parker (1983) state that in Ethiopia teff has no major disease and pest problems, especially in comparison with other cereal grains produced in Ethiopia (Engels *et al.* 1991).

The two most important diseases of teff in Ethiopia are teff rust (*Uromyces eragrostidis*) and head smudge (*Helminthosporium miyiakei*) (Ketema 1986; Cheverton & Chapman 1989). Teff rust is caused by the pathogen *Uromyces eragrostidis*, the aeciostage of which, in the USA, occurs on *Anthericum* species. *Anthericum* species have been found to occur in Ethiopia (Ketema 1993). In general very little research has been conducted to find resistance to diseases and storage pests because they are relatively unimportant (Engels *et al.* 1991). However, according to Ketema (1986), both teff rust and head smudge do cause significant yield losses in the humid south western parts of Ethiopia but no control measures had been developed up to 1986. Ketema (1993) reports that diseases are not a problem in the primary teff growing areas of Ethiopia and that teff suffers from fewer diseases than other cereals grown in those areas. However Ketema (1993) does mention that teff rust causes an average of 10 to 25 % loss, but that this does not result in grain losses which could be considered economically significant. One presumes that the 10 to 25 % loss refers to leaf loss. Ketema (1993) also reports that head smudge, on the other hand, can cause considerable damage and result in grain yield losses of up to 50%. This is particularly the case in the humid south western parts of Ethiopia.

Neither chemical control measures nor resistant cultivars have been developed for either teff rust or head smudge. It has however, been found that plants sprayed with tridemorph do show decreased rust infection levels from 75 to 80% down to a trace level (Ketema 1993).

Damping-off caused by *Drechslera poae* is another disease that has been observed in teff in Ethiopia. According to Ketema (1993) it is more severe in early than late plantings and at higher sowing rates. Infection levels have been estimated as high as 40 to 50 % but it can be controlled with a seed dressing of 2-methoxyethyl mercuric chloride (Ceresan) (Ketema 1993). However registration for this substance has been withdrawn in many countries. *Helminthosporium* leaf spot also occurs and infection levels are in the order of 25 to 30 %. These can be reduced to 1 to 2 % with the use of tridemorph spray (Ketema 1993). Other diseases that have been observed in teff in Ethiopia are given in Table 1 (Ketema 1993), however the occurrence frequency is not mentioned.

Table 1 Diseases observed on teff in Ethiopia (Ketema 1993)

Species	Type of disease
Alternaria sp.	saprophytic on the leaves, culms and inflorescence
Apashaeria eragrostidis	on the black tip of the glumes
Candida guilliermondii	yeast on the seed
Candida krusei	yeast on the seed
Cladosporium sp.	saprophytic
Collectotrichum graminicola	anthracnose
Consiporium sp.	saprophytic
Darluca filum	hyperparasite on the rust
Epiccocum nigrum	saprophytic
Mycosshaerella eragrostidis	on dry leaves
Phoma depressitheca	on leaves
Phyllosticta sp.	leafspot
Septoria eragrostidis	leafspot
Tilletia baldratii	seed smut

Ketema (1993) also reports (Table 2) on the fungi that were found to occur on teff, particularly on the seed. However again the incidence of occurrence is not mentioned.

Table 2 Fungi that were found to occur on teff in Ethiopia, especially on the seed (Ketema, 1993)

Species of fungi	
Alternaria alternata	*Derchslera ex Dustur*
Caldosporium colocasiae	*Drechslera sp.*
Drechslera bicolor	*Penicillium brevicompactum*
Drechslera ellisii	*Phoma sorghina*
Drechslera setariae	

Ketema (1993) also reports that there are two root infesting pathogenic nematodes in Ethiopia that have been identified as a *Paratylenchus sp.* and a *Pratylenchus sp.*.

2.6.5 Pests

A number of insect pests have been recorded on teff in Ethiopia (Table 3) (Ketema 1993).

Table 3 Insect pests and their status identified on teff in Ethiopia (Ketema 1993)

Scientific name	Common name	Status
Ailopus simulatrix	Clay grasshopper	Uncertain
Atherigonia hyalinipennis	Shootfly	Uncertain
Atherigonia sp.	Shootfly	-
Delia arambourgi	Barleyfly	Major
Decticoides brevipennis	Wello bush cricket	Major
Diuraphis noxius	Russian wheat aphid	Minor
Epilachna similis	Tef epilachna	Minor
Erlangerius niger	Black tef beetle	Major
Esyarcoris inconspicuus		Uncertain
Macrotermes subhyalinus	Mendi termite	Major
Mentaxya ignicollis	Red tefworm	Major
Medicogryllus spp.	Crickets	Uncertain
Rhopalosiphum maidis	Maize aphid	Minor
Spodotera exempta	Armyworm	Sporadic

Gebremedhin (1987) reports red tefworm (*Mentaxya ignicollis*) to be a serious pest of teff on the heavy soils or vertisols, which develop deep cracks when they dry out. The larvae hide in these cracks in the soil during the hot hours of the day and feed on the leaves and the developing grain during the early morning and in the evening. Cypermethrin (pyrethroid) and organophosphates such as fenitrothion and endosulfan are used alternatively to control red tefworm. The insecticides are used alternatively to avoid the development of resistant populations of these pests.

The important wild hosts of red tefworm are *Digitaria scalarum* and *Phalaris* spp.. Important natural enemies that have been identified are predators such as birds, ants, spiders and the hymenopterous parasitoid *Enicospilus rundiensis*. Ketema (1993) identifies insecticides that are recommended for the control of red tefworm (Table 4).

Table 4 Insecticides and the application rates recommended for the control of red tefworm (Ketema 1993)

Insecticide	Formulation	Application	
		Active ingredient	Product
Cypermethrin	25% e.c.	187.5 g ha^{-1}	750 ml ha^{-1}
Fenitrothion	50% e.c.	625.0 g ha^{-1}	1.25 ml ha^{-1}
Endosulfan	35% e.c.	700.0 g ha^{-1}	2ℓ ha^{-1}
Diazinon	60% e.c.	600.0 g ha^{-1}	1ℓ ha^{-1}
Cypermethrin	5% ULV	110.0 g ha^{-1}	2.2ℓ ha^{-1}
Fenitrothion	50% ULV	1150.0 g ha^{-1}	2.3ℓ ha^{-1}
Endosulfan	25% ULV	500.0 g ha^{-1}	2.0ℓ ha^{-1}

The recommended spraying time for tefworm is when 25 larvae m^{-2} occur. If the insecticide application is correctly timed, then a single application per season is sufficient to prevent economically significant losses (Ketema 1993).

The Wello bush cricket is a major pest of Ethiopia mainly in the altitude range 1550 to 2516 m asl. Initially these insects feed on the weeds on the field margins. However when those weeds dry off, the Wello bush cricket moves onto the teff. Therefore early planting is a way to avoid losses, as is the control of weeds on field perimeters before the cereal goes into heading. Insecticides that are effective are Lindane 20% emulsifiable compound or Lindane dust or Fenitrothion used as an ultra low volume spray (Ketema 1993).

Control measures used for other pests are 40% Aldrin WP for central shootfly and termites, and carboryl 85% WP or 95% trichlorfon for tef epilachna and black teff beetle (Ketema 1993). However, the registration for Aldrin has been withdrawn.

2.6.6 Weeds

In Ethiopia, according to Mersie & Parker (1983), weeds are one of the main yield limitations, especially grassy annual weeds, due to their similarity to teff. Weeds also have an extended germination period, which makes control difficult. Two major grass weed species in teff in Ethiopia are *Phalaris paradoxa* and *Setaria pallide-fusca*. *Phalaris paradoxa* is well adapted to waterlogged conditions as is often the case on vertisols and consequently *P. paradoxa* is a problem in those areas. *Setaria pallide-fusca* is a problem in the altitude range 1500 m to 2500 m asl (Mersie & Parker 1983).

Broad leaved weeds can be a problem but are easily controlled with broad leaf herbicides as opposed to grass weeds which present more of a problem in this regard (Stallknecht *et al.* 1993). Debelo (1992) recommends the use of either paraquat or glyphosate before ploughing, followed by later supplemental hand-weeding or chemical control in the form of 2,4- dichlorophenoxy acetic acid applied when teff is in the early tillering stage. In the Institute of Agricultural Research Annual Report (1990), the use of Brittox with one hand weeding is recommended on both red and black soils.

Ketema (1993) suggests one hand weeding at the tillering stage 25 to 30 days after emergence (dae). This is recommended if weed populations are low. With higher weed infestations a second weeding will be necessary at the stem elongation stage. Once the plants have reached the heading stage, no further weeding is recommended as it damages the plants. Ketema (1993) also gives a list of pre- and post-emergent herbicides that can be used on teff (Table 5).

Table 5 Pre-emergent and post-emergent herbicides recommended for use on teff (Ketema 1993)

Herbicide	Comments
1. Pre-emergence	General comments a) Must be applied 1 to 2 weeks before planting b) Will satisfactorily control broad leaved and grassy weeds, but not perennial weeds c) Glyphosate, terbutryne and primagram are toxic to teff d) Gesatan is not toxic
Gesatan 500 FW (Ametryne + Prometryne)	a) gives better results on clay than on loam soils
Chlorosulfuron	a) was tolerated by teff and controlled both *Phalaris paradoxa* and *Setaria pallide-fusca* b) the use of a herbicide safener NA (naphthalene-1,8-dicarboxylicanhydride) as a seed dressing increased teff tolerance by a factor of 3
Diclofop-methyl	a) teff was tolerant if protected by NA b) it controlled both *P. paradoxa* and *S. pallide-fusca* c) it could not be used as a post-emergent, even if NA was applied
2. Post-emergence	General comments a) all gave good control of broad leaved weeds but not of grasses and sedges b) should be applied at the early tillering stage (4 to 5 weeks after sowing)
2,4-D amine 480 2,4-D ester 720 MCPA 415 MCPA 625 2,4-D 36% + MCPA 31%	a) these were toxic to teff if applied at the recommended rates 2 to 3 weeks after planting b) if applied 4 to 5 weeks after planting, the toxicity was reduced c) 2,4-D was relatively toxic at all times of application d) teff was more susceptible to 2,4-D than to MCPA, but both affected roots more than the shoots e) teff was less sensitive to MCPA when applied in the later growth stages i.e. at the fifth leaf stage
Dichloprop 620 (2,4-DP)	-
Bromuron 60% (Mecoprop + MCPA)	-
ARD 12131 50% (Bromoxynil + CMPP)	-
Brittox 50.5% (Mecoprop + Bromoxynil + Ioxynil)	-
MSMA plus water	a) was tolerated by teff but gave only partial control of *S. pallide-fusca*
Barban (4-chloro-2-butynyl-3-chlorocarbanilate)	was tolerated by teff and partially controlled *P. paradoxa* and therefore possibly also other grass weeds

According to Unger (1989), the weed problem in teff is to some extent farmer-induced in Ethiopia as they often use unclean seed, which is weed contaminated. Therefore through more efficient seed cleaning practices, the weed problem could be reduced. Unger (1989) also suggests crop rotations as a means to reduce weed infestations since the frequent use of phenoxy herbicides in cereal monoculture results in heavy grass infestations. Furthermore, the seedbed preparation has an influence on weed populations. In Ethiopia tillage is often shallow with traditional implements which encourages perennial weeds such as *Digitaria scalarum*, *Convulvulus arvensis*, *Cynodon dactylon*, *Cyperus* spp., *Lactuca* spp. and *Pteridium aquilinum*. It also encourages annual weeds like *Giuzotia*, *Galium*, *Polygonum*, *Galinsoga*, *Snowdenia*, *Datura*, *Chenopodium* and *Setaria*.

In small-scale farming improved weed management through seedbed preparation will not be possible until improved tillage implements making deeper soil cultivation possible, are used. In large-scale farming, the working of the soil prior to planting reduces weed infestation levels. However, frequent tillage is not always advisable as it reduces the soil organic matter content through increased decomposition processes and creates erosion and compaction (Unger 1989).

During the growth of the crop, both mechanical and chemical weed control practices can be used. In Ethiopia hand weeding is a common practice, but this is only effective if the crop is not damaged in the process. Damage can occur if weeding is left to late, i.e. when the crop is already too advanced. In addition, hand weeding is time consuming and laborious and often only effective on a temporary basis and thus has to be repeated during the crop growth period. In Ethiopia phenoxy herbicides have been used on small-scale operations and are more economic than hand-weeding. However, the frequent use of 2,4-D or MCPA encourages grass weeds such as *Phalaris paradoxa*, *Setaria pallide-fusca*, *Lolium temulentum*, *Bromus pectinatus*, *Avena* spp. and *Snowdenia polystachia* (Unger 1989).

Unger (1989) emphasises that herbicide use cannot substitute for poor farming practices and that integrated weed management is required, employing more than one weed control measure and thereby reducing the effect on the environment and preventing a shift towards the more noxious weeds.

2.7 THE NUTRITIVE QUALITY OF TEFF HERBAGE AND GRAIN

2.7.1 Herbage quality

There are some herbage quality data available from South Africa and the USA, although it is not very comprehensive. The probable reason for this is that throughout the world teff is known mainly as a grain and only in some countries it is used as a pasture, mainly for hay production.

Teff straw is nutritious and palatable, with a high average leaf:stem ratio of 73:27 and a high digestibility of 65 %. The protein content was found to be between 1.9 and 5.2 % BOSTID (1996). The form of protein is not indicated in the text i.e. whether it is CP or N%.

According to the analyses given by Department of Agriculture KZN (1995), teff hay in the early bloom stage has a crude protein (CP) content of 121 g kg^{-1} and 86 g kg^{-1} in the full bloom stage. In comparison *Eragrostis curvula* hay, which is a perennial used extensively in South Africa, has a CP content of 102 g kg^{-1} in the early flowering stage and 72 g kg^{-1} in the full flowering stage. Compared with *E. curvula*, teff also has a higher Ca content, namely 3.9g kg^{-1} compared to 1.1g ka^{-1} of *E. curvula*.

Mosi & Butterworth (1985) analysed four cereal crop residues from Ethiopia (Table 6), and only oat straw contained sufficient crude protein for a maintenance diet for sheep. The oat straw was sufficient for sheep maintenance but not for weight gain. The solution to the problem was found by adding *Trifolium tembense* hay to the oat straw and so achieving weight gain in the animals in that way.

Table 6 The chemical composition of *Trifolium tembense* hay and four cereal crop residues (percentage of dry matter) (Mosi & Butterworth 1985)

Component	Fodder				
	Trifolium hay	Maize stover	Oat straw	Teff straw	Wheat straw
Dry matter %	90.1	91.0	91.9	91.1	92.4
Organic matter	89.5	88.2	91.9	90.8	89.5
Crude protein	20.1	5.1	6.2	3.6	2.3
Neutral detergent fibre	44.4	75.5	71.2	77.5	76.1
Acid detergent fibre	36.6	51.3	46.6	44.3	51.7
Lignin	4.8	4.8	6.6	5.1	6.4
Hemicellulose	7.8	24.2	24.6	33.3	24.3
Cellulose	31.8	46.5	40.0	39.2	45.3
ADF-ash	-	5.2	3.6	3.4	6.9
Phosphorus	0.30	0.17	0.15	0.25	0.22
Gross energy (MJ kg^{-1})	19.0	16.7	17.9	17.6	18.8

These results of Mosi & Butterworth (1985) are somewhat contradictory to the statements by other authors that teff straw is the preferred straw of Ethiopian farmers because it keeps their animals in better condition than if they are fed other crop residues. This discrepancy could again be related to the genotypes of teff that were chosen for this study. The authors report that they obtained the cereal straw of the different crops, teff, oats, wheat and maize, from the local market. This may not necessarily be representative of the teff straw of Ethiopia. What this study also shows, is that there is also very poor quality teff straw, which emphasises the need for selection for quality straw together with good grain yield.

2.7.2 Grain quality

Teff grain quality has been investigated particularly in Ethiopia since the grain is of national importance in that country, but some work has also been done in the USA. Various authors, namely Rouk & Mengesha (1963), Jones (1988), Engels *et al.* (1991) and Ketema (1993) have published quality analysis data for teff grain (Tables 7 to 10).

Table 7 Nutritional analysis (%) of teff, which was conducted on a moisture free basis (Rouk & Mengesha 1963)

Protein (%)	Fat (%)	NFE (%)	Ca (%)	P (%)
10 – 11	2 - 3	81	0.2	0.4

NFE = Nitrogen Free Extract

Table 8 Energy and protein content of teff and several other cereal crops together with mineral levels and amino acid spectrum (Jones 1988)

Cereal	Energy (cal g^{-1})	Protein (%)	Minerals *	Amino acid spectrum *
Teff	336	10.5	++	+++
Maize	356	8.3	+	+
Durum wheat	336	12.4	++	+++
Bread wheat	339	10.4	++	++
Barley	334	9.3	++	++
Finger millet	326	7.2	+++	+
Sorghum	342	7.3	+	+

* + = fair ++ = good +++ = excellent

Table 9 Averaged nutritional information for energy, protein, fat and carbohydrate as it was obtained from four unspecified teff cultivars (Engels *et al.* 1991)

Energy (calories)	Protein (g)	Fat (g)	Carbohydrate (%)
300	11.6	0.65	70.65

Table 10 Protein, fat, fibre, carbohydrate and ash concentration (%) of teff grain compared with five other cereal grains using the proximate analysis (Ketema 1993) expressed as percentage

	Teff	Wheat	Sorghum	Maize	Rice	Barley
Protein	11.0	11.0	8.6	9.4	9.7	8.5
Fat	2.6	1.9	3.8	4.4	1.8	1.5
Fibre	3.5	1.9	1.9	2.2	8.8	4.5
Carbohydrate	73.0	69.3	71.3	69.2	64.7	67.4
Ash	3.0	1.7	2.4	1.3	5.0	2.6

Ketema (1993) also found teff to contain higher levels of Calcium, Cobalt, Zinc, Aluminium and Boron than wheat, winter barley and sorghum.

In order to make injera, the traditional Ethiopian bread made from teff, the dough is fermented for 72 hours. Umeta & Faulks (1988) investigated the effect of the fermentation on the carbohydrate content of the teff comparing white and red teff. They measured changes in free sugar composition and changes in starch content (Table 11 and 12).

Table 11 Sugar composition (%) monitored throughout the fermentation process of white and red teff grain (Umeta & Faulks 1988). (Percentage of total sugars is given in parenthesis)

Fermentation period (h)	Fructose	Sucrose	Maltose	Malotriose	Total
White teff					
Flour	0	1.3 (93)	0	0.1 (7)	1.4
0	0.4 (16)	1.3 (52)	0.5 (20)	0.3 (12)	2.5
24	3.1 (62)	0.2 (4)	0.7 (14)	1.0 (20)	5.0
48	2.2 (85)	0	0.2 (8)	0.2 (8)	2.6
72	1.6 (80)	0	0.2 (10)	0.2 (10)	2.0
2nd fermentation	3.4 (87)	0	0.5 (13)	0	3.9
Baked	3.7 (93)	0	0.3 (7)	0	4.0
Red teff					
Flour	0	1.8 (95)	0	0.1 (5)	1.9
0	0.3 (11)	1.7 (63)	0.3 (11)	0.4 (15)	2.7
24	1.3 (62)	0.1 (5)	0.7 (33)	0	2.1
48	0.8 (62)	0	0.4 (31)	0.1 (8)	1.3
72	0.6 (60)	0	0.2 (20)	0.2 (20)	1.0
2nd fermentation	2.7	0	0	0	2.7
Baked	3.2	0	0	0	3.2

Umeta & Faulks (1988) found the starch to be the main energy source for the fermentation organisms resulting in a 9% loss in starch during the fermentation process (Table 12).

Table 12 Starch content (%) during the fermentation of red and white teff grain (Umeta & Faulks 1988)

Fermentation period (hours)	White teff (% DM)	Red teff (% DM)
0	78.5	78.7
24	74.8	74.9
48	73.8	73.9
72	71.9	72.1
2^{nd} fermentation	70.6	71.5
Baked	69.6	69.6

Umeta & Faulks (1988) suggested however that the loss in starch is not nutritionally significant since much of the carbohydrate appears to be incorporated into bacterial mass or be present as lactic acid and volatile fatty acids, all of which provide energy when ingested. Umeta & Faulks (1988) also found that both red and white teff were low in non-starch polysaccharides (NSP) i.e. approximately 5%. This is lower compared with wheat. Both teff varieties were high in glucuronic acid, similar to rice but unlike other major cereals. No significant differences were found either in total amount of NSP or in the composition of NSP during the fermentation process and during cooking. This indicates that the cell wall polysaccharides are not utilised by the fermenting organisms.

Jansen *et al.* (1962) determined the nitrogen and protein content of seven teff varieties compared with pearl millet (Table 13 & 14).

Table 13 The nitrogen and protein content (%) of seven teff cultivars (Jansen *et al.* 1962)

Sample	N content (dry weight %)	Protein (dry weight %) = N x 6.25
Kay Teff Wolliso	1.93	12.06
Teff Gondar	1.79	11.19
Teff flour Wolliso	2.01	12.56
Teff Kolla Duba	1.91	11.94
White Teff Jimma	1.55	9.69
Red Teff Jimma	1.75	10.94
"Combined" Teff	1.68	10.51
Pearl millet	1.68	10.51

Jansen *et al.* (1962) also compared the amino acid content of teff to that of pearl millet and whole egg (Table 14).

Table 14 The amino acid content of teff, pearl millet, whole egg and FAO pattern (Jansen *et al.* 1962)

Amino acid	"Combined" Teff (g $16gN^{-1}$)	Pearl millet (g $16gN^{-1}$)	Whole egg (g $16gN^{-1}$)	FAO Pattern (g $16gN^{-1}$)
Lysine	3.11	2.89	6.6	4.2
Histidine	2.14	2.08	2.1	-
Arginine	3.54	3.48	6.9	-
Threonine	3.34	2.50	4.2	2.8
Methionine	2.79	1.35	3.8	2.2
Cystine	2.50	3.19	2.4	2.0
Valine	5.25	4.49	7.2	4.2
Leucine	7.73	7.29	9.4	4.8
Isoleucine	4.07	3.09	7.5	4.2
Phenylalanine	4.87	3.46	5.8	2.8
Tyrosine	2.20	1.41	4.4	2.8
Tryptophan	1.30	1.62	1.4	1.4

All amino acids were determined by column chromatography, except cystine and tryptophan, which were determined by microbial assay.

As is the case in other cereals, lysine is the first limiting amino acid in teff. Jansen *et al.* (1962) and Cheverton & Chapman (1989) concluded that teff has a excellent essential amino acid balance and that the ratio of essential to non-essential amino acids in teff is high for a cereal product. Stallknecht *et al.* (1993) found the protein content of teff grain to range from 10 to 12%, similar to other cereal grains. They also reported teff to have a very high Ca content as well as high contents of P, Fe, Co, Al, Ba and Thiamine.

Cheverton & Chapman (1989) report the following nutritional information for teff grain

Energy	353 – 367 kcal $100g^{-1}$
Protein	8.6 – 11.5 %
Iron	0.011 – 0.033 %
Calcium	0.1 – 0.15 %

In BOSTID (1996) extensive nutritional information on teff grain is given, including minerals, vitamins and amino acids (Table 15).

Table 15 Nutritional information for teff (BOSTID 1996)

Main components	Content *	Essential amino acids	Content **
Moisture	11 g	Cystine	1.9
Food energy	336 kcal	Isoleucine	3.2
Protein	9.6 g	Leucine	6.0
Carbohydrate	73 g	Lysine	2.3
Fat	2.0 g	Methionine	2.1
Fibre	3.0 g	Phenylalanine	4.0
Ash	2.9 g	Threonine	2.8
Vitamin A	8 RE	Tryptophan	1.2
Thiamine	0.30 mg	Tyrosine	1.7
Riboflavin	0.18 mg	Valine	4.1
Niacin	2.5 mg		
Vitamin C	88 mg		
Calcium	159 mg		
Chloride	13 mg		
Chromium	250 µg		
Copper	0.7 mg		
Iron	5.8 mg		
Magnesium	170 mg		
Phosphorus	378 mg		
Potassium	401 mg		
Sodium	47 mg		
Zinc	2 mg		

* the content was not given per mass of grain ** no units were given

The amino acid content given by BOSTID (1996) is somewhat different from the values given by Jansen *et al.* (1962). However BOSTID (1996) omits units and hence a direct comparison is not possible. If however one compares the relative composition of the amino acids given by these two authors, then they are very similar as is illustrated in Table 16.

Table 16 Relative essential amino acid content of teff expressed as a percentage of the total as calculated from data given by Jansen *et al.* (1962) and BOSTID (1996)

Essential amino acids	Jansen *et al.* (1962) % of total	BOSTID (1996) % of total
Cystine	6.7	6.5
Isoleucine	11.0	10.9
Leucine	20.8	20.5
Lysine	8.4	7.8
Methionine	7.5	7.2
Phenylalanine	13.1	13.7
Threonine	9.0	9.6
Tryptophan	3.5	4.1
Tyrosine	5.9	5.8
Valine	14.1	14.0

BOSTID (1996) reported that teff has a higher food value than other grains such as wheat, barley and maize. This is attributed mainly to teffs' small size where it is almost always used as a whole grain i.e. germ and bran are consumed with the endosperm. The protein content of the grain is between 9 and 11 % which is slightly higher than the protein content for maize, sorghum and oats. In the USA some grain samples tested as high as 14 to 15 % protein. However according to the results of Ketema (1993), the protein content of teff is similar to that of wheat but higher than that of sorghum and maize grain. This is also the case in the data presented by Jones (1988). These differences could possibly be the result of variability between different types of teff or it could be a function of environmental effects.

BOSTID (1996) also mention the digestibility of teff to be high and this can most likely be attributed to the main protein fraction consisting of albumin, glutelin and globulin, which are the most digestible types of protein fractions. The albumin fraction is particularly rich in lysine. The mineral levels of teff are also good with an ash content of 3 % (BOSTID 1996; Ketema 1993). Teff is high in Fe, Ca, K and P. The Fe content is between 11 and 33 mg and Ca between 100 and 150 mg, which are higher than wheat, barley and sorghum. Unfortunately the unit of measure is not clearly defined. In Ethiopia the absence of anaemia seems to be correlated with teff consumption and its high Fe content. However not all teff samples showed high iron levels. Washed grains also show lower iron levels, thus the high iron levels could be the result of iron-rich dust which clings to the small grains. In some contradiction to BOSTID (1996), Riley *et al.* (1994) report teff to be lower in K than barley, oats and wheat but they also report teff to be higher in Ca, Fe, Mn and Zn compared with most other cereals. Riley *et al.* (1994) also report the high Fe content to be the result of soil and species contamination. Riley *et al.* (1994) also investigated the relation between nutritive value in the form of protein, amino acid and mineral content and the environment. The nutritive value of teff was investigated at low (1550 m), mid (1860 m) and high altitude (2400 m). It was found that generally altitude does affect the protein, amino acid and mineral content of teff. The low altitude samples contained more lysine than the mid and high altitude samples and the high altitude samples were more deficient than the mid altitude samples. Proline levels at mid altitude were twice that at low altitude and three times that at high altitude.

For a cereal grain, teff has a very good amino acid balance and according to Jones (1988) it is the closest to human dietary requirements compared with other cereals. It specifically contains high levels of methionine and cystine. Teff grain together with a pulse is said to give a near optimal amino acid balance for human nutrition especially with regard to lysine and the sulphur-containing amino-acids cystine and methionine (BOSTID 1996; Jones 1988).

The reasons why teff grain is more nutritious than other cereals is due to the very small seed size resulting in a greater proportion of bran and germ to endosperm, which are the parts of the seed where many nutritional components are concentrated. In addition, teff flour is mostly produced as a whole grain flour because the very small seed size makes separation of endosperm from the rest of the seed very difficult (BOSTID 1996.)

2.8 PRESENT UTILISATION OF TEFF

2.8.1 The utilisation of teff in Ethiopia

As is very often the case in developing countries, crops with multiple uses are preferred over crops with a single application, especially if such a crop can provide for both human and animal nutritional needs. This is the case with teff. The following scenario is typical for Ethiopia. During the dry season in Ethiopia the cattle are fed crop residues. It is important that the cattle maintain condition as the cattle have to be used as draught animals for ploughing when the planting season commences at the beginning of the rainy season. Of all the different grains grown in Ethiopia, teff straw is the crop residue on which the animals best maintain their condition (Jones 1988). In addition the grain provides a very nutritious food for human consumption (Jones 1988). From what is reported in the literature, the utilisation of teff is very strongly linked to both its use as an animal feed and its use for human nutrition. It is difficult to decide whether the use of teff as a grain in Ethiopia is first and foremost linked to the usefulness of the straw for the animals or whether there are strong cultural connotations linked to the grain resulting from its use over thousands of years and the straw as an animal feed is secondary.

In Ethiopia teff is one of the major cereal crops (Constanza *et al.* 1979; Engels *et al.* 1991; Ketema 1986; Mengesha *et al.* 1965). In terms of area planted, teff is their most important annual cereal crop at 1.34 x 10^6 ha. Maize, barley, sorghum, wheat and millets are respectively planted to 0.92, 0.89, 0.84, 0.64 and 0.19 x 10^6 ha. The mean grain production of teff is 1.13 x 10^6 t an^{-1} (Bechere 1995). Cheverton & Chapman (1989) put the total estimated teff grain production at 1.22 x 10^6 t an^{-1}.

The average grain yield in Ethiopia from farmers' fields is 0.41 t ha^{-1} according to Engels *et al.* (1991). However Cheverton & Chapman (1989) estimate the national average yield to be 0.9 t ha^{-1} from traditional cultural practices and landraces. Teff is usually grown with farmyard manure and in rotation with pulses (Skerman & Riveros 1990). With improved cultural practices and with fertilisers, the yield obtained from farmers' fields was 1.7 t ha^{-1} to 2.2 t ha^{-1} (Cheverton & Chapman 1989). Ethiopian farmers often use the so called "shifting stable" system. After harvesting the seed, the field to be used in the next season is closed off and the animals put in to feed on the crop residues for 10 to 15 nights per plot of land and in the process the field is manured (Skerman & Riveros 1990).

Teff is the staple cereal grain in Ethiopia (Cheverton & Chapman 1989) and it provides ⅔ of the human nutrition in Ethiopia (Stallknecht *et al.* 1993). It is not clear what that statement exactly means. It could be referring to ⅔ of all consumed food, or ⅔ of the nutritional value of the food consumed. In the Ethiopian Nutrition Survey of 1959 it was found that teff contributed ⅔ of the protein content of peasant's diets (Jones *et al.* 1978; Gupta & Tsuchiya 1991; Mersie & Parker 1983).

The grain is used primarily to make a pancake-like bread called "injera" (Alkämper 1973; Cheverton & Chapman 1989; Engels *et al.* 1991; Gupta & Tsuchiya 1991; Ketema 1986; Mengesha 1966). Other products made from teff grain are porridges, soups and alcoholic beverages (Cheverton & Chapman 1989).

The teff straw is widely used, mainly as a cattle feed in the dry season, but also as a building material to reinforce mud walls (Cheverton & Chapman 1989; Engels *et al.* 1991; Ketema 1986; Mengesha 1966). Cattle prefer the teff straw to other cereal residues (Engels *et al.* 1991). The peasant farmers rely on the teff straw to keep their oxen in good condition for the next season (Jones 1988), since ploughing resumes before there is green grass available for grazing (BOSTID 1996). In an analysis of cereal crop residues of Ethiopian cereals, teff was found to have the highest crude protein (CP) content at 6.3 % whereas maize and sorghum stover had 5.1 % and 3.2 % respectively. Protein is important in facilitating the breakdown of cell walls by rumen microbes. Therefore cereal residues must have a CP content of 4 to 9 % in order for ruminants to effectively use all the dietary cellulose (Jones 1988).

There are various reasons why teff is such a popular cereal in Ethiopia and is still used to the present day when other cereals can produce much higher yields. The reasons are related to the specific characteristics of the crop that allows for multiple uses, as mentioned above, and adaptations to adverse conditions. Teff is a reliable and low-risk crop that provides a stable yielding capacity (BOSTID 1996; Stallknecht *et al.* 1993). In the literature there are six reasons given in various publications as to what the desirable characteristics of teff are from the Ethiopian farmers' point of view.

Firstly, teff can be grown in areas prone to water stress and unreliable rainfall. In these areas it is often grown as a rescue crop. If farmers perceive that their spring planted cereals, such as maize and sorghum, will be a failure due to drought stress, they will re-plough the land and sow teff in late summer/early autumn (BOSTID 1996; Ketema 1986). The teff will then grow on the residual soil moisture and all the grain that has been pollinated will ripen without further rain (Jones 1988).

Secondly, on vertisols, which are often waterlogged (Jones 1988; Tefera *et al.* 1992), teff has the ability to withstand the temporary anaerobic conditions better than any other cereals such as sorghum, maize or wheat (Cheverton & Chapman 1989).

Thirdly teff is suitable for use in multiple cropping systems such as double-, relay- or inter-cropping. Teff is often inter-cropped with *Brassica carinate*, *Carthamus tinctorius* (safflower) or *Helianthus annuus* (sunflower) (Engels *et al.* 1991). Teff is also relay cropped with maize. To do this, the lower leaves of the maize plants are removed once the cob has formed and teff is then sown in the inter-row (Ketema 1986).

Fourthly, seed for grain can be stored for an extended period of time, at least five years, under traditional conditions. The seed remains viable for planting purposes under traditional storage conditions for up to three years. The seed has the advantage of not being attacked by storage pests such as weevils, due to the very small seed size. It is also not degraded by fungi. This reduces post-harvest costs and management, as no protective chemicals are required for storage (BOSTID 1996; Engels *et al.* 1991; Ketema 1986; Stallknecht *et al.* 1993; Tadesse 1993). These storage advantages make teff an ideal safeguard against famine (BOSTID 1996).

Fifthly, compared to other cereals in Ethiopia, teff has fewer pest and disease problems (Engels *et al.* 1991; Ketema 1993; Mersic & Parker 1983), thereby reducing the input costs of the crop and under subsistence conditions it allows for better yields.

Sixthly, teff has the lowest estimated percentage post-harvest loss compared to the other major cereals such as maize, sorghum, wheat and barley. For teff the estimated post-harvest loss is 3 % while that for maize and wheat is 25 % and 26 % respectively (Jones 1988). In addition teff grain has a high efficiency of utilisation with teff flour giving a milling return of 99 % while wheat gives 60 to 80 % (Tefera *et al.* 1990).

2.8.2 The utilisation of teff in South Africa

In South Africa teff is used primarily as a forage crop for hay production (Alkämper 1973; BOSTID 1996; Dickinson *et al.* 1990; Du Plooy 1957; Mengesha 1966; Riley *et al.* 1994; Skerman & Riveros 1990). The cultivar SA Brown used in South Africa is well adapted to hay making with its fine leaves and stems, which allows the forage to cure easily and quickly. The fineness of the herbage also makes it a palatable hay (BOSTID 1996; Dickinson *et al.* 1990; Du Plooy 1957). Teff has a high leaf : stem ratio (73:27) and a relatively high digestibility (65 %) (BOSTID 1996). Teff hay is generally fed to horses, dairy cattle and sheep (BOSTID 1996).

Frequently teff is used as a nurse crop for the establishment of perennial grasses. This is often practiced for erosion control, for example on road verges and mine dumps, where teff is part of the grass seeding mixture consisting mainly of perennial grasses. Teff gives a quick cover, holding the soil together while the perennial grasses are afforded the opportunity to establish (BOSTID 1996; Dickinson *et al.* 1990). Teff is also used as a nurse crop for establishing *Eragrostis curvula* pastures (Dickinson *et al.* 1990). *Eragrostis curvula* is a perennial grass and slow to establish. Again, teff in the mixed pasture provides quick cover and keeps out the weeds. In addition a hay cut can be obtained from the teff in the first year of the mixed pasture establishment.

2.8.3 The utilisation of teff in the USA

In the USA teff is used for both grain and forage with the grain mainly used as a health food (Stallknecht *et al.* 1993). According to BOSTID (1996), teff flour can be used as a thickener in soups, stews and gravies. It can also be used in porridges, pancakes, muffins, biscuits, cakes, stirfry dishes and puddings. It reportedly has a mild, slightly molasses-like sweet taste (BOSTID 1996).

Teff grain has a low gluten content and can thus be consumed by people suffering from gluten-intolerance. Consequently bread baked with teff flour remains relatively flat i.e. unleavened bread (Constanza *et al.* 1979; Stallknecht *et al.* 1993), although it does rise to some extent, more than expected (BOSTID 1996).

2.8.4 The utilisation of teff in other countries

The Royal Botanical Gardens at Kew distributed teff seed to various countries in the early 20th century, such as India, Australia and California. In 1916 Sykes introduced teff to Zimbabwe, Mozambique, Kenya, Uganda and Tanzania. In 1940 Horuity introduced teff to Palestine (Engels *et al.* 1991). If any of this seed was used for production or if teff is still produced either for grain or for hay in these countries is not reported in the literature. Engels *et al.* (1991) also report teff to be used as a grain in North and South Yemen. Mersie & Parker (1973) mention teff to be cultivated as a hay crop in Tanzania and Kenya, while Umeta & Faulks (1988) also include Burma and Pakistan as countries where teff is planted as a forage grass. According to BOSTID (1996), teff is used as an ornamental grass in Europe, USA and Japan. Injera is served as a speciality food in restaurants in many cities of the world, namely Washington, New York, Chicago, San Fransisco, London, Rome, Frankfurt and Tel Aviv (BOSTID 1996).

2.9 FUTURE UTILISATION AND POTENTIAL OF TEFF

Teff can be produced in areas with low agricultural potential. These could include areas that are periodically waterlogged, or areas with unpredictable rainfall, or with soils that have unfavourable physical and chemical properties such as vertic soils or low fertility soils. As mentioned earlier, 80 million hectares in Africa have vertic soils. As population pressures increase resulting in increased land pressure, so it becomes necessary to utilise areas marginal to agricultural production. With increased pressure on communal grazing lands, animals have to be given supplementary feed. A source of such feed could be cereal residues.

Many African countries face food shortages due to unreliable rainfall and overexploitation of resources. It is in these circumstances that teff could have a role to play. Many African countries have to increase their export earnings. Therefore high potential agricultural land has to be planted to export crops which in general are crops which require favourable conditions. The marginal land will then have to be used for food production and here a crop like teff could be used (Ketema 1986).

The use of teff as a health food, especially for people suffering from gluten intolerance, should be expanded. A series of recipes using teff flour (Riley *et al.* 1994) already exist. However, the development of further recipes, which particularly take into account the gluten-free dietary requirements will have to be undertaken. use of teff as a health food will also require the development of effective milling procedures for the very small grain. The technology is most likely already available but needs to become more widely known. To expand the health food market of teff will also require a concerted marketing campaign to make people aware of teff flour as an alternative to wheat.

Teff flour need not only be considered as a health food but could be marketed as an alternative flour for general use. But again, more recipes need to be developed, as the baking qualities of teff may be different to those of wheat flour. There may also be differences in the baking qualities of different teff types and consequently the screening and selection programme for pure grain types will have to take baking qualities into account. This may result in a cultivar with superior flour qualities, which could then be grown specifically for that purpose.

Possibly a small but high value market could be developed for teff as an ornamental grass. There is already some interest in this regard in Europe and Japan (BOSTID 1996). Again specific selections should be made to develop the best possible ornamental types.

Teff grain may also have potential as an animal feed for monogastric animals such as poultry and pigs. Teff grain has a good essential amino acid balance, is high in sulphur-containing amino acids and has a relatively high mineral content, especially calcium and iron.

In Africa the expected grain short-fall is 14×10^6 t an^{-1} and was expected to be 50×10^6 t ann^{-1} by the year 2000 (BOSTID 1996). Consequently cereal grains (major and minor cereals) will have to be produced in agriculturally marginal areas where environmental constraints and diseases reduce grain production potential. In these situations African grains like teff may be the best adapted. Teff contains the genotypes that can tolerate adverse conditions and thus improved varieties should be developed for grain production in these more adverse agricultural environments.

Teff has numerous outstanding characteristics, as mentioned earlier. Teff has the ability to become a crop of greater agricultural importance, especially in countries with unpredictable rainfall and difficult soils. It has the potential to be both a subsistence crop as well as a high value crop as a health food, or a gourmet food, or an ornamental grass. However many of these attributes will have to be thoroughly investigated and researched if teff is to reach its potential. Teff certainly provides a challenge to both forage scientists, agronomists and cereal scientists.

2.10 LIMITATIONS OF TEFF AS BOTH A GRAIN AND A HERBAGE

The limitations of teff as a grain are related to its small seed size. Such small seed requires an even and fine seedbed for good establishment. This requires more input in terms of land preparation than other crops might do. However, the subsistence farmers in Ethiopia work the land with traditional animal drawn implements or with hand tools and it has proved to be sufficient. The small seed size also makes harvesting and handling of the grain difficult.

The major limitation in terms of forage production is the lodging of the crop. The pasture will often lodge as it reaches the flowering stage. Lodging is aggravated by high rainfall and strong winds when the pasture reaches maturity, as is often the case with thunderstorms in the summer months. Excessive nitrogen fertilisation also encourages lodging. Once the pasture has lodged it is very difficult to cut, and wastage occurs. In this regard there are, however, differences between genotypes. It seems that some genotypes can be cut more easily than others can when they are lodged.

Regarding the improvement of teff through breeding, it is a disadvantage that teff is self-pollinated and is consequently difficult to cross. If the plants are to be crossed, hand crossing is required and plants have to be planted in pots and the florets emasculated. This is a very intensive and highly skilled task (Engels *et al.* 1991).

Both as a grain crop and as a forage crop, teff is compared with alternative crop species which are already well developed and where some of these limitations do not apply. Consequently from these comparisons teff looks like an inferior crop not ideally suited for production. However, the advantages of teff also have to be compared with these alternative crops.

2.11 FURTHER RESEARCH REQUIRED

In general and compared to other forage and grain crops *E. tef* is still very poorly researched. There are many aspects of the crop that can potentially be improved. Various authors have identified different aspects of the crop as the most important to be researched.

The need to improve the standibility of teff and find a solution to the lodging problem was identified a few decades ago and to date no satisfactory solution has been found. Alkämper identified lodging as a research priority in 1973 (Alkämper 1973). The reason why a solution has not yet been found could be related to the complexity of developing improved cultivars or it could be the result of too little effort being channelled into this task to date. According to Engels *et al.* (1991), lodging was still identified as the most urgent problem. The problem requires various solutions that can be used in combination. In terms of forage production determining fertilisation requirements and thus preventing fertility induced lodging, especially with regard to nitrogen might restrict the problem. The phenological stage at which the plants are cut for hay and the planting date at which the pasture is established may also have an effect. The observation that some types can be cut more easily than others when they have lodged should also be investigated further.

Regarding grain production, the lodging problem can be addressed through breeding cultivars with shorter culms and good standibility (Tefera *et al.* 1992). Alternatively the genepool can be screened for genotypes resistant to lodging. Growth inhibitors or growth retardants could also play a role. Shiferaw & Unger (1985) investigated the effect of two growth retardants, Phynazol and Floridimex T on the lodging behaviour and on some agronomic characteristics of one teff cultivar under Ethiopian conditions applied at two different growth stages. They found the Floridimex T to significantly reduce stem height, which resulted in a lower lodging percentage in the crop. There were however no significant differences between the untreated and the treated plots in terms of grain yield, panicle length, the number of branches per panicle, the seed weight per panicle and the number of reproductive tillers per plant. Further investigations are required using different growth retardants, more cultivars, and different application times and rates and also under different field conditions.

Both Jones *et al.* (1978) and Tefera *et al.* (1992) mention drought tolerance as an important aspect requiring future research. Jones (1988) also mentions the selection of types adapted specifically to various agro-ecological zones and particularly to drought prone areas, as a priority. Other research needs identified by Jones (1988) are improved grain yield, high response to fertilization, high yielding types for nutrient poor soils, identifying types with high nutritional straw value and at the same time high grain yield and resistance to pests and diseases, especially teff rust.

Bechere (1995) emphasised the need for both basic and applied research on genetics and breeding, agronomic aspects of the crop and its physiology. The inheritance patterns for useful traits have to be determined and understood for optimum use of types in future breeding programmes. BOSTID (1996) lists the research requirements as including lodging resistance, disease resistance, high harvest index, larger grain size and faster drying rate of the grain. Hybridising *E. tef* with some of the *Eragrostis* species called the "resurrection grasses" having an unrivalled drought tolerance is considered a possibility by BOSTID (1996). However when drought tolerance is sought it must be borne in mind that this should not be done at the expense of yield.

Mamo & Killham (1987) investigated the versicular-arbuscular mycorrhyzal (VAM) associations of teff. Mycorrhyza increase plant growth, especially in nutrient-poor soils, where the infected roots have a greater ability to take up nutrients. It was found that when the soil was not acid or when it was limed the teff showed increased growth when colonised by VAM. More research is required in this field, especially with regard to varying pH and competition from indigenous micro-flora. This could be a real advantage for growing teff in nutrient-poor soils. This would also apply to the nutrient poor soils often encountered in the revegetation of denuded and degraded areas.

There may also be some merit in developing a true dual purpose type, which could be grazed or cut for hay once or twice and then left to go to seed and still produce a substantial seed crop. Cutting the pasture could also reduce the lodging problem in the seed crop.

The management practices for teff grown under South African conditions both for herbage and seed production still have to be determined. These include fertilisation practices, chemical weed control practices, planting dates, cutting or grazing management, sowing rates in a pure stand and in mixtures with perennial grasses and production potential under various management regimes as well as in various climatic conditions. The response of teff to various environmental stimuli such as temperature and daylength needs to be investigated, as well as herbage quality of different types and under different management regimes.

If teff is to make substantial inroads into the health food market, then detailed research into the gluten content or lack thereof should be conducted.

2.12 CONCLUSIONS

From all the information available on teff to date, it is clear that the ancient crop of teff has numerous outstanding characteristics and attributes which give this species the potential to become an important crop in many parts of the world where the major cereals fail to perform due to environmental and climatic conditions. Teffs' potential as a health food also has the ability to make this an important cereal giving versatility of utilisation compared to other grains suitable for people suffering from gluten-intolerance. In addition to these very functional uses, teff also has the potential of a gourmet food.

In terms of herbage production the use of teff also has room for expansion. It is fast growing and can thus be grown in rotation with other crops. It could for example be planted in November/December in lands that had ryegrass ploughed out in early November and the new ryegrass pasture will only be established in February/March. It can thus provide a quick hay crop if the farmer needs hay for his rations, or the hay can be sold as a cash crop since there is often a demand for good quality teff hay, especially for the horse industry. With its ability to withstand relatively dry conditions and being a fast growing pasture, it can be used in seasons where drought is expected or in areas that inherently suffer dry spells.

This vast diversity in utilisation potential, in agro-ecological adaptations and morphological diversity could together allow teff to become a species of greater importance in the future. The management practices and teff's response to environmental stimuli such as very high temperatures and day length and how these impact on the production pattern, have to be determined in order to be able to promote the species and encourage production thereof in South Africa.

2.13 OBJECTIVES

According to the Agricola database 1970 to 1996 there have been 65 papers/mentions of teff in this time period. From 1988 to 2000 there have been 88 papers/mentions on teff (Biological Abstracts database, www.silverplatter.com). This clearly shows the increased interest in research on teff world-wide. In South Africa teff seed has for a long time been categorised as a commodity rather than a seed. In view of at least 1000 tons of teff seed being sold annually in South Africa (SANSOR 1993), it means that teff, compared with other pasture species, is extensively grown. The sale of ryegrass seed for example is also approximately a thousand tons annually. The South African teff market has consisted almost exclusively of one cultivar, 'SA Brown', since its introduction to South Africa in 1887. In 1930 an attempt was made to introduce two further cultivars Union Brown and Union White but they were disappointing in terms of hay production (Rhind 1973). However, in view of the vast diversity within the species (chapter 1.3) and the number of ecotypes that have been identified in Ethiopia, in excess of 2000 accessions have been collected by the Plant Genetic Resources Centre of Ethiopia (Ketema 1986), it was identified that there is potential for cultivar improvement over 'SA Brown'.

The use of teff in South Africa is mainly for hay production, whereas in Ethiopia it is a grain crop. Hence most of the research available on teff is with regard to teff as a grain crop. In South Africa not many research efforts have focused on teff. With the onset of a new teff cultivar development project at ARC – Range and Forage Institute[5], it became evident that for the successful release of new teff cultivars and the associated potential increased interest in teff as a pasture crop, it is essential to have sufficient agronomic information about the species. Since even basic agronomic research on teff hay production in South Africa was lacking, agronomic trials were initiated. The main emphasis was on teff herbage production but some aspects of seed production were also incorporated. Four agronomic aspects were identified as the most likely to impact on the herbage and seed production of teff and the need to establish the optimum production requirements. These were planting date, the growth stage at cutting the pasture, nitrogen fertilizer application levels and sowing rates. The traditional planting time of teff in South Africa has been November, but no research data could be found to substantiate this time as optimal in terms of temperature and daylength. The influence of the growth stage at which the pasture is cut was identified as a possible influence on optimising herbage production and the associated influence on the regrowth of the pasture. The objective of quantifying the response of teff to nitrogen application levels and sowing rates was with the view of establishing recommendations for farmers to use. The research was aimed at finding both scientific information with regard to herbage and seed production responses but also practical information for on-farm use. In addition the nature of the research was exploratory. This was in view of the lack of available information. Hence the

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importance of identifying future research requirements in understanding the growth and production responses of teff to environmental and agronomic variables and conditions.

3 HERBAGE PRODUCTION RESPONSE OF TEFF (*ERAGROSTIS TEF* (ZUCC.) TROTTER) TO PLANTING DATES

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Abstract

Traditionally in South Africa teff has been planted in November. However, there are no research data to substantiate or refute November as the optimum planting time in terms of maximising herbage production. Consequently the herbage production response to planting date was investigated in the KwaZulu-Natal Midlands of South Africa for three consecutive years. Planting was done at two-weekly intervals from the first week in September to the last week of March. For herbage production the response to planting date was best summarised by assessing the response for total yield for the season and the first herbage cut of each planting date treatment. Total yield followed a declining trend from the early September/October plantings (spring plantings) through to the March planting. The highest total yield was obtained from either September or October plantings. The trend for the first herbage cut from each planting date treatment was one of increasing yield from the early plantings, peaking from the November/December plantings and then decreasing again. Maximum total herbage production was achieved from September and October plantings, which gave yields of 9.40, 8.48 and 7.64 t DM ha^{-1} for the 1996/97, 1997/98 and 1998/99 seasons respectively ($P<0.05$). However maximum herbage production from cut one was achieved from the late November and December plantings with yields of 4.42, 4.72 and 3.78 t DM ha^{-1} for the seasons 1996/97, 1997/98 and 1998/99 respectively ($P<0.05$).

Additional key words: sowing dates, dry matter yield, daylength responses, floral induction

Introduction

Teff (*Eragrostis tef* (Zucc.) Trotter) is a determinate obligate annual tropical C4 grass with the Kranz-type anatomy and high chlorophyl a/b ratios (Kebede *et.al.* 1989). Teff has its centre of origin (Tefera *et al.* 1990) and centre of diversity in Ethiopia (Chapman 1992), where it is used mainly as a grain crop with the straw fed to cattle. In Ethiopia cattle are fed crop residues during the dry months. It was found that the livestock maintained the best condition on teff straw relative to other crop residues. In addition, the grain provides nutritious food for human consumption (Jones 1988). In South Africa teff is primarily used as a forage crop for hay production (Alkämper 1973; BOSTID 1996; Dickinson *et al.* 1990; Du Plooy 1957; Mengesha 1966; Riley *et al.* 1994; Skerman & Riveros 1990). The cultivar SA Brown used in South Africa is well adapted to hay making with its fine leaves and stems, which allows the forage to cure easily and quickly. The fineness of the herbage also makes it a palatable hay (BOSTID 1996; Dickinson *et al.* 1990; Du Plooy 1957), with a high leaf : stem ratio (73:27) and a relatively high digestibility (65 %) (BOSTID 1996). Teff hay is fed to horses, dairy cattle and sheep (BOSTID 1996).

The effect of planting date on both herbage and seed production in a grass is linked to various environmental factors that moderate growth responses. Growth response to environmental influence can be observed in the form of partitioning of photosynthate between vegetative and reproductive organs or the effect on floral initiation. Thus the cycle of pasture growth to harvest is influenced by temperature and daylength. For instance in sorghum long days had the influence of increased crop growth rate and thus increased biomass accumulation but decreased grain production (Yan & Wallace 1999). Bello (1999) also reported for sorghum that earlier planting coincided with the period of high water availability which resulted in longer periods of vegetative growth and a longer duration to panicle initiation with resulting lower grain yields. Sorghum is a short-day plant (Yan & Wallace 1999). According to Bello (1999) a progressive delay in planting had the effect of a decline in the duration of vegetative phase to panicle initiation. It also resulted in reduced plant height at panicle initiation but with an observable increase in grain yield. Thus in sorghum daylength, temperature and water availability influence biomass accumulation, flowering and grain yield.

Teff hay pastures in South Africa have traditionally been planted in November. There have however been no research data to substantiate or refute this as being the optimum planting date for maximum herbage or grain production. Since planting date has an influence on the herbage and seed production of other annual tropical grasses such as sorghum and millet it could also have an influence on teff. In view of the lack of research data and new, improved cultivars becoming available on the South African market in the near future, planting date trials were initiated to determine the influence on herbage production. The objective of the study was to determine the optimal planting date for total and first cut production of teff (cv. SA Brown) and to relate the influences of daylength, radiation use and temperature to herbage productivity in the KwaZulu-Natal Midlands of South Africa.

Procedure

Study area

The trial was conducted on the same site over three consecutive seasons, (the summers of 1996/97, 1997/98 and 1998/99). The site for the trials was located on the Cedara research station (29°32'S, 30°17'E) of the KwaZulu-Natal Department of Agriculture and Environmental Affairs in the Midlands region of KwaZulu-Natal province in South Africa. The research station lies at an altitude of 1076 m above sea level, with long-term annual means of 885 mm, 22.3°C, 9.4°C and 16.2°C for rainfall, and maximum, minimum and average daily temperatures respectively (Agromet)[1]. Rainfall and temperature data for the duration of each planting date treatment are given in Appendix 1 and 2.

The soil type is a Hutton soil form, which is an orthic A horizon over a red apedal B horizon (Soil Classification Working Group 1991). This is a well-drained soil.

Land preperation

The initial land preparation was done in late winter with a plough and a disc harrow. The weed seeds were allowed to germinate and then the site was worked at a shallow depth prior to each planting with a tine cultivator to eliminate the newly germinated weeds. The main weed in spring was yellow nutsedge. The yellow nutsedge was not completely controlled with the cultivation but the population was substantially reduced.

Fertilization

The soil P and K levels were raised to the recommended levels according to the soil analyses[2], which are 20 g kg^{-1} for P (AMBIC) and 120 g kg^{-1} for K. The P (single superphosphate (10.5)) and K (KCl (48)) fertilizer was spread onto the entire site before cultivation in order to work the fertilizer into the seedbed. The acid saturation was 5% and the pH (KCl) was 4.52. The N fertilizer was applied as LAN (28) at 50kg N ha^{-1} after emergence when the seedlings were 50 to 100 mm tall. In the herbage production plots 50kg N ha^{-1} and 50kg K ha^{-1} was applied after each cut in the form of 1:0:1 (47) compound fertilizer. The K was applied in order to avoid soil K depletion due to the herbage removal at each cut, as would be the case in a hay pasture situation. The N and K fertilization levels applied after each cut and N after germination, were chosen according to application rates used in other pasture trials at the same site.

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Treatments and measurements

The herbage trial was seeded to 'SA Brown', had 15 planting dates as treatments with three replications in a randomised complete block design. Planting commenced in the first week of September and treatments were planted at two-weekly intervals thereafter to mid March. The sowing rate was 15 kg ha^{-1} row planted with an inter-row spacing of 150 mm and a gross plot size of 2m x 10m ($20m^2$). The net plot size was 1.4m x 8.6m ($12.04m^2$). The treatments were cut, when the plots reached the 10 to 20 % heading stage, with a reciprocating mower set at a blade height of 80mm. The entire green weight for each net plot was weighed before a sample of approximately 500g was taken from each plot weighed, dried at 90°C and then weighed again. The wet to dry mass ratio was used to estimate the net plot dry mass.

Statistical analysis

The analysis of variance (ANOVA) was used to determine the effects of the planting date treatments on dry matter yield. Differences between means ($P<0.05$) were assessed using least significant differences (LSD). Error bars on the bar graphs are used to indicate the standard deviation of the mean (standard error) (Steel & Torrie 1980). The yield data were also regressed using linear regression against the climatic data variables using Genstat software (Genstat 5 Committee 1995). The climatic variables are the mean over the duration of the growth period for each planting date treatment (Appendix 1).

Results and discussion

Total herbage production

Planting date has a strong influence on total herbage production obtained from teff. This was shown in all three years of the trials. The yield response observed in each of the three consecutive seasons was similar (Figures 1 to 4). In two of the three trials the maximum yield was from a September planting (9.40 and 8.48 t DM ha^{-1} in 1996/97 and 1998/99 respectively) and once from an October planting (7.64 t DM ha^{-1} in 1997/98) (Figures 1 to 3). In order to maximise total herbage yield a spring planting is required. Planting after mid October led to a reduction in yield in all three years. The exact planting date that results in maximum yield cannot be identified exactly as this varied between the three years. In the second season, 1997/98, the first two planting dates gave a very low total yield and it was only from the third planting date onwards that yields similar in magnitude to the other two seasons were achieved (Figure 2). The most likely reason for this variable optimum date is the climatic conditions prevailing in each particular spring. Teff is a tropical to sub-tropical annual C4 grass (Engels *et al.* 1991) and is not frost tolerant (Alkämper 1973). Thus planting very early in spring could be marginal if conditions are cool or if very dry. For C4 grasses the optimal temperature range for net photosynthesis is 35 to 40°C, while the optimum daily air temperature for dry matter accumulation is 30 to 35°C. Growth is severely reduced at daily air temperatures below 20°C (Jones 1985). Kebede *et al.* (1989) suggest that in the major teff growing regions of Ethiopia, the average day temperature is 25°C and the average night temperature 15°C.

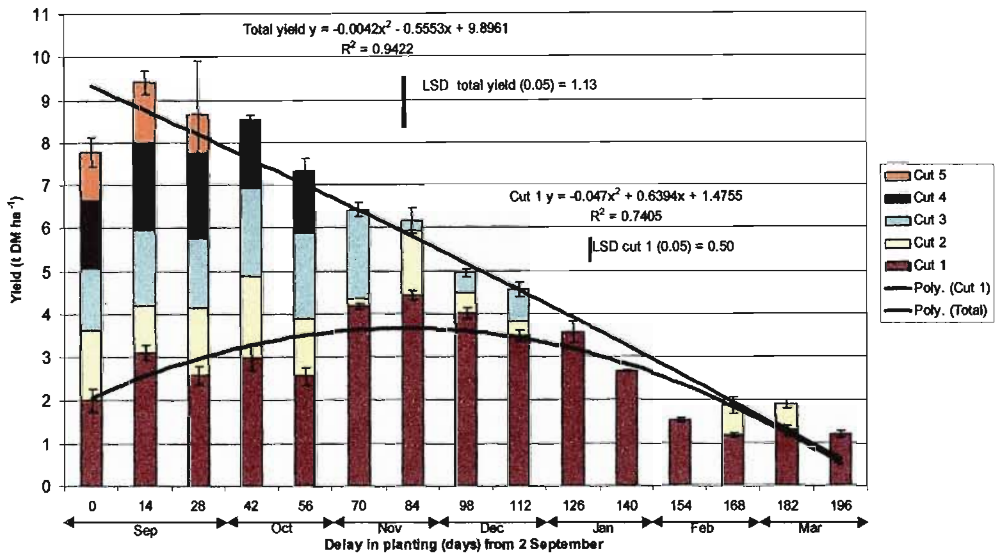

Figure 1 Cumulative dry mass herbage yield of teff seeded at different times of year in 1996/97. Error bars on the bars of cut 1 and total yield are used to indicate the standard deviation of the mean (standard error).

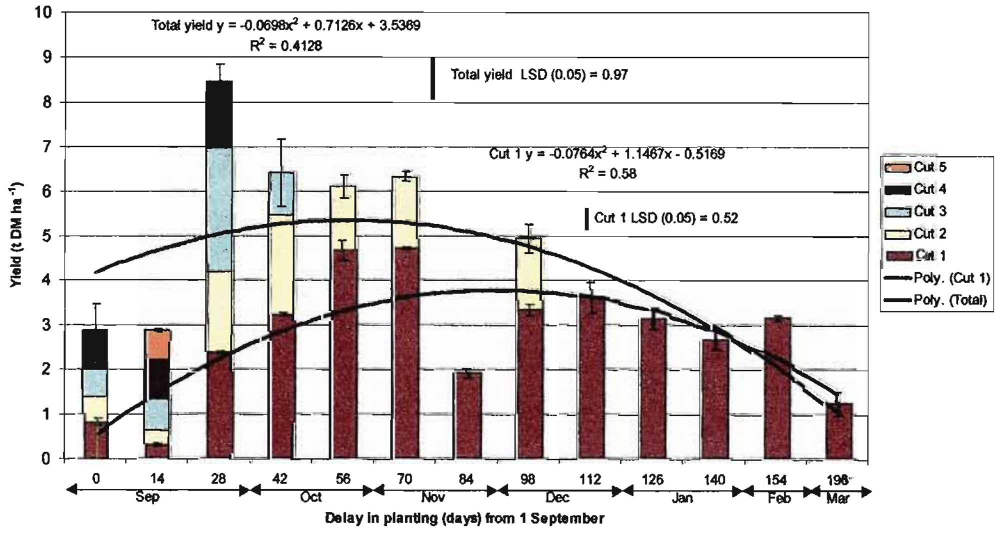

Figure 2 Cumulative dry mass herbage yield of teff seeded at different times of year in 1997/98. Error bars on the bars of cut 1 and total yield are used to indicate the standard deviation of the mean (standard error).

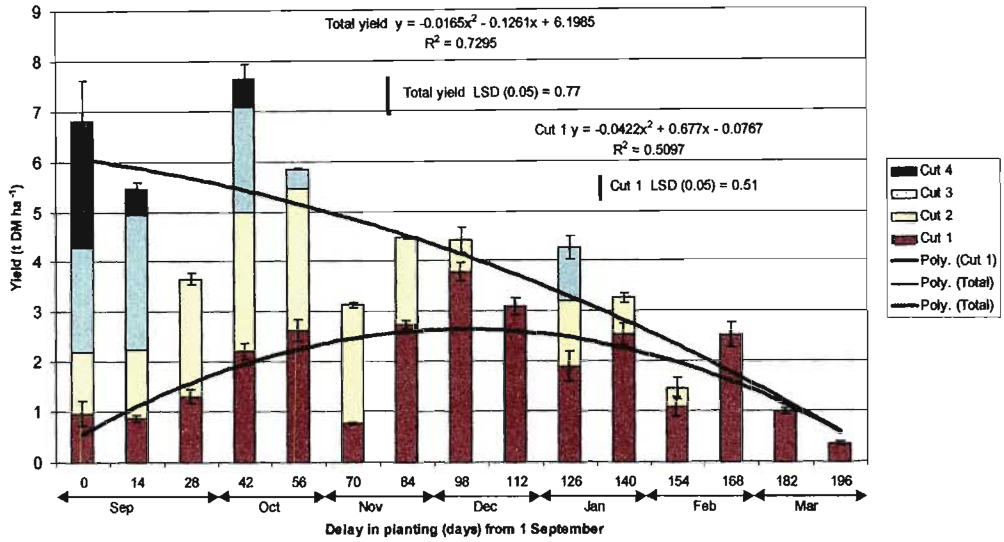

Figure 3 Cumulative dry mass herbage yield of teff seeded at different times of year in 1998/99. Error bars on the bars of cut 1 and total yield are used to indicate the standard deviation of the mean (standard error).

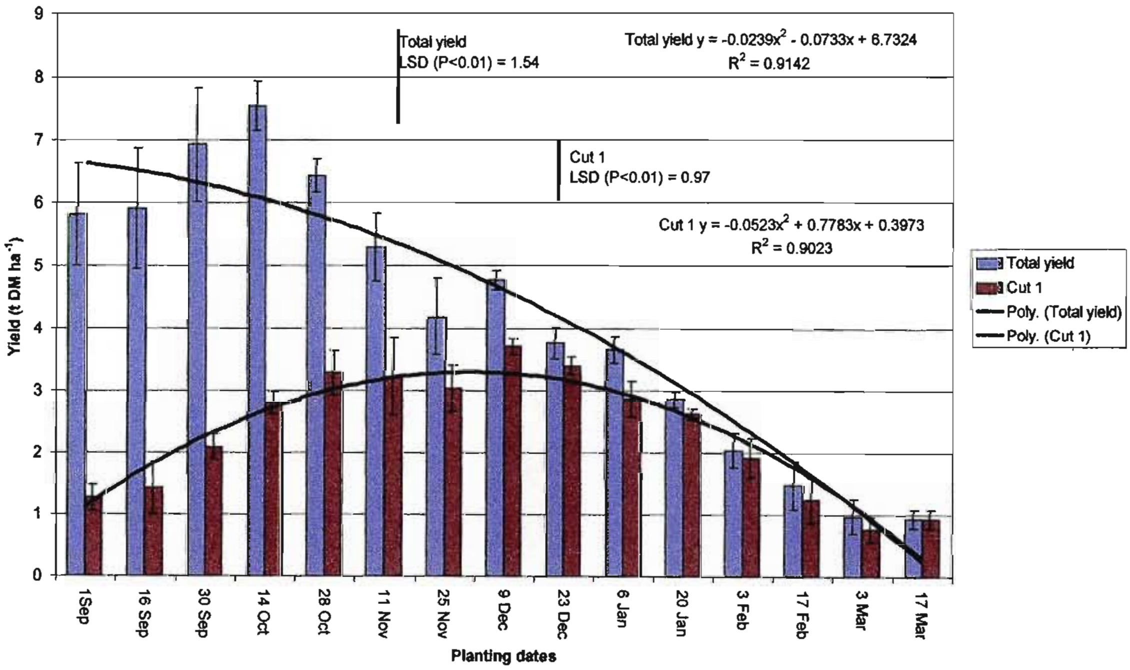

Figure 4 Mean dry mass herbage yield of the seasons 1996/97, 1997/98 and 1998/98 of cut 1 and total yield of teff seeded at different times of year. Error bars on the bars of cut 1 and total yield are used to indicate the standard deviation of the mean (standard error).

According to Jones (1985) the soil temperature is one of the most important factors in spring growth of C4 forage grasses in subtropical regions. Soil temperature is also a very important factor in the germination and early growth of annual crops such as maize and grain sorghum grown in temperate and sub-tropical regions and at high altitudes in the tropics. The temperature of the soil surface determines the rate of leaf initiation in millet during the seedling stage (Ong & Monteith 1985). The exact origin in Ethiopia of teff cv. 'SA Brown' used in these trials is not known. Depending on the site of origin in Ethiopia and the associated altitude, 'SA Brown' could be susceptible to low spring air and soil temperatures. Given that teff is a C4 grass some susceptibility to low temperatures can be assumed. The minimum temperatures at Cedara in spring are mostly below 15°C. Low spring temperatures may thus influence the germination rate, leaf initiation rate and also the dry matter accumulation through influencing the photosynthetic rate. Research by Kebede *et al.* (1989) shows that the biochemical and biophysical processes of teff cultivars 'Red Dabi' and 'DZ-01-354' associated with internal leaf photosynthesis were potentially most active in the temperature range 35 to 42°C. Even though temperatures at the trial site in spring were below optimal, the spring plantings in all three seasons produced the highest total herbage yields with total yield decreasing as planting was delayed. However, the first plantings did not necessarily produce the highest seasonal yield (Figures 1 to 3).

The climatic variables recorded were minimum and maximum temperature, rainfall and daylength. The yield responses obtained cannot be adequately explained in terms of any of these three climatic variables. Climatic variables provide indications as to what could have played a role in the yield responses. In future trials soil temperature, seasonal radiation and soil water content would be useful additional measurements.

According to the stepwise regression (Table 1) the yield response for total yield was to some extent linked to changes in daylength. This however only applied for the 1996/97 and 1998/99 trials and not for the 1997/98 trial. In Ethiopia the daylength variation between summer and winter is a change from 12 hr 30 min to 11 hr 30 min (Loch & Ferguson 1999). At Cedara the changes between spring and summer are from 11 hr 30 min in spring to 14 hr 06 min in mid-summer and 11 hr in April, at the end of the growing season[3]. The long daylengths and high summer temperatures coincide with the third and fourth and sometimes second cut obtained from the spring i.e. September and October plantings and the first cut of the summer plantings. According to Yan & Wallace (1999), long days result in increased crop growth rates but generally decreased partitioning of photosynthate to the reproductive organs. This

[3] Durban Weather Bureau, South Africa.

could account for the higher herbage yields of individual cuts during the mid-summer period. The yield response could also be linked to radiation differences rather than only daylength. In future studies of this nature radiation data should also be recorded to allow for the separation of the daylength and the radiation response.

Table 1 Stepwise regression analysis for climatic variables influencing total yield of teff hay for the seasons 1996/97, 1997/98 and 1998/99

1996/97	Daylength	Sig. (t)	Max temp	Sig. (t)	R^2
Total yield	y = -31.15 + 2.794x	0.005			0.510
Total yield	y = -15.99 + 9.16x	<0.001	y = -15.99 – 4.070x	<0.001	0.888

1997/98	Daylength	Sig. (t)			R^2
Total yield	y = -18.7 + 1.718x	0.094			0.165

1998/99	Daylength	Sig. (t)	Rainfall	Sig. (t)	R^2
Total yield	y = -20.43 + 1.865x	0.005			0.430
Total yield	y = -48.0 + 4.38x	0.02	y = -48 – 1.568x	0.131	0.493

The observation that the highest total yields in all three seasons were obtained from so-called spring plantings could simply be the result of these plantings having the longest growing season and the majority of the plants' growth season falling in the summer months as explained earlier. Hence, once conditions after winter are sufficiently warm, including soil temperature, and there is sufficient soil water available, spring plantings will result in higher herbage yields than summer seedings. This postulate requires close monitoring of the conditions prevailing during the first spring plantings.

For the 1996/97 season the first two weeks of September had only 7.1 mm rainfall. The germination of the first planting was delayed by a number of days due to dry conditions. On the second day after planting 1.3 mm was recorded but this was not likely to have been sufficient for germination since the soil was very dry and the seeds were planted at a depth of 5 to 10 mm. In the second week 3.1 mm was recorded after which the second planting was made. In the week following the second planting another 2.6 mm rain fell followed by 42 mm in the first week in October just prior to the third planting. Visually there was no obvious difference between the first and the second planting and flowering took place at almost the same time. However the yield of the first planting was lower than that of the second, especially for the first cut (Figure 1). It thus seemed that the environmental factors leading to the one weeks delay in germination and emergence had an influence on the plants phenology.

The equivalent first two plantings in the 1998/99 season did not show much delay in germination and the yields of individual cuts were similar, except for the fourth cut, which was also the last (Figure 3). During the two weeks prior to the first planting 25.7 mm rain was recorded with another 6.7 mm evenly distributed in the two weeks after the first planting and 8.7 mm in the two weeks after the second planting. This would have provided more than sufficient soil water for germination.

The yield response of the first two plantings of the 1997/98 season was very different to the other two seasons data with regard to the herbage yield produced (Figure 2). These plantings produced extremely low yields. This is despite the fact that regrowth did occur. The first planting produced four cuts and the second planting five cuts. The plants were much shorter than in the equivalent plantings in the other two seasons and the plants reached the 20% inflorescence emergence stage in fewer days. The yield of the third planting was high and of expected magnitude when compared with the other two seasons. Conditions prior to the third planting must have been of a particular nature to result in the dramatically reduced yield of the first two plantings. Comparison of the temperature differences between the three seasons over the first 27 days of the trial, i.e. the time period prior to the third planting, revealed that the average maximum temperature was 20.6°C for the 1997/98 season while it was 23.3°C for the 1996/97 season and 22.7°C for the 1998/99 season. Thus the 1997/98 trial, which gave the very low yields for the first two plantings also had a lower average maximum temperature, approaching the 20°C mentioned by Jones (1985) as the temperature below which the growth of tropical plants is reduced. The mean minimum temperature during this 27 day period for the 1997/98 trial was 9.3°C, which was similar to the 9.5°C for the 1998/99 trial. The 1996/97 trial had the lowest mean minimum temperature of 8.5°C. The average mean temperature for this 27 day period was lowest for the 1997/98 trial at 14.9°C while for the 1996/97 trial it was 15.9°C and 16.1°C for the 1998/99 trial. Thus 1997/98 had a lower mean maximum and lower mean temperature over the first 27 days of the trial, but not a lower minimum temperature. By comparing the growing degree day index (GDD) (Jones 1985) calculated with the base temperature of 6°C, the index for the 1997/98 trial was 250.6 while it was 277.2 for the 1996/97 trial and 273.4 for the 1998/99 trial. If the base temperature is taken as 10°C, as for most tropical species, the GDD index for the 1997/98 trial was 138.6, for the 1996/97 trial 166.8 and 166.5 for the 1998/99 trial. In both cases the GDD index for the 1997/98 trial over the first 27 days was lower than for the other two trials. Whether this lower value could have influenced the flowering behaviour and thus herbage production of the plants for the remainder of their growing season, is not clear and needs to be investigated in more detailed studies. If the flowering behaviour was influenced by the lower GDD index, it could have resulted in a change in the partitioning of photosynthate as opposed to the other two seasons. More photosynthate could have been partitioned towards the reproductive organs and less to the vegetative organs, resulting in reduced biomass accumulation. This could have resulted in a generally smaller and weaker plant, which then did not have the capacity to produce large amounts of biomass after defoliation. The time interval between successive cuts was shorter than in the equivalent treatments in the other two seasons. This could be the result of all the floral primordia having been initiated early on and they were at various stages of elongation and emergence when the pasture was cut. Possibly in the treatments of the other two seasons the initiation of floral primordia occurred over a more extended period of time. There is a need to monitor and measure more precisely floral primordia initiation and elongation.

The amount of rainfall during the germination period of the first two plantings of 1997/98 could not adequately explain the low yield response, especially in comparison to the rainfall in the other two seasons. The 1996/97 and 1998/99 seasons received less rainfall during the germination period than the 1997/98 season.

According to Squire (1990), the temperature and photoperiod experienced by the plant during the inductive period influences the number of leaves that are initiated. If the temperature during the first four weeks of the 1997/98 trial was below optimum for teff then the plants could in response have produced fewer leaf primordia. If the first four weeks would be within the inductive period for teff, then the lower temperatures could have resulted in smaller plants that gave lower herbage yields. The length of the pre-inductive phase and thus the start of the inductive phase during which vegetative primordia are produced, is not known. However, teff being an annual cereal and known to be fast-growing and 'SA Brown' having shown to have one of the shorter days to maturity as compared to other genotypes, it could be expected to have a very short pre-inductive period. Squire (1990) reported that among the cereals early maturing genotypes tend to have a very short pre-inductive phase and their apex initiates vegetative primordia for a shorter period than late maturing genotypes. The pre-inductive phase can be as short as two to three days after germination in some species.

The yield response of the first two plantings of the 1997/98 trial would require further specific investigations to determine a more detailed explanation of the yield reponse. These investigations could include aspects such as the influence of dehydration-rehydration of the seed after full imbibition had already occurred. Other investigations could look at whether stresses in the form of moisture and temperature have an influence. Temperature stress could include low air and soil temperatures. The response to stress could be a reduced number of leaf primordia or seed dormancy.

The number of cuts that were obtained from each planting date treatment for each season was generally highest in the spring plantings and declined with a delay in planting (Figures 1 to 3). Hence the number of times regrowth after cutting is possible in the pasture declines as the season progresses. The objective was to cut the plots when they were at 20% inflorescence emergence. From other trials done with teff at ARC-RFI Cedara, the observation was made that if the pasture is allowed to grow past the 20% flowering stage, lodging is very likely which results in wastage at cutting and generally makes the cutting operation very difficult. Due to unfavourable weather conditions, the 20% flowering criterion could not always be applied and some treatments were cut at a more advanced stage of flowering. From the data, especially in the first two plantings, of the 1996/97 trial and the first four plantings in the 1998/99 trial there seemed to be no adverse effects on regrowth, even if 80 to 100% of the plot was showing inflorescence emergence, provided the pasture was not excessively lodged.

Some plantings gave very poor or no regrowth after cutting, although in some cases the preceding and following treatments produced regrowth (Figures 1 to 3). These treatments seem to have one of two factors in common. Firstly in many of the treatments where poor regrowth occurred, the pasture was completely lodged at cutting. The second observation was that where lodging did not occur, but regrowth was poor or nothing, the days immediately post cutting were hot (28 to approximately 33°C) with no rain. Under these conditions, especially if the cutting height was nearer 50mm, resulting in removal of most of the leaf material, the plants were adversely affected by the hot and dry conditions. There was minimal leaf material left after cutting. According to Jones (1985) a cutting height of less than 100mm in C4 grasses can severely reduce dry matter production due to excessive leaf area removal, severe depletion of non-structural carbohydrate reserves and a reduction in the number of live tillers. Unfortunately the available harvesting equipment for these trials cuts at a height of between 50 and 80 mm. Exactly what influence the cutting height has on teff regrowth needs to be more fully investigated.

Towards the end of the growing season the autumn plantings did not produce regrowth as the days were becoming shorter and the minimum temperatures were more regularly below 10°C, which is below the temperature range of tropical plants (Jones 1985). According to Yan & Wallace (1999) stress due to lack of moisture or low or high temperatures establish the beginning and end of the growing season at a site.

First cut herbage production

As was the case with total yield, planting date also had an influence on the first cut harvest obtained from each planting date. The general trend in all three seasons was one of increasing yield with delay in planting reaching a maximum in the mid-summer plantings (November to December) and decreasing thereafter (Figures 1 to 3). For the 1996/97 season the maximum yield came from planting on 25 November, for the 1997/98 season from planting on 10 November and for the 1998/99 season from planting on 7 December.

According to the stepwise regression (Table 2) daylength had the most influence on first cut yield from the climatic data recorded (R^2 = 0.798 for 1996/97, R^2 = 0.466 for 1997/98 and R^2 = 0.333 for 1998/99). If the average daylength for the growing period of the first cut is calculated it shows that for the 1996/97 trial the late November planting had the highest average daylength of 14 hours. For the 1997/98 trial the early November planting had an average daylength of 13 hr 55 min with only the late November and early December plantings averaging marginally higher at 13 hr 56 min. Similarly in the 1998/99 trial the early December planting had an average daylength of 13 hr 57 min with only the late November planting having a marginally longer average daylength of 13 hr 58 min. Thus at the longest daylengths the teff plants are able to accumulate the most herbage for the first cut. Again according to Yan & Wallace (1999) long days result in increased crop growth rates or increased rate of biomass accumulation. In most cases the highest yielding treatments also coincided with the lower number of days to flowering when compared to all other treatments. The high herbage yield for these treatments could thus be the result of the longer daylengths giving higher total radiation but possibly also a faster growth rate since the days to flowering for these treatments tended to be lower than the spring and autumn treatments.

Table 2 Stepwise regression analysis for climatic variables influencing the yield of the first herbage cut of teff for the seasons 1996/97, 1997/98 and 1998/99

1996/97	Daylength	Sig. (t)	Rainfall	Sig. (t)	Growth days	Sig. (t)	R^2
cut 1	y = -14.06 + 1.278x	<0.001					0.798
cut 1	y = -13.91 + 1.227x	<0.001	y = -13.91 + 0.1433x	0.146			0.818
cut 1	y = -15.73 + 1.260x	<0.001	y = -15.73 + 0.2180x	0.046	y = -15.73 + 0.0203x	0.122	0.842

1997/98	Daylength	Sig. (t)	Rainfall	Sig. (t)	Flowering %	Sig. (t)	R^2
cut 1	y = -14.63 + 1.316x	0.006					0.466
cut 1	y = -10.87 + 0.885x	0.088	y = -10.87 + 0.555x	0.166			0.520
cut 1	y = -12.49 + 0.995x	0.042	y = -12.49 + 0.845x	0.046	y = -12.49 – 0.0171x	0.090	0.619

1998/99	Daylength	Sig. (t)	Mean temp	Sig. (t)	Rainfall	Sig. (t)	R^2
cut 1	y = -8.65 + 0.8x	0.014					0.333
cut 1	y = -12.72 + 0.691x	0.023	y = -12.72 + 0.287x	0.087			0.439
cut 1	y = -24.1 + 1.483x	0.030	y = -24.1 + 0.424x	0.033	y = -24.10 – 0.506x	0.171	0.488

According to Ong & Monteith (1985) temperature is the main factor which determines the time from sowing to maturity for an annual day neutral crop while the availability of light within the growing season determines the upper limit to the amount of dry matter the crop can accumulate when water is not limiting. The rate of dry matter production depends on temperature. The average maximum and minimum temperature during the growing period of the treatments that gave the highest yield for cut 1, were not the highest of the season. In each of the three trials the average temperatures were higher in the plantings following the one producing the maximum yield for the first cut, than the maximum yielding planting dates. This could indicate that the optimum temperature requirements for maximum dry matter production of teff were met at those treatments where the temperature was lower than the maximum for the summer season. Hence the most favourable conditions for maximum dry matter accumulation were at the maximum daylengths but not maximum temperatures at this site. Yan & Wallace (1999) report that in sorghum long days had the influence of increased crop growth rate and thus increased biomass accumulation. The number of leaves produced in millet is determined during the seedling stage (growth stage 1 (GS1)) and the duration of the seedling stage is determined largely by daylength. The rate of leaf and root primordia development in seedlings depends strongly on temperature of the meristem tissue and in some species on daylength (Ong & Monteith 1985). Considering that teff originates from the relatively high altitudes of 1800m to 2400m above sea level at low latitudes of 5° to 15° N in the tropics where conditions would be milder in comparison to lower lying areas at that latitude, the plants may be adapted to optimum temperatures that are lower than the average for tropical species. According to Kebede *et al.* (1989) the temperatures in the major teff growing regions in Ethiopia are 15 to 25°C minimum and maximum temperatures. Thus the temperatures in the KwaZulu-Natal Midlands during November and December are closer to these temperatures which are most likely optimal for maximum growth rate in teff. The highest temperatures of the summer season are during January and February. Ketema (1997) reports that the daylength during the growing season for teff in Ethiopia is approximately 12 hours. When teff was grown in England during the long day conditions of approximately 16 hours of summer the plants grew taller with a longer vegetative phase than was the case at 12 hour daylengths. Hence at the approximately 14 hour daylengths during the growing season of the planting date treatments, that gave maximum dry matter production, the vegetative phase could have been longer than for earlier and later planted treatments. This could then have allowed for more leaves being produced and thus more dry matter accumulation was possible. The length of the reproductive phase is not known nor is the reason for the fewer days to flowering in the later plantings, compared with spring planted treatments.

The anomalies in terms of low yield for cut 1 were the late November planting (24 November) in the 1997/98 trial and early November planting (9 November) in the 1998/99 trial. In both cases these treatments yielded significantly lower yields than the preceding and following plantings. During the first week after sowing of the late November planting of the 1997/98 trial, conditions were cold with maximum temperatures below 18°C and minimum temperatures below 10°C and rainfall of 74.9 mm. These temperatures were lower and the rainfall much higher than for other treatments. These weather conditions could have affected the germination and consequently the population resulting in lower dry matter yield. Very different conditions prevailed during the germination period of the early November of the 1998/99 where conditions were hot with only 0.5 mm rainfall. Germination was delayed and during this time yellow nutsedge germinated providing excessive competition for the teff which eventually resulted in poor establishment with 75% of the plots consisting of yellow nutsedge.

Conclusion

The objective of the study was to determine the optimal planting date for maximising herbage production from teff. These results show that planting date has an influence on both the total herbage production of the pasture and on the herbage yield obtained from the first cut. The trials have shown that the influence of planting date on herbage yield is mainly due to daylength and temperature differences that are associated with delaying the planting from spring through to summer and autumn. Temperature and rainfall following a cut also had an influence. Spring plantings are required to maximise total herbage production while the maximum herbage production from the first cut is obtained from early to mid-summer plantings. The exact planting dates are dependent, in addition to the daylength, on the specific climatic conditions of the season. The main climatic conditions were found to be temperature and rainfall. These results from agronomic field trials provide a broad indication of the influence of planting date. However, more detailed studies are required to identify specific processes and responses within the plants that result in the observed herbage yield responses. Grain yield responses should also be investigated, but in areas better suited, climatically, to seed production than the Moist Midlands Mistbelt (Kemp 1996), where heavy thunderstorms and moist conditions are prevalent at the time of seed maturity.

From an applied point of view these trials have given valuable information for the production of teff in the farm situation and resulted in a renewed interest in the species as a hay pasture crop. The results have shown that a higher herbage yield is possible than previously thought to be the potential of the species in South Africa. Furthermore, these results will enable farmers to choose a spring or a summer planting depending on whether yield maximisation is the aim or whether a single high yielding hay cut with a possible smaller second hay cut is considered desirable. This would have to be considered in economic terms.

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4 HERBAGE PRODUCTION OF TEFF (*ERAGROSTIS TEF* (ZUCC.) TROTTER) CUT AT FOUR GROWTH STAGES

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Abstract

The influence of growth stage at cutting on *Eragrostis tef* (Zucc.) Trotter pastures for hay production was assessed with regard to herbage yield maximization. Four growth stage treatments were used, namely vegetative, piping, early flowering and full flowering before seedset. The study was conducted in two consecutive seasons with a trial in 1996/97 and 1997/98 in the KwaZulu-Natal Midlands of South Africa. The yield trend for the first cut was one of increasing herbage yield with advancement of growth stage at cutting. The trend for total yield differed in the two seasons, decreasing in the first season and increasing in the second season with advancement in growth stage. Yield response was to some extent influenced by climatic conditions at the time of planting and also at the time of cutting the individual treatments, which influenced the yield magnitude of individual cuts. The growth stage treatments influenced the number of cuts that could be taken from a treatment and this was similar for both seasons. The most number of cuts could be taken from the vegetative treatment with a similar number from the piping and the early flowering treatment. The least number of cuts were taken from the full flowering treatment.

Additional key words: phenological stage

Introduction

In order to maximise herbage yield from a pasture for hay production it is necessary to have sufficient plant material accumulated for the hay-making operation, while at the same time cutting at the growth stage that will ensure maximum regrowth for the next cut. Furthermore the herbage quality has to be of an acceptable level.

The age and the type of plant tissue that is removed at a defoliation event determine how quickly the plant recovers. The loss of meristematic tissue has far greater influence on plant recovery than the loss of biomass or leaf area (Richards 1993). Whether or not meristematic tissue is removed during the cutting process largely depends on the cutting height and whether the plant is already in the reproductive stage and apical meristem elongation has commenced. In grasses with synchronous tiller development the loss of active shoot meristems in one defoliation event depends on the phenological development of the plant (Richards 1993). Regrowth after defoliation is also dependent on either continual terminal growth or on tillering and for maximum dry matter production there must be a balance between the two. If the plant has to rely on tillering because terminal growth points have been removed, the plant is more reliant on root reserves (Clapp & Chamblee 1970). This can be a disadvantage in terms of rate of refoliation. Teff is a plant that is not strongly tillered. Observations in field plots suggest that regrowth probably comes from the terminal shoots although some tillering from the basal node also takes place.

The hypothesis to be tested in this study was the growth stage or phenological stage at which the pasture is cut has an influence on the herbage yield of teff in terms of the total yield obtained from the pasture and thus the influence on the regrowth. The influence on herbage quality was also taken into account in terms of optimal growth stage for defoliation.

Procedure

Study area

Teff was grown over two consecutive summers (1996/97 and 1997/98). The site for the trials was located on the Cedara research station (29°32'S, 30°17'E, altitude 1076 m asl) in South Africa. Mean annual rainfall is 885 mm, mean maximum and minimum temperatures are 22.3°C and 9.4°C respectively (Agromet)[1]. The soil type was a Hutton soil form, which is an orthic A horizon over a red apedal B horizon (Soil Classification Working Group 1991). This is a well-drained soil. Mean weather data for the seasons are given in Appendix 2.

Land preparation

The initial land preparation was done with a plough and a disc harrow. The weed seeds were allowed to germinate and then the site was reworked at a shallow depth with a tine cultivator to eliminate the newly germinated weed seedlings. The final seedbed preparation was done with a tine cultivator on the day of planting.

Fertlization

The soil P and K levels were raised to the recommended levels of 20 g kg^{-1} P (AMBIC) and 120 g kg^{-1} K according to the soil analyses[2] using single super phosphate (10.5) and KCl (48) respectively. Fertilizer was spread over the entire site before cultivation with the tine

[1] Agromet, ARC – Institute of Soil, Climate and Water, Private Bag X79, Pretoria 0001, South Africa.

cultivator in order to work the fertilizer into the seedbed. The acid saturation of the soil was 14% and the pH (KCl) was 4.31. Nitrogen fertilizer, LAN (28), (50kg N ha^{-1}) was applied after seedling emergence when the seedlings were 50 to 100 mm tall. Each plot was top dressed with 50kg N ha^{-1} and 50kg K ha^{-1} after each cut in the form of 1:0:1 (47) combination fertilizer. The K was applied in order to avoid depletion due to the herbage removal at each cut, as would be the case in a hay pasture situation. The N and K fertilization levels applied after each cut and N after germination, were chosen according to recommended application rates used in other pasture trials at the same site.

Treatments and measurements

The trials were seeded with cultivar 'SA Brown' with four growth stage treatments as criteria for cutting the plots (vegetative, piping, early inflorescence emergence and full inflorescence emergence stage but before seedset) in five replications in a randomised complete block design. The 1996 trial was planted on 28 November 1996 and terminated on 4 April 1997 and the 1997 trial on 18 September 1997 and terminated on 22 December 1997. Termination was the result of lack of regrowth in any of the plots in the trial. The sowing rate was 15 kg ha^{-1} row planted with an inter-row spacing of 150 mm and a gross plot size of 2 m x 7 m ($14m^2$). The net plot size was 1.4 m x 4.2 m ($5.88m^2$). The treatments were cut with a reciprocating mower set at 50 mm blade height to determine the herbage production when the plots reached the required growth stage of the specific treatment based on visual assessment. The entire green weight for each plot was weighed and then a sample of approximately 500g was taken and weighed for each plot, dried at 90°C and then re-weighed in order to determine the dry matter ratio. Net plot dry mass was estimated from the measured ratios. In the 1996/97 trial a herbage sample for quality analysis was taken from two randomly chosen replications from each treatment of the first cut. Heat units were calculated using the daily mean temperature and subtracting the base temperature of 6°C.

Statistical analysis

The analysis of variance (ANOVA) was used to determine the effects of the planting date treatments on dry matter herbage yield. Differences between means ($P<0.05$ and $P<0.01$) were assessed using least significant differences (LSD). For the 1996/97 trial data linear regression (Steel & Torrie 1980) was used to assess the influence of heat units on the treatment yield. No statistical analyses were done on the herbage quality samples as these were bulked samples.

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Results and discussion

The objective of this experiment was to determine the influence of growth stage at cutting on the herbage yield and quality of teff hay. Both years trials gave similar yield trends for the first cut but total yield response differed between years.

The response of the 1996 trial was one of increasing yield with advancement in growth stage (Table 1). There was no significant difference between the yield of the early flowering treatment and full flowering treatment ($P<0.05$). There were however highly significant yield increases between the vegetative and the piping treatment and the last two treatments (early flowering and full flowering). In the 1997 trial there was also a yield increase with advancement of growth stage at cutting (Table 1). The increase was gradual for the first three treatments (piping, early flowering and full flowering) with a sharp increase in the full flowering treatment. There was no significant difference ($P<0.05$) between the vegetative and piping treatment but there was a significant yield increase in the early flowering and the full flowering treatment. Except for the full flowering treatment all treatments gave higher yields for the first cut in the summer planted 1996 trial as opposed to the spring planted 1997 trial.

Table 1 Herbage yield (t DM ha^{-1}) of the individual cuts and total yield for the growing season of each of the growth stage treatments for the 1996 and 1997 trials

1996 Growth stage at cutting	Cut 1	Cut 2	Cut 3	Cut 4	Cut 5	Cut 6	Total
Vegetative	2.00	0.61	0.82	1.36	1.63	0.70	7.12^{bc}
Piping	2.99	1.68	0.75	1.61	0.42	0	7.45^{c}
Early flowering	4.75	0.19	0.53	0.44	0	0	5.91^{ab}
Full flowering	4.76	0	0	0	0	0	4.76^{a}
1997 Growth stage at cutting	**Cut 1**	**Cut 2**	**Cut 3**	**Cut 4**	**Cut 5**	**Cut 6**	**Total**
Vegetative	0.63	0.45	0.34	0.63	2.95	0	5.04^{a}
Piping	0.90	1.70	0.48	2.97	0	0	6.05^{b}
Early flowering	1.77	0.14	0.71	2.94	0	0	5.56^{ab}
Full flowering	4.98	2.74	0	0	0	0	7.72^{c}

The result for total yield was a decreasing yield trend with advancement in growth stage in the 1996 trial while it was an increasing yield trend in the 1997 trial (Figures 1 and 2). The two trials were planted at different times of the year, 1996 in summer and 1997 in spring. According to the data from the experiments investigating planting date (Kassier & Greenfield n.d.), the spring planting should have given a higher total yield, especially for the early flowering treatment as this growth stage was used in the planting date experiments.

The total herbage yield obtained for the duration of growth for each of the four treatments for the 1996 trial was a trend of decreasing yield with advancement in growth stage (Figure 1). The piping treatment yielded slightly more than the vegetative treatment although not significantly so (P>0.05). The yield of the early flowering treatment is significantly lower than the piping treatment as was the yield of the full flowering treatment (P<0.05). The trend for the 1997 trial (Figure 2) was opposite to the 1996 trial increasing with advancement in growth stage. The lowest total yield was obtained from the vegetative treatment and the second lowest from the early flowering treatment. These two treatments yielded significantly lower (P<0.01) than the full flowering treatment. The yield of the vegetative treatment was also significantly lower (P<0.01) than that of the piping treatment.

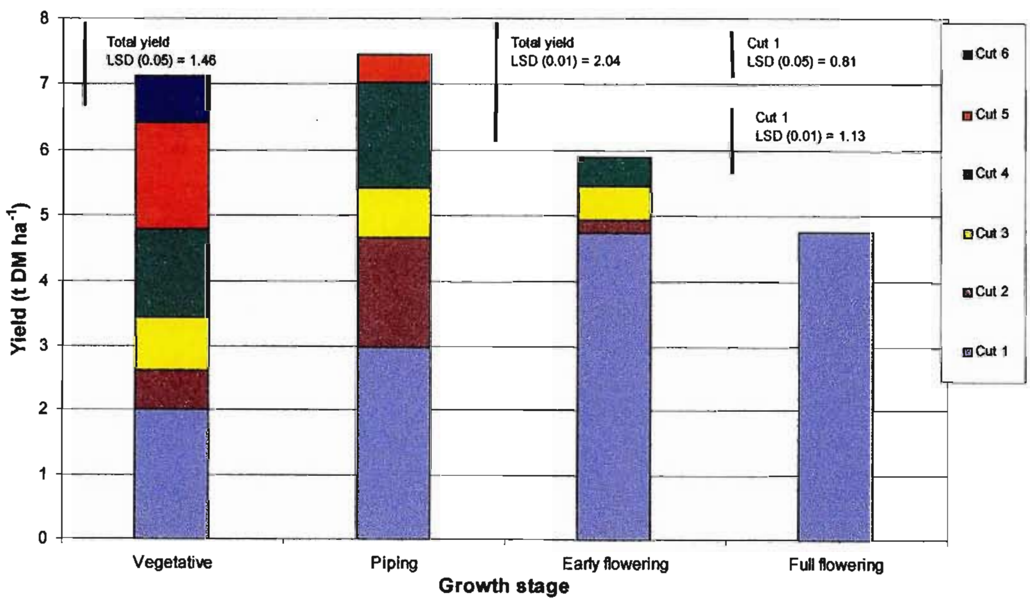

Figure 1 Cumulative dry mass herbage yield (t DM ha $^{-1}$) for the four growth stage treatments at cutting for the 1996 trial. The trial was planted on 28 November 1996.

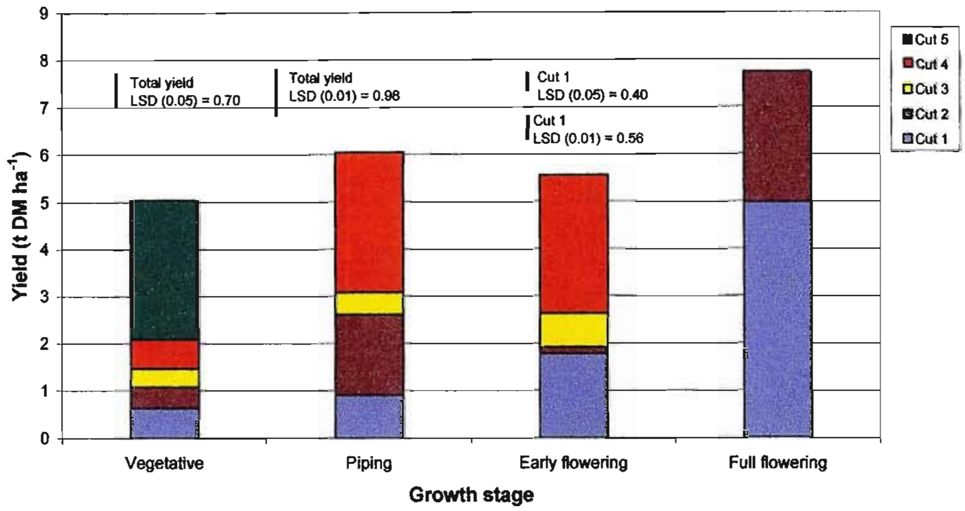

Figure 2 Cumulative dry mass herbage yield (t DM ha $^{-1}$) for the four growth stage treatments at cutting for the 1997 trial. The trial was planted on 18 September 1997.

In the 1997 trial the first three treatments, vegetative, piping and early flowering, gave very low yields (Figure 2) in comparison with the 1996. The vegetative treatment gave five cuts, however the first four cuts were very low yielding (0.63, 0.45, 0.34 and 0.63 t DM ha^{-1}). In the piping treatment the first and third cuts gave low yields of only 0.9 and 0.48 t DM ha^{-1}. The second cut yielded more at 1.7 t DM ha^{-1}. The early flowering treatment gave very low yields for the second and third cut of 0.14 and 0.71 t DM ha^{-1}. The final cut of the vegetative, piping and early flowering treatments produced very similar high yields compared with the preceding cuts of those treatments. (2.95, 2.97 and 2.94 t DM ha^{-1}) (Figure 2). However at this point all the treatments were at the full flowering stage and no longer in their respective growth stages as per the treatments. The yield of the final cut of the vegetative, piping and early flowering treatments was also of similar magnitude to the second cut of the full flowering treatment.

In contrast in the 1996 trial the vegetative and the piping treatments yielded similarly within each cut over the season. The early flowering treatment gave a high yielding first cut (4.75 t DM ha^{-1}) but three subsequent small cuts. The full flowering treatment was completely lodged at the first cutting and produced no regrowth at all. Due to lodging the mower was unable to cut all the material in the plot. Thus the actual yield was slightly higher than recorded. The harvested herbage reflected the effective yield that would have been obtained in a practical situation where the pasture would have been cut for hay.

Comparing the results of the 1996 growth stage trial of the early flowering treatment with the yield obtained from the almost equivalent planting date in the 1996 planting date trial, the yields are similar. The first cut in the planting date trial yielded 4.42 t DM ha^{-1}, while in the growth stage trial it yielded 4.75 t DM ha^{-1} (Figure 1). The growth stage trial gave four cuts with one very small cut of 0.19 t DM ha^{-1} and the planting date trial gave three cuts with the last two cuts of similar magnitude in both trials. Thus the large number of cuts obtained from the vegetative (six cuts) and the piping (five cuts) treatments in the growth stage trial, was related to the growth stage treatment and not the planting date.

The full flowering treatment in the 1996 trial was only cut once with no regrowth after the first cut. This treatment, in all five replications, was completely lodged at the time of cutting. A similar trend was observed in the planting date experiments (Kassier & Greenfield n.d.) where there was no regrowth when the pasture was completely lodged at cutting. If there was no lodging, and even though in full flower, there was some regrowth. This was the case in the 1997 trial where the full flowering treatment produced regrowth for a second cut (2.74 t DM ha^{-1}) that amounted to just over half the yield obtained from the first cut (4.98 t DM ha^{-1}). The exact reason for the lack of regrowth from lodged plants was not apparent. It could be that the tiller meristems were in some way damaged when the plants lodged. The influence could also be the result of shading of the lower parts of the stem, which causes the stems to turn a pale colour due to a lack of photosynthate. This would also mean less non-structural carbohydrate reserve in the stubble. The light colour of the stubble in lodged plants has been observed in many trials. More detailed research would be required to determine influence on photosynthate and carbohydrate reserves on lodged pasture.

The low yields of the first three treatments of the 1997 trial, excluding the last cut (Figure 2) show a similar trend to the almost equivalent planting date treatment in the planting date trial of the same year (Kassier & Greenfield n.d.). In the planting date trial it was also observed that the yield of individual cuts was very low. The comparison is again with the early flowering treatment. In the growth stage trial this trend is also evident in the vegetative and piping treatments. Thus factors other than the growth stage influenced the yield response more strongly. The climatic data for September 1997 show that the mean daily maximum temperature was 20.5°C and the mean daily minimum temperature 9.5°C. According to Jones (1985) the growth of C4 plants is severely reduced at temperatures below 20°C. Hence it could have been that the temperature during September 1997 was bordering on the lower limits for teff. Equally, the soil temperature could have been lower than is optimal for teff. This could have resulted in the plants producing fewer leaves. According to Ong & Monteith (1985) in millet, the soil temperature determines the rate of leaf initiation during the seedling stage. In addition to the low temperature, the rainfall for September 1997 was only 26.1 mm which is 31.2 mm below the long-term mean of 57.3 mm. Of the 26.1 mm rainfall only 6.8 mm were received from planting on 18 September 1997 to the end of September. The dry conditions could thus also have had an adverse influence on productivity. The combination of low temperatures and low rainfall could have resulted in smaller plants with fewer leaves and thus producing weaker regrowth. Richards (1993) mentions that the abiotic conditions that limit the availability of resources such as light, water or nutrients before or after defoliation can have decisive effects on the plants ability to recover from defoliation. In this case it would have been the adverse soil water conditions. If the plants were allowed to grow out as in the case of the full flowering treatment they developed sufficiently to produce the yield of 4.98 t DM ha^{-1}.

Some of the explanation of the difference in regrowth after the first cut in the early flowering treatment and the full flowering treatment may lie in the climatic conditions prevailing after cutting of the two treatments. The conditions on 3 November 1997 when the early flowering treatment was cut for the first time and produced almost no regrowth for the second cut were very different compared with the conditions on 10 November 1997 when the full flowering treatment was cut and produced a substantial amount of regrowth. Similarly the early flowering treatment, also cut on 10 November 1997 for the second cut produced more regrowth for the third cut compared with the second cut (Figure 2). On 3 November there was no rainfall in the week prior to cutting and also no rain for three days after the plots were cut. In addition the mean daily maximum temperature during the four days before cutting was 30°C. After cutting the temperatures were also high with a maximum temperature on the third day post-cutting of 33.7°C. Conditions around 10 November were milder with four cool days after cutting with three days below 19°C and 23.8°C on the fourth day. Furthermore 26.5 mm rainfall that fell during this period which was followed by warm days (>25°C up to 31°C). It seems that the conditions immediately pre- and post cut influenced the regrowth of the plants, as was also mentioned by Richards (1993). The warm dry conditions being unfavourable and cooler conditions even if <20°C to be more favourable immediately after cutting. Also according to Richards (1993) one of the immediate effects of defoliation is that root elongation ceases and that the fine roots may begin to die and decompose. Thus warm and dry conditions post cutting would, through the effects on the root system also compromise regrowth potential. Other factors are likely to also play a role in the amount of regrowth that is produced, could include the height of the cutting and the associated removal or not or meristematic tissue. The cutting height was 50 mm, which is considered low for tropical grasses. According to Jones (1985) a cutting height less than 100 mm in C4 grasses can severely reduce dry matter production due to excessive leaf area removal, severe depletion of carbohydrate reserves and a reduction in the number of live tillers. These factors would have to be studied in more detail on a more intensive level than is possible in these type of field trials.

Another aspect that could have played a role in the very low yield of the second cut of the early flowering treatment of both the 1996 and the 1997 trial could be the status of the carbohydrate reserves in the stem at that particular growth stage. According to Shanahan (1991) in maize, the TNC content of the whole stem declined during the period from anthesis to mid-grain fill and then increased substantially thereafter from mid-grain fill to physiological maturity. If a similar process occurs in teff where the emerging inflorescences become a major sink for carbohydrates and the reserves in the stem are consequently severely depleted, it would mean that the stubble remaining after cutting is low in stored carbohydrates. This would result in poorer regrowth than if the pasture was cut before or after this particular growth stage.

The very high yield of the last cut of the vegetative, piping and early flowering treatments of the 1997 trial can be explained by the regrowth after the second to last cut going directly to full flower without producing much vegetative material first. In both seasons trials it was only possible to cut the first two harvests at the designated growth stage for the first three treatments. From the third harvest onwards in most treatments this became very difficult, especially in the 1996 trial, as the regrowth of the plants was reproductive growth or flowering stems, rather than only leaf material (Table 2). This occurred in all the treatments including the vegetative treatment. This flowering influenced to a large extent the total yield obtained from the 1997 trial in that the final cut obtained from the vegetative, piping and early flowering treatments was large due to the fact that all plants were in full flower (Figure 2).

The trend for the yield of cut one of the 1996 trial, where herbage yield increased with advancement in growth stage, was to some extent linked to the heat units ($R^2 = 0.78$, Figure 3). The longer the plants are left uncut in progressive treatments the more biomass they are able to accumulate. The added accumulation of biomass appears to be accounted for to some extent by the additional heat units the treatment received. There is however no such correlation between climatic variables and the yield of the 1997 trial. The increase in biomass accumulation was mostly from vegetative to piping to early flowering with almost no increase between early flowering and full flowering. Hence the results show that in this specific season

(1996) there was no advantage, in terms of herbage yield, to leave the pasture to grow beyond the early flowering stage. At this point the so-called ceiling yield could have been reached where the rate of tissue production equals the rate of tissue senescence (Jones & Lazenby 1988). Likewise there was also no advantage in terms of the decreasing herbage quality (Figure 4) associated with advancement in growth stage.

Table 2 Duration of the growth period (days) of each cut for the 1996 and 1997 trials. The cumulative days are given in brackets

1996 Growth stage at cutting	Cut 1	Cut 2	Cut 3	Cut 4	Cut 5	Cut 6	Total
Vegetative	36	14 (50)	13 (63)	21* (84)	19*(103)	25*(128)	128
Piping	40	23 (63)	21* (84)	19*(103)	25*(128)	-	128
Early flowering	50*	34* (84)	19*(103)	25*(128)	-	-	128
Full flowering	63*	-	-	-	-	-	63
1997 Growth stage at cutting	**Cut 1**	**Cut 2**	**Cut 3**	**Cut 4**	**Cut 5**	**Cut 6**	**Total**
Vegetative	40	7(47)	7(54)	11(65)	31*(96)	-	96
Piping	43	11(54)	11(65)	31*(96)	-	-	96
Early flowering	47*	7*(54)	11*(65)	31*(96)	-	-	96
Full flowering	54*	42*(96)	-	-	-	-	96

* plants were at the flowering stage when cut

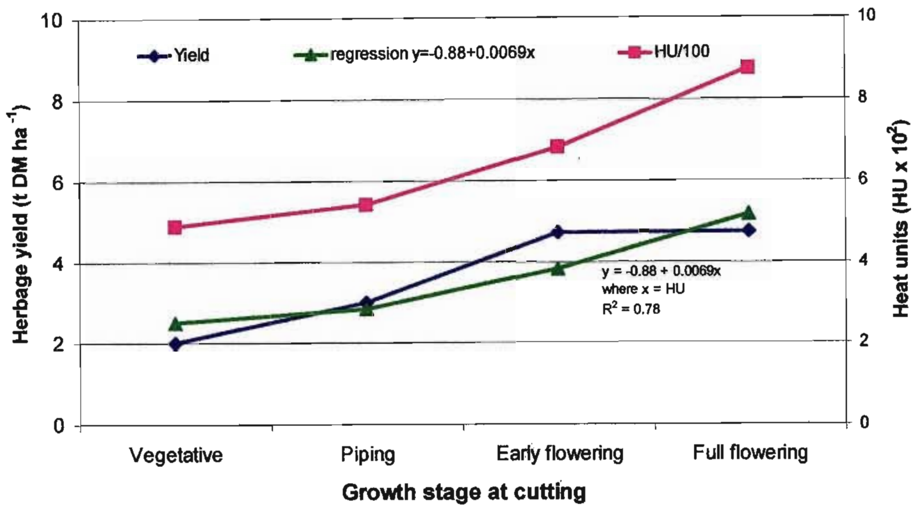

Figure 3 The relation between herbage yield (t DM ha^{-1}) and heat units (shown as HU x10^{-2}) for the four growth stage treatments in the 1996 trial.

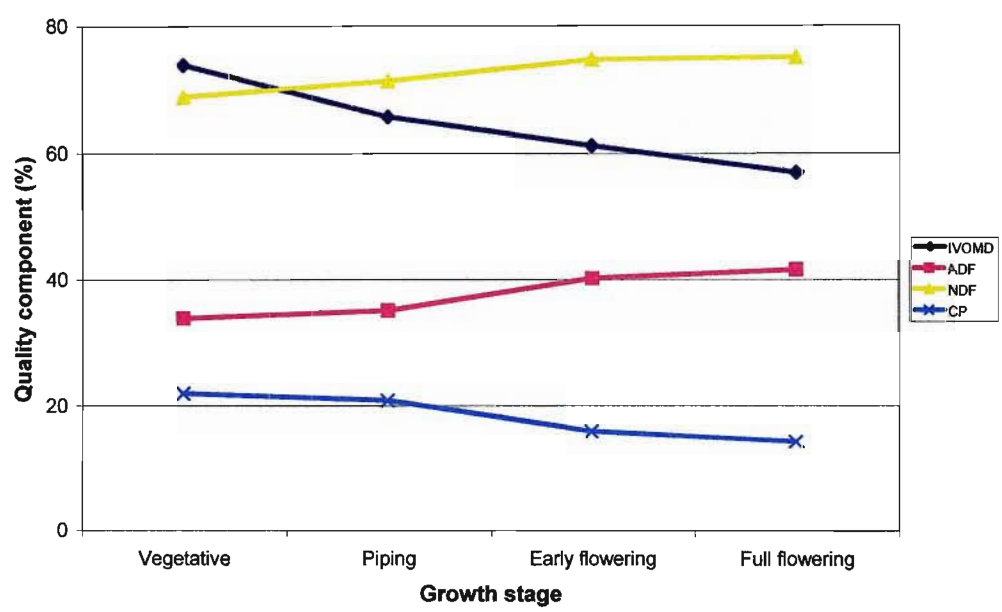

Figure 4 Changes in herbage quality of cut 1 of the 1996 trial for IVOMD (*in vitro* organic matter digestibility), ADF (acid detergent fibre), NDF (neutral detergent fibre) and CP (crude protein).

Herbage quality data (Figure 4) were obtained for the 1996 trial. Both the *in vitro* organic matter digestibility (IVOMD) and the crude protein (CP) showed a decreasing trend with advancement in growth stage. The IVOMD declined more sharply than the CP. The largest difference in IVOMD was between the vegetative and the piping treatment with the piping treatment 8.15% lower than the vegetative treatment. The largest difference in CP was 4.8% and was between the piping and the early flowering stage.

The acid detergent fibre (ADF) and the neutral detergent fibre (NDF) increased with advancement in growth stage. The highest increase was between the piping and the early flowering treatment. The increase was 5.09% for ADF and 3.39% for NDF. According to deFigueiredo & Thurtell (1998) NDF>75 and ADF>40 is an indication of poor quality forage. The results show that NDF and ADF for the early flowering treatment were 74.74% and 40.23% and for the full treatment it was 75.1% and 41.63%. Thus in terms of herbage quality there is no justification to allow the pasture to grow out beyond the early inflorescence emergence stage.

The largest drop in CP was from piping to early flowering. Therefore considering the herbage quality aspect, it would be advisable to cut the pasture in the piping stage, which in terms of total yield for the 1996/97 season, was also the highest. Botha & Rethman (1994) found the same scenario with babala where a lower defoliation frequency, gave higher total yields but higher defoliation frequency gave higher herbage quality. In practice this would have to be weighed up in terms of financial implications. The pasture harvested in the piping stage had to be cut five times to achieve the maximum yield. As for the early flowering treatment in practice a farmer may not have taken the additional three harvests after the first cut as they were of very low yield. The one cut of 4.75 t DM ha^{-1} of the early flowering treatment may have been more advantageous financially than the five cuts required to obtain 7.45 t DM ha^{-1} from the piping treatment. In contrast the higher quality of the hay from the piping stage treatment may have resulted in sufficiently higher hay prices or animal production that the additional cutting costs would have been warranted.

According to the results of the 1997 trial cutting the pasture at the piping stage would have resulted in loss of herbage yield (Figure 2) as opposed to the full flowering treatment. This is particularly so considering that the largest cut obtained from the piping treatment was in actual fact at the full flowering stage and thus of equally low quality as the full flowering treatment.

These two season's results, 1996 and 1997, do not give a clear picture as to what the optimum growth stage should be at cutting in order to maximise herbage yield. The yield response is strongly influenced by particular climatic conditions prevailing during the season and it seems especially those conditions at the beginning of the season. In addition the trade-off between herbage quality loss and increased dry matter yield would have to be assessed in terms of financial considerations. In order to avoid the situation of relatively low yield from the 1997 trial as opposed to the 1996 trial, a slightly later planting would be advisable. The data from the planting date trials conducted in the same season (Kassier & Greenfield n.d.) showed that the yield obtained from the end of September planting was far higher than the yield from early to mid September plantings. Thus it is important, especially if the pasture is grown under rain-grown conditions, to wait for the onset of reliable spring rains and mean air temperatures and possibly also soil temperatures to be high enough. The exact temperatures, both air and soil, that are limiting to teff herbage production would have to be studied in more detail to allow for an even better decision making process in terms of planting time of teff pastures to maximise production. Yield maximization can then be achieved by choosing a desirable growth stage at cutting.

In terms of the exact growth stage at cutting that is optimal for maximum herbage production it will be expedient to determine the leaf life span of teff which would help avoid leaf senescence. The pasture could then be cut before the onset of biomass loss or as the ceiling yield is reached. The height of defoliation or stubble height and its influence on herbage production may also be important in future studies. Work done by Clapp and Chamblee (1970) on the regrowth of millet and sorghum hybrids showed that in order to maximise herbage production it is necessary to have different cutting heights as the season progresses.

A recent trend in teff utilization that has emerged in South Africa in the last two years is to use the pasture for grazing. In this regard the growth stage at which the pasture is defoliated is just as important in order to maximise production and could be a topic of future research. Ockerby *et al.* (2001) found that by defoliating sorghum plants in the seedling stage partially exposed expanding leaves reset the plants development to an earlier phase and thus delayed the onset of the reproductive phase. If a similar process takes place in teff it could be advantageous especially in the grazing situation where extended vegetative growth would result in better herbage quality for the grazing animal.

Conclusions

Growth stage at cutting influenced herbage yield. Yield was, however, also affected by other conditions such as temperature and rainfall and whether the pasture was lodged or not. Cutting height could also have influenced the yield, as a cutting height of 50 mm is low for tropical grasses. According to Jones (1985) cutting tropical grasses lower than 100 mm can reduce dry matter production.

A trend of increasing yield was observed for the first cut or harvest with advancement in growth stage. This was the case in both seasons (1996/97 and 1997/98). However the total yield trend differed between the two seasons and was more strongly influenced by climatic conditions than the growth stage cutting treatments. The influence of the growth stage treatments at cutting was in the number of times the pasture could be cut. The actual yield at each cut was largely influenced by climatic conditions. These included both temperature and rainfall at the beginning of the season, when the trial was planted and the conditions that prevailed in the few days pre- and post cutting. The non-structural carbohydrate status in the stem at the time of cutting, and thus in the remaining stubble after cutting could also have influenced the regrowth potential of the pasture. This could be linked to a very specific growth stage.

The optimum growth stage at cutting can not only be assessed in terms of herbage yield maximization but also involves a trade-off with herbage quality. Increased quantity with advancement in growth stage results in decreased quality. The compromise will depend on the objective in terms of use of the hay, the quality of herbage required and the associated financial implications.

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5 RESPONSE OF TWO TEFF (*ERAGROSTIS TEF* (ZUCC.) TROTTER) CULTIVARS TO NITROGEN APPLICATION RATES

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Abstract

The study of teff herbage and grain responses to fertilizer N application conducted over two seasons with two cultivars SA Brown and TEF 373 (Dessie Tacker) showed that maximum herbage production was achieved at fertilizer N applications between 75 and 150 kg N ha^{-1} applied in two split applications. The applications of N must be split according to expected yield distribution between the hay cuts. Yield distribution is related to the planting date of the pasture. There was no effect of N application on lodging. There was a positive response of herbage CP content to fertilizer N application. The N fertilizer use efficiency was highest at 75 kg N ha^{-1} and decreased logarithmically to 300 kg N ha^{-1}. The grain trials were unsuccessful due to unfavourable weather conditions at the time of grain maturity.

Additional key words: fertilization rates

Introduction

The primary use of teff in South Africa as a hay crop rather than as a grain crop differs from that in most other countries. Consequently what little literature there is on the crop's response to N fertilization and hence fertilizer recommendations relate to grain yield. Also these responses were obtained under environmental conditions, such as the Ethiopian Highlands, which are very different to those pertaining in South Africa. Only a few authors make reference to N fertilization recommendations for Ethiopia. Bechere (1995) recommends 40 kg N ha^{-1} for light soils and 60 kg N ha^{-1} for black soils. Jones (1988) reports that teff in Ethiopia produces well without added mineral nutrients but does respond sufficiently to artificial fertilizers which farmers will use if available. According to Jones (1988) an important objective for teff improvement is to develop cultivars with a high response to artificial fertilizers. According to Skerman & Riveros (1990) teff in Ethiopia is usually fertilized with farmyard manure or grown in rotation with leguminous crops. Ketema (1993) gives the general recommendation for teff production in Ethiopia as 32 kg N ha^{-1}. It is also mentioned that N produces more straw while P ensures a good grain yield. The recommendation is further to apply N in split applications as this increases the grain yield without influencing the straw yield. Ketema (1993) recommends that further studies are needed to determine fertilizer requirements under various conditions. Shiferaw & Unger (1985) link N fertilization to lodging problems in the teff, reporting that fields that received N fertilizer and adequate rainfall had particular problems with lodging of the crop.

With regard to N fertilization for teff in South African literature, du Plooy (1957) advises that small amounts of N may be used, but that on heavy, fertile black soils fertilizers would not be necessary. He also mentions that teff has a tendency to lodge when rich soils are fertilized. According to Dickinson *et al.* (1990) two topdressings of 50 kg N ha^{-1} should be given if teff is grown on low fertility soils and when two to three hay cuts are expected and that the first topdressing should be applied just after emergence. If the soil has been well fertilized for previous crops and when only one hay cut is expected then only minimal amounts or no N should be applied. Dickinson *et al.* (1990) also refer to excessive N causing luxurious growth which results in increased lodging. In view of the sparse information available the response of teff to fertilizer N application was investigated.

A further reason for investigating the crops response to nitrogen application, is the possible link to the lodging problem experienced with teff, as mentioned by various authors. By attempting to quantify the amount of nitrogen that is required by the crop for good production and good herbage quality, excessive application can be avoided and in that way the lodging of the crop can be reduced. Solutions to the lodging problem obviously go beyond the application of N alone, and include other management practices as well as plant breeding.

In this study the influence of N application on seed production was simultaneously investigated as there are no data for South African conditions. Excessive N could result in luxurious herbage growth and influence the seed yield, also through lodging before seedset. Once there are new cultivars on the market, seed will have to be produced under optimum conditions in order to maximise seed yield.

Procedure

Study area

The nitrogen application study was conducted during two consecutive seasons and different sites in the summers of 1996/97 and 1997/98 at Cedara Research Station (29°32'S, 30°17'E, altitude 1076 m asl). The mean annual rainfall is 885 mm, the mean maximum, minimum and long-term average temperatures are 22.3°C, 9.4°C and 16.2°C respectively (Agromet).[1] Mean weather data are given in Appendix 2. The soil type at the 1996/97 trial site was a Dresden soil form, which is an orthic A horizon over a hard plinthic B horizon. This soil has a relatively shallow A horizon and can become temporarily water-logged during heavy rainfall, especially in summer. At the 1997/98 site the soil type was a Hutton soil form, which is an orthic A horizon over a red apedal B horizon (Soil Classification Working Group1991). This is a well drained soil.

The two sites on which the trials were conducted are very different and so was the utilization in the seasons prior to the trials being planted. The site for the 1996/97 trial is on a shallow, poorly drained soil. The site was not ploughed in the season prior to the trial. The previous crop was a mixed pasture of ryegrass and rye, which had been on the site for two years and had been grazed by sheep. The 1997/98 trial was planted on a site with a deep, well-drained soil. The site had previously been ploughed every season and was under agronomic crops.

Land preparation

The initial land preparation was done in late winter with a plough and a disc harrow. The weed seeds were allowed to germinate and then the site was worked at a shallow depth with a tine cultivator to eliminate the newly germinated weeds. The final seedbed preparation was done with a tine cultivator on the day of planting.

Fertilization

The soil P and K levels were raised to the recommended levels of 20 g kg $^{-1}$ P (AMBIC) and 120 g kg^{-1} K for tropical grasses according to the soil analyses (Fertrec[2]). The P (single superphosphate (10.5)) and K (KCl (48)) fertilizer was spread over the entire site before the incorporation with the tine cultivator was done. The acid saturation of the soil was 35% and the pH (KCl) was 3.99. The N limestone ammonium nitrate (LAN (28)) was weighed for each plot according to the treatments and applied by hand to each plot. The first N fertilizer was applied after germination when the seedlings were 50 to 100 mm tall. The second application was done after the first herbage cut.

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Treatments and measurements

Two cultivars ('SA Brown' and 'TEF 373') were grown under five levels of N application (0, 75, 150, 225 and 300 kg N ha^{-1}) in a 2 x 5 factorial with four replications. 'SA Brown' was then the only locally available teff cultivar. 'TEF 373' was imported from the USA where it is called Dessie Tacker[3]. Fertilizer was applied as split dressings in the ratio of $^{2}/_{3}$ applied after emergence and 1/3 applied after the first herbage cut. The application was split in a ratio of 2:1 as the general indication from teff hay growers is that the herbage production is split in this ratio between the first and the second cut and that usually there is no third cut.

The 1996/97 trial was planted on 9 December 1996 and the 1997/98 trial on 29 October 1997. Prior to establishment of the trial soil samples were taken for analyses of residual soil N. Unfortunately during the course of the year the laboratory responsible for the analysis of these samples was closed and hence no results were obtainable for residual soil N.

The seeding rate was 15 kg ha^{-1} row planted with an inter-row spacing of 150 mm. The gross plot size of both the 1996/97 and the 1997/98 trial was 2 m x 7 m (14 m^2). The net plot size of the 1996/97 trial was 1.4 m x 4.2 m (5.88 m^2) and of the 1997/98 trial 1.4 m x 5.6 m (7.84 m^2). The 1996/97 trial had wider border rows to allow for the cutting of individual plots at different times as and when they reached the required growth stage for cutting. For the first season's trial this provision was necessary since it was unknown whether or not the two cultivars had similar phenological development. In addition, it was not known whether the fertilizer treatments would affect the time to cutting. From the first years trial it was evident that all plots could be cut at the same time, hence the narrower border rows in the second season and the associated larger net plot size. Visually, no differences in maturity could be observed due to cultivar or N fertilization differences.

The plots were cut with a reciprocating mower set at 50 mm blade height. The plots were cut when the plants reached 10 to 20 % floral emergence on visual assessment. Each cut plot was weighed fresh and a sample of approximately 500g was taken and sealed in a plastic bag. The green samples of each plot were weighed, dried at 70°C in a forced draught oven for 72 hours and then weighed again for the determination of the dry matter percentage. The dried samples of the first cut were milled and analysed for herbage quality parameters using NIRS[4]. The quality parameters were crude protein (CP), in vitro organic matter digestibility (IVOMD),

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acid detergent fibre (ADF) and neutral detergent fibre (NDF). The quality data are only available for the 1996/97 trial.

An identical trial was planted in both seasons for the measurement of grain production. The fertilizer N treatments were applied in their entirety after crop emergence. At grain maturity the border rows were cut and the net plot harvested and threshed.

Statistical analysis

Analysis of variance (ANOVA) was used to determine the effects of the N levels on the dry matter yield and herbage quality. Differences between means were assessed using least significant differences (LSD) ($P< 0.05$, $P< 0.01$). Error bars are used to indicate the standard deviation of the mean (standard error) (Steel & Torrie 1980).

Results and discussion

Herbage yield response

The 1997/98 trial was cut twice with the second cut producing more herbage than the first for both cultivars (Figures 1 and 2). For the first cut there were no significant differences ($P>0.05$) between the N level treatments. In the second cut ($P<0.05$) 'SA Brown' yielded the highest at 75 kg N ha^{-1} while for 'TEF 373' it was at 150 kg N ha^{-1}. The highest total yield for cultivar SA Brown was obtained at 75 kg N ha^{-1}, which was not significantly different ($P>0.05$) to the 150 kg N ha^{-1} treatment. These two treatments differed from the remaining treatments ($P<0.05$). The same applied for 'TEF 373' however the highest yield in this cultivar was achieved at 150 kg N ha^{-1} N with the 75 kg N ha^{-1} treatment not significantly lower. From the fitted polynomial the highest yield was obtained at an N level slightly above 75 kg N ha^{-1} for both cultivars in the 1997/98 trial.

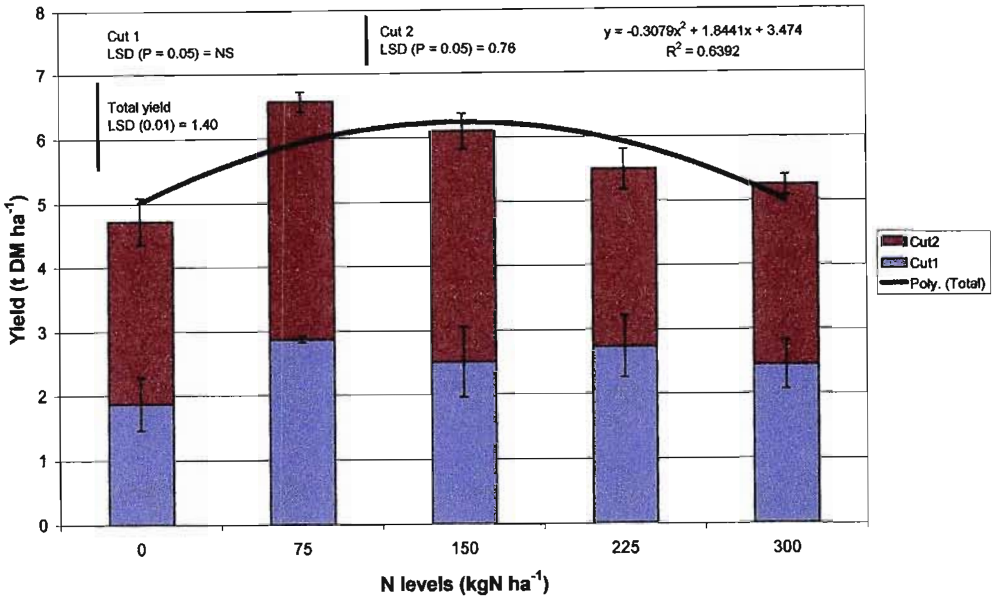

Figure 1 Cumulative dry mass herbage yield of cultivar SA Brown at five fertilizer N applications for the season 1997/98. Error bars on the bars of cut 1 and total yield are used to indicate the standard deviation of the mean (standard error).

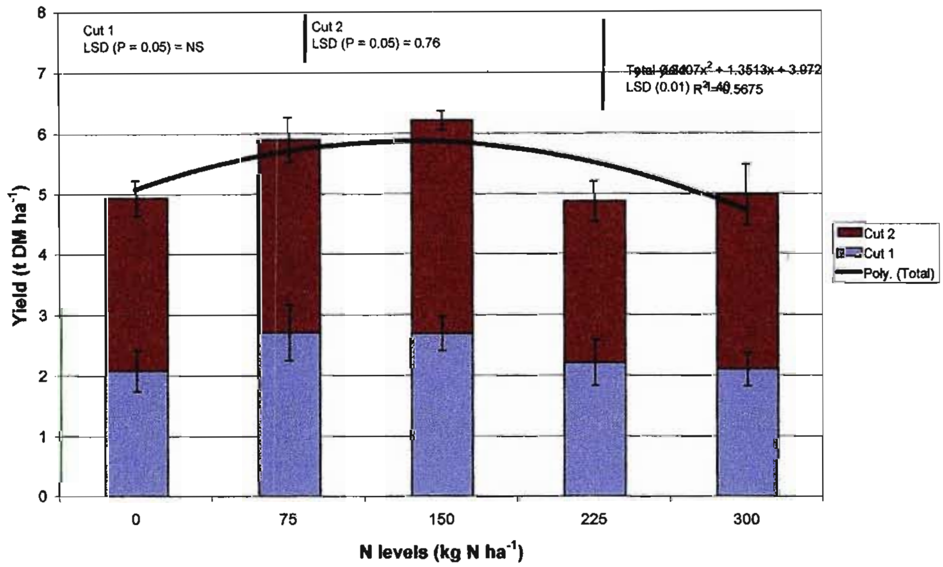

Figure 2 Cumulative dry mass herbage yield of cultivar TEF 373 at five fertilizer N applications for the season 1997/98. Error bars on the bars of cut 1 and total yield are used to indicate the standard deviation of the mean (standard error).

The 1996/97 trial was cut three times with the first cut accounting for most of the herbage yield obtained from the trial (Figure 3 and 4). There were no statistically significant differences in herbage yield (P>0.05) between the N level treatments or cultivars in the three individual cuts or the total yield for the season. Although the differences were not statistically significant the two cultivars seem to respond slightly differently to the N fertilization. 'SA Brown' decreased in yield with increased N up to 150 kg N ha^{-1} and then increased again. 'TEF 373' responded in the opposite way by increasing in yield up to 150 kg N ha^{-1} and then decreasing again.

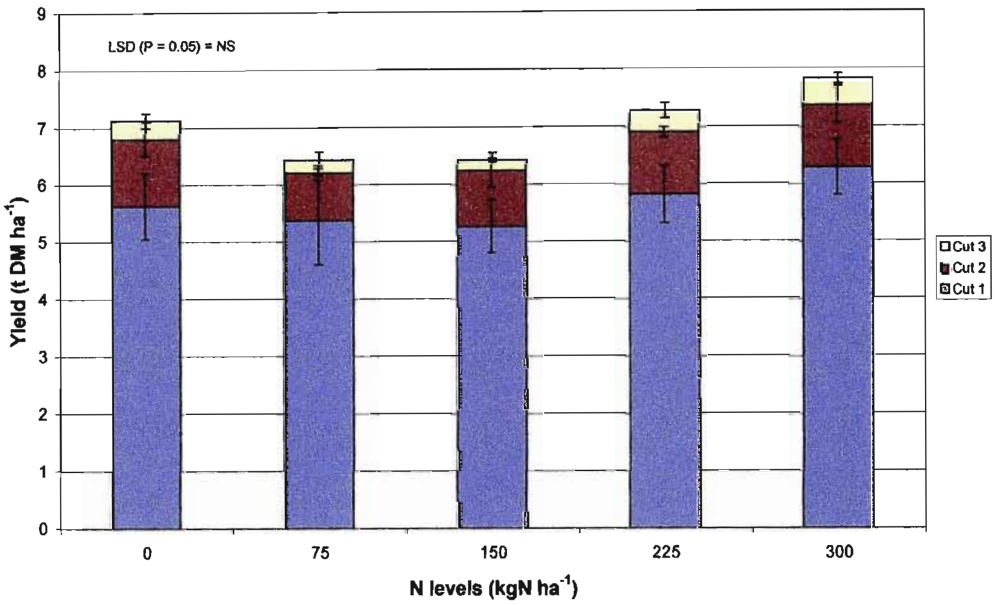

Figure 3 Cumulative dry mass herbage yield of cultivar SA Brown at five fertilizer N applications for the season 1996/97. Error bars on the bars of cut 1 and total yield are used to indicate the standard deviation of the mean (standard error).

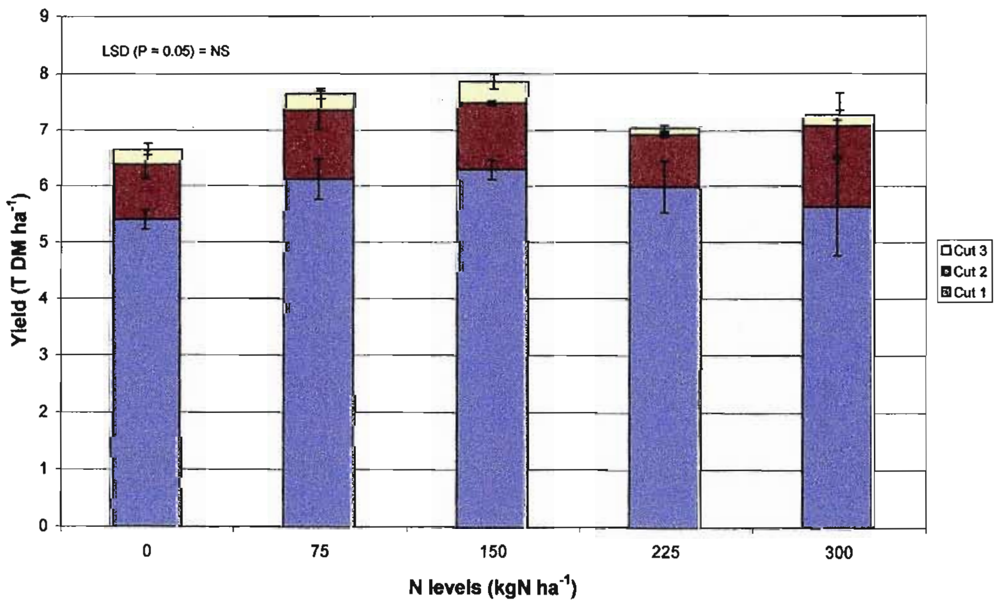

Figure 4 Cumulative dry mass herbage yield of cultivar TEF 373 at five fertilizer N applications for the season 1996/97. Error bars on the bars of cut 1 and total yield are used to indicate the standard deviation of the mean (standard error).

The lack of response to N treatments in the 1996/97 trial could mean that the inherent N status of the soil was high enough for the requirements of the teff. A better indication of this may have been obtained from the soil samples that were to be analysed for residual N content. According to Wiedenfeld (1998) a lack of fertilizer response indicates that adequate residual soil N was present at the beginning of the study. According to Stevenson (1982) the quantity of residual mineral N in the rooting zone significantly influences crop responses to applied fertilizer N. Residual N in the soil can come from non-fertilizer sources such as the decomposition of organic matter and crop residues (Stevenson 1982). The 1996/97 site had the ryegrass/rye pasture from the previous season ploughed in during late winter and thus the organic matter content of the soil would have been high. Schroeder *et al.* (1985) also found smaller responses to applied N fertilizer on soils with higher organic matter content. Considering that there was some response for 'TEF373', although not significant, this could have been due to 'TEF 373' having a higher N requirement than 'SA Brown' as was the indication in the 1997/98 trial. According to Stevenson (1982) there are not only differences in N requirements between species but also between selections within a species.

The N fertilizer application was done in a split application in the ratio 2:1. Further trials would be required to investigate the influence of a split application and what the optimal ratio would be. It may be necessary for instance to have equal applications of N after each cut, especially for spring planted teff pastures. In spring planted teff the yield distribution between cuts is more even than is the case for summer plantings (Kassier & Greenfield n.d.). From spring plantings, depending on conditions it is also likely to obtain three or four cuts and thus a N application after each cut may be more optimal rather than applying the bulk of the N after emergence. The yield distribution of the 1996/97 trial, which was a summer planting was different to the 1997/98 trial which was a spring planting. In the 1996/97 trial most of the seasons' yield was obtained from the first cut (Figure 3 and 4). In this case applying most of the N after germination was a good decision. In the 1997/98 trial the yield distribution was more equal, with the higher proportion obtained from the second cut (Figure 1 and 2). In this case an equal application of N after germination and after the first cut would have been preferable. According to Eckard *et al.* (1995) higher dry matter production was achieved in *Lolium multiflorum* with frequent small topdressings as opposed to fewer heavy applications. Such a management practice is also likely to increase the N use efficiency. With high rates in a single application the losses are higher through volatilization and leaching. The aim should be to provide sufficient N for each regrowth period. The use of split applications in the humid tropics where losses due to denitrification and leaching are excessive is also advocated by Stevenson (1982). Further studies are required on teff to determine the N application strategies and these should be linked to planting time as that influences the expected seasonal yield and yield distribution between harvests.

The data obtained lack predictive value and is of a descriptive nature, especially in view of the response differences for 'SA Brown' between the two seasons. Without determining the amount of residual N in the soil, it is difficult to make specific recommendations with regard to N fertilization. In addition the amount of N released from the organic matter in any particular season is dependent on the climatic and soil conditions such as temperature and moisture. The major determinant for the appropriate N fertilization rate is the crop and its probable yield (Stevenson 1982).

Herbage quality

Herbage quality was determined for the 1996/97 trial. There were no differences in NDF, ADF and IVOMD difference (P>0.05) across the N treatments. Whitehead (1995) states that N has little effect on the fibre content (cell wall material) of the herbage sampled at the same growth stage. It also has little effect on the constituent materials of fibre (cellulose and lignin). The digestibility is also not much affected by N application. Hence the results for the teff are consistent with the findings mentioned by Whitehead (1995).

The CP content generally showed a positive response to N application level (Figure 5). There were no differences between the two cultivars. The CP value for the two cultivars for the five N levels showed that the herbage from the 0 N treatments had a significantly lower (P<0.01) CP content for 'SA Brown' than the remaining treatments which did not differ significantly (P<0.01) from each other. For 'TEF 373' the 0 N treatment had a significantly lower CP content than the 300 kg N ha^{-1} treatment. Pieterse *et al.* (1997) found the same response of increased CP with increased N application level in *Panicum maximum*. The CP content of 'SA Brown' decreased slightly at the highest N level. This being only one years data, it would be useful to repeat and confirm the trends, especially in view of the 1996/97 trial showing no significant response in terms of herbage yield.

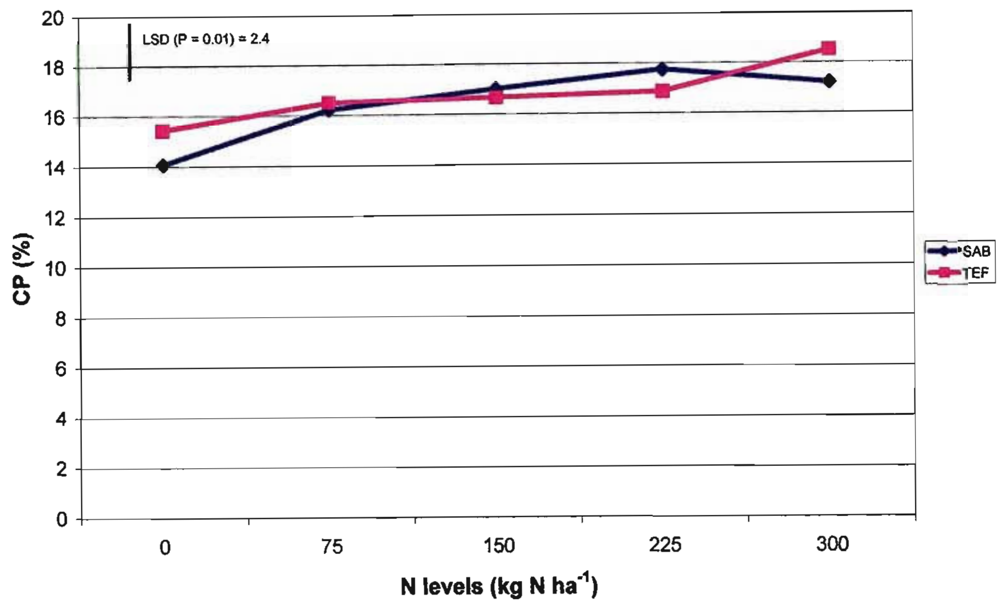

Figure 5 CP content of the herbage of SA Brown (SAB) and TEF 373 (TEF) across five fertilizer N application levels for the season 1996/97.

The DM % for both cultivars in both seasons did not show any particular trend in response to N fertilizer application.

Fertilizer use efficiency

The N use efficiency decreased logarithmically with N application (Figure 6). The highest production efficiency was achieved at the lowest N application of 75 kg N ha^{-1}. In 1996/97 'TEF 373' had a higher efficiency at the lowest N level than 'SA Brown', but in the 1997/98 the inverse was found. Pieterse *et al.* (1997) found the same trend with *P. maximum* where the highest efficiency was achieved at 80 kg N ha^{-1}, which was their lowest N level and efficiency decreasing with higher N levels. They also reported that the same result was found for *Digitaria eriantha* in field trials. They found no interaction between cultivars and N levels. This was also the case for the teff. Even though 'TEF 373' produced the highest herbage yield at 150 kg N ha^{-1}, the production efficiency was best at 75 kg N ha^{-1}.

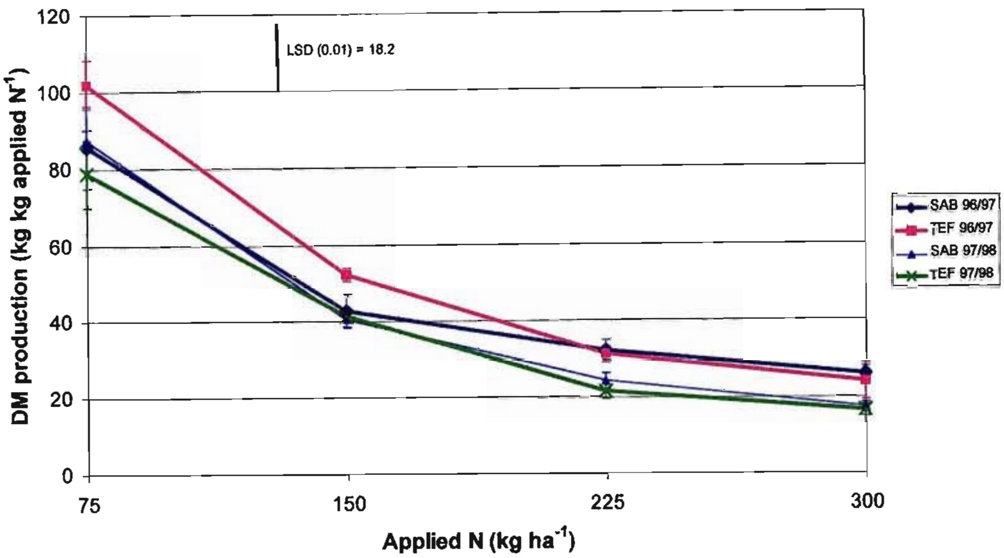

Figure 6 Herbage production efficiency in terms of kg DM per kg N applied of the teff cultivars SA Brown (SAB) and TEF 373 (TEF) for the 1996/97 and 1997/98 seasons.

Alkämper (1973) reports that teff has a low utilization capacity of various fertilizers.

Influence on lodging

According to some authors, as mentioned in the introduction, excessive N application increases the lodging of the pasture. This did not occur in the trials conducted. There was some lodging, but with no obvious trend in response to N application levels.

Grain production

The grain production trials investigating N level response were unsuccessful in both seasons. Thunderstorms and wet conditions at the time of grain maturity resulted in shattering of most of the grain. The amount of grain obtained from most plots was not measurable. In addition the 1996/97 trial had Egyptian geese nesting in some of the plots which were consequently completely destroyed.

Further research required

The influence of various N application strategies in terms of how to split the application should be further studied. This should be done in association with different planting dates e.g. spring vs summer. The planting date influences the number of hay cuts that can be obtained from the pasture and also the size of the individual cuts (Kassier & Greenfield n.d.).

The influence of N application on herbage quality should also be further researched and could include aspects such as the influence on the non-structural carbohydrates. According to Whitehead (1995) these are often substantially reduced with high N fertilizer rates. This would be of particular importance if the pasture is to be ensiled since lower soluble carbohydrates would result in lower lactic acid levels and therefore a poorer quality silage.

Further studies could examine the influence on palatability. Again Whitehead (1995) reports that the palatability sometimes declines with N application. This was specifically reported for grass made into hay where the hay was fed to sheep.

The influence of N application rates on teff grain production should also be investigated. This would provide most useful information if done in the sward situation. However the field study of seed production responses on teff are difficult in a humid environment as thunderstorms at the time of seed maturity can cause heavy losses through shattering of the seed. These trials would have to be located in more climatically suitable seed production areas than the Moist Midlands Mistbelt (Kemp 1996) in KwaZulu-Natal province. The time of N application for a teff grain crop could be important. In the case of rice N applied early in the season results in increased plant height and lodging and less grain yield and lower protein content (Stevenson 1982). In cereals, excessive vegetative growth could also use available soil water at the expense of grain yield. This would be particularly the case in drier regions (Stevenson 1982).

Conclusions

Even though the data are incomplete and the response of 'SA Brown' herbage production differed between the two seasons, the general recommendation for N fertilization of teff is according to the fitted polynomial slightly above 75 kg N ha^{-1} for the season. The distribution of the split applications would depend on the expected yield distribution between the hay cuts, which is dependent on the planting date. Fertilizer N application positively influenced CP content of the herbage.

There was no response of lodging of the pasture to fertilizer N. There was some lodging in some plots but not correlated to the N application treatments.

The response of grain yield to N application would have to be measured in a more suitable climate where rainfall is not prevalent at the time of grain maturity.

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6 RESPONSE OF TEFF (*ERAGROSTIS TEF* (ZUCC.) TROTTER) TO SOWING RATES

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Abstract

Five sowing rates 5, 10, 15, 20 and 25 kg ha^{-1} were used together with two cultivars, 'SA Brown' and 'TEF373' ('Dessie Tacker'), in trials in 1996/97 and 1997/98 to measure the herbage and seed yield responses to sowing rates. The herbage yield response for the 1996/97 growing season showed no differences across sowing rate treatments although there were differences between the two cultivars at the lowest and highest sowing rate. In the 1997/98 trial there was a herbage yield response to sowing rates. For 'SA Brown' the herbage yield at 5 kg seed ha^{-1} was less than at all other sowing rates, while for 'TEF373' the herbage yield at both the 5 and 10 kg seed ha^{-1} treatments was lower than the higher seeding treatments. Weed infestation levels in both herbage production trials were highest at the lower sowing rates. The seed production trials were unsuccessful due to unfavourable weather conditions at seed maturity and harvesting.

Additional key words: plant population, seeding rate

Introduction

In the literature the recommended sowing rate for teff varies considerably. Sowing rates recommended by Dickinson *et al.* (1990) are 7 to 10 kg ha^{-1} on sandy soils and 12 to 15 kg ha^{-1} on clay soils, while Stallknecht *et al.* (1993) recommend 5 to 8 kg seed ha^{-1}. Recommendations made by Ketema (1993) in Ethiopia are between 15 to 55 kg ha^{-1}. More specifically, 25 to 30 kg ha^{-1} broadcast by hand, and 15 kg ha^{-1} if broadcast or drilled mechanically. Bechere (1995) recommended 25 kg ha^{-1} on light soils and 30 kg ha^{-1} on black soils. In South Africa different seed companies also recommend different rates varying from 5 to 25 kg seed ha^{-1}.

The optimal sowing rate would depend on the intended utilization of the pasture. Utilization could be for hay, for grazing, for seed or grain production or for revegetation. In the case of revegetation teff is often planted in seed mixtures with perennial grasses. There may also be different optimal sowing rates for different teff cultivars, as these may be stronger or weaker tillering types or types with different leaf-to-stem ratios. Bidinger & Raju (2000) mention that there is some evidence for pearl millet that plant types with limited tillering capacity may not have the ability to adjust as effectively to changing plant populations as high tillering cultivars.

The study reported on here investigated the influence of five seeding rates on herbage production for hay and on seed production of teff. There are variations in the recommendations given by various authors. Teff is a cheap seed with the current price approximately R7.00 kg^{-1}. Hence if there are advantages to higher seeding rates in terms of herbage and seed yield optimization, it would make economic sense to use higher rates.

Procedure

Study area

The study was conducted during two consecutive seasons (summers of 1996/97 and 1997/98) on two different sites of the Cedara Research Station (29°32'S, 30°17'E, alt 1076 m asl). Seasonal rainfall for 1996/97 was 547.8 mm and for 1997/98 581.3 mm (Agromet).[1] The duration of the 1996/97 and 1997/98 trials was 121 and 161 days respectively. The soil type of the 1996/97 trial site was a Dresden soil form, which was an orthic A horizon over a hard plinthic B horizon. This soil has a relatively shallow A horizon and can become temporarily water-logged during heavy rainfall especially in summer. The 1997/98 site that was located on a Hutton soil form, which ws an orthic A horizon over a red apedal B horizon (Soil Classification Working Group1991). The latter soil is well drained.

Land preparation

Land was initially prepared by using a mould board plough followed by a disc harrow. The weed seeds were allowed to germinate and then the site was worked at a shallow depth with a tine cultivator to eliminate the newly germinated weeds. The final seedbed preparation was achieved with a tine cultivator on the day of planting.

Fertilization

The soil P and K levels were raised to the recommended levels of 20 g kg^{-1} P (AMBIC) and 120 g kg^{-1} K according to the soil analyses[2]. The P (single superphosphate (10.5)) and K (KCl

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(48)) fertilizer was spread over the entire site before cultivation with a tine cultivator, to incorporate the fertilizer into the seedbed. The acid saturation of the soil was 29% and the pH (KCl) was 4.08. Nitrogen fertilizer in the form of limestone ammonium nitrate (LAN (28)) was applied after emergence, when the seedlings were 50 to 100 mm tall at a rate of 50 kg N ha^{-1} in the herbage production trial and 75 kg N ha^{-1} in the seed production trial. A further 25kg N ha^{-1} was applied after the first cut in the herbage production trial.

Treatments and measurements

For both the herbage and the seed production trials two cultivars of teff were used. 'SA Brown' was then the only locally available teff cultivar. The second cultivar was imported from the USA and designated in the trial as 'TEF373'[3] (Dessie Tacker).

Five sowing rates (5, 10, 15, 20 and 25 kg ha^{-1}) were combined with two cultivars and arranged in a 2 x 5 factorial design and replicated four times. The plots were row planted with an inter-row spacing of 150 mm. The gross plot size of both the 1996/97 and the 1997/98 trials was 2 m x 7 m (14 m^2). The net plot size was 1.4 m x 5.6 m (7.84 m^2). The plots were cut with a reciprocating mower set at 50 mm blade height. The plots were cut when the plants reached the early flowering stage i.e. as the first 10 to 20% of the plots showed signs of inflorescence emergence. This was a visual assessment. The entire green weight of the net plot was weighed and a sample of approximately 500g was taken and sealed in a plastic bag. The green samples of each plot were weighed, dried at 90°C and then weighed again to determine the dry matter ration. Net plot dry mass was estimated from the measured ratios.

Statistical analysis

Analysis of variance (ANOVA) was used to determine the effects of the sowing rates on the dry matter yield and herbage quality parameters. Differences between means were assessed using least significant differences (LSD) ($P < 0.05$, $P < 0.01$) (Steel & Torrie 1980).

Results and discussion

Herbage yield

1996/97 trial

The 1996/97 sowing rate trial was planted on 10 December 1996 i.e. a mid-summer planting where the majority of the yield is obtained from the first cut. In this trial the first cut and the total yield for the growing season resulted in significant differences between the two cultivars

[3] The Teff Company, P.O. Box A, Caldwall, Idaho, USA.

SA Brown and TEF 373 (Table 1, Figure 1). At the 5 and the 25 kg seed ha^{-1} treatments 'SA Brown' gave a significantly higher yield than 'TEF 373' ($P<0.05$). The total yield of 'SA Brown' was also significantly higher at the $P<0.01$ level for the 25 kg ha^{-1} sowing rate treatment. There were however no yield differences across the sowing rate treatments for either of the cultivars. The sowing rate treatments did not significantly affect the herbage production of 'SA Brown' or 'TEF 373' in the 1996/97 trial.

Table 1 Mean weed infestation (%) and total herbage yield (t DM ha^{-1}) of the three harvests for the 1996/97 and 1997/98 trials

Seed rate	Seasonal herbage yield (t DM ha^{-1})				Mean weed infestation (%) of 3 cuts			
(kg ha^{-1})	SA Brown		TEF 373		SA Brown		TEF 373	
	1996/97	1997/98	1996/97	1997/98	1996/97	1997/98	1996/97	1997/98
5	8.00	6.58	5.99	6.54	29	38	64	46
10	6.96	8.60	6.48	7.06	48	31	44	42
15	7.28	8.72	6.32	7.89	36	18	34	31
20	7.39	9.10	6.81	9.04	16	25	35	28
25	8.51	9.30	7.11	8.89	13	22	29	30
CV %	14.3	18.5	14.3	18.5	-	-	-	-
LSD (0.05)	1.22	1.81	1.22	1.81	-	-	-	-
LSD (0.01)	1.76	2.63	1.76	2.63	-	-	-	-

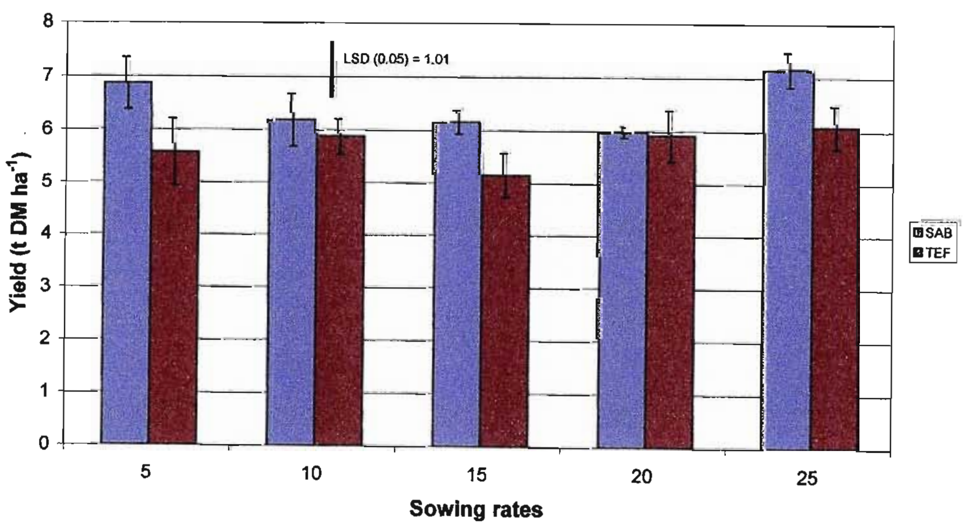

Figure 1 Herbage yield of the first cut of the 1996/97 trial for cultivars SA Brown and TEF 373 for the five sowing rate treatments. Error bars on the bars of cut 1 and total yield are used to indicate the standard deviation of the mean (standard error).

Although the sowing rate treatments did not significantly influence the herbage yield, the percentage weeds in the plots were related to the sowing rate treatments. For both 'SA Brown' and 'TEF 373' the lowest herbage yield coincided with the highest weed percentage and the highest yield with the lowest weed percentage (Table 1). For both cultivars the lowest weed infestation occurred at the highest sowing rate of 25 kg seed ha^{-1}. Generally the higher weed infestations occurred at the lower sowing rates, especially at the 5 kg seed ha^{-1} treatment.

1997/98 trial

The 1997/98 trial was planted in spring (29 October 1997) and the majority of the herbage yield was obtained from the second cut with the first and third cuts giving yields of similar magnitude. In this trial, as opposed to the first seasons trial, there were significant herbage yield differences between the sowing rate treatments for both cultivars. For both 'SA Brown' and 'TEF 373' in the first cut the 5kg ha^{-1} sowing rate treatment resulted in a significantly lower yield ($P<0.05$) than the 10, 20 and 25 kg ha^{-1} treatments (Figure 2). For the total yield of the growth season the 5kg ha^{-1} treatment for 'SA Brown' gave a lower yield than all remaining treatments ($P<0.05$) while the yield difference between the 5 and the 25kg ha^{-1} treatments was highly significant ($P<0.01$) (Table 1). The total yield of the growth season for 'TEF 373' resulted in both the 5 and 10 kg ha^{-1} treatments producing significantly less herbage than the 20 and 25 kg ha^{-1} treatments ($P<0.05$). There were no differences between the two cultivars.

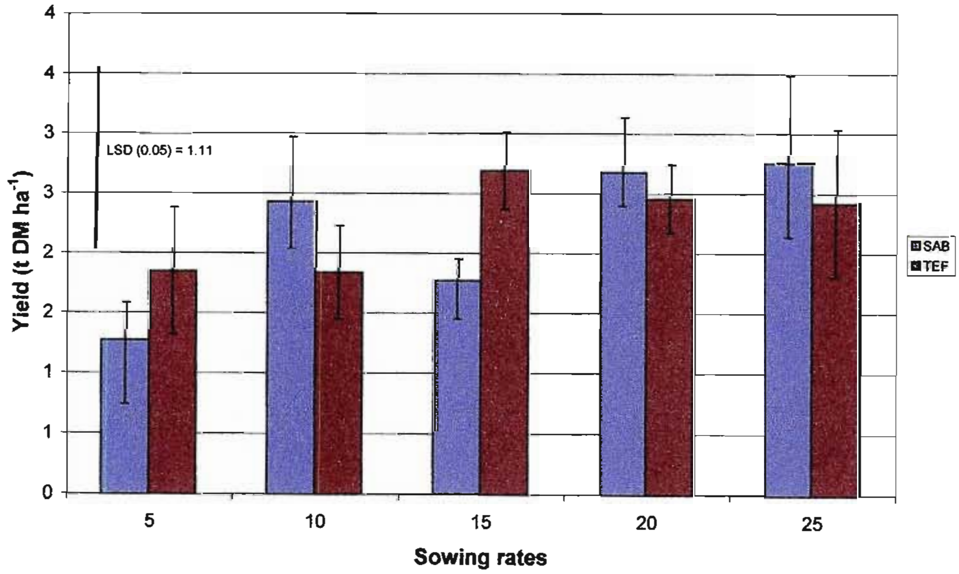

Figure 2 Herbage yield of the first cut of the 1997/98 trial for the cultivars SA Brown and TEF 373 at the five sowing rate treatments. Error bars on the bars of cut 1 and total yield are used to indicate the standard deviation of the mean (standard error).

The weed infestation percentages showed a similar trend as for the first season where the lowest yields are associated with the highest weed infestations and the highest yields had the lowest weed infestation percentages (Table 1).

In treatments of both trials, except two treatments in the 1996/97 trial, the weed infestation percentages for 'TEF 373' were consistently higher than for 'SA Brown' (Table 1). The reason for this could be that these are two different types of teff cultivars. The cultivar SA Brown is what can be considered a hay-type while 'TEF 373' is more a grain type. There may be differences in leaf-to-stem ratio and also tillering or size of the tuft. This would influence the thickness of the sward and hence the amount of light that can penetrate to the soil surface to allow weed seeds to germinate.

Both years' results indicate that at the lower sowing rates the weed infestation levels are higher. The lower herbage yield associated with the lower sowing rates could be a combination of a sub-optimal plant population in terms of achieving maximum biomass production per unit area and the associated weed infestations. At the lower sowing rates teff is not able to compensate the lower plant population with bigger tufts and hence there is more available space for weed establishment. The weed infestation levels can be limited by using higher sowing rates. In addition, the higher weed content would also result in lower quality herbage. This could be both in terms of nutritional content and in terms of acceptability and palatability of the hay.

Seed yield

The seed yield trials were unsuccessful in both the 1996/97 and the 1997/98 seasons. The main problem was the occurrence of heavy thunderstorms at the time of seed maturity, which resulted in most of the seed shattering. In addition Egyptian geese nesting in some of the plots of the seed trial further destroyed the 1996/97 trial. Due to the wet summer conditions and the prevalence of thunderstorms the Moist Midlands Mistbelt is not an ideal area for teff seed production.

It may be possible to obtain some seed yield results by increasing the plot size substantially and thus obtaining at least some measurable yield. The best option would be to investigate the influence of sowing rate on seed production in an area with more suitable climatic conditions.

Further research

Determining optimal sowing rates for teff seed production would have to be further studied in areas suited to seed production. In the USA teff grain is produced in Idaho were conditions are dry at the time of harvesting but the fields are flood irrigated during the growth season of the crop (pers. comm[4]). In South Africa similar conditions may prevail for example in parts of the Karoo in areas where sufficient water is available for flood irrigation.

Sowing rates are more likely to have an influence on seed production than on herbage production if teff is similar to other grasses in this regard. According to Loch *et al.* (1999) the major difference between establishing pasture plants for forage and establishing them for seed production lies in the emphasis placed on the 'thickening-up' phase. The aim with a seed crop is to start with a high initial population and so eliminate the thickening-up phase. Higher seeding rates than those recommended for pasture use are required and normally pasture seeding rates should be doubled for seed crops.

Sowing rates for teff as a grazing pasture should also be studied. In such a study the problem of plants being pulled out by the grazing animals would have to be taken into account. Teff is also used extensively in seed mixtures with perennial grasses for re-vegetation purposes. There could be some merit in determining the influence of different proportions of teff in the mixture since teff is quick to establish and fast to grow, as is required of a nurse crop. However if the teff component is too high it could compromise the establishment of the perennial grasses through shading.

Amongst some farmers it is a common practice to mix teff and *Eragrostis curvula* when they want to establish an *E. curvula* pasture for hay. The reason for the mixture is that the teff provides a hay crop in the first year while the *E. curvula* is establishing and it helps in smothering weeds. Again the optimal seed mixture for this practice has not been established. A dense stand of the teff could provide too much shading and possibly also deplete some nutrients during its growth season. This could lead to insufficient levels of nutrients available for the establishment of the perennial grass. At the end of the growth season the nutrients from the decomposing teff would again become available to the perennial grasses.

Conclusions

Taking both herbage yield and weed infestation levels into account, a sowing rate of at least 15 kg ha^{-1} and higher is indicated from the data obtained over the two seasons. Considering that teff seed is relatively inexpensive, in comparison to other pasture grasses, a sowing rate of at least 20 kg ha^{-1} would be the recommended rate in terms of both weed infestation levels and

[4] W. Carlson, The Teff Company, Caldwall, Idaho USA

yield. Although there was no significant yield difference between 15 and 20 kg ha^{-1} seeding rates the herbage yields tended to be higher at 20 kg ha^{-1} and the weed infestation lower than at 15 kg ha^{-1}.

None of the sowing rates used in this study was high enough to negatively affect the herbage yield or promote lodging. Even though there was some lodging it did not correspond with any particular seeding rate. At higher sowing rates there may be influences such as increased lodging due to spindly plants. According to Loch *et al.* (1999) seed production in tropical grasses requires double the seeding rate of pastures established for herbage production. If this principle also applies to teff, then the sowing rates used in this study for the seed trial were too low and the influence of higher rates would have to be investigated.

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7 DISCUSSION AND CONCLUSIONS

To be in a position to make management decisions to optimise herbage or seed production from a pasture, it is essential to know the response of the pasture to environmental variables and management inputs. The environmental variables affecting pasture production are, amongst others soil and air temperature, daylength (radiation) and rainfall. Some of the management inputs that can be adjusted are seeding rate or plant population, cutting frequency and height and fertilization.

The responses of teff to agronomic management practices and environmental variables were studied by measuring the yield responses to planting date, phenological stage at cutting, seeding rates and N fertilization levels. These variables possibly had an effect on the germination, the growth rate, the flowering behaviour of the plants and on the carbohydrate reserves in the plants and consequently on the regrowth potential. There are influences on regrowth associated with the lodging behaviour of the pasture. The nutritional value of the pasture is influenced by both the phenological stage and some quality parameters are affected by N fertilization. The fertilization inputs have to be synchronised with the yield response of the grass to environmental variables such as planting date through the influence of daylength and the consequent influence on yield distribution. Seeding rates have indirect influences on herbage production through weed infestation levels and possibly at very high seeding rates through the influence of lodging.

The effects of temperature, daylength and rainfall play an important role in the response of teff to planting date. The temperature effects are important in the successful germination of the pasture. This is of consequence in spring plantings as teff is a C4 grass (Engels *et al.* 1991) and therefore sensitive to low air and soil temperatures. For tropical grasses daily air temperatures below 20°C severely reduce growth and soil temperature is one of the most important factors influencing the growth of C4 forage grasses in subtropical regions (Jones 1985). Soil temperature also affects the rate of leaf initiation in species such as millet (Ong & Monteith 1985) and consequently affects the herbage production potential. Temperature also influences the photosynthetic rate and thus the rate of biomass accumulation. Temperature also has an influence on the regrowth of the pasture after cutting and this is linked to rainfall during that period. If conditions are hot and dry the pasture is less likely to produce good regrowth as opposed to moderate, moist conditions immediately pre- and post cutting. Hence moisture and temperature stress or the lack thereof have an influence on yield. This was found in both the planting date and the growth stage trials.

Daylength had a major influence on the herbage production. According to Yan & Wallace (1999) increased daylength results in increased biomass accumulation and generally decreased partioning of photosynthate to reproductive organs. The highest herbage yields were obtained during the longest days, but this is likely to also be linked to the higher radiation during the mid-summer months. Spring plantings are required to maximise seasonal or total herbage production, while summer plantings maximise the production from the first cut. Thus the choice of planting date will depend on the yield target and whether a single large hay cut or a number of smaller cuts is desirable.

The role of carbohydrate reserves and the partitioning of photosynthate are important for both herbage and seed production. The partitioning of photosynthate, as mentioned earlier, is to some extent linked to daylength. Hence the choice of planting date for herbage or seed production would be influenced accordingly. The influence of carbohydrate reserves is mainly through affecting the regrowth potential of the pasture. Hence the importance of the amount of reserves left in the stubble after cutting. In maize this is linked to the phenological stage of the plant where the carbohydrate reserves in the stem were lowest during the period anthesis to mid-grain fill and then increased again thereafter (Shanahan 1991). This could be similar in teff as there were definite differences in regrowth in response to different growth stages at cutting. The influence of growth stage at cutting is also manifested in the herbage quality as there is a decrease in herbage quality with increased phenological age. The optimum growth stage at cutting is thus a trade-off between quantity and quality and a farmers decision when to cut will depend on the purpose for which the herbage is to be utilised.

With regard to influences of pasture management such as N fertilization, the response is difficult to quantify, especially in the short time of two seasons. The soil dynamics make the predictions of crop N requirements by soil testing difficult but it can provide some indications (Schroeder *et al.* 1985). The interaction and transformation of soil N between plant available inorganic and unavailable organic fractions makes soil N complicated (Schumann 2000). According to Schroeder *et al.* (1985) there is a close relation between N applied, soil N and leaf N. In terms of a forage crop the influence on both production and on herbage quality factors is important. Nitrogen fertilization rates above 150 kg N ha^{-1} provide no increased herbage yield, although there are positive influences on CP content. The efficiency of applied N in terms of herbage produced is also best at the lower N fertilization rates. There are also indications of response differences to applied N fertilizer between cultivars. Differences can exist not only between species but also within species (Stevenson 1982). The yield distribution differences associated with different planting times need to be integrated with the split N application ratio to be used.

Sowing rate differences also showed response differences between cultivars as was manifested through the weed infestation levels of the pasture. The sowing rates used in the study did not result in herbage yield differences but rather in weed infestation differences. Lower sowing rates resulted in higher weed infestation levels. This is important in terms of both herbage yield and herbage quality of the resulting hay. Higher sowing rates are therefore advantageous, especially in view of the low seed cost of teff. The influence on seed yield could be different to herbage yield as the size of the plant could potentially influence the seed yield potential. The weed infestation levels with regard to seed yield are also important with regard to the resulting seed quality. The cultivars more suited to grain production tend to be less leafy than the hay types and thus seem to result in a more open sward that is more prone to weed infestation. Hence even higher seeding rates than the ones used in this study may be applicable to some grain cultivars and conditions of known high weed seed banks in the soil on the area to be planted.

There are numerous further research questions with regard to the herbage and seed yield response of teff to environmental variables and to pasture management inputs, that this exploratory research has identified. The influence of all the studied variables on grain yield would have to be further investigated in areas suited to teff grain production. These are areas with sufficient water for irrigation but have dry conditions prevailing at the time of seed maturity. In order to optimise grain yield is would also be useful to study the response of planting time as it may influence the partitioning of photosynthate between vegetative and reproductive plant parts. The growth response of teff to stress conditions such as low air and soil temperatures and possibly other variables that determine the beginning of the growth season for successful establishment and production. In view of the new practice of using teff for grazing influences of growth stage at defoliation and possibly various grazing and fertilization strategies could be necessary for optimal production from the pasture.

There is little doubt that teff has a role to play in both resource poor and commercial agriculture, in developing and first world situations. Considerable research is required to be able to market teff grain as a gourmet and health food. Research is also required to provide farmers with more refined management recommendations for different situations for both commercial and resource poor and small scale farmers.

Various research needs have been identified as a result of this study.

1. Detailed studies are required into the factors influencing germination especially in spring, inclusive of environmental factors such as soil temperature and soil water.
2. Factors influencing regrowth, like cutting height and lodging need further research by investigating the depletion of carbohydrate reserves, reduction of number of live tillers and residual leaf area in the stubble after defoliation.
3. The role of phenological stage at cutting in terms of photosynthate partitioning and carbohydrate reserves in the plant and the associated effect on regrowth.
4. The grazing management of teff needs to be investigated, as this is a completely new use of teff pastures.
5. The influence of planting date, seeding rates and weed infestations on teff seed production require further research. This is especially of importance if teff is to be produced for grain purposes.

In order to develop the market for teff grain there will have to be research into milling and recipe development. Some of these technologies may already be available but not widely known.

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APPENDICES

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APPENDIX 1

WEATHER DATA FOR THE SEASONS 1996/97, 1997/98 AND 1998/99 FOR EACH PLANTING DATE TREATMENT

Appendix 1.1 Duration of the growing season (total yield)

1996/97			Mean values of weather data variables for the duration of the growing season for each planting date treatment					
Delay in planting	Beginning & end date	Total yield t DM ha^{-1}	Max temp. °C	Min temp. °C	Rainfall mm/day	Daylength hr:min/day	Mean temp °C	No. of days
0	2/9 – 7/3	7.77	24.1	13.2	3.2	13:13	18.6	186
14	16/9 – 7/3	9.40	24.1	13.5	3.4	13:20	18.8	172
28	30/9 – 7/3	8.67	24.2	14.0	3.7	13:27	19.1	158
42	14/10 – 7/3	8.55	24.5	14.1	3.8	13:32	19.3	144
56	28/10 – 7/3	7.33	24.8	14.4	3.9	13:36	19.6	130
70	11/11 – 7/3	6.42	25.0	14.6	4.2	13:38	19.8	116
84	25/11 – 4/4	6.16	24.6	14.6	4.3	13:18	19.6	130
98	9/12 – 4/4	4.96	24.8	14.7	4.2	13:14	19.8	116
112	23/12 – 4/4	4.57	24.7	14.9	3.9	13:07	19.8	102
126	6/1 – 19/2	3.56	25.2	15.4	3.3	13:35	20.3	44
140	20/1 – 7/3	2.67	25.2	15.3	3.1	13:12	20.3	46
154	3/2 – 4/4	1.52	24.1	14.4	2.9	12:26	19.3	60
168	17/2 – 15/5	1.88	22.2	11.3	3.5	11:48	16.8	87
182	3/3 – 15/5	1.90	21.8	10.6	3.4	11:36	16.2	73
196	17/3 – 15/5	1.19	21.2	9.6	4.0	11:24	15.4	59
1997/98			Mean values of weather data variables for the duration of the growing season for each planting date treatment					
Delay in planting	Beginning & end date	Total yield t DM ha^{-1}	Max temp. °C	Min temp. °C	Rainfall mm/day	Daylength hr:min/day	Mean temp °C	No. of days
0	1/9 – 6/1	2.87	21.0	14.0	4.8	13:07	17.5	127
14	15/9 – 26/2	2.87	23.7	13.4	3.5	13:22	18.6	164
28	29/9 – 26/2	8.48	23.9	13.7	3.8	13:29	18.8	150
42	13/10- 26/2	6.42	22.6	15.9	5.8	13:35	19.3	136
56	27/10- 26/2	6.11	24.2	14.2	3.9	13:40	19.2	122
70	10/11– 26/2	6.33	24.1	14.4	4.3	13:43	19.2	108
84	24/11– 30/1	1.92	23.9	14.1	4.0	13:56	19.0	67
98	8/12- 16/3	4.94	25.0	15.2	3.8	13:29	20.1	98
112	22/12- 26/2	3.60	24.4	15.6	4.9	13:37	20.5	66
126	5/1- 26/2	3.11	25.7	15.9	4.6	13:30	20.8	52
140	19/1- 16/3	2.63	25.1	15.6	3.9	13:05	20.4	56
154	2/2- 7/4	3.13	25.0	15.1	4.2	12:34	20.0	64
196	16/3- 29/4	1.23	24.8	13.0	2.3	11:39	18.9	44

Note: Due to excessively wet conditions the plantings for 168 and 182 days delay in the 1997/98 trial could not be planted.

Appendix 1.1 continued

1998/99			Mean values of weather data variables for the duration of the growing season for each planting date treatment					
Delay in planting	Beginning & end date	Total yield t DM ha^{-1}	Max temp. °C	Min temp. °C	Rainfall mm/day	Daylength hr:min/day	Mean temp °C	No. of days
0	1/9- 28/1	6.81	23.8	12.5	3.0	13:14	18.2	149
14	14/9- 9/2	5.46	24.2	13.0	3.6	13:23	18.6	148
28	28/9- 6/1	3.65	23.6	12.6	3.4	13:28	18.1	100
42	12/10- 18/3	7.64	25.1	14.0	3.7	13:27	19.6	157
56	26/10- 18/3	5.85	25.4	14.4	3.9	13:30	19.9	143
70	9/11- 25/2	3.13	25.1	14.6	4.9	13:43	19.9	108
84	23/11- 25/2	4.48	24.9	14.7	5.2	13:44	19.8	94
98	7/12- 5/3	4.42	25.5	15.2	4.2	13:37	20.4	88
112	21/12- 9/2	3.09	25.4	15.5	4.6	13:49	20.4	50
126	4/1- 7/5	4.27	25.7	13.9	2.8	12:32	19.8	123
140	18/1- 7/4	3.25	26.4	14.8	3.2	12:47	20.6	79
154	1 /2- 7/5	1.46	25.6	13.4	2.0	12:09	19.5	95
168	15/2- 7/4	2.52	25.9	14.4	1.7	12:23	20.7	51
182	1/3- 7/5	1.00	25.4	12.7	1.2	11:44	19.1	67
196	15/3- 7/5	0.37	24.6	11.9	1.1	11:32	18.2	53

Appendix 1.2 Duration of the growth period of the first herbage cut

1996/97			Mean values of weather data variables for the duration of the growing season for each planting date treatment						
Delay in planting	Beginning & end date	Total yield t DM ha^{-1}	Max temp. °C	Min temp. °C	Rainfall mm/day	Daylength hr:min/day	Mean temp °C	No. of days	Inflorescence emergence %
0	2/9- 25/11	2.00	22.9	11.1	1.7	12:42	17.0	84	80
14	16/9- 25/11	3.10	22.7	11.6	1.9	12:54	17.2	70	80
28	30/9- 25/11	2.58	22.7	12.4	2.4	13:06	17.6	56	20
42	14/10-11/12	2.97	23.2	12.6	2.7	13:29	17.9	58	20
56	28/10-17/12	2.55	23.9	13.0	2.9	13:42	18.5	50	20
70	11/11 - 6/1	4.17	24.8	13.6	5.0	13:55	19.2	56	20
84	25/11- 16/1	4.42	25.1	14.4	5.3	14:00	19.7	52	20
98	9/12 – 29/1	4.00	25.7	15.2	6.1	13:57	20.4	51	20
112	23/12 - 5/2	3.48	25.8	15.6	5.2	13:50	20.7	44	20
126	6/1 – 19/2	3.56	25.2	15.4	3.3	13:35	20.3	44	20
140	20/1 – 7/3	2.67	25.2	15.3	3.1	13:12	20.3	46	80
154	3/2 - 4/4	1.52	24.1	14.4	2.9	12:36	19.3	60	100
168	17/2 – 4/4	1.16	23.6	14.2	3.5	12:24	18.9	46	20
182	3/3 –14/4	1.28	22.9	12.6	4.0	12:02	17.8	42	10
196	17/3 – 15/5	1.19	22.2	11.5	5.4	11:24	16.9	59	20

Appendix 1.2 continued

1997/98			Mean values of weather data variables for the duration of the growing season for each planting date treatment						
Delay in planting	Beginning & end date	Total yield t DM ha^{-1}	Max temp. °C	Min temp. °C	Rainfall mm/day	Daylength hr:min/day	Mean temp °C	No. of days	Inflorescence emergence %
0	1/9 – 22/10	0.81	21.4	10.1	2.1	12:12	15.7	51	20
14	15/9 - 3/11	0.29	22.7	11.0	2.1	12:35	16.9	49	20
28	29/9 –21/11	2.37	23.0	12.0	2.6	13:02	17.5	53	20
42	13/10-5/12	3.22	22.4	12.2	3.4	13:24	17.3	53	50
56	27/10 - 6/1	4.67	23.2	13.0	3.4	13:47	18.1	71	40
70	10/11 - 6/1	4.72	22.7	13.0	3.9	13:55	17.8	57	20
84	24/11- 30/1	1.92	23.9	14.1	3.9	13:56	19.0	67	100
98	8/12 - 30/1	3.32	25.0	14.9	3.3	13:56	19.9	53	60
112	22/12- 26/2	3.60	25.4	15.6	4.9	13:37	20.5	66	100
126	5/1 – 26/2	3.11	25.7	15.9	4.6	13:30	20.8	52	100
140	19/1 – 16/3	2.63	25.1	15.6	3.9	13:05	20.4	56	20
154	2/2 – 7/4	3.13	25.0	15.1	4.2	12:34	20.0	64	20
196	16/3 – 29/4	1.23	24.8	13.0	2.3	11:38	18.9	44	50

1998/99			Mean values of weather data variables for the duration of the growing season for each planting date treatment						
Delay in planting	Beginning & end date	Total yield t DM ha^{-1}	Max temp. °C	Min temp. °C	Rainfall mm/day	Daylength hr:min/day	Mean temp °C	No. of days	Inflorescence emergence %
0	1/9- 23/11	0.97	23.1	10.8	1.5	12:39	16.9	83	80
14	14/9– 30/11	0.87	23.8	11.4	2.2	12:56	17.6	77	80
28	28/9- 10/12	1.31	23.3	11.7	3.3	13:15	17.5	73	80
42	12/10-10/12	2.21	23.8	12.0	3.4	13:26	17.9	59	100
56	26/10-30/12	2.63	24.2	13.1	3.9	13:45	18.6	65	20
70	9/11 - 6/1	0.77	24.4	14.1	4.5	13:54	19.2	58	10
84	23/11-21/1	2.73	24.6	14.5	5.4	13:58	19.5	59	50
98	7/12- 28/1	3.78	25.0	14.1	3.8	13:57	20.1	52	20
112	21/12 -9/2	3.09	25.4	15.5	4.6	13:49	20.4	50	10
126	4/1 – 17/2	1.91	25.5	15.3	5.5	13:36	20.4	44	10
140	18/1 – 5/3	2.54	26.2	15.6	4.2	13:16	20.9	46	40
154	1 /2 – 18/3	1.09	26.7	15.2	3.2	12:53	20.9	45	100
168	15/2 – 7/4	2.52	26.9	14.4	1.7	12:23	20.7	51	80
182	1/3 – 7/5	1.00	25.4	12.7	1.2	11:44	19.1	67	100
196	15/3 – 7/5	0.37	24.6	11.9	1.1	11:32	18.2	53	100

Note: Due to excessively wet conditions the plantings for 168 and 182 days delay in the 1997/98 trial could not be planted.

APPENDIX 2

MEAN WEATHER DATA FOR THE DURATION OF THE TRIALS OF 1996/97, 1997/98 AND 1998/99

Appendix 2.1 Mean weather data

Spring/summer 1996/97	Mean min temp. (°C)	Mean max temp. (°C)	Rainfall (mm)
September 1996	8.6	23.5	7.0
October	12.0	21.2	91.5
November	12.8	23.7	81.8
December	14.5	26.0	124.5
January 1997	15.3	24.8	213.7
February	14.9	25.0	63.1
March	14.2	23.5	102.7
April	9.2	21.5	131.9
Spring/summer 1997/98	**Mean min temp. (°C)**	**Mean max temp. (°C)**	**Rainfall (mm)**
September 1997	9.5	20.5	26.1
October	11.1	22.8	91.4
November	12.2	21.5	117.2
December	14.1	24.8	70.7
January 1998	15.2	25.2	123.0
February	16.2	25.9	164.7
March	14.2	24.5	95.5
April	12.0	24.5	39.6
Spring/summer 1998/99	**Mean min temp. (°C)**	**Mean max temp. (°C)**	**Rainfall (mm)**
September 1998	9.4	22.2	18.2
October	11.0	22.8	64.7
November	13.0	25.0	107.5
December	13.7	23.4	145.0
January 1999	15.8	25.9	164.9
February	15.0	26.0	113.8
March	14.7	26.7	62.5
April	11.5	24.5	14.9

APPENDIX 3
ANOVA TABLES

Appendix 3.1 Planting date trials

A3.1.1 1996/97 Cut 1

Source of variation	df	SS	MS	F	F (table) 0.05	0.01
Blocks	2	0.1685	0.0843			
Treatments	14	51.0174	3.6441	40.69	2.04	2.75
Error	28	2.5074	0.0896			
Total	44	53.6933				

A3.1.2 1996/97 Seasonal (total) yield

Source of variation	df	SS	MS	F	F (table) 0.05	0.01
Blocks	2	0.1016	0.0508			
Treatments	14	361.9063	25.8505	55.20	2.04	2.75
Error	28	13.1129	0.4683			
Total	44	375.1208				

A3.1.3 1997/98 Cut 1

Source of variation	df	SS	MS	F	F (table) 0.05	0.01
Blocks	2	0.0245	0.0123			
Treatments	13	81.6999	6.2846	66.6406	2.12	2.91
Error	26	2.4520	0.09431			
Total	41	84.1764				

A3.1.4 1997/98 Seasonal (total) yield

Source of variation	df	SS	MS	F	F (table) 0.05	0.01
Blocks	2	0.7228	0.3614			
Treatments	13	193.8559	14.9120	42.2718	2.12	2.91
Error	26	9.1790	0.3528			
Total	41	203.7507				

A3.1.5 1998/99 Cut 1

Source of variation	df	SS	MS	F	F (table) 0.05	0.01
Blocks	2	0.1347	0.06734			
Treatments	14	43.2257	3.0876	32.8248	2.04	2.75
Error	28	2.6337	0.0941			
Total	44	45.9941				

A3.1.6 1998/99 Seasonal (total) yield

Source of variation	df	SS	MS	F	F (table) 0.05	0.01
Blocks	2	0.3121	0.1561			
Treatments	14	179.5911	12.8279	60.4527	2.04	2.75
Error	28	5.9415	0.2122			
Total	44	185.8447				

Appendix 3.2 Growth stage trials

A3.2.1 **1996/97 Cut 1**

Source of variation	df	SS	MS	F	F (table) 0.05	0.01
Blocks	4	2.9762	0.7440			
Treatments	3	28.0005	9.3335	27.2408	3.49	5.95
Error	12	4.1116	0.3426			
Total	19	35.0882				

A3.2.2 **1996/97 Seasonal (total) yield**

Source of variation	df	SS	MS	F	F (table) 0.05	0.01
Blocks	4	2.4796	0.6199			
Treatments	3	22.6317	7.5439	6.7646	3.49	5.95
Error	12	13.3825	1.1152			
Total	19	38.4938				

A3.2.3 **1997/98 Cut 1**

Source of variation	df	SS	MS	F	F (table) 0.05	0.01
Blocks	4	1.2772	0.3193			
Treatments	3	59.9100	19.9700	234.8528	3.49	5.95
Error	12	1.0204	0.0850			
Total	19	62.2076				

A3.2.4 **1997/98 Seasonal (total) yield**

Source of variation	df	SS	MS	F	F (table) 0.05	0.01
Blocks	4	1.4407	0.3602			
Treatments	3	20.1852	6.7284	26.09	3.49	5.95
Error	12	3.0947	0.2579			
Total	19	24.7206				

Appendix 3.3 N fertilization trials

A3.3.1 1996/97 Cut 1

Source of variation	df	SS	MS	F	F (table) 0.05
Cultivars	1	0.43	0.43	0.39	4.17
N levels	4	1.00	0.25	0.23	2.69
Cvs x N levels	4	3.76	0.94	0.85	2.69
Error	30	33.25	1.11		
Total	39	38.45			

A3.3.2 1996/97 Seasonal (total) yield

Source of variation	df	SS	MS	F	F (table) 0.05
Cultivars	1	0.83	0.83	0.41	4.17
N levels	4	1.94	0.48	0.24	2.69
Cvs x N levels	4	7.35	1.84	0.9	2.69
Error	30	61.19	2.04		
Total	39	71.30			

A3.3.3 1996/97 N fertilizer efficiency

Source of variation	df	SS	MS	F	F (table) 0.05	0.01
Cultivars	1	285.60	285.605	2.68	4.26	7.81
N levels	3	22819.10	7606.366	71.25	3.01	4.72
Cvs x N levels	3	480.35	160.1175	1.50	3.01	4.72
Error	24	2562.22	106.7592			
Total	31	26147.28				

A3.3.4 1996/97 Herbage quality CP

Source of variation	df	SS	MS	F	F (table) 0.05	0.01
Cultivars	1	1.20	1.20	0.65	4.17	
N levels	4	45.00	11.25	6.06	2.69	4.02
Cvs x N levels	4	7.79	1.95	1.05	2.69	
Error	30	55.68	1.86			
Total	39	109.67				

A3.3.5 1997/98 Cut 1

Source of variation	df	SS	MS	F	F (table) 0.05
Cultivars	1	0.15	0.15	0.27	4.17
N levels	4	3.14	0.78	1.38	2.69
Cvs x N levels	4	0.83	0.21	0.36	2.69
Error	30	17.10	0.57		
Total	39				

A3.3.6 1997/98 Seasonal (total) yield

Source of variation	df	SS	MS	F	F (table) 0.05	0.01
Culrivars	1	0.58	0.58	0.90	4.17	
N levels	4	13.39	3.35	5.19	2.69	4.02
Cvs x N levels	4	1.32	0.33	0.51	2.69	
Error	30	19.37	0.65			
Total	39					

Appendix 3.4 Sowing rate trials

A3.4.1 1996/97 Cut 1

Source of variation	df	SS	MS	F	F (table) 0.05	0.01
Cultivars	1	5.60	5.60	7.87	4.17	7.56
Seed rates	4	4.06	1.02	1.43	2.69	
Cvs x seed rates	4	2.26	0.56	0.79	2.69	
Error	30	21.32	0.71			
Total	39	33.24				

A3.4.2 1996/97 Seasonal (total) yield

Source of variation	df	SS	MS	F	F (table) 0.05	0.01
Cultivars	1	11.80	11.80	11.46	4.17	7.56
Seed rates	4	5.99	1.50	1.45	2.69	
Cvs x seed rates	4	3.17	0.79	0.77	2.69	
Error	30	30.90	1.03			
Total	39	51.86				

A3.4.3 1997/98 Cut 1

Source of variation	df	SS	MS	F	F (table) 0.05
Cultivars	1	0.05	0.05	0.06	4.17
Seed rates	4	5.61	1.40	1.64	2.69
Cvs x seed rates	4	3.32	0.83	0.97	2.69
Error	30	25.68	0.86		
Total	39	34.66			

A3.4.4 1997/98 Seasonal (total) yield

Source of variation	df	SS	MS	F	F (table) 0.05
Cultivars	1	3.33	3.33	1.46	4.17
Seed rates	4	35.20	8.80	3.85	2.69
Cvs x seed rates	4	3.15	0.79	0.34	2.69
Error	30	68.55	2.29		
Total	39	110.23			