EVALUATION OF FORAGE YIELD AND QUALITY OF SORGHUM, SUDANGRASS AND PEARL MILLET CULTIVARS IN MANAWATU

DAVISON SILUNGWE

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EVALUATION OF FORAGE YIELD AND QUALITY OF SORGHUM, SUDANGRASS AND PEARL MILLET CULTIVARS IN MANAWATU

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Abstract

Sorghum, sudangrass and pearl millet are versatile summer forages which are able to be grazed or conserved as silage; however there is little recently published information on the performance of these crops in New Zealand. A trial was carried out at Massey University, Palmerston North, in order to compare forage yields, forage quality, crop morphology and seed quality of four sorghum *x* sudangrass hybrids (Pac 8421, Pac 8423, Pacific BMR and Bettagraze), two sudangrass (Superdan 2 and Sprint), one sweet sorghum (Sugargraze); and one pearl millet (Nutrifeed) cultivars, sown on the 8 and 21 December 2009. Two harvests were taken at approximately 100 cm plant height, leaving a residual of 15 cm. Nutritive values of the whole plant: crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), metabolisable energy (ME), and soluble sugars and starch (SSS) were determined, using near infrared reflectance (NIR). Accelerating ageing was used to assess seed vigour.

Yields were significantly (P = 0.005) affected by plant date; mean yield for the 2nd plant date (11,356 kg DM/ha) was significantly lower than the 1st, (12,792 kg DM/ha). Pac 8423 (13,953 kg DM/ha), Sugargraze (13,262 kg DM/ha), Bettagraze (12,704 kg DM/ha) and Sprint (12,426 kg DM/ha), were the highest yielding group. There was a significant interaction (P<0.0001) between sowing date and cultivar, for yield at the second harvest; cultivar differences for the first sowing date were larger than that for the second, which suffered more from cool autumn temperatures.

Crude protein ranged from 10.3 to 18%, NDF 57.2 to 65.2%, ADF 32.9 to 35.5%, ME 10.1 to 11 MJ/kg DM and SSS 1.2 to13.9%. CP and ME were negatively associated with plant height and yield, whilst CP was strongly and positively related to ME.

Despite late sowing, most cultivars achieved high yields of relatively high quality forage. Significant differences amongst cultivars were observed. New cultivars displayed the potential to increase forage yield.

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List of Abbreviations

AA	accelerated ageing
ADF	acid detergent fibre
AOAC	Association of Official Analytical
ATP	adenosine triphosphate
BMR	brown mid rib
BMR	brown mid rib
°C	degree Celsius
Ca	calcium
cm	centimetres
CP	crude protein
DM	dry matter
DMD	dry matter digestibility
FAO	Food and Agriculture Organisation
g	gram
GLM	general linear model
ha	hectare
HCN	hydrogen cyanide
HCN-p	hydrogen cyanide potential
HG	hydrocyanic glycosides
ICP-OES	inductively coupled plasma optical emission spectrometry
IVDMD	in vitro dry matter digestibility
Kg	kilogram
LSD	least significant difference
MAF	Ministry of Agriculture and Forestry
ME	metabolisable energy
Mg	magnesium
mg	milligram
MJ	megajoules
mm	millimetres
N	nitrogen
Na	Sodium

NDF	neutral detergent fibre
NIR	near infrared spectrometry
NZ	New Zealand
NZMS	New Zealand Meteorological Service
P	phosphorus
PCRU	pasture and crop research unit
PH	plant height
RNA	ribonucleic acid
RUE	radiation use efficiency
SNZ	Statistics New Zealand
SSS	soluble sugars and starch
TT	thermal time
USA	United States of America
WU	water use

CHAPTER 1: GENERAL INTRODUCTION

The New Zealand (NZ) economy is based on agriculture, which includes dairy, beef and deer. The numbers of dairy cattle, beef cattle, sheep and deer are estimated to be 5.1, 4.101, 34.088 and 1.146 million, respectively (SNZ, 2009). Livestock production in New Zealand is largely dependent upon grazing pastures, which contain temperate grasses and legumes.

In order to ensure high livestock production, high quality feed and high levels of dry matter intake are required. The growth of pasture is seasonal and supplements may be required; for example, in summer due to low soil moisture. As a consequence, feed for livestock in New Zealand includes a mixture of grazed pasture, pasture silage, cereal silage and other supplements. Maize (*Zea mays*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare*) and oats (*Avena sativa*) are used as cereal forage crops.

In New Zealand, maize is generally preferred as the main summer cereal crop because it is capable of producing higher yields of high quality silage and it is able to store high amounts of energy (Douglas, 1980). In addition, it has excellent intake characteristics compared to other cereals, such as sorghum, pearl millet and sudangrass (Keana *et al*., 2003). However, maize has disadvantages; it is not suitable for grazing, since it cannot re-grow, and it is very vulnerable to water stress during tasselling, silking and grain filling (Douglas, 1980; Gerlach & Cottier, 1974).

New Zealand has undergone considerable changes in its precipitation pattern over the past three decades, meaning that during summer and autumn, dry conditions can be experienced in many regions of the North Island (Ummenhofer *et al*., 2007). In particular, drier conditions are mainly experienced over the North Island during March, April and May (1 to 3% per year drier than normal months), over the South Island's east coast during March to May and from June to August (1 to 3% per year drier), and over the west coast of the South Island during December to February (up to 2% per year drier) (Ummenhofer *et al*., 2007). Gerlach (1974) identified Canterbury, Appleby, Nelson, Blenheim and Marlborough as some examples of areas in New Zealand that experience drought in late summer and early autumn. This drought has been attributed to the La-Nina weather pattern (MAF, 1999).

Drought causes reduced pasture production, a low quality of standing rough feed, low reserves of supplementary feed (which are very costly to replenish), decreased milk yields in dairy cows and reduced growth rates in beef cattle leading to unfinished livestock (Cox, 1968). In order to ensure that there is sufficient feed for their animals, some farmers either buy the extra feed needed or they sell some animals so that the scarce available feed can be fed to the remaining stock (Gerlach & Cottier, 1974; MAF, 2009).

Furthermore, cash flow is reduced because of a decline in the value of the livestock production and decreased purchases of stock. The shortage of feed during late summer and early autumn also results in the price of supplements increasing drastically due to high demand (MAF, 2008). In addition, depending on the degree of scarcity, there is a high possibility of prices becoming very unstable. Inadequate provision of supplement feed to animals, during summer time, remains the main technical constraint in animal production (Zerbini & Thomas, 2003).

High electricity costs associated with pumping water and inadequate (or no) irrigation infrastructures are some of the limiting factors that are making it difficult for farmers to irrigate large areas and to irrigate forage crops (Causley, 1990). In addition, water supply and distribution problems in New Zealand have become a debateable issue. Due to this situation, forage growers in dry areas of New Zealand can find it difficult to produce quality and adequate forage maize, (and/or wheat and barley yields) in order to meet livestock feed demands (MAF, 2008).

Dairy production has continued to increase in New Zealand with the result that the gap between feed demand and feed supply, in late summer and early autumn, has increased. Consequently, the production of quality and adequate feed, to meet the feed nutritive requirements of animals is being encouraged (MAF, 2008). Douglas (1980) recommended the promotion and adaption of summer annual crops, such as sorghum (*Sorghum bicolour* (L.) Moench), sudangrasses (*Sorghum sudanense* (Piper) Stapf) and pearl millet (*Pennisetum glaucum*) for use as alternative forage crops in drier areas in order to bridge the feed shortage gap.

The hybrids of these crops have the potential to compete favourably with maize silage, in terms of yield and nutritive values (Ketterings *et al*., 2005). In addition, they have the ability to provide nutritious forage during late summer and early autumn when cool season perennial grasses have become dormant: as warm season perennial pastures are not nutritious (Causley, 1990; Gerlach & Cottier, 1974). Growing these drought tolerant crops in drought prone areas may be the most useful strategy to ensure efficient use of water in agriculture.

Sorghum, sudangrass and pearl millet are warm-zone cereals grown as forage for livestock, in regions where high temperature and low rainfall during summer and early autumn result in feed deficits on pastoral farms. The attributes of these crops include heat and drought tolerance, high yield potential, good water use efficiency, good re-growth potential after cutting or grazing, few pest and disease problems and an ability to be sown late (Wheeler & Mulchahy, 1989). In addition, if forage is grazed *in-situ,* they reduce the costs of producing cereal forage crops, since less growing inputs are used and there are no harvesting costs incurred (Cerosaletti *et al*., 2002; Marsalis *et al*., 2010). Consequently, livestock farmers in cooler areas, such as the southern North Island, are interested in growing these crops even though they require warmer temperatures for germination and growth than other summer cereal forages, for example, maize (Douglas, 1980). Growing sorghum species and pearl millet, as forage crops, has of late increased steadily in many countries of the world including the United States of America, Mexico and Australia (Zerbini & Thomas, 2003) and New Zealand (MAF, 2008).

The optimum temperature for sorghum growth ranges from 25 to 30 °C (Ketterings *et al*., 2007). Sorghum base temperature (temperature at which there is zero development) is approximately 8 to 12 °C (Hammer *et al*., 1989) and pearl millet is 10 to 12 °C (Ong & Monteith, 1984). In order for sorghum species and pearl millet to germinate well and have good crop establishment in New Zealand, at least 16 to 18 °C soil temperature at 10 cm depth is required, because these crops are sensitive to coldness (Gerlach & Cottier, 1974).

These crops are capable of withstanding drought due to their deep, fibrous and prolific root systems which are able to absorb water from deep down in the soil profile (Blum, 2005; Farre & Faci 2006). In addition, sorghum leaf blades and sheath are covered with a heavy white coat (a powdery bloom of wax) (Singh & Singh, 1995) which is deposited as filaments of almost 0.8 μ (m) in diameter, thus creating a mesh-work approximately 110 μ (m) thick (Sanchez-Diaz *et al*., 1972). This prevents plant from water loss when prevailing conditions are hot and dry; also their leaves fold under during drought, thus further preventing water loss (Singh & Singh, 1995). Mechanisms, such as decreased leaf area index, leaf area, and plant size, help to limit loss of water and decrease injury to plants (Blum, 2005). Moreover, under drought stress, the plants are able to decrease water use (WU) (Blum, 2005). When this occurs, plants become dormant and they only resume growth when moisture availability improves (Ketterings *et al*., 2005).

Despite sorghum possessing these positive attributes, when feeding forage sorghums to livestock as supplement feed there is the potential for cyanide and nitrate poisoning to occur (Wheeler *et al*., 1990). Cyanide and nitrate poisoning of stock has been reported in New Zealand (Ellison, 1994; Gerlach & Cottier, 1974). Ellison (1994) reported a 4% to 27% mortality rates in reported cases in New Zealand.

However, current cultivars on the New Zealand market have low concentrations of cyanide content compared to old cultivars, because of the extensive breeding that has taken place (Cottier, 1973). Cyanide poisoning is a greater problem than nitrate poisoning in livestock. However, nitrate poisoning is the most wide spread toxicity related to the grazing of sorghum (Ellison, 1994). The other problem with using sorghum species is that their digestibility falls rapidly as the plants mature, in addition to there being insufficient content of sulphur and sodium to supply stock requirements (Wheeler & Mulchahy, 1989).

1.1. Objectives of the study

The study was designed to:

a) Compare forage yields and crop morphology of sorghum, sudangrass and pearl millet cultivars.
b) Determine and compare the nutritive values: crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF), metabolisable energy (ME), and soluble sugars & starch (SSS) of sorghum, sudangrass and pearl millet cultivars.
c) Determine the effect of sowing dates on forage yield and crop morphology of sorghum, sudangrass and pearl millet.

1.2. Synthesis and organisation of this thesis

Chapter 1 introduces the study, and highlights the situation of pasture production in late summer and early autumn seasons. The literature review (Chapter 2) reviews the factors affecting forage yield and quality, including maturity at harvest, genotype/variety, management practices and environmental conditions during the growing season. Chapter 3 reports on the materials and methods used in this research. These include cultivars, experimental site and environment, field experiment layout and measurements, yield and quality determinations, seed quality assessment and data analysis. Chapter 4 describes the results of yield and quality parameters, seed quality and the relationships between yield, agronomic traits and forage quality. Chapter 5 discusses the results, and Chapter 6 concludes the thesis and outlines recommendations for further research on improving the use of summer annual crops in New Zealand.

CHAPTER 2 : REVIEW OF LITERATURE

2.1. Introduction

Forage is defined as the edible parts of plants, other than the separated grain that can provide feed for grazing animals: or that can be harvested for feeding (Wilkins, 2000). Forage consists of herbage, hay and silage, browse and straw. Forage crops are grown annually or biennially to be grazed *in situ***,** or harvested as a whole crop (e.g. sorghum, maize, kale). Maize, wheat, barley and oats are the most commonly grown cereal forage crops in New Zealand (MAF, 2008). According to Kemp *et al*. (1999), the following forage species are grown in New Zealand for animal production:

Grasses

a) Perennial grasses

i. Perennial ryegrass (*Lolium perenn*)
ii. Tall fescue (*Festuca arundinacea*)
iii. Cockfoot (*Dactylis glomerata*)
iv. Phalaris (*Phalaris aquatic*)
v. Brown top (*Agrostis capillaries*)

b) Annual grasses

i. Italian ryegrass (*Lolium multiflorum*)

Legumes

i. White clover (*Trifolium repens*)
ii. Red clover (*Trifolium pratense*)
iii. Subterranean clover (*Trifolium subterraneum*)
iv. Lotu (*Lotus pedunculatus*)
v. Birdsfoot trefoil (*Lotus corniculatus*)
vi. Caucasian clover (*Trifolium ambiguum*)
vii. Lucerne (*Medicago sativa*)

Pasture herbs

i. Chicory (*Cichorium intybus*)
ii. Plantain (*Plantago lanceolata*)

From the above list, the most commonly used pasture species in New Zealand are white clover and perennial ryegrass. However, during late summer and early autumn, the production of these pastures is greatly affected by drought, with perennial grasses becoming dormant and warm season perennial pastures having a reduced nutrition (Kemp *et al*., 1999; Mitchell, 1956). In addition, summer forage production is negatively influenced by the dry spells experienced in dry prone areas. This interrupts the steady supply of supplements required to ensure desirable animal production. In order to bridge this gap, the growing of alternative drought tolerant crops is recommended.

The adaptation, yield potential, and feeding value for a specified livestock programme, are factors that influence the selection of the type or variety of summer annual to be sown (Posler *et al*., 1983). Summer annual grasses have variable growth rates, re-growth ability, plant height, leaf/stem ratio, forage yield and quality. Therefore, farmers need to follow recommended production practices, harvest procedures and conservation management (green chop, pasture, hay or silage) for each variety, in order to maximise their nutritive value.

2.2. Background

Interest in the use of summer annual crops (sorghum, sudangrass and pearl millet) in New Zealand developed as early as 1911. During the 1911 growing season, extremely dry weather was experienced in New Zealand; this resulted in a drastic decline in milk production in most drought prone areas. Lonsdale (1911) suggested the use of summer forage crops, which he described as *salvation crops*, since they had the potential to supply a dairy herd with succulent feed during periods of drought.

From that time on, interest in the use of drought tolerant crops (sorghum, sudangrass and pearl millet) increased. By 1915, sorghum varieties, such as Early Amber Cane, Planter's Friend and *Sorghum saccharatum*, were on the local market for use as hay or silage (Brown, 1916). Hybrids developed by crossing sorghum and sudangrass were generally preferred to sweet sorghum and sudangrass. However, despite new cultivars with high yielding potential, low concentration and good digestibility being introduced on-to the New Zealand market in recent years, the number of hectares of sorghum, sudangrass and pearl millet under cultivation remains low.

Crush and Rowarth (2007) stated that the lack of cold tolerant cultivars and low feeding quality, compared to temperate forage grasses, are the limiting factors for the use of C4 crops in New Zealand. Even cultivars with low concentrations of cyanide still have the potential to poison stock if they are grazed too young (Wheeler *et al*., 1990). Furthermore, relative low digestibility and a rapid decline in feeding value have lead most forage growers to be sceptical of growing annual summer crops for summer supplementation. In addition, seed production for forage grass is a challenge in New Zealand; this is due to pressure on the land used to produce forage seed in order to grow high value crops, such as vegetables (Rowarth, 1997). However, Crush and Rowarth (2007) pointed out that C_4 grasses have the potential to increase dry matter production to levels not yet seen in New Zealand. Cyanide poisoning is also called prussic acid or hydrogen cyanide poisoning (HCN) (Bertram *et al*., 2005).

There is little recently published information on the performance of sorghum, sudangrass and pearl millet forage crops in New Zealand, with active research being done only in the 1960s, 1970s and early 1980s (Cottier, 1973; Gerlach & Cottier, 1974). Crush and Rowarth (2007) singled out the loss of scientific interest in the use of these crops in New Zealand, as the reason why little recent work has been done in this area. Therefore, the only available research information on sorghum, sudangrass and pearl millet was gathered during the 1960's, 1970's and 1980's (Cottier, 1973; Gerlach & Cottier, 1974).

2.3. Forage sorghum

Sorghum is the fifth most important cereal crop, after wheat, rice, maize and barley (Bean *et al*., 2009; FAO, 2010). There are approximately 20 species of grasses native to tropical and subtropical regions in the genus Sorghum (Reich, 2008). According to Gerlach and Cottier (1974), sorghum originated in Ethiopia and then spread to different parts of Africa and other areas, such as India, South East Asia, Australia and the United States of America.

2.3.1. Types of forage sorghum

Douglas (1980) classified forage sorghum into three groups: sweet sorghum, sudangrass and sorghum *x* sudangrass hybrids: these all display morphological differences. However, all have high yield potential to be grown for high quality pasture or silage and/or hay (Watson *et al*., 1993).

Forage breeders have crossed sudangrass and sorghum, to produce forage varieties with improved nutritive values and productivity (Kalton, 1988; Miron *et al*., 2007; Moyer *et al*., 2004). Through extensive breeding efforts and selection, forage sorghum hybrids have been bred to improve yielding potential, re-growth capacity, number of tillers per plant, leafiness, digestibility, disease and pest resistance, and low prussic acid content (Kalton, 1988).

Sorghum varieties have also been improved by crossing them with sorghum mutants containing the Brown Mid Rib (BMR) gene in order to improve yield and digestibility (Miron *et al*., 2007). The BMR gene was discovered in 1931 (Oliver *et al*., 2004) and it is linked with decreased lignin content and increased forage digestibility (Porter *et al*., 1978). According to Cherney *et al.* (1988), BMR is a noticeable marker related to decreased lignin content in sorghum, pearl millet and maize. Reich (2008) indicated that it is expressed in the mid-rib of leaf, stem, rind, pith and vascular tissue of plants.

Plate 2.1: Brown mid rib (BMR) of sorghum.

In the sorghum industry, three BMR genes (BMR-6, BMR-12 and BMR-18) are mainly used to produce BMR hybrids (Porter *et al*., 1978). Incorporation of the BMR trait into sorghum and sudangrass has improved the digestibility of these forages due to a decreased in lignin content and cell wall concentration in the dry matter (Miller & Stroup, 2003; Reich, 2008).

Lignin content has been reduced by approximately 10 g/kg (Oliver *et al*., 2004), resulting in a 30% increase in animal voluntary intake (Casler *et al*., 2003). However, Miller and Stroup (2004) found that lignin concentration of stem and leaf tissues, in BMR maize, pearl millet and sorghum, decreased up to 50% and 25%, respectively. Miron *et al.* (2007) concluded that dry matter yields and digestibility of BMR hybrids are comparable with maize.

Although the BMR trait is desirable in summer annual crops, it is associated with decreased yields, reduced vigour of plants and high lodging (Casler *et al*., 2003; Miller & Stroup, 2003; Pedersen *et al*., 2005). Casler *et al*. (2003) found that BMR phenotypes had 15% and 30 % reduction in forage yield, for first and second cuts. Low plant vigour and health were attributed to disruptions in lignin biosynthesis (Reich, 2008). In order to avoid plant lodging in BMR hybrids, Bean *et al*. (2009) proposed a lower seed sowing rate, the optimum application of nitrogen fertiliser and timely harvesting.

However, Reich (2008) reported that focused breeding has reduced the linkage of BMR genes and poor yield. Due to this situation, new hybrids with high plant vigour, reduced lodging and yielding potential have been released onto the market (Miller & Stroup, 2003).

2.3.1.1. Sweet sorghum

Sweet sorghum has a vigorous growth habit and it is late maturing (Leep, 2005). Reich (2008) stated that the leaves are very coarse, with plants being typically tall and generally later maturing than sorghum *x* sudangrass and sudangrass. Sweet sorghum yields are comparable to maize when both crops are irrigated, and higher than maize in dry areas (Anderson & Guyer, 1986; Leep, 2005; Reich, 2008). They also have low tillering capacity and re-growth rate after grazing/cutting (Gerlach & Cottier, 1974). Due to this fact, they are not recommended for grazing, they are mainly harvested for silage once they are past heading in order to maximise dry matter yield rather than quality (Gerlach & Cottier, 1974; Watson *et al.*, 1993). The levels of cyanide in sweet sorghum are higher than other summer annual grasses (Gerlach & Cottier, 1974; Leep, 2005).

2.3.1.2. Sudangrass

Sudangrass is native to Sudan in Africa; it is a tall annual forage crop with erect stems and narrow leaves (Cumberland, 1974; Gerlach & Cottier, 1974; Karlovsky, 1966; Walton, 1983). It is very fine stemmed with exceptional tillering capacity and excellent re-growth after grazing or cutting (Anderson & Guyer, 1986; Cottier, 1973; Leep, 2005; Reich, 2008). However, sudangrass produces less forage yield compared to other summer annuals (sweet sorghum and sorghum *x* sudangrass). Sudangrass is, therefore recommended for either grazing or forage conservation.

Despite sudangrass yielding more poorly than sorghum *x* sudangrass, it is the quickest source of forage during summer time, especially as a pasture, due to its high digestibility (Anderson & Guyer, 1986; Ball, 1998; Karlovsky, 1966; Watson *et al.*, 1993). Plants do not tolerate frost and in cold conditions they become dormant. However, they will resume growth when the prevailing weather becomes favourable (Armah-Agyeman *et al.*, 2002)

2.3.1.3. Sorghum x sudangrass

Sorghum *x* sudangrass is a cross between sorghum (*Sorghum bicolour* (L) Moench) as the female parent and sudangrass (*Sorghum sudanense* piper) as the male parent (Reich, 2008). They are the most common forage hybrids, and they are considered as possible forage alternatives to maize silage in drought prone areas, as well as under wet conditions (Ketterings *et al*., 2007). According to Leep (2005) and Gerlach and Cottier (1974), these hybrids are intermediates of sweet sorghum and sudangrasses in terms of character expression (medium tillering, re-growth capacities and nutritive values). Anderson and Guyer (1996) found that the rate of re-growth after grazing is lower than sudangrass. The hybrids are higher yielding than sudangrass and pearl millet, but they yield less than sweet sorghum. Stems contribute about 50% to their final yield (Anderson & Guyer, 1986; Leep, 2005).

Sorghum *x* sudangrass are not suitable for hay due to the thickness of their stems, which are difficult to cure, or to crush and crimp. Under less frequent cutting, they are more vigorous. In order to ensure an excellent quality, it should be harvested at least 45 to 60 cm (Undersander & Lane, 2001).

2.4. Pearl millet

This is a summer annual grass that originates in Africa and India. Of all the millets and miscellaneous cereals, pearl millet is the most important crop, and it has the greatest potential. It is robust and quick growing and can be interchanged with sorghum and maize (Rachie & Majmudar, 1980). It is more drought resistant than sudangrass, but it does not tolerate cold and wet soils. In order to ensure desirable growth, sowing time needs to be synchronised with optimum temperatures.

Pearl millet produces a higher number of leaves than sudangrass and it has thin stems, profuse tillering and a medium plant height. These are all desirable characteristics for forage yield and quality. The leaf/stem ratio is significantly higher than sudangrass and sorghum *x* sudangrass (Ball, 1998). Hence, it produces excellent pasture and it has better digestibility than sorghum *x* sudangrass hybrids grown under the same environment.

Pearl millet is very sensitive to frost and a temperature as low as 2 to 3 °C is sufficient to kill the plants (Rachie & Majmudar, 1980). Pearl millet is also more sensitive to a low residual stubble height than other summer annual grasses (Stephenson & Posler, 1984). Hence, it is more sensitive to overgrazing. At least 20 cm of residual stubble is recommended for best re-growth. It is not used for hay because it has coarse stems (Beaty *et al*., 1965).

2.5. Seed quality

Seed quality is the collection of seed properties (germination capacity, seed vigour, seed moisture content, analytical purity, species purity, uniformity, cultivar purity, cultivar health and size) that give the seed value for sowing purposes (Esbo, 1980). The importance of these properties is not equal and differs depending on the situation.

The two quality components of interest in this study are as follows:

2.5.1. Germination

Germination capacity is the percentage of normal seedlings of pure seed (Almekinders & Louwaars, 1999). Robert and Gurmu (1990) explained that germination consists of three processes, namely; imbibition, radicle emergence and coleoptile growth. In order for these processes to occur, favourable environmental conditions (water, oxygen, an appropriate temperature and for some seed light) are needed. However, excess water can negatively impact germination and emergence, because it can directly damage the seed and limit the air (oxygen) supply in the soil, thus creating anaerobic conditions that can result in seed or seedling death (Hampton *et al*., 1999; Martin, 1986).

In order for sorghum species and pearl millet to germinate well, they require a soil temperature of at least 16 to 18 °C at a depth of 10 cm (Gerlach & Cottier, 1974). Below 15 °C the growth rate of sorghum species is slow, and at less than 10 °C, seedling injury occurs (Gerlach & Cottier, 1974). Rapid germination and emergence occurs when the soil temperature is at least 21°C (Undersander *et al*., 1990). Moreover, a firm and well prepared seed bed will support full seedling establishment. A desirable stand of healthy plants is achieved by sowing high quality seed at the correct time.

Uniform germination is an advantage to plant establishment, because plants will grow at the same rate, in order to use available resources equally, this will prevent some weak seedlings dying by being suppressed by stronger plants (Walton, 1983). In addition, it ensures a uniform canopy cover within rows and it also allows management practices to be undertaken at the same time. Generally, sorghum takes 3-10 days to emerge after sowing (Vanderlip, 1993). Seed maturity and size, external abiotic conditions (moisture, air and soil temperatures), and external biotic conditions (diseases), are the three factors that affect seed germination and seedling emergence. These factors determine the time between sowing and seedling emergence.

Cool and wet conditions reduce a crop stand, since they promote a favourable environment for the development and establishment of disease that can seriously damage the crop by damaging or killing the emerging seedlings (Vanderlip *et al*., 1973). Moreover, in cool soils, the emergence of sorghum seedlings is delayed and once emerged growth is slow, this allows weeds to establish faster than the actual crop. As a result, the crop is suppressed to some extent, since weeds will shade emerging seedlings and use growing resources before the forage is established. Large seeds produce more vigorous seedlings that are tolerant to adverse conditions, and shrunken seeds germinate poorly and produce weak seedlings (Acquaah, 2005). However, this varies, depending on the cultivar's genetic potential. Pederson and Toy (2001) found that untreated red coloured seeds had a higher seedling emergence than the white seed phenotype, because red pericarp has been linked to grain mould resistance.

Under unfavourable conditions, the slow growth rate of seedlings negatively influences emergence (Free *et al*., 2010). At low temperatures, oxygen uptake is decreased because mitochondrial activity is reduced (Lyons & Raison, 1970), thus resulting in a reduced concentration of adenosine triphosphate (ATP) and other nucleotides (Stewart & Guinn, 1969). Guinn (1971) also reported that the RNA, protein and lipid soluble phosphate are decreased, thus resulting in potential emergence and/or seedling vigour being affected.

In New Zealand, around 60% and 20 to 50% field germination was reported when sorghum seed was planted on clay loam and peat, respectively (Taylor *et al*., 1974). In the USA, field establishment of sorghum averaged 75% (Vanderlip *et al*., 1973). In contrast, field emergence has also been reported from 32 to 60% (Pedersen &Toy 2001) and 35 to 93% (Ibrahim *et al*., 1993). Singh and Dwaliwal (1972) reported 55% seedling emergence when the minimum temperature was 15°C. A range of approximately 20 to 50% has been indicated as the difference between field and laboratory germinations (Vanderlip *et al*., 1973). Due to these discrepancies in sorghum germination, this study is also evaluating the seed vigour of different cultivars and exploring the association between laboratory tests results and field emergence.

In the case of favourable field conditions, both standard germination and vigour tests can be correlated with field emergence. Hence, both can be used to predict field performance, because a vigour test will not be more superior to standard germination. However, under adverse conditions, vigour tests correlate strongly with field germination (Perry, 1987).

2.5.2. Seed vigour

Seed vigour is the capacity of the seed to perform when prevailing conditions are adverse (Almekinders & Louwaars, 1999). Walton (1983) defined seed vigour as the ability of the seed to emerge, withstand cold or dry conditions, resist the attack of soil and seed borne microorganisms and compete with other plants. Perry (1978) defined seed vigour as “The sum total of these properties of the seed which determine the level of activity and performance of seed or seed lot during germination and seedling emergence”.

Seed vigour comprises those seed properties that determine the potential for fast, uniform emergence and the development of normal seedlings when grown within a wide range of field conditions (Zaychuck & Foster-Stubbs, 2004). Seed germination is dependent on a cultivar’s genetic potential and its abilities to withstand adverse conditions that it can be exposed to during germination. High vigour seeds are able to withstand unfavourable conditions and thus ensure excellent establishment and crop stand, for maximum forage yield. A seed vigour test is conducted, in order to evaluate its physiological quality and the potential for the seed to tolerate field stress (low or high soil temperature and/or moisture and soil crusting), when the crop is planted under unfavourable conditions (Hampton & TeKrony, 1995).

Low seed vigour and a loss of viability are mainly caused by seed ageing (Hampton & TeKrony, 1995). This deterioration continues until the ability of the seed to germinate is lost. According to Hampton and Tekrony (1995), seed deterioration normally begins at physiological maturity (before harvest) and continues during the harvest, processing and storage stages. However, the deterioration rate of a seed is dependent on the genetic potential of the seed, as well as the production and environmental factors under which the seed is grown. Loss of enzymes, respiration and hormonal changes, impaired protein and Ribonucleic acid (RNA) synthesis, genetic damage and production of toxic metabolites are all either the cause of or a result from seed deterioration (Priestley, 1986).

Seed deterioration results in decreased speed and uniformity of germination, decreased ability to withstand environmental stresses experienced in the growing field and poor seedling emergence and growth (Roos, 1980). Although seed lots may have nearly the same high germination values, they may be at different physiological ages. This will be reflected in variable seed vigour and different performance abilities. The higher the vigour of the seed, the better the seedling emergence is (Hampton & TeKrony, 1995). Perry (1987) reported that the determination of seedling growth (seedling dry matter, seedling height and number of normal seedlings) is the easiest way to assess vigour. This method is mainly used in crops where the first leaf emerges through coleoptile, for example; maize, barley, rice, and sorghum.

According to Perry (1987), seed viability is a primary component of any assessment of quality. The viability of seed is tested by the use of a tetrazolium test, since it focuses on the internal conditions of the embryo. A colourless solution, 2, 3, 5-triphenyl tetrazolium chloride, is used as an indicator, to show reduction processes that occur within living cells. Seeds are soaked in a tetrazolium test solution so that this solution can be imbibed by the seeds. Once it is imbibed by the seed, it interacts with the reduction processes of living cells and it accepts hydrogen from the dehyrogenases. If cells are living, 2, 3, 5-triphenyl tetrzolium chloride is hydrogenated to form a red, stable and non-diffusible substance called tryphenyl formazan. Therefore, if cells are living, the embryo will be stained red. However, if cells are dead, the embryo will be colourless, or it will have colourless (unstained) patches (Hampton & TeKrony, 1995).

An accelerated ageing (AA) test has been suggested as the best method for determining seed vigour in sorghum species (Pedersen & Toy, 2001). Delouche and Baskin (1973) described this method as inducing physiological stress, where high temperature and relative humidity are used to deteriorate (or age) seeds. In this method, seeds are subjected for a short period to two environmental stresses (high temperature and high relative humidity), these are the conditions generally responsible for seed deterioration. Seed lots that withstand these ageing conditions and retain germination potential, equal or almost the same as the original standard germination are considered to be of high vigour (Hampton & TeKrony, 1995). If deterioration occurs, it is at a slower rate than low vigour seed.

Depending on crop species, Hampton and TeKrony (1995) specified ageing temperatures from 41 to 45 °C and ageing duration from 48 to 144 hours. Ibrahim *et al*, (1993) found 43 °C for 72 hours and 48 °C for 48 hours to be effective in separating sorghum seed by vigour. From the two temperatures, 43 °C for 72 hours was recommended as the best ageing temperature and durations because of consistent germination.

Ibrahim *et al*. (1993) found that as the ageing duration increased, seed moisture also increased. Hampton & TeKrony (1995) specified that; after ageing sorghum seed at 43 °C for 72hours, the moisture content should be 28 to 30%. Ibrahim *et al*. (1993) found 29 to 30% moisture content after 72 hours of ageing, at 43 °C and 45 °C.

Freshly harvested sorghum seed has higher germination after accelerated ageing (and hence higher vigour) than carry-over seed (Ibrahim *et al*., 1993). Petersen and Toy (2001) reported 84 to 99% and 85 to 99% as un-aged germination of grain sorghum at 5 and 10 days, respectively. When grain sorghum seed was aged at 48 °C for 48hours, at close to 100% relative humidity, the germination was 87 to 96% and 89 to 97% after 5 and 10 days. Fresh sorghum seeds aged at 43 °C for 48 hours, 43°C for 72 hours, 45 °C for 48 hours, and 45 °C for 72 hours, had post accelerated ageing germinations ranging from 96 to 98%, 93 to 96%, 95 to 99%, and 53 to 84%, respectively, while two year old seed aged at 43 ^{o}C for 48 hours, 43 ^{o}C for 72 hours, 45 ^{o}C for 48 hours, and 45 °C for 72 hours, had post accelerated germination of 80 to 87%, 64 to 68%, 41 to 58% and 4 to 13%, respectively (Ibrahim *et al*., 1993).

As the seeds were exposed to high temperatures and relative humidity, the germination of seeds with low vigour reduced, because they were unable to withstand the adverse effects of ageing. However, the seeds with high vigour withstood these environmental factors and they were able to achieve high germination. Therefore, freshly harvested seed had a higher post-accelerated germination than over carry-over seeds, since they were less deteriorated than the carry-over seed.

2.6. Forage yield

Forage yield is influenced by tiller density, plant height, stem diameter, number of leaves and leaf area (Chaudhry *et al*., 1990; Chu & Tillman, 1976; Hussain *et al*., 1991; Ping *et al*., 2005). As these agronomic traits increase, forage yield is also increased. However, the performance of different forage crops is primarily based on the type of forage crop or variety grown, as well as the prevailing growing environment (Maiti & Soto, 1990).

In New Zealand, potential yield of sorghum *x* sudangrass have been estimated to be 29,000 kg DM/ha and 21,000 kg DM/ha for irrigated and non-irrigated crops, respectively, after 112 days (Chu & Tillman, 1976). Sorghum yields of 18,000 to 20,000 kg DM/ha were reported by Piggot and Farrell (1984) in the Manawatu. Taylor (1977) reported ranges of 16, 500 to 28,000 kg DM/ha and 8,600 to 12,800 kg DM/ha of sorghum silage grown on a peat site in Sweetwater, and on a sand site in Cape View, respectively. The silage yields were high because the crops were harvested at the soft dough stage and hence, seed component contributed greatly to the yield. Douglas (1980) reported 13,600 kg DM/ha, as an average yield of forage sorghum. Karlovsky (1966) reported sudangrass silage yield harvested at 122 days ranging from 8,238 to 9,885 kg DM/ha. However, Cottier (1973) suggested more than 8000 kg DM/ha as a cumulative yield of sudangrass and sorghum *x* sudangrass under non-irrigated conditions.

In Harakeke, Appleby, Wairau Valley and Waimea West in New Zealand, Rhodes (1977) reported final cumulative yields of two cutting regimes of sorghum *x* sudangrass hybrid (Sudax), cut to 5 cm stubble residual height as 3, 830, 13,750, 2,850 and 13,540 kg DM/ha, respectively. In addition, pearl millet yielded 5, 050 kg DM/ha in Harakeke and 7, 020 kg DM/ha in Appleby. The yields at the Harakeke and Wairau Valley sites were poor due to dry periods and poor crop establishment. In a study of three cutting regimes, Cottier, (1973) found individual yields of each cutting; 3,230, 3,160 and 2,130 kg DM/ha for sorghum *x* sudangrass and 2,740, 3,110 and 2,160 kg DM/ha for sudangrass. The cumulative dry matter yields of sorghum *x* sudangrass and sudangrass were 8,520 and 8,010 kg/ha DM, respectively. In another three cutting regimes of three sorghum *x* sudangrass hybrids growth after 77 days, in Waikato (New Zealand), Gerlach and Cottier (1974) reported cumulative DM yields of 9,520, 9,360 and 9,740 kg DM/ha. From these findings, it can be seen that the cumulative yields of forage sorghum were determined by the cultivar grown, its re-growth abilities, the longevity of the growing season, the harvesting stage, the growing environments available and the general management of the crop whilst in the field. The higher the yielding potential and regrowth ability, and the longer the growth period, the higher the yield would be.

In comparison studies between maize and sorghum, in different regions (Auckland, Manawatu and Nelson), maize and sorghum yielded 5,200 to 12,000 and 3,100 to 8,200 kg DM/ha, respectively. Approximately 5,000 to 10,000 kg DM/ha was stated as the potential yield for maize greater than sorghum (Douglas, 1980). With the improved sorghum cultivars on the market, competition between maize and sorghum cultivars is expected, under same growing environment. Sorghum is likely to be higher yielding in the drier areas, than maize.

Since sorghum will re-grow, it can be cut either once (single cut) or several times (multiple cuts). Rahman *et al*. (2001) grouped sorghum as either single cut (e.g. sweet sorghum) or multi cuts (e.g. sorghum *x* sudangrass and sudangrass). Increasing the number of cuttings reduces the dry matter production of the re-growths. This is attributed to loss of vigour in plants, and to some extent, the reduction of the number of tiller/ m^2 and decreased yield per tiller (Rahman *et al*., 2001). Beuerlein *et al.* (1968) found that treatments, which had 0, 1, 2, 3 and 4 cuttings had cumulative yields of 17,242, 17,120, 12,690, 8,903 and 1,924 kg DM/ha.

Yield potential differs with environment. In tropical regions, high yields (30,000 kg DM/ha) have been achieved because of high temperatures that favour higher growth rates (Plucknett *et al*., 1971). Factors such as moisture, fertility, temperatures, diseases and pests can all influence yields. In New Zealand, sorghum yield potential is over 20, 000 kg DM/ha, if conditions are favourable, but can be reduced by 50% due to moisture limitation (Taylor *et al*., 1974). In New South Wales, Australia, which has a sub-tropical climate, the yield potential is also 20,000 kg DM/ha (Cameron, 2006; Muldoon, 1986). Lower potential yields have been reported in the USA (10,500 to 12,700 kg DM), Spain (12,300 to 14,100 kg DM/ha) and South African (12,200 kg DM/ha), due to less favourable growing conditions (Kilcer *et al*., 2005; Lloveras, 1990; Snyman & Joubert, 1996).

2.7. Factors affecting forage yield

Generally, the yield and quality characteristics of forage crops are determined by the harvesting stage, genotypes grown, management practices and environmental factors (temperature, drought and sowing time) (Piggot & Farrell, 1984; Reddy *et al*., 2002). This is because interactions between genotype, stage of maturity at harvest and re-growth ability, heavily influence forage yield and nutritive value (Ketterings *et al*., 2005).

Buxton and Casler (1993) suggested that forage growth rate, development rate, yield and forage quality, reflect the cumulative effects of the plant's environment. As plants are growing, they experience environmental fluctuations and stresses that alter their plant morphology and their rate of development in addition to limiting yield and changing quality.

Peacock and Heinrich (1984) pointed out poor crop establishment, low fertility and inadequate amount of moisture, as factors that lead to poor crop standards, poor growthas a consequence a lower amount of radiation being intercepted, thus detrimentally affecting forage yield and the amount of supplement available. When factors, such as light interception and temperature, soil moisture and nutrients, are not limiting, faster and optimum plant growth is achieved, for example; increased plant height, stem diameter, leaf number and area, thus resulting in an increased plant dry matter yield (Ayub, 2009).

The factors that affect forage yield are as follows:

2.7.1. Maturity at harvest

Maturity at the harvest of forage plays an important role in yield determination. Generally, total dry matter increases as harvesting is delayed, especially when harvesting occurs between pasture and boot stage (66% DM) (Worker & Marble, 1968).

During the early growth stages of a forage crop, leaf yields are double that of those of stems but, at later stages, stem yields are twice those of leaves (Nelson & Moser, 1994). In a study to determine the relative proportion of leaves, stems and heads of sudangrass and sweet sorghum, Farhoomand and Wedin (1968) found that the dry matter content was highest in the heads, and least in the stems. As the plant starts forming seeds, dry matter in leaves and stems is remobilised to the seeds. However, changes in forage quality also need to be considered since, as the dry matter content increases, digestibility of NDF, lignin, starch, sugar content and crude protein, are all reduced (Kilcer *et al*., 2003). Given that maturity affects yield and quality, forage intended for either dairy animals or fattening should be balanced between dry matter production and quality, whilst forage for maintenance should be comprised of maximum dry matter production, in order to achieve the intended goals, such as, high productivity, lactation, calving and profit (Hodgson & Brookes, 1999).

2.7.2. Genotype/ variety

Genotype or variety plays an important role in determining yield. For example, late maturing cultivars are likely to have more yield than early maturing ones, since the stem components and number of leaves are higher (Taylor *et al*., 1974). In addition, tall forage cultivars yield more than short cultivars due to the strong positive relationship between plant height and yield, and taller forage have longer time to accumulate dry matter. Plant height, number of shoots or tillers/m^2, tillering capacity, leaf/stem ratio, and yielding potential, are some of the most important factors that influence the choice of variety to be grown, since they have a direct influence on total forage yield (Assaeed, 1994).

In addition, forage species differ in their production potential, their adaptation to adverse conditions and their ability to re-grow after grazing/cutting. In drought prone and warm areas, sorghum performs better than maize, because sorghum is drought tolerant (Taylor *et al*., 1974). Maize out-yields sorghum *x* sudangrass and sudangrass cultivars in a normal growing season.

Cottier (1973) found no significant differences between sorghum *x* sudangrass and sudangrass cultivars, because all cultivars were able to recover from three cuttings, unlike pearl millet and Japanese millet that only recovered from two cuttings due to poor recovery growth. This resulted in sorghum *x* sudangrass and sudangrass cultivars out-yielding pearl millet and Japanese millet. Also, Taylor (1977) found that sorghum *x* sudangrass is higher yielding than Japanese millet. Moreover, Gerlach and Cottier (1974) reported that sorghum *x* sudangrass and sudangrass cultivars are higher yielding than sweet sorghum, when grown for forage due to better recovery after grazing than sweet sorghum. Due to this factor, sweet sorghum was recommended for silage. However, Taylor (1977) found that sorghum *x* sudangrass were generally quicker establishing and 19% higher yielding than sudangrass cultivars. Irrigated forage sorghum is estimated to out-yield non-irrigated forage sorghum by 8,800 kg DM/ha (Chu & Tillman, 1975). When sweet sorghum is allowed to grow up to the silage stage (soft dough stage), it may show better results than maize silage (Gerlach & Cottier, 1974).

Worker and Marble (1968) found that sorghum *x* sudangrass had higher dry matter than sweet sorghum and sudangrass, when it was harvested at the boot and flower stage of maturity, and sudangrass was lower than sweet sorghum at boot stage but the difference was not significant. However, sweet sorghum yielded significantly more than sorghum *x* sudangrass and sudangrass, when harvested at the soft-dough stage. Furthermore, Worker and Marble (1968) indicated that there is a small difference in yield between sweet sorghum and sorghum *x* sudangrass. Therefore, the final use of the pasture to be grown, in addition to the expected nutritive value being targeted, will enable farmers to select the forage type to be grown, in order to achieve their objectives.

At all harvest stages (boot, full flower and soft dough) sorghum *x* sudangrass out-yielded sudangrass, except when grown as pasture (Worker & Marble, 1968). In addition, Worker and Marble (1968) also observed that the cumulative yield of sweet sorghum was low, due to its slow recovery and lack of profuse tillering ability. However, sorghum *x* sudangrass and sudangrass possess good ability of re-growth.

2.7.3. Management practices

The management practices of the forage crop have a significant effect on final yield. This is because management practices affect the availability of growing resources, absorption and utilisation of growing resources, health of the growing plants and the development and growth of plants. Generally, if forage crops are well managed, plants will be in good health thus allowing a high radiation interception, longer duration of light interception and a higher accumulation of dry matter (White *et al*., 1999).

2.7.3.1. Plant population density

Taylor *et al*. (1974) found that as plant population density increased, yield also increased. However, at a certain point, a diminishing return point is reached. This is attained when plant density is too high, resources for growth are limited and light interception is reduced. Furthermore, Taylor *et al*. (1974) found that sorghum cultivars that tillered 30-40% more than other cultivars on a sand soil in Cape View, yielded less than less tillered cultivars, due to the high competition for soil moisture. Chu and Tillman (1976) recommended a plant population of 80 plants and 73 plants per m^2 for irrigated and non-irrigated sorghum, respectively. Gerlach and Cottier (1974) reported more than 60 plants per m^2 as being the optimum plant population. In Nelson and Marlborough, Rhodes (1977) reported poor crop establishment, due to low temperatures, which reduced forage yield.

2.7.3.2. Fertiliser application

Under favourable conditions of solar radiation, soil moisture and temperature, the supply of the major nutrients, such as nitrogen (N), potassium (K) and phosphorus (P), promotes the development of canopy leaf area and increases the leaf size and tillering (Buxton & Fales, 1994; Moot *et al*., 2007; Rhykerd & Noller, 1974). Nitrogen fertiliser application increases the rate of photosynthesis (McDonald *et al*., 1995). In addition, good soil conditions create a favourable environment for excellent root growth, in addition to water and nutrient uptake. If the environment is poor, the change in plant growth reduces forage quantity and quality. Phosphorus inadequacy inhibits metabolic processes, such as the formation and translocation of sugars and starch in the plants protein system resulting in a reduced yield and quality. If the recommended nutrients are suppied and other factors are favourable, forage yield and quality will be improved.

Adequate application of nutrients is required to ensure that emerging seedlings are well nourished in order to have an early and vigorous growth rate. High and rapid establishment will enable forage seedlings to overtake weeds and develop an early crop canopy cover, which suppresses weeds and helps conserve soil moisture (Undersander & Lane, 2001). When this occurs, all available growing resources will be used efficiently: and interception of radiation and conversion of light to biomass will be improved significantly, resulting in a better yield. A well fertilised forage crop is needed to ensure that top leaves are healthy for maximum interception of radiation and for a greater accumulation of dry matter content.

2.7.3.3. Diseases, insect pests and weeds

In forage sorghum production, foliar diseases are rare because diseases mainly infest the plants during the later stage of growth. However, Piggot and Farrell (1984) reported both Anthracnose and Red Rot disease outbreak in sorghum *x* sudangrass in New Zealand. These diseases are spread by rain splashed conidia of *Colletotrichum graminicolum* (Pande *et al*., 1994). Yield loss, due to diseases, are prevented or reduced by using resistant varieties, sowing disease free certified seed and by ensuring optimum growing conditions (soil fertility, pH, crop rotation and good sanitation) (Undersander and Lane, 2001).

Leaf disease and insect pest attacks reduce the photosynthetic area of the leaves, such that the quantity of radiation intercepted is reduced. This negatively affects the efficiency of the conversion of radiation into biomass (White *et al*., 1999). Since intercepted solar radiation and yield are positively correlated, then disease and insect pest attacks have a greater possibility of reducing forage yield.

2.7.4. Environmental conditions

Crop production is affected greatly by the environment in which they grow. In order to have higher yields, farmers/agriculturists select a variety or hybrid, which is suitable for their specific environment and they attempt to ensure that a favourable environment is provided; this is because hybrids of the same crop respond differently to the prevailing weather conditions. Environmental factors, which are below optimum for plant growth and development, can be described as stressful (for example, low/high temperature, water deficit, nutrient deficiency, diseases and pests; and low/high solar radiation). Marsalis (2006) pointed out drought, overcast days, frost, low temperatures, shading, herbicide damage, hail and disease, as factors that suppress or disrupt the growth of sorghum leaves. Furthermore, it was also stressed that these factors play an important role in the contribution of increased levels of nitrate and HCN in the plants.

2.7.4.1. Temperature

Temperature is the major climatic determinant of crop growth because, as it increases, sorghum growth rate also increases (Taylor *et al*., 1974). Temperature influences growth and development at all growth stages of sorghum. According to Farrar (1988), temperature changes sink metabolism through a reduction (or increase) in the speed of individual reactions and a change in the rate of active transport across membranes; it also affects enzyme activity and changes the concentration of various enzymes through modifications of gene expression. Therefore, optimum temperature is required, because it allows the metabolic and physiological processes of the plants to occur normally.

Temperate and tropical plant species' metabolic and physiological processes occur at 0 to 35 °C and 10 to 45 °C, respectively. However, their maximum efficiency is at 25 to 30 °C (temperate) and 30 to 35 °C (tropical) (Cherney *et al*., 1988). Tiryaki and Andrews (2001) reported that cold temperatures will cause poor and non-uniform crop stand establishment because sorghum seed germination and seedling establishment is susceptible to cold temperatures.

The base temperature for sorghum is about 8 to 12 °C (Hammer *et al*., 1989), and pearl millet is 10 to 12 °C (Ong & Monteith, 1984). In order to have good crop establishment and rapid seedling growth, at least 16 to 18 °C soil temperature at 10 cm depth is required, because sorghum is vulnerable to cold soils (Gerlach & Cottier, 1974). A range from 25 to 30 °C is considered optimum for growth of sorghum species (Ketterings *et al*., 2007). Ong and Monteith (1984) found that pearl millet forage yield is highest when the temperature is 22 °C.

In New Zealand, sorghum and millet growth requires daily maximum temperatures over 25 °C (Valentine & Kemp, 2007). Temperatures below 15 °C slow down the growth rate of sorghum species (Gerlach & Cottier, 1974).

According to Doggett (1988), temperature stress has an influence on the actual length of the growing season, it also influences morphological development of tillers, when water availability is adequate. Cool temperatures (below 18 °C) during four to six leaf stages promote tillering (Doggett, 1988). However, some cultivars do not tiller, despite being exposed to low temperatures under short days. Higher temperature increases dry matter production and tiller size, but it reduces tiller number, leaf/stem ratio and organic nitrogen concentration in dry matter (Deinum & Dirven, 1975). A temperature rise from 13 to 23 °C increases the rate of leaf formation (leaves/day) of sorghum (Peacock & Wilson, 1984). In addition, Sullivan (1961) found that high temperatures increase nutrient uptake, for example nitrogen and phosphorous.

Peacock (1982) specified that non freezing temperatures (less than 10 to 15 °C) cause chilling injury to sorghum. When this occurs, the injured leaf area of the plant (as a result of chilling) reduces the photosynthetic capacity of sorghum, whilst low temperatures reduce the efficiency of the conversion of photosythate into plant biomass (Peacock & Heinrich, 1984). Furthermore, Ludlow (1980) explained that a ground frost of -2 to -4 °C kills all the foliage of most pasture species grown in the tropics. When this occurs, the amount of available green leaf is drastically reduced and yield is also reduced.

2.7.4.2. Drought

Water deficit (when transpiration is greater than water absorption by roots), is one of the most important environmental stresses that influences growth and development of the plants. Mittler (2006) stated that drought and heat stresses are the most common variety of abiotic stress conditions which occur simultaneously in agricultural fields. The combination of these factors has an adverse effect on the growth and productivity of forage, rather than its quality (Buxton & Fales, 1994).

Sorghum species possess physiological and morphological attributes that allow them to be either resistant or tolerant to moisture stress. For example, the number of secondary roots of sorghum is double the number of that for maize at a given stage of growth. Hence, sorghum is able to absorb water from deep in the soil profile, and therefore, it performs better than maize in drought prone areas (Miller & Stroup, 2004).

In the case of severe drought, maize extracts more of its water from the top soil (0-45 cm) and sorghum from the sub-soil (45-135 cm), whilst pearl millet absorbs water from all layers (0-135 cm) (Singh & Singh, 1995). Therefore, pearl millet is preferred, when water supply is insufficient for maize or sorghum. Due to this factor, pearl millet is considered to be a good performer, even in those areas where maize and sorghum cannot do well (Singh & Singh, 1995).

In addition, sorghum has epicuticular waxes (waxy bloom) deposited over abaxial leaf sheath surfaces, abaxial leaf blades near the ligule, and both emergent and non-emergent culms. Epicaticular wax is associated with plant resistance to drought, since it reduces evapo-transpiration (Sanchez-Diaz *et al*., 1972; Peterson *et al*., 1982). Furthermore, sorghum maintains stomata opening at low levels of leaf water, through osmotic adjustment (Ludlow *et al*., 1990) and it also delays reproductive development in drought conditions (Wright & Smith, 1983).

When sorghum species and pearl millet are grown under erratic rainfall, high yields can be expected, as long as the rainfall is between 450 to 650 mm (Reddy *et al*., 2002). In contrast, Fanous (1967) indicated that pearl millet requires 200 to 800 mm of annual rainfall. Miller & Stroup (2004) reported that sorghum uses approximately 40-50% of the total water requirement of maize, in order to produce the same amount of dry matter. Maize requires up to 770 mm per year of rainfall for good yield and high quality (Al-Kaisi & Yin, 2003). Water requirement for maize is higher than sorghum, due to its early sowing date and longer growing season (Martin *et al*., 1976).

According to Singh and Singh (1995) sorghum has a greater tolerance to water deficit than maize and it has been chosen as the best alternative to maize in drought prone areas. As conditions become unfavourable, sorghum species stop growing, and they only resume growth when conditions are favourable. During this dormant period, metabolic activities are reduced and photo-assimilates are conserved in the plants. When conditions become favourable, sorghum utilise the reserved photo-assimilates and growth is increased (Amaral *et al*., 2003). Due to this attribute, sorghum grown under a drought environment normally yields more than non-drought tolerant crops, such as maize (Staggenborg *et al*., 2008).

2.7.4.3. Sowing date

The sowing date is critical, if the full length of the growing season is to be used. Sowing time has a great influence on development and growth of forage crops, since it determines the interaction between growth and development and periods of stress (Gururanjan, 1993). Early summer sowings are recommended for high yields as livestock can be allowed to graze sudangrass, peal millet and sorghum *x* sudangrass two to three times. This is only possible if the prevailing weather conditions are favourable. Delayed sowing also has a possibility of the plants being injured by early frost or wet autumn weather in either mid-March or early April (Causley, 1990). The sowing time for forage sorghum is determined by soil temperature at sowing, when harvest is expected, and the end use of the crop.

In New Zealand, early sowing of warm season forage crops is a challenge, due to the low temperatures experienced in early summer and result in slow germination and establishment. In addition, sowing early (late October) in the Manawatu is risky, because frost is likely to be experienced before late December (Causley, 1990). Therefore, in order to maximise yield, timely sowing is required to ensure that optimum growing conditions are available. Sorghum requires higher temperatures than maize for maximum germination and early growth. A number of sowing dates are recommended for sorghum and pearl millet in New Zealand; not before November (Brown, 1916), 5 November (Causley, 1990), mid-November (Piggot & Farrell, 1984), around 20 November (Dibble, 1915), November to December (Rhodes, 1977), and late December (Gerlach & Cottier, 1974). All these sowing dates are recommended with the aim of avoiding seedlings being damaged by adverse environmental factors, which could occur in the early and late stages of the growing season, also to maximise yield. Causley (1990) reported that sorghum *x* sudangrass forage (Sudax- cultivar) sown on 5 to 25 November, 3 to 10 December, and 17 to 24 December in New Zealand should be ready for grazing during early, mid and late February, respectively. Mid December is the last date for sowing maize for silage in New Zealand, in order to maximise yield and avoid expected frost in the month of May (McCormick, 1971).

Causley (1990) found that sowing time influenced herbage DM accumulation in sorghum *x* sudangrass. For example, forage sorghum planted on 5 November, 12 November, 19 November, 26 November, 3 December, 10 December, 17 December and 24 December in New Zealand yielded 5,400, 6,000, 4,900, 4,400, 2,400, 1,400, 1,100 and 500 kg DM/ ha as first harvests at flowering. Second harvests yields also at flowering stage, were 13,900, 13,300, 12,200, 11,200, 8,200, 7,400, and 6,000 kg/DM/ha. Piggot & Farrell (1984) reported mean yields from mid and late November sowings of sweet sorghum hybrid, as being 14,600 and 11,400 kg DM/ha, and yields after re-growth were 8,700 and 7,700 kg DM/ha, respectively, harvested at soft dough stage.

The yield data above indicates that the sowing time of forage sorghum has an influence on the final yield. This is because the plants are being subjected to different growing conditions and they retain different abilities to respond to these conditions. In favourable growing environments, the plants will show increased growth and development rates, resulting in higher forage yield. Conversely, under unfavourable conditions, growth rate is reduced and yields are lower.

2.8. Relationship between sowing date and temperature

The sowing date is based on soil temperature at 10 cm depth for good germination, establishment and crop stand so that yield can be maximised. The earlier the optimum soil temperature (16 to 18 °C) is attained, the earlier the potential sowing date will be. Early sowing enhances higher yields and adequate feed during late summer and early autumn, when supplement feeds are generally needed on pastoral farms (Piggot & Farrell, 1984).

2.9. Forage quality

Forage quality is described as the potential of forage to produce the desired animal response. Occasionally, forage quality and forage nutritive value are considered to be synonymous (Collins & Fritz, 2003). According to Collins and Fritz (2003), forage quality comprises nutritive value, anti-quality factors (alkaloids, glycosides, toxic amino acids and phenolic compounds) and potential intake, whilst forage nutritive value describes nutrient concentrations, digestibility and by products of digestion. In contrast, Waghorn *et al*. (2007) described nutritive value as a measure of a diet's ability to meet animal requirements for production and maintenance. Since all nutritive value components are part of the forage quality, then 'forage quality' and 'nutritive values' words can be used interchangeably. Feed quality (digestibility, metabolisable energy, neutral detergent fibre, acid detergent fibre and crude protein) of specific forage is influenced by amounts and types of compounds in the forage (Moot *et al*., 2007). Therefore, the level and balance of nutrients in the feed reflect the feeding value to the animals.

Collins and Fritz (2003) divided forage into two primary components; cell contents (organic acids, proteins, lipids, starch and sugars) and cell walls (structural carbohydrates e.g. cellulose and hemicelluloses, lignin, other phenolics, cutin and silica). Cell contents are the most readily and highly digestible (90-100%) by ruminants and non-ruminant herbivores, whilst cell walls are the fibrous fraction of forage that is not easily digested. According to Litherland and Lambert (2007), the ratio between cell contents and cell wall will influence the digestion dynamics. Therefore, animal productivity on a forage diet is determined by the amount of intake, digestibility, and digestion rates of cell wall components (hemicelluloses, cellulose, lignin, silica, pectin and cutin).

Forage species and cultivars differ in fibre concentrations, vulnerability of fibre to microbial digestion, crude protein concentrations, and soluble sugar and starch concentration. Due to this factor, the maintenance of forage quality at a level that will ensure desirable levels of gain or milk production is the primary goal in forage management by livestock farmers.

The most important components that determine the suitability of forage feed are crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF), metabolisable energy (ME) and soluble sugars and starch (SSS).

The crude protein quantity in plants is influenced by the type of species grown, management practices, and maturity at harvest (Humphreys, 2005). When the sorghum plants are young and growing rapidly, crude protein content may be 20%, but as they increase in height, and near maturity, this declines to 7% or less (Leep, 2005). According to Valentine and Kemp (2007), maize (a commonly used summer cereal) has a crude protein content of only 7% which is below the requirement of 19% for milking cows, or growing cattle and other ruminants. Therefore, if the feed given to animals has low protein content, then a protein-rich supplement such as Lucerne is needed.

Acid detergent fibre (ADF) predicts forage digestibility (Barne & Marten, 1979). The lower the lignin content, the more ADF fraction is digestible, and the higher the energy value of the forage (Bean *et al*., 2009; Fulgueira *et al*., 2007). Neutral detergent fibre (NDF) indicates the cell wall contents of forage, and hence, this determines the rate of digestion. Feed that is highly digestible encourages high feed intake because the faster the digestion rate, the more quickly the digestive track will be emptied, and the more space made available for the next meal. The higher the NDF digestibility, the higher the energy supplied is.

In New Zealand, metabolisable energy is used as the standard for expressing feeding value (Waghorn *et al*., 2007). Therefore, animals that are fed poor forage will have low and poor utilisation of available energy for maintenance, production, and growth. The amount of gross energy in the forage crop is dependent on the composition of the cell wall in forage plants and the efficiency of digestion of the fibre part by the micro-organisms in rumen. The higher the proportion of total dry matter digested the more energy (Barriere *et al*., 2003; Collins & Fritz, 2003). Forage of higher digestibility will provide more energy for livestock per unit of DM consumed, than less digestible forage (Cerosaletti *et al*., 2002). Soluble sugars consist of a variety of non-structural carbohydrates, water soluble sugars (fructan), or organic acids.

2.9.1. Cyanide poisoning

Forage sorghums have the potential to release hydrogen cyanide (HCN) or prussic acid when consumed by animals because sorghum contains the cyanogenic compound dhurrin [(s)-p-hydroxymandelonitrate β-D-glucopyranoside] (Fjell *et al*., 1991). Dhurrin is a natural secondary compound found in vacuoles of the epidermal cells of sorghum leaves. This natural secondary compound offers a defense mechanism against herbivores (Wheeler *et al*., 1990; Busk & Moller, 2002). Dhurrin is the precursor of hydrocyanic acid, an anti-nutritional factor found in plants (Zagrobelny *et al*., 2008).

Sorghum synthesises cyanogenic glucoside dhurrin (β-D-glucopyranosyl-oxy-(s)-p-hydroxymandelonitrite) from L-tyrosine (Halkier & Moller, 1989). The biosynthesis of dhurrin in older plants is slower than catabolic turnover; hence, older plants will have a lower accumulation of dhurrin than young plants (Zagrobelny *et al*., 2008). The enzyme (beta-glucosidase) responsible for the hydrolysis of Dhurrin is found in mesophyll cells (Wheeler, *et al*., 1990). When leaf tissues are intact dhurrin is non-toxic, but any damage (by wilting, chewing, crushing, cutting and trampling) to the leaf tissues allows the mixing of dhurrin and the enzyme, which results in the release of hydrogen cyanide (HCN). If the cyanide concentration is sufficiently high, poisoning of the stock feeding on the forage can occur (Fjell *et al*., 1991).

The type of sorghum or the cultivar, the stage of growth, and the prevailing environments influence the amount of HCN in forage sorghum (Gerlach & Cottier, 1974). Temperature, genotype, age, nitrogen and phosphorus nutrition, wilting and light intensity are the primary factors that affect HCN potential (HCN-p). The level of HCN which is considered safe varies. For example, Fjell *et al*. (1991) reported ranges of 0 to 600 mg/kg and 600 to 1000 mg/kg of HCN levels, as being considered safe and potentially toxic, respectively. In contrast Vogel *et al*. (1987) reported a concentration of 0 to 500 mg/kg, 500 to 750 mg/kg and greater than 750 mg/kg as being safe, with doubtful toxicity and very poisonous, respectively. Takamitsu (1973) specified approximately 2.042 mg per kg for cattle (about 1 g of HCN for a cow of 500 kg) as a dose that would kill animals. The concentration of prussic acid which is toxic will depend on the conditions of the animal, the other feeds given to the animal, and the degree of hunger of the animal. Toxicity is at maximum, when the growth sorghum is negatively affected by drought, frost or trampling, or when damage is inflicted on the plants by insects (caterpillars and grasshoppers) and diseases (Bertram *et al*., 2005).

The stage of harvesting also has an impact on the concentration of anti-nutrition factors, for example; cyanogenic glucoside. The amount of cyanogenic glucoside dhurrin that accumulates in different plant tissues (leaves, seedlings, roots and seeds) of sorghum depends on the particular species and the age of the crop (Gorz *et al*., 1977; Halkier & Moller, 1989). For example, shoots of sorghum seedlings contain 30% of dhurrin on a dry-weight basis (Halkier & Moller, 1989). The concentration of dhurrin is greater in sorghum leaves at the seedling stage than at maturity (Vogel, *et al*., 1987; Takamitsu, 1973). The amount of dhurrin in the plant reduces with increasing plant size (Gorz *et al*., 1977). In re-growths after cutting/grazing, the HCN concentration is also very high in young leaves and in tillers, but it is decreased in the stem, leaf blade and sheath as sorghum height increases (Takamitsu, 1973).

The method of harvesting forage sorghum influences cyanide poisoning, mainly the harvesting procedures and growth stage of the crop. Forage sorghum hay has more potential to cause HCN poisoning than when grazed at the correct height, since animals eat large quantities of the hay more quickly than fresh sorghum. However, for ensiled sorghum, HCN-p is low because HCN is released as gas during fermentation (Wheeler, *et al.,* 1990). In addition, the ensilage of sorghum reduces nitrate accumulation in the feed by 40 to 60% (Fjell *et al.,* 1991).

2.9.2. Nitrate poisoning

Nitrate levels in sorghum are expressed as either nitrate ion (NO_3^-) or nitrate nitrogen (NO_3-N) (Adams *et al*., nd). Harms & Tucker (1773) reported that when nitrate is absorbed by the plants from the soil, it is converted into hydrocyanic glycosides (HG), which are the intermediate constituent between nitrate and amino acids. Under favourable conditions for protein synthesis, HG does not accumulate in the plant. However, under unfavourable environmental and nutritional conditions to enhance protein synthesis, HG will accumulate in the plants (Harms & Tucker, 1973). This high concentration of HG results in nitrate poisoning in ruminants.

Bertram, *et al*. (2005) reported that unfavourable conditions, such as drought, cold weather, cloudy weather, or stress by insect damage or herbicide application affecting the growing parts of the plant, can all have a significant effect on the nitrate content of the plants. These factors affect enzyme activity in the plant, and as a result the conversion of nitrate to protein is interrupted (Fjell *et al*., 1991). If the plant parts are unable to transform the accumulated nitrate into protein due to stress, then nitrate is accumulated.

The concentration of NO_3^- in forage (dry matter basis) from 0 to 600 mg/kg is considered virtually safe, 600 to 1300 mg/kg, moderately safe in most cases, 1300 to 2000 mg/kg, potentially toxic and greater than 2000 mg/kg, dangerous (Gillingham *et al*., 1969). A concentration of approximately 2000 mg/kg of NO3-N in sorghum is considered to be sufficient to cause nitrate poisoning in ruminants (Sunaga *et al*., 2005). The risk of a high accumulation of nitrate means that applications of excess amounts of nitrogen fertiliser to forage sorghum, should be avoided (Sunaga *et al*., 2008).

High accumulation of NO_3-N has been reported where excessive fertilisation of forage sorghums by either manure or chemical fertilizers have been used (Sunaga *et al*., 2005). This has been attributed to the high accumulation of the available nitrate. The increase in HCN-p due to N application was attributed to the particular type of protein synthesis in sweet sorghum (Harms & Tucker, 1973). In order to ensure a low potential of cyanide and nitrate poisoning in forage sorghum, it is important to monitor the rate and frequencies of N applications very closely because high application of N, increases *Cyanogenic glycoside* synthesis (Gillingham *et al*., 1969).

2.10. Summary

Different researchers have documented different concentrations of sorghum, pearl millet and maize components (Table 2.1).

Table 2.1: Means of crude protein, acid detergent fibre, neutral detergent fibre, metabolisable energy and soluble sugars and starch of different forage crops (sorghum, pearl millet and maize) reported by different researchers.

Forage type	Stage at harvest	CP (%)	ADF (%)	NDF (%)	ME (MJ/kg DM)	SSS (%)	Source
Sorghum	Vegetative	15.8	31.0-36.0	61.0 -63.0	.	.	Bosley *et al*, (2005)
Pearl millet	vegetative	20.9	30.7	50.1	9.4	.	Fulkerson *et al*, (2008)
Maize silage	Milk line	5.4 - 8.2	18.2 -29.5	30.8 – 51.0	10.3 - 12.4	35.0-40.0	de-Ruiter *et al*, (2007)
Maize silage	Milk line	8.2	32.6	54.9	9.7	.	Fulkerson *et al*, (2008)

2.11. Factors affecting forage quality

Maturity stage, genotype and harvesting conditions are the primary factors that affect forage quality. Temperature and soil moisture during the growing season, soil fertility, and type of cultivar are considered as secondary factors. Management practices or climatic conditions determine the total quantity of leaves of forage crop, and they also influence final quality of the crop (Collins & Fritz, 2003; Nelson & Moser, 1994).

All these factors affect forage quality because they influence the anatomy and morphology of the forage plants (Collins & Fritz, 2003). Van Soest *et al*. (1978) and Snaydon (1972) pointed out that factors which reduce plant development are known to maintain forage quality. Snaydon (1972) commented further that it is the distribution and conversion of photosynthetic products and absorbed soil nutrients which determine the composition of forage at harvest.

The factors that influence forage quality are as follows:

2.11.1. Maturity at harvest

Maturity of forage at harvest is the fundamental factor that affects forage quality, because it plays an important role in determining the fibre content of the crop that has been harvested. As the forage crop develops, the chemical composition is modified, hence, its fundamental impact on forage quality (Buxton & Fales, 1994). With age, digestibility and crude protein content decline drastically, whilst neutral detergent fibre (NDF) and acid detergent fibre (ADF) contents increase steadily (Humphreys, 2005; Nelson & Moser, 1994; Rachie & Majmudar, 1980; Reid *et al*., 1964; Worker & Marble, 1968), and fat and ash contents reduce (Worker & Marble, 1968). The leaf/stem ratio also decreases with age (Taylor et *al*., 1974). In contrast, the total sugar percentage increases with delay in harvest (Worker & Marble, 1968). The quantity of lignin also increases with age, in order to enable the plants to support their weight (McDonald *et al*., 1995). However, as discussed earlier, digestibility is reduced and hence metabolisable energy is also reduced. The reduction of nutritive value with age is a central management consideration in forage production (Humphreys, 2005).

The relative proportion of the plant parts change as the plant ages with mature plants having older tissues, more dead material and possibly a high proportion of stem material, all of which reduce digestibility (Valentine & Kemp, 2007). For these reasons, forage sorghum is recommended to be harvested while vegetative (Black *et al*., 1980; Caravetta *et al*., 1990b), because the reproductive process (flowering) results in a decrease in the leaf/stem ratio and hence a lower forage quality (de-Ruiter *et al*., 2007). In sorghum hybrids, the shift from vegetative to reproductive growth is fast and hence there is a rapid reduction in forage quality (Bean *et al.,* 2009). However, if the forage crop is harvested after grain formation, the highly digestible grain may partly offset the reduction in leaf/stem ratio and stem quality (Nelson & Moser, 1994).

Snyman and Joubert (1996) reported means of in vitro dry matter digestibility (IVDMD) and crude protein of sorghum harvested at the pipe (just before heading stage), bloom (flowering stage) and ripe stages (at the physiological maturity stage and after maximum total dry weight has been achieved) as 67.4% and 14.5%; 61% and 9.4%, 58% and 8.4%, respectively. At the booting stage, sorghum was highly digestible, and had higher crude protein concentration than at flowering and ripe stages. However, there was no significant difference between bloom and ripe stages, in terms of crude protein. A range of 7.07 to 9.01% of crude protein of sorghum harvested at the soft dough stage was reported by Yosef *et al*, (2009). Cerosaletti *et al,* (2002) found that BMR sorghum *x* sudangrass cut at 86, 117, 150 and 175 cm had NDF content of 51.6, 55.5, 57.7 and 58%; and crude protein was 18.3, 13.5, 10.5 and 7.9%, respectively. There was no significant difference in NDF at 117, 150 and 175 cm, but NDF at 86 cm was significantly lower than others. The crude protein concentrations were significantly different from each other.

Wedin (1970), in a study to evaluate yield and chemical composition using four cutting regimes of; five cuts consecutively at 46cm, three cuts at 92cm, two cuts at 137cm and one cut at the hard dough stage, concluded that there were significant differences in dry matter yields (1,950, 6,290, 7,750 and 13,460 kg DM/ha) and crude protein (18.4%, 15.2%, 11.6% and 5.8%), respectively. As the number of the harvests increased, IVDDM reduced in order, from 70.1 to 67.7 to 65.4, and finally to 57.0%. Farhoomand and Wedin (1968) found that as the proportion of leaves decreased, the crude protein of leaves and stems reduced from 28.1 to 16% and from 12.6 to 6.1%.

2.11.2. Plant species and genotype/variety

The forage quality of different species or cultivars of the same species may vary significantly. This is attributed to differences in anatomy, morphology and chemical compositions. Leafier genotypes have significant digestibility (Reddy *et al.*, 2002). Genotypes with larger leaves may have low digestibility due to greater photosynthetic efficiency, whilst greater photosynthetic efficiency leads to more sunlight being converted into forage yield. The greater the rate of dry matter accumulation, the higher the lignifications of the tissues, and the lower the digestibility (Buxton & Fales, 1994). Hence, leaf anatomy contributes greatly to the quality of forage.

Collins and Fritz (2003) commented that cool grasses are 13% higher in digestibility and their crude protein is higher than in warm season grasses. Warm season C_4 grasses have a low digestibility due to higher concentration of structural polysaccharides (cellulose and hemicelluloses) (Buxton & Fales, 1994). As temperature increases, C_4 grasses grow well, thus producing more vascular tissue (Ford *et al.*, 1979). Wilson and Minson (1980) reported an average reduction of 0.6 units of dry matter digestibility of C_4 grasses, for each 1°C rise in growth temperature.

McDonald *et al.* (1995) explained that tropical grasses have greater vascular bundles and thicker walled bundle sheaths and hence they have a high concentration of lignin. In addition, their mesophyll cells are more densely crowded than in temperate grasses. Furthermore, intercellular air spaces, in tropical and temperate grasses are 3 to 12% and 10 to 35% of leaf volume, respectively. As a result tropical grasses have a higher tensile strength than temperate grasses, thus making them slower to degrade mechanically and microbially, also their voluntary dry matter intake is reduced.

Generally, crude protein reduces as plants mature. Crude protein reduction is faster in sudangrass than in sweet sorghum because sudangrass makes a rapid recovery after grazing/cutting (Farhoomand & Wedin, 1968). As a result, the available N in the soil is utilised quickly and therefore there will be less available to maintain the crude protein content in the re-growths. Higher yielding cultivars have excellent nitrogen uptake ability, assimilation and efficiency of nitrogen utilisation (Moyer *et al.*, 2004), they also have lowest digestibility compared to low yielding cultivars (Kalton, 1988). The highest soluble sugars (13.8%) were obtained in tall forage types.

Oliver *et al.* (2004) found that the amount of lignin in maize is less than in sorghum hybrids and hence it is more easily digested than sorghum, but BMR forage sorghum hybrids have less lignin than maize and conventional sorghum. Reich (2008) found that BMR varieties produce less lignin compared to other types of sorghum. Pearl millet has low hydrocyanic acid content, thus giving it an advantage over sorghum *x* sudangrass, and hence, Sotomayor-Ríos and Pitman (2000) suggested that pearl millet has no HCN-p. An additional advantage of pearl millet is that it is rich in protein, calcium, phosphorous and minerals (Rachie & Majmudar, 1980). Most sudangrasses used as forage also have low HCN-p compared to either grain or sweet sorghum varieties (Gorz *et al.*, 1977). Undersander and Lane (2001) suggested that the HCN-p of sorghum *x* sudangrass hybrids is intermediate between sorghum and Sudangrass.

Sunaga *et al.* (2005) reported that different varieties of sweet sorghum will have different concentrations of NO_3-N, depending on the ability of the genotype to accumulate nitrate. Sorghum stems and conductive tissues accumulate more nitrates with more accumulation in the lower one-third of the plant stem (Harms & Tucker, 1973). The concentration is lower in the leaves than stems because the enzyme responsible for the conversion of nitrate to amino acids (nitrate reductase) is found in leaves (Harms & Tucker, 1973).

2.11.3. Management practices

Management practices contribute greatly to the determination of forage quality. Chemical, morphology or physiology changes in a plant occur after an application of fertiliser because the plants respond to the amount of nutrients available by either reducing/increasing their growth or decreasing/increasing the nutrient contents in their tissues, or both (Buxton & Fales, 1994; Sullivan & Graber, 1947). The application of nitrogen (N) fertiliser increases N concentration in plant tissues and water concentration (Noller & Rhykerd, 1974). This results in increased crude protein level because the nitrogen absorbed is used in the synthesis of protein when nitrate (NO_3) is reduced to ammonium (NH_4) before incorporation into amino acids (Buxton & Fales, 1994). In addition, other nutrients such as phosphorous, chlorine, magnesium, and potassium of both leaf and stem are increased as their uptakes are improved.

2.11.4. Environmental conditions

The environment in which forage crops are grown influences the forage quality. This causes yearly, seasonal and geographical differences in forage quality (Buxton, 1996). Environmental conditions affect quality by changing the leaf/stem ratio. In addition, environmental stresses affect senescence rates and the quality of dead plant material. The morphological development of the growing forage crop is partly controlled by the environmental conditions and hence, this determines the quantity and quality of each part of the plant (Buxton & Fales, 1994).

Stem growth is greater than leaf growth when the temperature is high. In addition, NDF and ADF concentrations are increased by high temperatures (Buxton & Fales, 1994; Fulgueira *et al*., 2007; Nelson & Moser, 1994), whereas non-structural carbohydrates concentrations (soluble sugar concentration) are lowered (Buxton & Fales, 1994; Ford *et al*., 1979; Wilson *et al*., 1991). Furthermore, Wilson *et al.* (1991) suggested that temperature variation changes digestion of cell walls by changing cell thickness. A thick cell wall is likely to be digested more slowly than a thin cell wall. Cell walls deposited when temperatures are low contain less lignin, and therefore higher digestibility is achieved because storage carbohydrates (total non-structural carbohydrates) accumulate in the leaf tissue (Ford *et al*., 1979). In addition, high temperatures reduce leaf/stem ratio (Lascano *et al*., 2001). Due to these changes, the digestibility of the forage decreases.

Plants grown in hot and dry environments will have thick cell walls, thick cuticles and their tissues will be highly lignified (Levitt, 1980). In case of severe drought, leaf growth is restricted and more senescent material can be observed (Humphreys, 2005). These factors cause loss of forage quality, since the material become less digestible and less palatable to the livestock. Mild water stress improves the forage quality of a crop compared to a crop grown under normal water conditions because the leaf/stem ratio and digestibility of both leaf and stem components are increased (Wilson & Ng, 1975).

2.12. Summary

The New Zealand economy is heavily dependent on agriculture, and its livestock sector contributes greatly to export earnings which drive the economy. The provision of sufficient and high quality feed improve and maintain the profitability of the livestock sector. A mixture of grazed pastures, pasture silage, cereal silage and other supplements are used as feed in New Zealand. However, the growth of these crops is seasonal and this can result in some disturbances in the feed supply system. During late summer and early autumn, many regions may experience drought. Hence, there is a shortage of feed in these areas as the production of non-drought tolerant crops, such as maize and wheat, are significantly affected by low moisture. Therefore, supplements are required to reduce the gap between feed demand and the supply of feed, in order that milk production in dairy cows, growth rates in beef stock and cash flow can all be improved and maintained.

Sorghum, sudangrass and pearl millet have a greater potential to be grown in the warm-zone areas of New Zealand, and being used extensively as supplements in late summer and early autumn because they; are drought tolerant, have high yield potential, good water use efficiency, good recovery growth after grazing/cutting, and they are less likely to be attacked by pests and diseases. With the incorporation of the BMR gene in these crops, they have the potential to compete favourably with maize in terms of nutritive values and yield.

Currently, in New Zealand, there is little recently published information on the performance of sorghum, sudangrass and pearl millet. The only available information was gathered during the 1960s, 1970s and 1980s. From the late 1980s, to the present time, no research has been conducted because research workers lost interest in sorghum, sudangrass and pearl millet due to the lack of cold tolerant cultivars, low digestibility and rapid decline in feeding value, and also the fear of sorghum's potential to cause cyanide poisoning in livestock.

CHAPTER 3 : MATERIALS AND METHODS

3.1. Experiment One

This experiment was conducted in order to compare the effect of the sowing date on forage yield, crop morphology and nutritive values of sorghum and sudangrass hybrids and a pearl millet cultivar. The parameters measured were: dry matter yield (DM), growth rate, yield per tiller, plant height (PH), increase in plant height per day, increase in plant height per unit of thermal time, tillers density, and nutritive values, including; crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF), metabolisable energy (ME), and soluble sugars & starch (SSS). In this study, two cutting regimes (1^{st} cut and 2^{nd} cut) were conducted for cultivars except for maize and Sugargraze.

3.1.1. Experimental site & environment

The trial work was conducted on the Pasture and Crop Research Unit (PCRU), Massey University, Palmerston North (40^{o} 22'56.29 S; 175^{o} 36'26.20 E). The soil type on the PCRU is a Manawatu sandy loam, a recent soil from alluvium, proximate to the Manawatu River. Previously, the paddock had been in ryegrass/white clover pasture for four years. Before sowing, four random soil samples were collected at 0-15 cm, and then mixed to obtain a composite sample which was sent to Hill Laboratories, Hamilton, to determine the nutrient status of the soil (Table 3.1). Potassium, calcium, magnesium and sodium were determined by 1M neutral ammonium acetate extraction followed by the Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) method (Hill laboratories). Total soil nitrogen (N) content and potentially mineralisable N were determined by the Kjeldah procedure and an anaerobic (waterlogged) incubation method, with a seven day incubation at 40 °C, extraction in 2M KCl, and measured by technicon (Tarrytown, NY) Auto Andyer (Sparling & Schipper, 2002). For phosphorous, an Olsen test method was used. This revealed adequate phosphate and potassium for the forage crops and consequently only N fertiliser (100 kg N/ha) was applied after crop emergence. Prior to cultivation, glyphosate herbicide was sprayed at 3 l/ha, in order to kill existing vegetation. Hand weeding and push hoes were used to control weeds that emerged during the growing period. No other pesticides were used. The field was cultivated to ensure desirable seed bed preparation.

Table 3.1: Chemical characteristics of soil at the trial site, 0-15cm.

Nutrient	Amount (mg/kg)
Nitrogen	76.8
Phosphorous	36.0
Potassium	86.0
Calcium	1380.0
Magnesium	146.4
Sodium	27.6

3.1.2. Plant materials

One sweet sorghum, four sorghum *x* sudangrass hybrids, two sudangrass and one pearl millet cultivars were evaluated. One maize hybrid was included in the trial for comparative purposes. Cultivar descriptions are outlined in Table 3.2:

Table 3.2 : Cultivars used in the experiment.

Cultivar	Species	Pedigree
Sugargraze	Sweet sorghum	sweet sorghum *x* sweet sorghum
Bettagraze	Sorghum *x* sudangrass	sorghum *x* sudangrass
Pacific BMR	Sorghum *x* sudangrass	BMR sorghum *x* sudangrass
Pac 8421	Sorghum *x* sudangrass	BMR sorghum *x* sudangrass
Pac 8423	Sorghum *x* sudangrass	BMR sorghum *x* sudangrass
Superdan 2	Sudangrass	sudangrass x sudangrass
Sprint	Sudangrass	sudangrass x sudangrass
Nutrifeed	Pearl millet	*Pennisetum* sp
39G12	*Zea mays*	Maize hybrid

*BMR: Brown midrib

These cultivars were selected for evaluation because they are sold on the New Zealand market and are commonly grown by farmers, except Pac 8421 and Pac 8423, which are experimental hybrids most likely to be released as new cultivars, in the near future.

3.1.2.1. Sugargraze

Sugargraze is a late flowering cultivar with a high sugar content that improves its feed quality and increases its palatability resulting in minimal feed wastage (Pacificseed, 2009). In addition, it has very high dry matter production and desirable resistance against a wide range of diseases. This cultivar is recommended for silage production because the coarse stems do not wilt easily for hay production.

3.1.2.2. Bettagraze

Bettagraze is a late maturing hybrid grown as pasture because it has rapid early growth and quick recovery after grazing/cutting, high sugar content, high leaf/stem ratio and high yielding potential. Hence, it is an excellent summer feed for dairy, beef and sheep. In addition, it is used for silage production (Pioneer, 2008).

3.1.2.3. Pacific BMR

Pacific BMR is a brown mid-rib cultivar with high digestibility (60-65%) due to its lower lignin content, it has greater than 20% crude protein and it is a first choice for milk solid production by farmers. It is mainly used as pasture and hay (Pacificseed, 2009).

3.1.2.4. Superdan 2

Superdan 2 is a sudangrass with rapid regrowth. It is thin stemmed, tolerant to heavy grazing and has high yield potential. Generally, it is used for pasture, hay and making round bale silage (Pacificseed, 2009).

3.1.2.5. Sprint

Sprint is a quick flowering cultivar with high protein content, very high dry matter production, high tillering ability, fast growth and regrowth; it has thin stems and good cold soil emergence. It is used for intensive grazing and hay making (Pacificseed, 2009).

3.1.2.6. Nutrifeed

Nutrifeed is a pearl millet, rich in protein content and energy content and it has no potential for cyanide poisoning. It makes an excellent pasture for livestock, especially when grazed at the correct height (Pacificseed, 2009).

3.1.2.7. 39G12

Zea mays CV 39G12 is a dual purpose maize hybrid with high yield potential and drought tolerance, it also shows early growth (Pioneer, 2010)

3.1.2.8. Pac 8421

This is a BMR cultivar with a BMR gene that improves digestibility and reduces the lignin synthesis in forage sorghum.

3.1.2.9. Pac 8423

This is also a BMR cultivar with higher digestibility and low fibre content.

3.1.3. Field experiment layout

Treatments (cultivars) were arranged in a completely randomised block design, with four replicates, with each block representing a replicate. The trial was sown on 8 December and again on 21 December 2009 (re-randomised) at the same site after soil temperature had reached 16 to 18°C. Maize was only planted in the early sowing date trial because the second sowing was considered too late for maize. All plots, apart from maize were sown with a cone seeder (15 cm row spacing) as recommended (Causley, 1990; Chu & Tillman, 1976) for forage crops in New Zealand. Plots were 10 m long and 1.5 m wide. Sowing rates of 20 and 15 kg/ha (Causley, 1990; Gerlach & Cottier, 1974) were used, in order to target 90 to 110 and 90 to 120 plants/m^2 for sorghum and pearl millet, respectively (Pacificseed, 2009). The maize plots consisted of four rows spaced at 75 cm. Maize was sown by hand at 110,000 plants/ha.

3.1.4. Field measurements

Meteorological data was collected from an Ag-Research Grasslands weather station located 300 m from the trial site. After crop establishment, a seed establishment count was conducted along a 100 cm length of a randomly selected row. Four rows were selected for each plot. The results were expressed in plants/m^2. Field emergence was calculated by dividing seedling emergence by seeds planted/m^2. Seedlings were considered emerged when coleoptiles were visible above the soil (Brar & Stewart, 1994).

Plant height (PH), leaf/stem ratio, tiller density, dry matter yield (DM), growth rate, individual plant yield, increase in plant height per day and increase in plant height per unit thermal time were also determined. Tillers/m^2 counts were conducted in each plot immediately after each harvest (Casler & Boe, 2003). Four 100 cm length of row within each plot were randomly selected for yield and quality determinations. The weight per tiller was calculated by dividing dry matter by population density. Plant height was measured weekly as the height between the horizontal curve of the tallest leaf and the soil surface (Ketterings *et al.*, 2007) (Plate 3.3). However, plant height measurements for the initial and re-growth of the first sowing started late on day 46 and continued to day 57, when plants were approximately 100 cm and from day 20 to day 46, respectively, instead of from the day of emergence to the harvest stage. For the initial and re-growth of second sowing it was from day 33 to day 58 and from day 22 to 37. The reason for the delay was that a conclusion had not been reached about how plant height was required to be measured.

Four 0.15 m^2 quadrants per plot were sampled for yield determination. The two outer rows of each plot were not sampled. The 1st and 2nd cuts of the first and second sowings were undertaken on 2 February (58 days after sowing) and 22 March (46 days after cutting), and 16 February (57 days after sowing) and 26 March, 2010 (37 days after cutting), respectively, for all cultivars except Sugargraze. The 1st cuts for Sugargraze of the first and second sowings were, on 23 February (78 days after sowing), and 3 March, 2010 (73 days after sowing), respectively. Maize was harvested on 20 April 2010 (134 days after sowing) at approximately 30 to 35% whole crop dry matter (DM). The first cuttings of both sowings and the second cutting of the first sowing were undertaken at approximately 100 cm plant height, except for Sugargraze at 150 cm in accordance with recommended management for each cultivar (Cottier, 1973; Pacificseed, 2009; Taylor, 1977). The second cutting of the second sowing was undertaken at approximately 50 cm due to frosting. Sugargraze plots were harvested only once, as a result of low temperatures that caused poor re-growth.

After the first harvest, the plots were immediately trimmed (simulating grazing), using a sickle-bar cutter to 15 cm residual height above ground level, this was to ensure that sufficient assimilates or reserves remained in the stump of cut plants to support the re-growth (Stephenson & Posler, 1984) (Plates 3.4 and 3.5). However, after sampling the second cuts of both sowings for yield determination, the remaining plants in each plot were not trimmed so that 50% of the ear emergence (heading) could be scored (Pedersen & Toy, 1997). Ear emergence measurement ceased when frosting adversely affected the trial.

The thermal time (TT) of sorghum and pearl millet was calculated using the following formula, which involved daily maximum and minimum temperatures and a base temperature of 10 °C (Maiti & Soto, 1990). This base temperature was chosen because it is the temperature at (or below) which there is no sorghum and pearl millet plant development (Maiti & Soto, 1990). TT was determined from seed emergence (starting date of phenophase) to each day when plant height was measured: and from cutting (Starting date of phenophase) to each day when plant height was measured for the initial growth and re-growth, respectively until harvesting plant height (ending date of phenophase). Thereafter, the required TT for sorghum and pearl millet to reach 50 cm and 100 cm plant heights, were predicted using plant height and TT data.

$$TT = \sum_{a}^{b} \left\{ \left[\frac{T_{max} + T_{min}}{2} \right] - T_b \right\}$$

Where:

TT = Thermal Time (°C day)

T_{max}/T_{min} = Daily maximum/minimum temperature (°C)

T_b = Base temperature(i.e. 10 °C)

a = Starting date of phenophase

b = Ending date of phenophase

3.1.5. Laboratory procedures

The yield and forage quality determinations of all cultivars, were carried out as indicated below:

3.1.5.1. Yield determination

Immediately after harvest, the fresh weight of each cultivar was determined. After weighing, ten tillers were randomly sampled from the harvested material from each plot to determine the DM %, then they were dissected into leaf and stem components, to allow calculation of the yield of each component and the leaf/stem ratio. For maize, three plants were collected for the calculation of DM %. The separated samples were dried in a forced air oven at 70 °C for 72 hours or until no further weight loss was recorded (maize) (Wheeler *et al*., 1980).

Using the dry matter percentage, the initial and re-growth yields per hectare for each cultivar were calculated. The cumulative yield, which is the summation of two individual cuttings of each treatment for each sowing, was also determined. Growth rate (kg DM/ha/day) and the increase in plant height per day were determined by dividing DM and the final plant height by the number of days from sowing or trimming to each harvest, respectively (Assaeed, 1994). Dry weight per tiller was calculated by dividing DM with plant population (Nuwanyakpa *et al*., 1979).

3.1.5.2. Forage quality

All sorghum, sudangrass and pearl millet samples for the initial harvest of the first sowing date used for dry matter determination were ground using a cyclone mill and then passed through a 1.0 mm screen (Ketterings *et al*., 2007; Marsalis *et al*., 2010), 27g of each sample was sent to the Animal Nutrition Laboratory, Institute of Food Nutrition and Human Health, Massey University for quality analysis. Biomass from the 2^{nd} cut of the first sowing and the 1^{st} and 2^{nd} cuts of the second sowing were not analysed for quality due to financial constraints. Crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), metabolisable energy (ME) and soluble sugars and starch (SSS) were measured. These nutritive values were estimated by near infrared reflectance (NIR) spectrometry (Collins & Fritz, 2003; Ketterings *et al*., 2005; Kilcer *et al*., 2005; Marsalis *et al*., 2010).

The NIR was calibrated by the manufacturer for each component by scanning finely ground pasture samples in a range from 400 nm to 2500 nm. When calibrating, wet chemistry methods, such as the Association of Official Analytical (AOAC) 968.06 on a LECO FP-2000 combustion analyser (LECO Corporation, St Joseph, Michigan, USA), were used to analyse samples. To determine determining crude protein, an enzymatic gravimetric method was used, using tecator fibertec system (Foss Tecator Sweden) for ADF and NDF, sulphuric acid phenol, and AOAC 996.11 and amylase method for soluble sugar and starch by the methods of Van Soest *et al*. (1991). Metabolisable energy (ME) was calibrated by calculating from predicted dry matter digestibility (DMD) values (Clarke *et al*., 1982). The resulting NIR calibrations against the wet chemistry results for each component typically had a correlation of 0.90.

3.1.6. Analysis of data

The Proc GLM procedure of SAS (SAS Inc, Cary, North Carolina, 2002-2008) was used to analyse all variables. The least significant differences (LSD) were used in order to separate means at P = 0.05. Proc CORR was used to explore the relationship between yield, other agronomic characteristics (plant height, tiller density and leaf/stem ratio), and forage quality. Linear regression was used to determine the relationships among crude protein, metabolisable energy, yield, and plant height.

Data from each sowing date was analysed separately due to differences in the number of treatments. It was then combined and analysed in order to evaluate the differences among cultivars and between sowing dates. The combined analysis of the 1st cut and total dry matter (TDM) data included all sorghum, sudangrass and pearl millet cultivars, but the 2nd cut data did not include Sugargraze, because of its late poor recovery growth. In addition, maize was not included in the combined analysis because it was excluded in the second sowing, since this time was considered too late for sowing maize. Interactions were tested for significance ($P<0.05$) for both sowing dates and cultivars.

In this study, the model used for the combined analysis was as below:

$$Y_{ijkl} = \mu + A_i + B_j + C_k (B_j) + A_i \times B_j + E_{ijkl}$$

Where,

Y_{ijkl} = l^{th} observations in the i^{th} treatment group (cultivar), j^{th} group (date), k^{th} treatment (block) nested in j^{th} treatment (date) and i^{th} (treatment) interaction with j^{th} treatment (date).

μ = general mean

A_i = cultivar effects

B_j = sowing date effects

$C_k (B_j)$ = block effects nested in sowing date

$A_i \times B_j$ = cultivar by sowing date

E_{ijkl} = random residual error

i = 1 to 8

j = 1 to 2

k= 1 to 4

Plate 3.1: Tillering stage of first sowing whilst second sowing (behind) is becoming established (Photograph: 7 January, 2010).

Plate 3.2: Established plants showing the almost closed canopy of different cultivars (Photograph: 11 February, 2010).

Plate 3.3: Measuring plant height of the initial growth of second sowing of Bettagraze (Photograph: 16 February, 2010).

Plate 3.4: Trimming of initial growth to 15 cm stubble height (Photograph: 5 February, 2010).

Plate 3.5: Trimmed plots (15 cm) of Bettagraze (Photograph: 5 February, 2010).

Plate 3.6: Regrowth of Bettagraze after 1st harvest (Photograph: 3 March, 2010).

Plate 3.7: Frost damage of the re-growth of the second sowing of Pacific BMR (Photograph: 26 March, 2009).

3.2. Experiment Two

Experiment Two involved the assessment of seed vigour of one sweet sorghum (Sugargraze), three sorghum *x* sudangrass hybrids (Pac 8421, Pac 8423, and Pacific BMR, all brown midrib (BMR) hybrids), two sudangrass (Sprint and Superdan 2) and one pearl millet (Nutrifeed) hybrids. This was undertaken by evaluating accelerated germination, un-aged germination and seedlings growth (seedling coleoptile length, seedling dry biomass; seedlings root biomass and remaining food reserves). The experiment was conducted at the Massey University, Seed Technology Laboratory, Palmerston North, New Zealand. The experiment was conducted from 17 August to 20 September, 2010. Laboratory seed testing was conducted after harvesting and analysing of field data, approximately nine months after field sowing. Seeds from these cultivars were stored in a 5 °C cold room after field sowing (packaged in transparent plastic papers), except for Bettagraze which was packaged in kraft paper.

After the field data analysis, it was observed that the field emergence percentages of some cultivars were less than the standard germination (90%) of cereal crops (Copeland, 1976). As a result of this observation, Experiment Two was designed to determine if the low germination was due to the seed being of low vigour or not performing in unfavourable field conditions. Prior to testing seed vigour, the seed moisture content was determined, in order to ensure that all seed moisture content was within 10 to 14%. Outside of this range, seed moisture content in addition to seed vigour can influence post-ageing germination. Bettagraze had a moisture content of 15.1% and this is considered high for ageing the seed. This high moisture was attributed to the original storage material (kraft paper) used, since it is water permeable, thus allowing the hygroscopic seed to absorb water from the cold room environment. In order to bring the Bettagraze seed moisture within the recommended ageing moisture range, it required pre-drying. However, there was (unfortunately) a human error in relation to pre-drying at an incorrect temperature. Therefore, Bettagraze had to be eliminated from the laboratory tests.

The objectives of this experiment were as follow:

a) To determine the seed vigour of sorghum, sudangrass and pearl millet forage cultivars, and rank the cultivars in terms of potential performance.
b) To determine a suitable accelerated ageing (AA) temperature and ageing duration for testing the seed vigour of sorghum, sudangrass and pearl millet forage cultivars
c) To correlate seed vigour tests with field emergence, in order to ascertain if there are strong relationships between seed vigour tests and field performance of sorghum, sudangrass and pearl millet forage cultivars.

3.2.1. Accelerated ageing test

The seeds of the seven cultivars evaluated were subjected to a short period of two environmental stresses (high temperature and high relative humidity) most responsible for rapid seed deterioration. Before each seed lot was subjected to the accelerated ageing conditions, it was mixed thoroughly using a centrifugal divider. A representative sample was then drawn by using the centrifugal divider to split the seeds into four sub-samples, with each sub-sample forming a replicate.

The experiment comprised four treatments (three ageing temperature and ageing duration combinations; and one control):

a) 41 °C /72 hours with 100% relative humidity (Ibrahim *et al*., 1993)
b) 43 °C /72 hours with 100% relative humidity (Hampton & TeKrony, 1995)
c) 45 °C /48 hours with 100% relative humidity (Ibrahim *et al*., 1993)
d) Control

A complete randomised design replicated four times was the experimental design used, and the layout can be seen below (Ibrahim *et al*., 1993):

Table 3.3: Treatment combinations used for seed vigour assessment of different sorghum, sudangrass and pearl millet cultivars.

Cultivar	Replication 1				Replication 2				Replication 3				Replication 4			
	Trt 1 (°C / h)	Trt 2 (°C / h)	Trt 3 (°C / h)	Trt 4	Trt 1 (°C / h)	Trt 2 (°C / h)	Trt 3 (°C / h)	Trt 4	Trt 1 (°C / h)	Trt 2 (ºC / h)	Trt 3 (ºC / h)	Trt 4	Trt 1 (ºC / h)	Trt 2 (ºC / h)	Trt 3 (ºC / h)	Trt 4
Pac 8423	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl
Pac 8421	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl
Pacific BMR	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl
Sugargraze	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl
Sprint	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl
Superdan 2	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl
Nutrifeed	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl	41/72	43/72	45/48	Ctrl

From each cultivar, 4 x 15 g of seeds (15 g from each replicate) was taken for three ageing conditions (41 ºC /72, 43 ºC /72, and 45 ºC /48) and one control. The weighed seed of 15 g was placed on the screen tray inserted into an inner chamber (plastic box) containing 40 ml of water (Hampton & TeKrony, 1995; Ibrahim *et al*., 1993). Seeds were placed in a single layer at a uniform distance above the water's surface in the inner chamber (Plate 3.8). A single layer of seeds was used to ensure that water absorption was uniform, and that there was no variation in seed moisture at the end of the test. The lid was placed on the inner chamber and the boxes were transferred to an ageing chamber running at the correct ageing temperature. Within each replicate for each cultivar, for each ageing temperature, the boxes were transferred to the ageing chamber, at the same time for each ageing duration. To ensure that post-ageing tests (moisture determination and germination testing) could be completed within one day, different replicates were set to age on different days. The control seed was not aged.

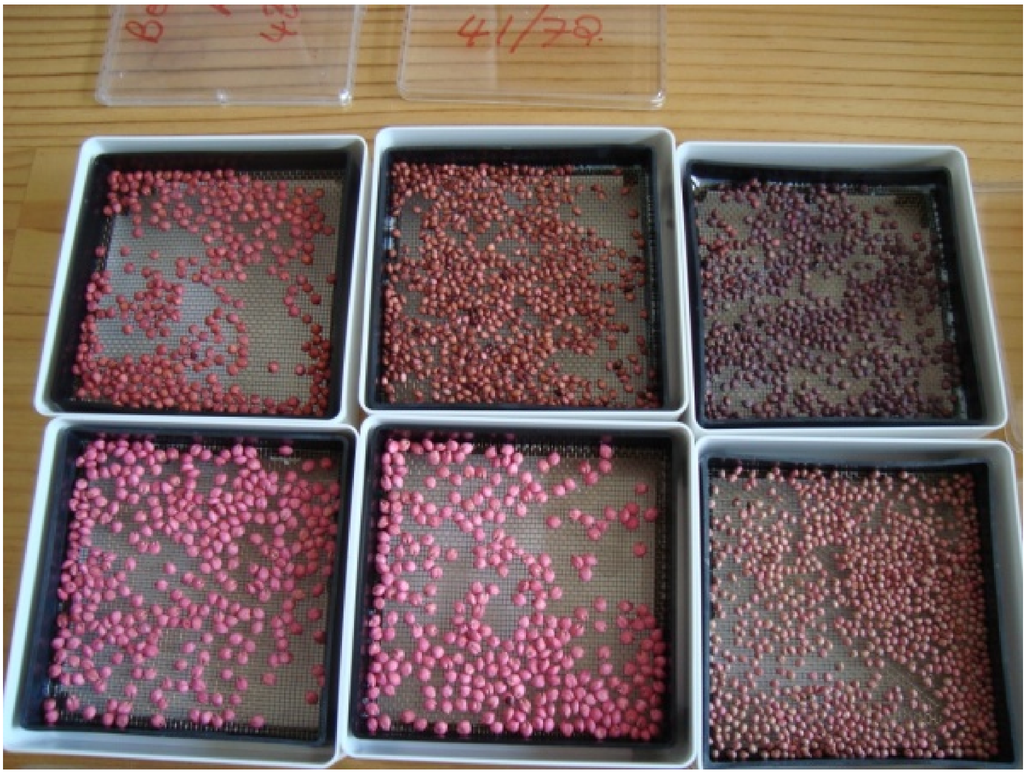

Plate 3.8: Seed distributed as a single layer on the screen tray before accelerated ageing of the seed.

To allow air circulation, the boxes were placed on the middle and upper shelves of the ageing chamber with sufficient space between them. Moreover, the temperature within the accelerated ageing chamber was monitored and maintained. However, a variation of ± 0.3°C was allowed (Hampton & TeKrony, 1995). At the exact time (± 15 minutes) at the end of the ageing period, seeds in the inner chambers were removed from the outer chamber (OSU, 2003). In order to maintain constant and uniform temperatures during the ageing period, the doors of the ageing chambers were closed for the whole period of ageing.

3.2.2. Seed Moisture determination

The seed moisture content of each sub-sample was determined before the seeds were aged through drying the ground seed in a 130 ºC for two hours (ISTA, 2010). After ageing the seed, the samples were removed from the ageing chamber, and immediately, 4 to 5 g of seed from each inner ageing chamber was weighed and put in a moisture tin, for moisture determination. In order to accurately determine the moisture content of the species used in this study it was necessary to grind the seed (to increase the surface area for efficient drying) prior to moisture determination. At the post-AA seed moisture the seed moisture is too high for the seed to be ground, therefore, a two-stage moisture determination needed to be done. The first stage was to dry the seed for 10 minutes at 130 ºC. After 10 minutes, the tins were removed from the oven and put in the laboratory for two hours, and then re-weighed again to determine moisture content after pre-drying (seed moisture content = S_1).

For the second stage of the moisture determination, pre-dried seeds were ground before putting again in an oven at 130 ºC for two hours (with lid off the vial). After drying the seed in the oven, the tins were removed from the oven and the lids were immediately replaced on the tins, which were then transferred to desiccators, for 40 minutes cooling. After 40 minutes, the tins were re-weighed for the second moisture determination (seed moisture content = S_2). The final moisture content, following the accelerated ageing, was determined by the following formula (ISTA, 2010; Nijenstein *et al.*, 2007)

$$\text{Final moisture} = S_1 + S_2 - \left(\frac{S_1 x\, S_2}{100}\right)$$

3.2.3. Seed germination and vigour tests

Following this ageing process, a standard germination test was conducted using 50 seed sample from each sub-sample for both aged seed (three ageing combinations) and control seed. The 50 seeds from each sub-sample were placed equidistantly on two moist paper towels (38 lb regular weight seed germination paper, Anchor Paper Company, St Paul, Minnesota) (Plate 3.9). The seeds were then covered with another paper towel. The paper towels were sufficiently moistened to ensure that the amount of moisture required for germination was reached. Approximately 2 cm of the base of the papers was folded upwards, and then the papers were rolled loosely into a tube and held with a rubber band on the top. Thereafter, the rolls were placed in wire baskets and sealed in a plastic bag with a rubber band to maintain moisture. The wire baskets were placed in the germinator maintained at alternating temperatures of 20/30°C (ISTA, 2010).

After 4 days of incubation in the germinator, an interim count was conducted, and results were expressed as percentage. All the normal seedlings, un-germinated seeds and not yet normal seedlings were placed back in the germinator until the 10^{th} day, when a final germination count was conducted. On this day, germination was assessed by recording normal seedlings, abnormal seedlings and un-germinated seeds as described in the handbook of Seedling Evaluation (Don, 2003). Seedlings were classified as normal if all essential structures and primary roots were intact and showed acceptable defects (such as minor discoloured or necrotic spots, healed splits or cracks and superficial cracks or splits), also if shoot system components were intact and had acceptable defects e.g. coleoptile (minor discoloured or necrotic spots, loose twists and a split of one third or less from the tip) and primary leaf (minor discoursed or necrotic spots and slightly reduced growth). Seedlings as a whole were considered abnormal if they were; deformed, fractured, consisted of fused twin seedlings, yellow or white in colour, spindly, glassy and part of the seedling showing decay symptoms as a result of primary infection; and if one or more of their essential structures were defective (Don, 2003).

After determining the post-ageing germination (percentage of normal seedlings of the aged seeds), control germination (percentage of normal seedlings of the un-aged seeds), and dead seeds for each treatment and cultivar, all normal seedlings from each sub-sample were dissected into coleoptile, roots and remaining food reserves. Thereafter, the seedling growth (coleoptile length, coleoptile dry matter, root dry matter and remaining food reserves) of normal seedlings only, was determined, in order to assess the seed vigour of different cultivars (Copeland, 1976; Evans *et al.*, 1961; Perry, 1987).

The coleoptile length, coleoptile dry matter, root dry matter, and remaining food reserves per seedling of different cultivars were determined by measuring these, and then the results were divided by the number of normal seedlings germinated from each sub-sample as shown by the formula below.

$$\bar{X} = \frac{\sum x}{n}$$

Where x is the observed value

n is the number of observations for each parameter

$\sum$ is the sum of all observed x values

$\bar{X}$ is the mean value of x

The dry matter contents of coleoptiles, roots and remaining food reserves were determined after drying the separated normal seedlings in an oven at 65 ºC for 48 hours (Free *et al.*, 2010).

A tetrazolium test was conducted on un-germinated seeds to determine their viability. The seeds were dissected longitudinally, through the middle of the embryonic axis and ¼ of the endosperm using a scalpel, before soaking the seeds in 1.0% tetrazolium solution in beakers (50ml). This was to ensure that the tetrazolium solution penetrated into the inner seed tissue. After incubating the soaked seeds for three hours at 30 °C, the tetrazolium solution was drained from the beaker using a sieve, and then cut surfaces were examined under the microspore, in order to assess the staining level of the embryo. Seeds were considered viable when the embryo was completely stained (Plate 3.12), and non-viable when the embryo was not completely stained (Plate 3.13). It can be noted that because the endosperm is not living tissue it does not stain (Hampton & TeKrony, 1995).

3.2.4. Analysis of data

All variables were analysed using SAS Proc GLM procedure of SAS 9.2 (SAS Inc, Cary, North Carolina, 2002-2008). Where significant effects were detected in the ANOVA (P=0.05), and means were compared using the LSD Test. This enabled cultivars to be ranked in terms of germination and vigour. Simple correlation was used to evaluate the relationship between all the laboratory test results (accelerated germination, standard germination, coleoptile length; coleoptile dry matter, seedling root dry matter and remaining food reserves) and field seedling establishment for sowing dates (December 8 and December 21) (Vanderlip *et al*., 1973). Simple correlation linear regression coefficients were determined on cultivar means (Kulik & Yaklich, 1982).

Plate 3.9: Seed spread on the moistened germination paper before being covered with the third paper towel.

Plate 3.10: Seed germination of control seed at the final germination count.

Plate 3.11: Measuring the coleoptile length of normal seedlings.

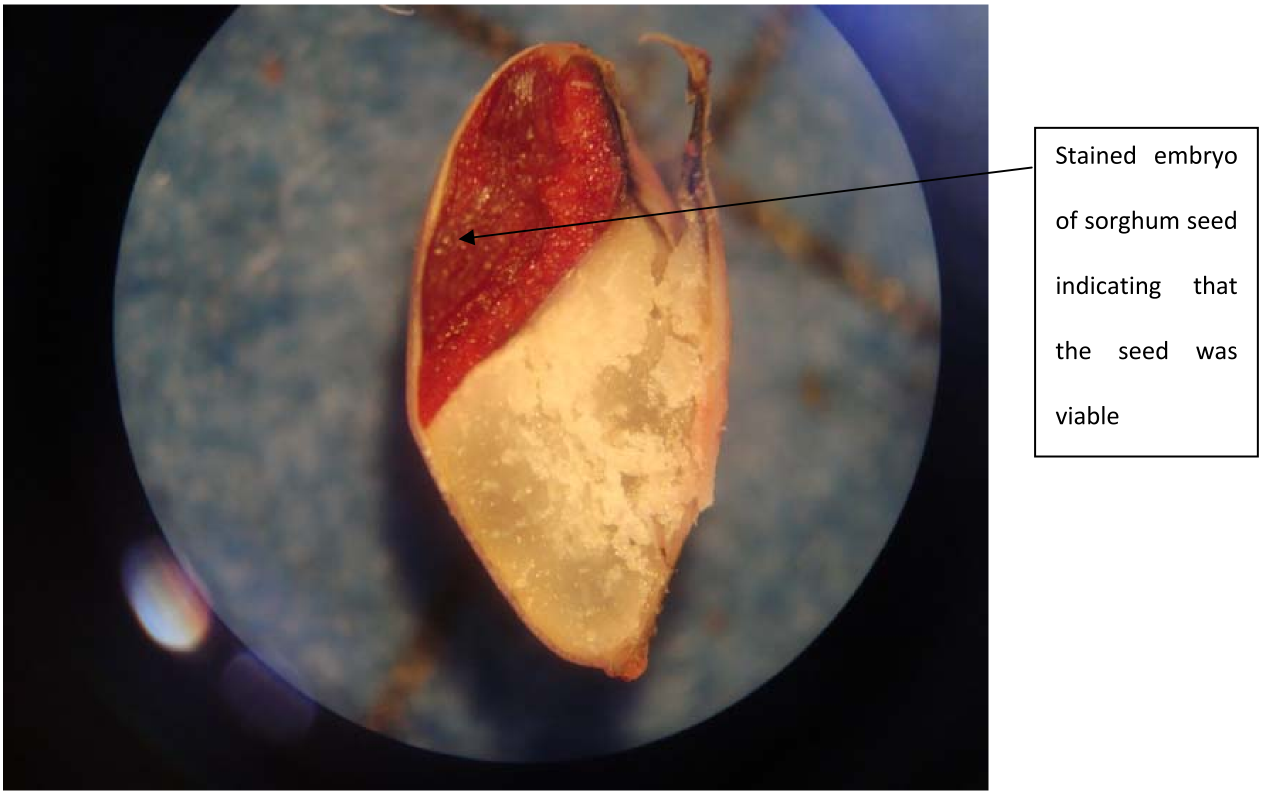

Plate 3.12: Stained sorghum embryo indicating that the embryo is viable. Note the unstained endosperm even in viable seed.

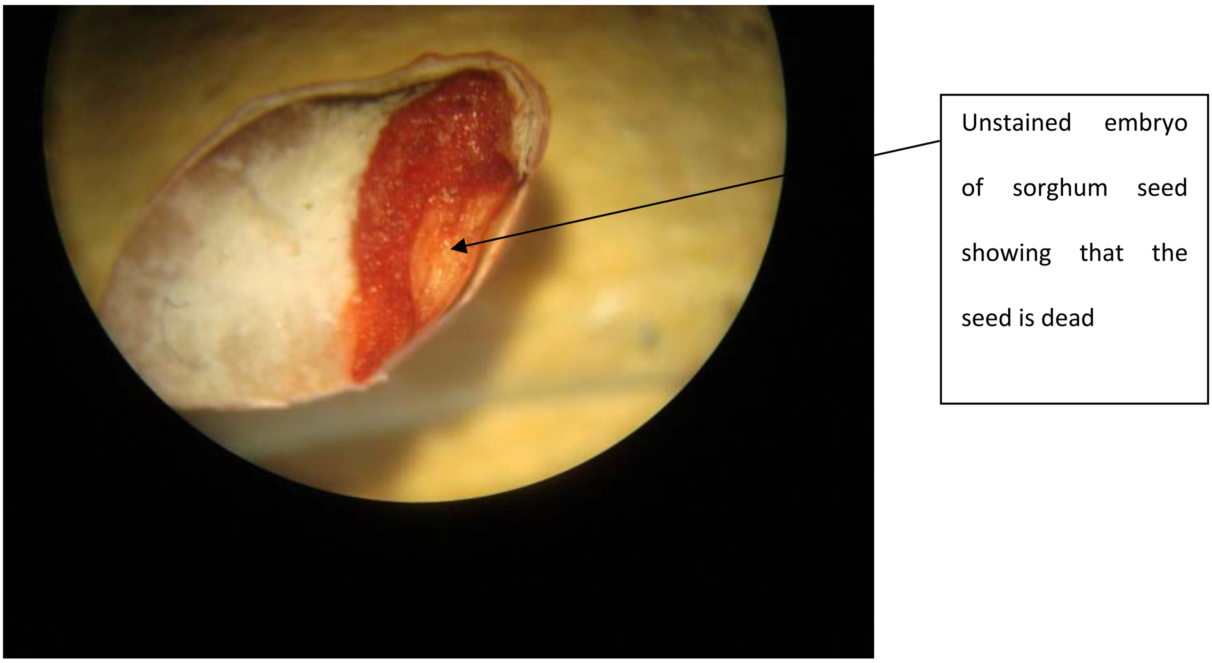

Plate 3.13: Unstained sorghum embryo indicating that the embryo is non-viable.

CHAPTER 4: RESULTS

4.1. Weather

The 2009 spring in Palmerston North was cold and wet, meaning that soil temperatures did not reach the minimum required for germination of these warm-zone crops until early December (Table 4.1). In November and December 2009 and in March 2010 air temperatures were below the long-term mean, however, above average air temperatures were experienced in February 2010. Air and soil temperatures were higher for the later sown crop during establishment and from emergence up until the 1st cut, but cooler temperatures in March 2010 resulted in the mean temperature after the 1st cut of the 2nd sowing being lower than the 1st sowing (Table 4.2).

Table 4.1: Mean air temperatures (ºC) for the 2009/2010 season compared to the long-term mean (1928-1980) (NZMS, 1983), recorded at AgResearch Grasslands (40°23’ S, 175°37’ E), Palmerston North.

	Month				
	November	December	January	February	March
2009/2010 mean	13.0	15.4	17.3	18.7	15.9
Long term mean	14.2	16.1	17.3	17.6	16.4

Table 4.2: Summary of mean air and soil temperatures (ºC) for each crop production phase at each sowing date. Temperatures recorded at AgResearch Grasslands, Palmerston North.

	Sowing date			
Growing period (2009/2010)	8/12/2009		21/12/2009	
	Air	Soil	Air	Soil
Sowing to emergence	15.0	15.5	17.1	17.6
Emergence to first cut	17.1	17.7	17.8	18.1
First to second cut	17.4	17.8	16.6	16.9
Mean	16.5	17.0	17.2	17.5

4.2. Forage yield

There were significant yield differences among cultivars for the 1st cut and total dry matter yield, but not the 2nd cut (Table 4.3). The highest yielding group of cultivars included Pac 8423 (13,953 kg DM/ha), Sugargraze (13,262kg DM/ha), Bettagraze

(12,704 kg DM/ha) and Sprint (12,426 kg DM/ha). Interactions between cultivar and sowing date were observed for yield at the 2nd cut, total dry matter (TDM) and the leaf/stem ratio for the 1st cut (Table 4.3). The interaction between cultivar and sowing date for yield at the 2nd cut is shown in Figure 4.1. The overall means of the 2nd cut yield, and leaf/stem ratio did not differ significantly across sowing dates and cultivars. At the second harvest there was little effect of cultivar from the second sowing date, but a large cultivar effect was observed at the first sowing date (Pac 8423 and Pac 8421were much higher yielding) (Table 4.3).

The sowing date had a significant effect on yield at both harvest dates and on total yield; total yield was highest for the December 8 sowing (12,792 kg DM/ha) compared with December 21 (11,356 kg DM /ha) (Table 4.3). However, the effect of sowing date varied with harvest period. For the 1st cut, yields were higher with later sowing, whereas for the 2nd cut yields were higher with earlier sowing. The relative difference between sowing date was highest for the 2nd cut where yields for the early sowing date were more than twice those of the later sowing. This is reflected in growth rates for each sowing date over each harvest period (Tables 4.5). Mean growth rates were highest at the 2nd cut (129.6 kg/ha/day) for the early sowing, but for the later sowing date growth declined greatly over the 2nd harvest period (77.8 kg/ha/day). For the first cuts, the means of the growth rates of the first sowing and second sowings were 115.5 and 145.9 kg/ha/day, respectively.

The 2nd cut yields of cultivars Bettagraze, Nutrifeed, Pac 8421, Pac 8423, Pacific BMR, Sprint and Superdan 2 reduced from 7,777, 5,755, 4,356, 8,118, 5,218, 5,634 and 4,857 kg DM/ha to 3,205, 2,196, 2,583, 3,377, 2,721, 3,231 and 2,840 kg DM/ha, respectively (Figure 4.1). Pac 8423 and Bettagraze had higher 2nd cut yields than all other cultivars when sown early but were similar to other cultivars with later sowing. Delaying sowing by 14 days reduced the mean TDM across cultivars by 1616 kg DM/ha, thus representing an 11.2% reduction in yield. In addition, the second cut growth rates were also reduced with delayed sowing from 169.0 to 86.6, 125.1 to 59.4, 94.7 to 69.8, 176.5 to 91.3, 113.4 to 73.5, 122.5 to 87.3, and 105.6 to 76.8 kg DM /ha/day for Bettagraze, Nutrifeed, Pac 8421, Pac 8423, Pacific BMR, Sprint and Superdan 2, respectively (Table 4.5).

Table 4.3: Combined analysis of yield, growth rate, leaf/stem ratio and tillers per m^2 for the two sowing dates.

Variety	Combined Yield (kg DM/ha) Cut 1	Yield (kg DM/ha) Cut 2	TDM	Growth rate (kg DM/ha/day) Cut 1	Growth rate (kg DM/ha/day) Cut 2	Leaf/stem ratio Cut 1	Leaf/stem ratio Cut 2	Tillers per m^2 Cut1	Tillers per m^2 Cut 2
Betagraze	7213	5491	12704	144.3	127.9	1.8	1.6	240	340
Nutrifeed	5848	3975	9823	116.6	92.2	1.8	1.6	332	308
Pac 8421	7325	3469	10794	144.2	82.3	2.0	1.7	249	348
Pac 8423	8206	5747	13953	163.5	133.9	1.9	1.6	233	338
Pacific BMR	6125	3970	10095	121.9	93.5	1.9	1.6	192	277
Sprint	7994	4432	12426	159.4	104.9	1.8	1.5	378	520
Sugargraze	13262	.	13262	176.4	.	1.6	.	205	.
Superdan 2	7365	3849	11214	146.8	91.18	2.0	1.6	376	518
Signficance	0.0001	NS	0.04	0.02	NS	NS	NS	0.0001	0.002
LSD $_{(0.05)}$	1177	.	2574	28	.	.	.	26	86
Plant Date									
Dec. 8	6997	5959	12792	115.5	129.6	1.9	1.6	297	381
Dec.21	8837	2879	11356	145.9	77.8	1.8	1.6	254	376
Significance	0.01	<0.0001	0.04	0.0008	0.0004	0.002	NS	0.03	NS
Cultivar x dates	NS	0.02	0.02	NS	0.03	0.003	NS	NS	NS

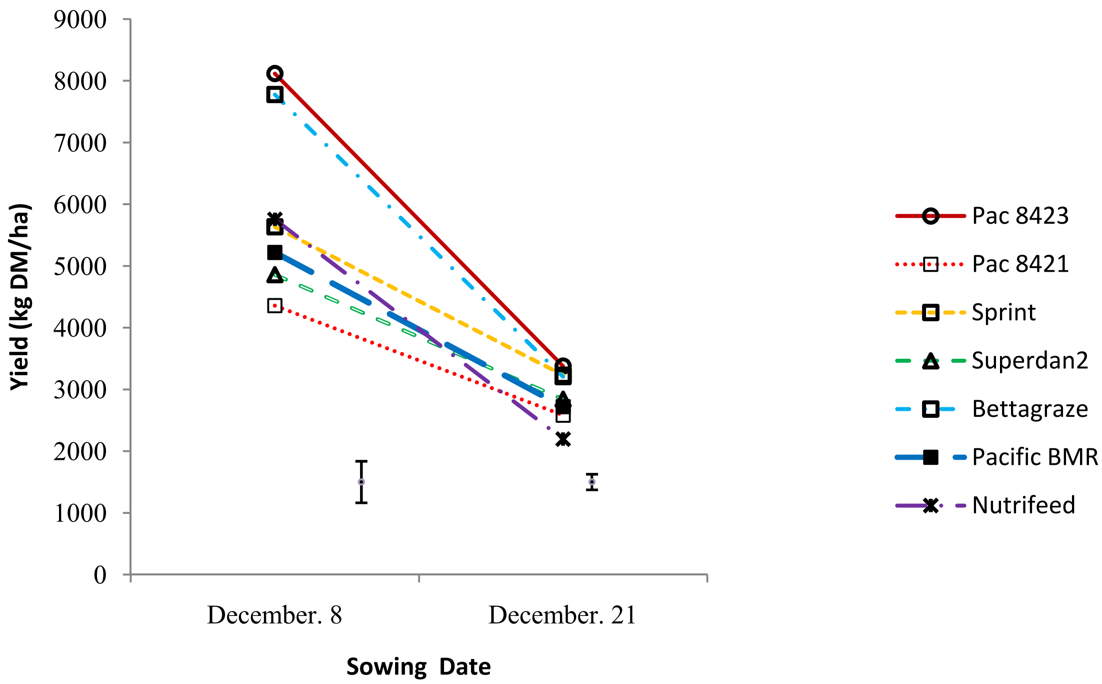

Figure 4.1: The interaction between sowing date and cultivar on yield at the 2nd harvest. (Error bars are 2 x SEM).

Cultivar differences for weight per tiller were observed for both cuts of the 1st sowing date, and the 1st cut of the 2nd sowing dates. However, there were no significant differences in weight per tiller for the 2nd cut of the 2nd sowing. For the 1st and 2nd cuts of the 1st sowing, and the 1st and 2nd cuts of the 2nd sowing, weight per tiller ranged from 1.5 to 5.3 and 0.9 to 2.6 g/plant DM, and 2.1 to 8.1 and 0.6 to1.0 g/plant DM, respectively (Table 4.5). With delayed sowing, the mean tiller weight increased from 2.6 g/plant DM to 3.9 g/plant DM for the 1st cut, but for the 2nd cut, it reduced from 1.7 to 0.8 g/plant DM (Table 4.5).

4.2.1. Tiller density

There were significant differences among cultivars for tiller density of both 1st and 2nd cuts of both sowing dates (Table 4.3). For the 2nd cut, Bettegraze, Nutrifeed, Pac 8421, Pac 8423 and Pacific BMR did not differ significantly for tiller density. Tiller density of the 1st cut of the first sowing date averaged across cultivars was significantly different ($p=0.03$) from the first cut of the 2nd sowing date. The first cut (297 tillers/m^2) of the 1st sowing date had greater tiller density than the 1st cut (254 tiller/m^2) of the 2nd sowing date. However, there were no significant differences between the 2nd cuts of both sowing dates (Table 4.3). Averaged across cultivars, tillers density increased by 28.3%

(from 297 to 381 tillers/m^2) and 48.0% (from 254 to 376 tillers/m^2) after cutting for the 1^{st} and 2^{nd} sowing dates, respectively (Table 4.4). Tiller density was strongly influenced by cultivar, Sprint and Superdan 2 had higher tiller densities than all other cultivars at both harvest times (Table 4.4). There was no cultivar and sowing date interaction for tiller density.

4.2.2. Leaf/stem ratio

Leaf/stem ratio for the 1^{st} cut of the 1^{st} sowing indicated significant differences among cultivars, while the 2^{nd} cut of the 1^{st} sowing and the 1^{st} and 2^{nd} cuts of the 2^{nd} sowing had no significant differences (Table 4.4). Mean leaf/stem ratio (1.9) across cultivars for 1^{st} cut of the first sowing date was significantly higher than the mean leaf/stem ratio (1.8) across cultivars for the 1^{st} cut of the 2^{nd} sowing date. However, mean leaf/stem ratios for re-growth across cultivars for both sowing dates were similar (Table 4.3).

Means across cultivars and sowing dates for leaf/stem ratio ranged from 1.8 to 2.0 and 1.5 to 1.7, for the 1^{st} and 2^{nd} cuts, respectively (Table 4.3). The interaction between cultivar and sowing date for the leaf/stem ratio of first cut arose, whereas in Nutrifeed the leaf/stem ratio for the 1^{st} cut increased with later sowing, in all other cultivars the ratio declined, though in Pac 8423 and Pac 8421 the decline was minor and they were not significant (Figure 4.2). In this study, neither sowing date nor cultivar influenced leaf/stem ratio.

4.2.3. Plant height

Plant height was measured at the time of each yield assessment, and showed significant differences among cultivars. The mean heights at the 1^{st} cut (combined for both sowing dates) were 154.4 cm, 135.1 cm, 130.1 cm, 129.9 cm, 118.9 cm, 113.8 cm, 98.8 cm and 87.7 cm for Sugargraze, Pac 8423, Sprint, Bettagraze, Superdan 2, Pac 8421, Pacific BMR and Nutrifeed, respectively. No lodging of plants was observed in this study.

The increase in plant height averages per day, for the initial growth of the 1^{st} sowing from day 46 to day 57, ranged from 1.0 to 2.2 cm/day; and a range of 1.1 to 2.7 cm/day was recorded from day 20 to day 46 of its re-growth. The 2^{nd} sowing showed increases in plant height for initial growth of between 0.7 and 2.6 cm/day from day 33 to day 58. However, plant height growth for the re-growth was between 0.8 and 1.4 cm/day from day 22 to day 37.

Table 4.4: Means of leaf/stem ratio, tiller density (tillers/m^2) and plant height (cm) for the cultivars sown for both sowing dates.

	Sowing Date One (8/12/2009)						Sowing Date Two (21/12/2009)					
	Leaf/stem ratio		Tillers per m^2		Height (cm)		Leaf/stem ratio		Tillers per m^2		Height (cm)	
Cultivar	Cut 1	Cut 2	Cut1	Cut 2	Cut1	Cut 2	Cut 1	Cut 2	Cut 1	Cut 2	Cut 1	Cut 2
Betagraze	2.0	1.6	265.0	341.0	118.8	110.8	1.7	1.6	215.0	338.0	140.9	45.3
Nutrifeed	1.7	1.6	342.0	347.0	76.9	103.4	1.8	1.7	320.0	268.0	98.4	47.2
Pac 8421	2.0	1.7	267.0	325.0	106.0	106.6	1.9	1.7	233.0	371.0	121.5	46.0
Pac 8423	2.0	1.6	261.0	320.0	119.6	121.9	1.9	1.7	204.0	357.0	150.6	51.7
Pac BMR	2.0	1.6	208.0	261.0	89.1	82.1	1.8	1.7	176.0	292.0	108.4	38.4
Sprint	2.1	1.4	412.0	518.0	122.7	118.3	1.7	1.6	343.0	522.0	137.4	49.0
Sugargraze	1.6	.	228.0	.	153.9	.	1.7	.	182.0	.	154.8	.
Superdan 2	2.1	1.6	392.0	550.0	109.6	100.1	1.8	1.6	360.0	485.0	128.2	49.3
Means	1.9	1.6	297	381	112.1	106.2	1.8	1.6	254	376	130.0	46.7
Significance	0.0001	NS	0.0001	0.0001	0.0001	0.0001	NS	NS	0.0001	0.0001	0.0001	NS
LSD $_{(0.05)}$	0.1	.	60.0	93	16.2	10.9	.	.	50.0	68.0	13.0	.

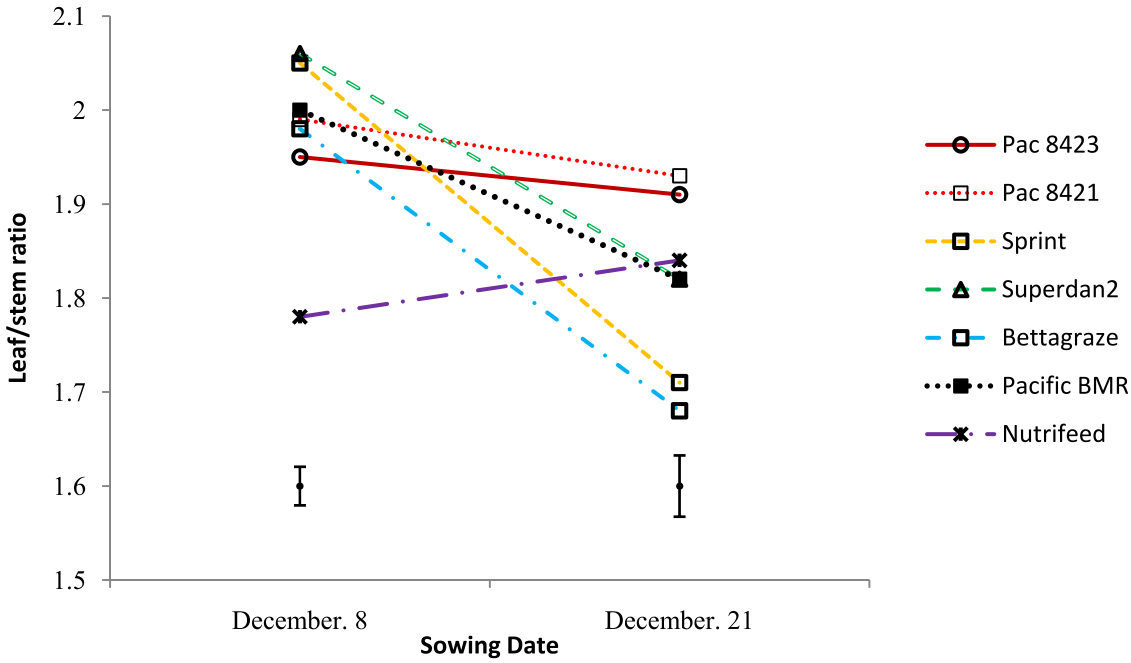

Figure 4.2: The interaction between sowing date and cultivar on leaf/stem ratio at the first harvest cut. (Error bars are 2 x SEM).

Table 4.5: Means weight per tiller and growth rates for cut 1, cut 2 and TDM of the cultivars sown for both sowing dates.

	Sowing Date One (8/12/2009)					Sowing Date Two (21/12/2009)				
	Weight per Tiller (g/plant DM)		Growth rate (kg DM/ha/day)			Weight per Tiller (g/plant DM)		Growth rate (kg DM/ha/day)		
Cultivar	Cut 1	Cut 2	Cut 1	Cut 2	TDM	Cut 1	Cut 2	Cut 1	Cut 2	TDM
Betagraze	2.3	2.3	104.8	169.1	133.5	4.0	1.0	145.7	86.6	122.7
Nutrifeed	1.5	1.7	88.0	125.1	104.6	2.1	0.8	115.1	59.4	93.4
Pac 8421	2.7	1.4	126.1	94.7	112.1	3.4	0.7	130.0	69.8	107.9
Pac 8423	2.9	2.6	124.3	176.5	147.6	4.4	0.9	159.5	91.3	131.6
Pacific BMR	2.6	2.0	93.8	113.4	102.6	4.0	0.9	119.0	73.5	101.3
Sprint	1.7	1.1	120.6	122.5	121.4	2.7	0.6	157.2	87.3	130.0
Sugargraze	5.3	.	155.7	.	155.7	8.1	.	197.0	.	197.0
Superdan 2	1.6	0.9	111.5	105.0	108.8	2.3	0.6	144.4	76.8	118.1
Means	2.6	1.7	115.5	129.6	123.3	3.9	0.8	145.9	77.8	125.2
Significance	0.0001	0.001	0.0017	0.003	0.0001	0.0001	NS	0.0007	NS	0.0001
LSD $_{(0.05)}$	0.8	0.8	28.4	41.9	20.9	1.2	.	32.7	.	24.4

4.2.4. Ear emergence

The time of 50% ear emergence was monitored in all plots. Ear emergence (heading) only occurred in the early planted plots and only in Bettagraze, Pac 8421, Pac 8423 and Sprint which reached 50% ear emergence 73, 89, 78 and 81 days after cutting, respectively. The onset of cool temperatures in March (Table 4.2) and the damage effect of frost (grass minimum temperatures of -0.8 and -3.2 ºC on March 13 and 18, respectively) halted plant growth and consequently ear development.

4.2.5. Thermal time

The predicted thermal time required for sorghum, sudangrass and pearl millet cultivars to be grazed at 50 cm were averaged between 202.5 to 213.0 ºC days and 217.6 to 253.7 ºC days for initial and re-growth, respectively (Figures 4.3 and 4.4). At 100 cm, 318.9 to 322.9 ºC days and 332.4 to 413.8 ºC days were predicted for initial and re-growth (Figures 4.5 and 4.6). In this study, approximately 100 cm plant height for initial and regrowth of the 1st sowing date were attained after thermal time means accumulated to 323.8 and 338.6 ºC days. And for the initial growth of the 2nd sowing date to achieve at least 100cm, an accumulation of 372.4 ºC days were required. Due to frost damage that killed re-growth of plants of the second sowing date, in order to reach an average of 46.7cm, 244.4 ºC days were needed.

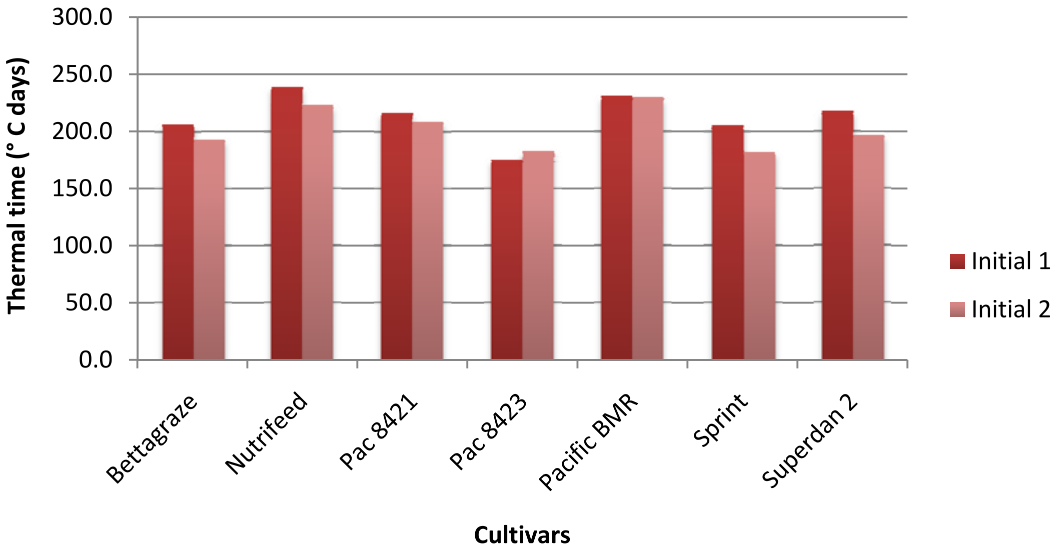

Figure 4.3: Predicted thermal time (ºC days) requirements for different cultivars to reach 50 cm plant height of initial growth for both sowing dates (Initial 1= Initial for Date 1 and Initial 2= Initial for Date 2).

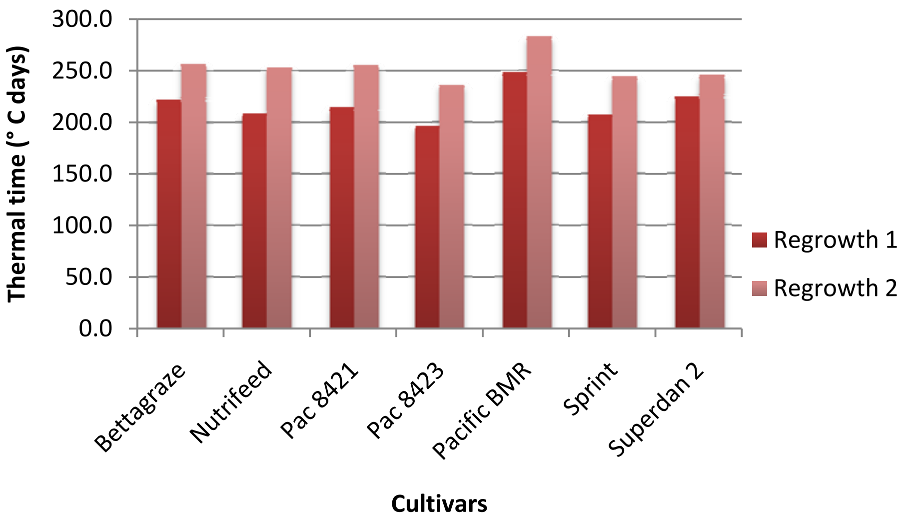

Figure 4.4: Predicted thermal time (ºC days) requirements for different cultivars to reach 50 cm plant height of re-growth for both sowing dates (Re-growth 1= Re-growth for Date 1 and Re-growth 2= Re-growth for Date 2).

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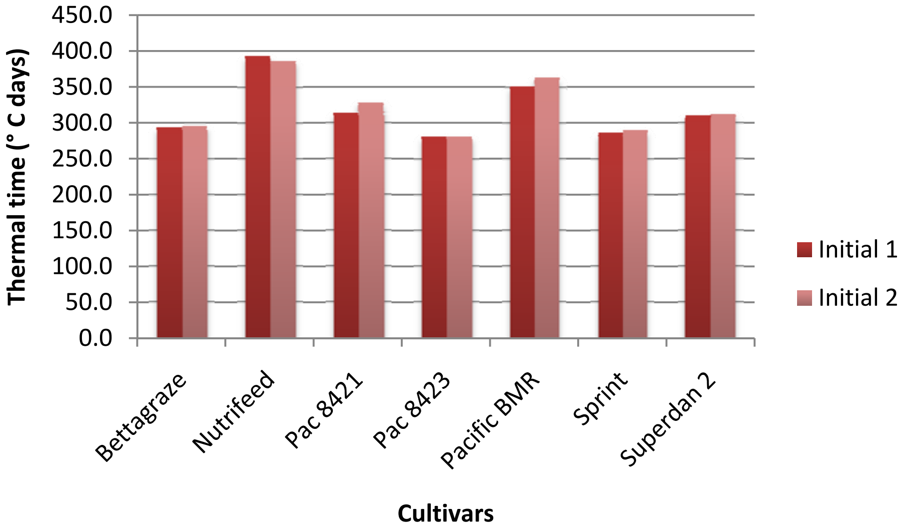

Figure 4.5: Predicted thermal time (ºC days) requirements for different cultivars to reach 100 cm plant height of initial growth for both sowing dates (Initial 1= Initial for Date 1 and Initial 2= Initial for Date 2).

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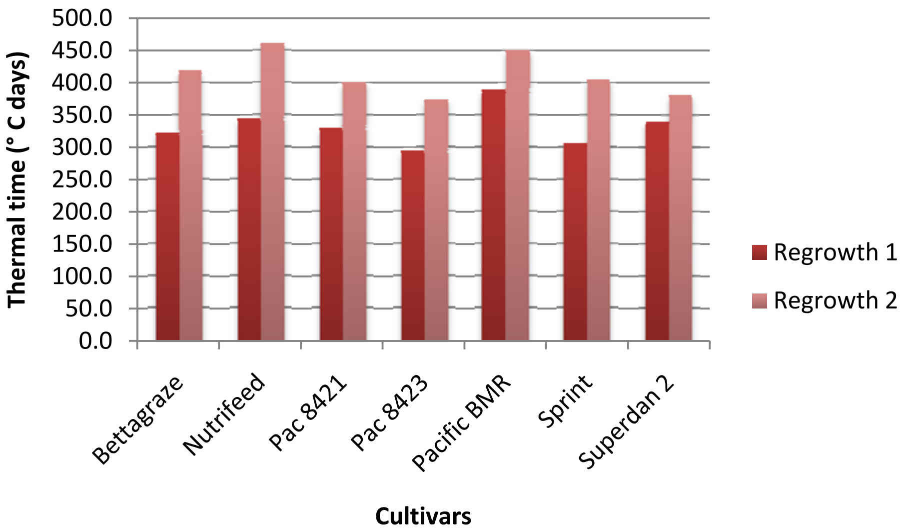

Figure 4.6: Predicted thermal time (ºC days) requirement for different cultivars to reach 100 cm plant height of re-growth for both sowing dates (Re-growth 1= Re-growth for Date 1 and Re-growth 2= Re-growth for Date 2).

Differences were observed among cultivars in plant height response to thermal time, except for the 2nd cut of the 2nd sowing. The increase in plant height per unit of thermal time for initial growth and re-growth of the 1st sowing date ranged from 0.3 to 0.6 and

0.4 to 0.5 cm/ ºC days, respectively. In case of the 2nd sowing date, increases in plant height per unit of thermal time were from 0.3 to 0.5 cm/ ºC and 0.3 to 0.4 cm/ ºC days for initial growth and re-growth. The growth curves for different cultivars in response to thermal time are shown in Figures 4.7, 4.8, 4.9 and 4.10.

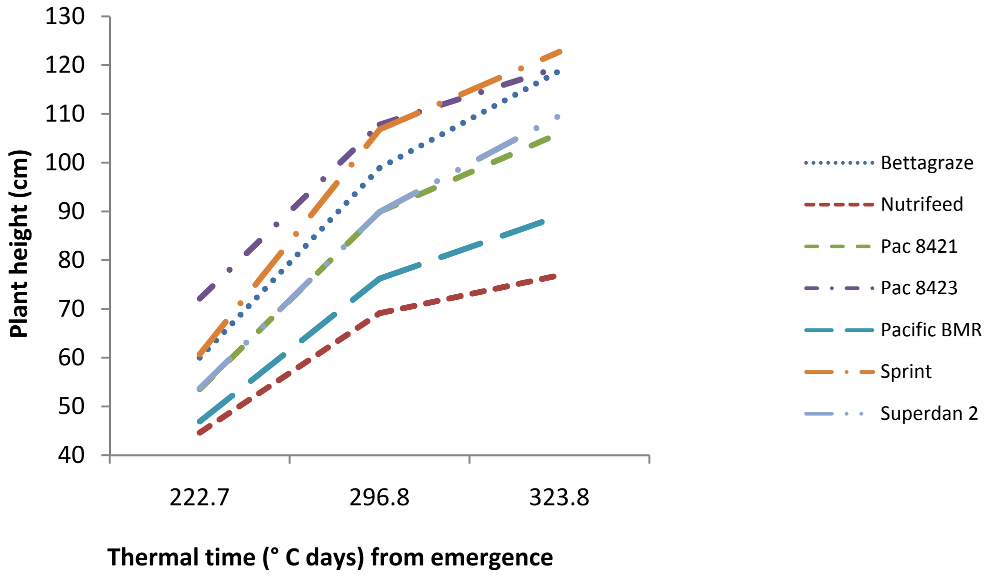

Figure 4.7: Growth curves of different cultivars of the initial growth for the first sowing date.

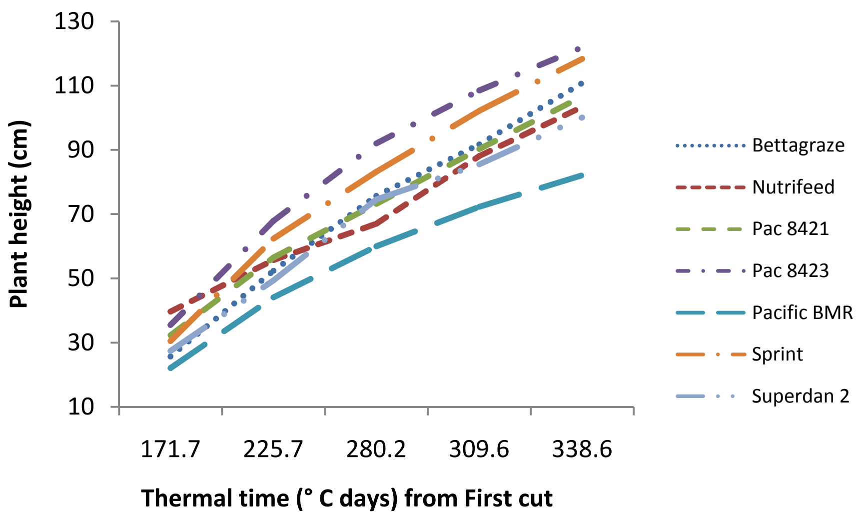

Figure 4.8: Growth curves of different cultivars of the re-growth for the first sowing date.

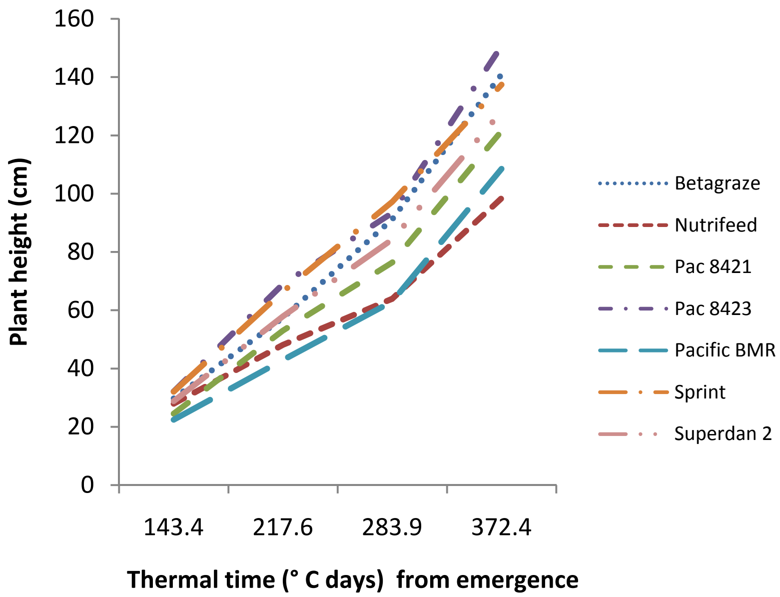

Figure 4.9: Growth curves of different cultivars of the initial growth for the second sowing date.

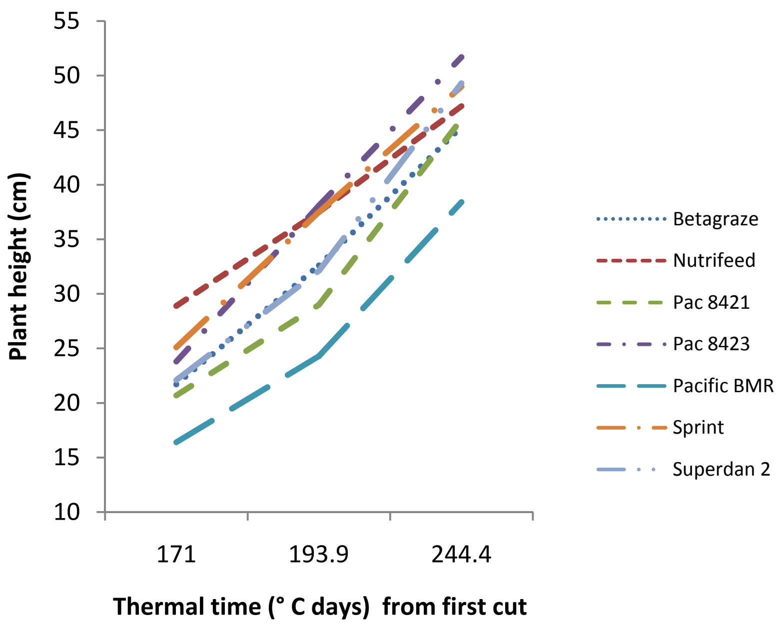

Figure 4.10: Growth curves of different cultivars of the re-growth for the second sowing date.

4.2.6. Relationship between yield, plant height and tiller density

The association between height, tiller density and yield was initially explored using correlation analysis. There was no correlation between yield and tiller density but yield showed a highly significant linear relationship with plant height (Figure 4.11).

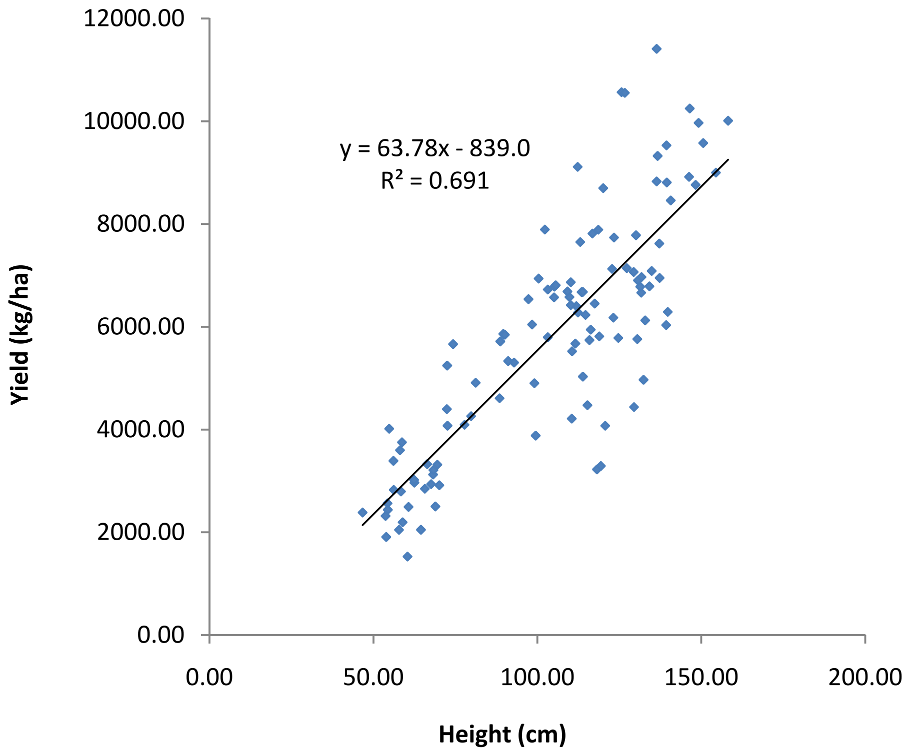

Figure 4.11: The regression between yield and plant height for different cultivars at both sowing dates and harvest times.

4.3. Forage quality

The nutritive values (metabolisable energy, crude protein, acid detergent fibre, neutral detergent fibre and soluble sugars and starch) of different sorghum, sudangrass and pearl millet cultivars were assessed in this experiment for comparative purposes. Cultivar differences were observed for all measures of forage quality assessed (Table 4.6).

Table 4.6: Means of whole plant metabolisable energy (ME), crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF) and soluble sugars and starch (SSS) of different sorghum, sudangrass and pearl millet cultivars for cut 1 of first sowing date.

Cultivars	ME (MJ/kg DM)	CP (%)	ADF (%)	NDF (%)	SSS (%)
Bettagraze	10.3	16.1	35.5	62.8	6.2
Nutrifeed	10.8	18.0	33.9	61.1	1.2
Pac 8421	10.8	16.0	34.2	60.6	7.9
Pac 8423	10.3	14.2	36.5	63.1	7.6
Pacific BMR	11.0	16.8	32.9	57.2	10.3
Sugargraze	10.1	10.3	36.2	65.2	13.9
Sprint	10.4	14.7	36.3	62.0	8.5
Superdan 2	10.5	15.0	35.2	59.9	7.2
Mean	10.5	15.1	35.1	61.5	7.8
Significance	0.0001	0.0001	0.0009	0.003	0.0001
LSD $_{(0.05)}$	0.3	2.0	1.6	3.4	1.4

4.3.1. Metabolisable energy (ME)

Significant cultivar differences (p = 0.0001) were observed, the metabolisable energy (ME) ranged from 10.1 to 11.0 MJ/kg DM (Table 4.6). Pacific BMR had the highest ME, but it was not significantly different from Nutrifeed and Pac 8421. The metabolisable energy of Superdan 2, Bettagraze, Pac 8423, and Sprint did not differ significantly. Sugargraze had the lowest ME content.

4.3.2. Crude protein (CP)

Crude protein differences among cultivars were significant ($P<0.0001$). Sugargraze had the lowest CP with Nutrifeed the highest. However, the CP percentage in Nutrifeed did not differ significantly from Bettagraze, Pac 8421 and Pacific BMR, but it did differ from Pac 8423, Sprint and Superdan 2.

4.3.3. Acid detergent fibre (ADF)

There were significant differences among cultivars. The lowest ADF content of forage was found in Pacific BMR and the highest in Pac 8423 (Table 4.6). The ADF content of Pac 8423 was not significantly different from that of Bettagraze, Sugargraze, Sprint and Superdan 2, but the ADF was significant in Pacific BMR, Nutrifeed and Pac 8421.

4.3.4. Neutral detergent fibre (NDF)

NDF concentration differed significantly (P=0.003) among cultivars. Pacific BMR had significantly lower NDF concentration than Sugargraze, Sprint, Nutrifeed, Bettagraze, Pac 8421, and Pac 8423, but not Superdan 2. Sugargraze had the highest concentration but this was not significantly different from Sprint, Pac 8423 and Bettagraze.

4.3.5. Soluble sugars and starch (SSS)

The SSS concentration in Sugargraze was significantly higher than all other cultivars. Pacific BMR was second with Sprint, Superdan 2, Pac 8423, and Pac 8421 third equal, followed by Bettagraze and Nutrifeed.

4.3.6. Relationship between agronomic traits and forage quality

Crude protein showed a strong positive correlation (R^2=0.59) with ME (Figure 4.12). However, CP was negatively correlated with yield (R^2=0.65) (Figure 4.13) and plant height (R^2=0.71) (Figure 4.14). Metabolisable energy was negatively correlated with plant height (R^2=0.60) (Figure 4.15), and weakly, negatively correlated to dry matter yield (R^2=0.37) (Figure 4.16).

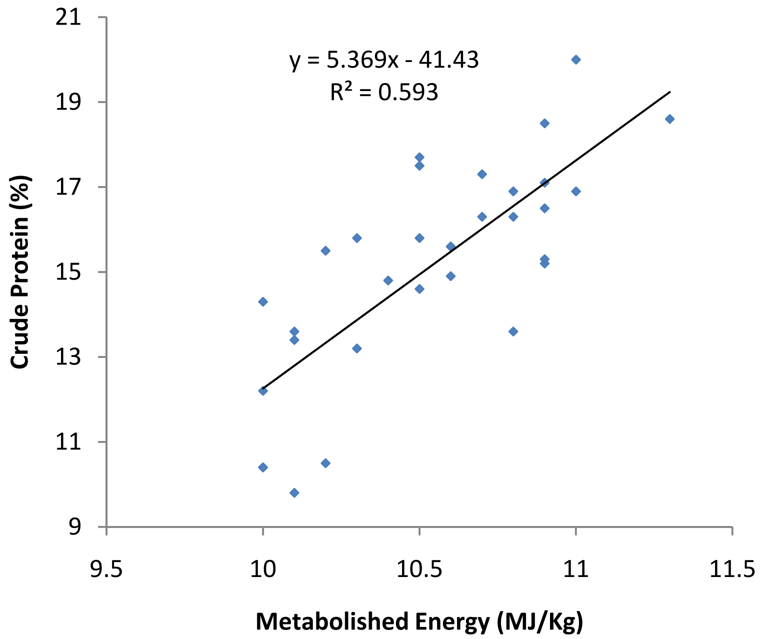

Figure 4.12: The relationship between metabolisable energy and crude protein concentration for sorghum, sudangrass, and pearl millet cultivars for forage harvested at the first cut of the first sowing.

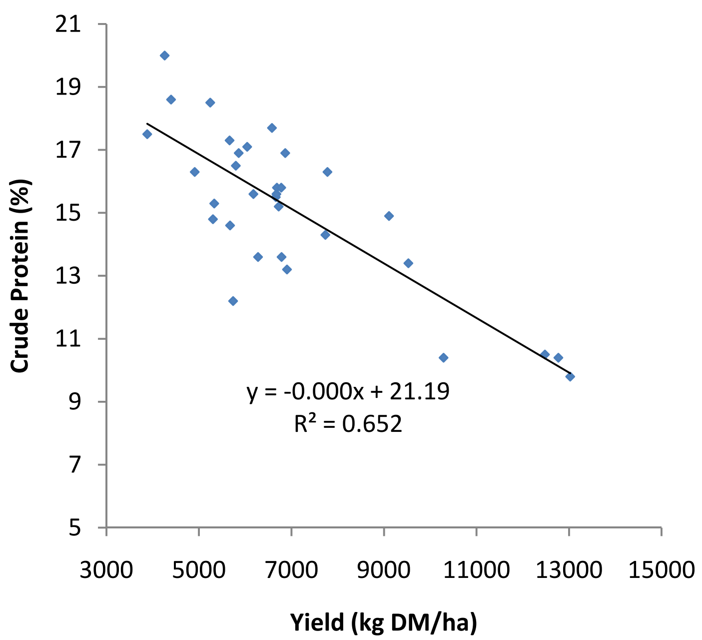

Figure 4.13**:** Relationship between yield and crude protein concentration for sorghum, sudangrass and pearl millet cultivars for forage harvested at the first cut of the first sowing.

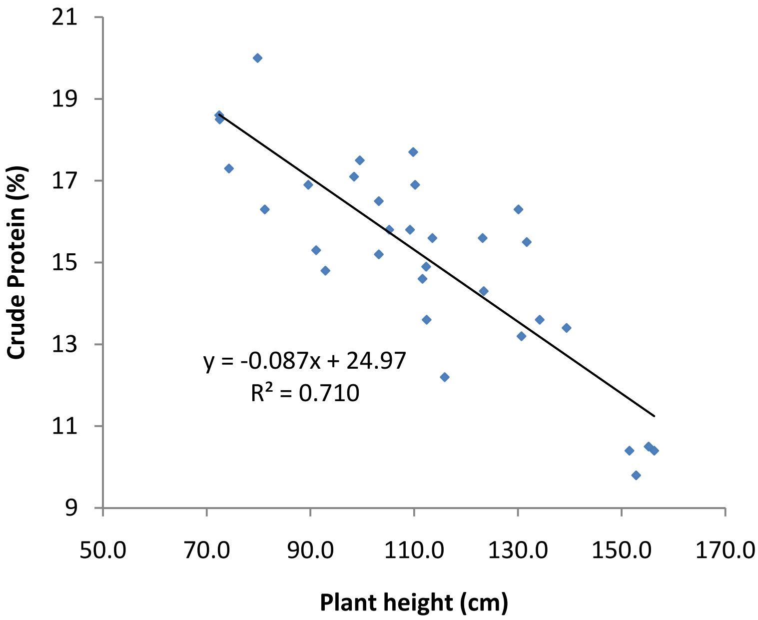

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Figure 4.14: Relationship of plant height and crude protein concentration for sorghum, sudangrass and pearl millet cultivars for forage harvested at the first cut of the first sowing.

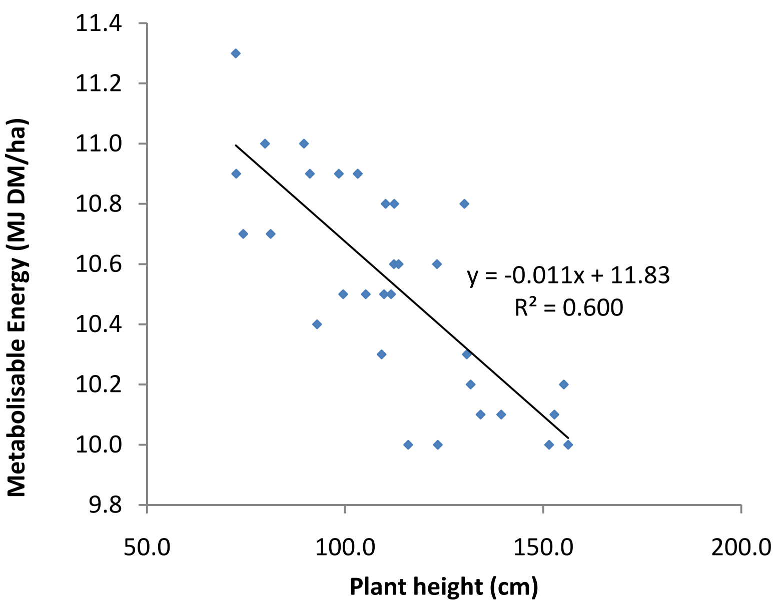

Figure 4.15: Plant height and metabolisable energy relationship for sorghum, sudangrass, and pearl millet cultivars for forage harvested at the first cut of the first sowing.

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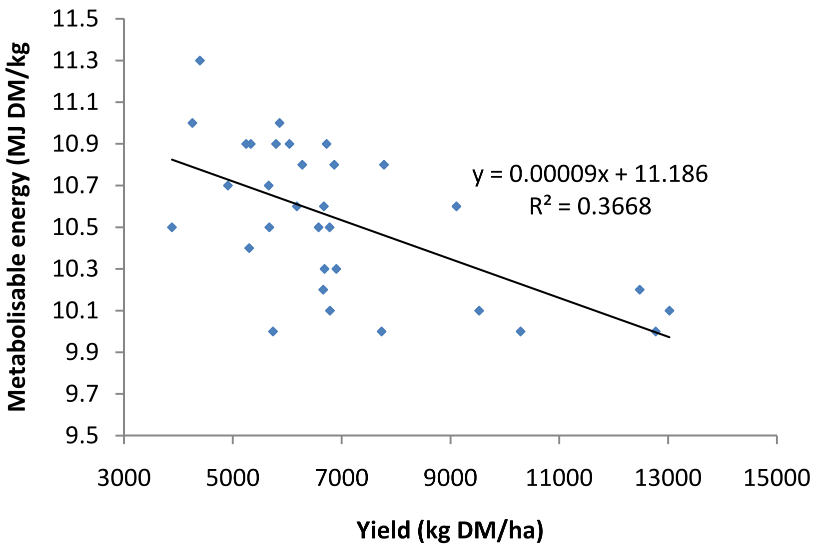

Figure 4.16: Yield and metabolisable energy relationship for sorghum, sudangrass and pearl millet cultivars for forage harvested at the first cut of the first sowing.

4.4. Seed quality

Germination and seed vigour of the seeds of sorghum, sudangrass and pearl millet cultivars were assessed in order to determine and compare their germination percentages and seed vigour. The cultivars were ranked according to assessed seed vigour. Furthermore, the relationships between laboratory tests and field emergence were explored.

4.4.1. Germination and seed vigour

There were significant differences for the interim and normal germinations, and remaining food reserves between cultivars for different treatments for both control and aged seed (Tables 4.7, and 4.8). Furthermore, significant differences in abnormal seedling percentage, dead seed percentage, dry matter accumulation per seedling, root weight per seedling and coleoptiles length were observed between cultivars (Appendices 2 and 3). Significant cultivars x temperature interactions for interim, normal germinations and remaining food reserves across all treatments were observed (Table 4.9).

For accelerating ageing T41-D72, there were no significant differences between Nutrifeed and Sprint. However, Sprint was similar to Superdan 2. Sugargraze and Pacific BMR were the lowest. Pac 8421 and Pac 8423 had the highest normal germination. In addition, T43-D72, Pac 8421, and Pac 8423 had highest normal germination. And then the order of germination was as follows: Nutrifeed, Sprint, and Superdan 2 intermediate; and Sugargraze and Pacific BMR were the lowest.

When the accelerating temperature was increased to T45-D48, the germination of Sprint and Superdan2 reduced drastically and hence they were similar to Sugargraze and Pacific BMR. However, it was observed that Nutrifeed, Pac 8421 and Pac 8423 maintained good accelerating ageing germination despite adverse ageing conditions. Also, there were no significant differences among Pac 8421, Pac 8423, Nutrifeed, Sprint and Superdan 2 for normal germination of control treatment, but these were significant to Sugargraze and Pacific BMR.

The interim germination percentages for control, T41-D72, T43-D72 and T45-D48 treatments ranged between 70% to 97%, 42% to 97%, 43% to 98% and 22% to 97%, respectively (Table 4.7). Normal germination ranged from a low of 75% to a high of 99%, 50% to 98%, 52 to 97% and 35 to 97% for control, T41-D72, T43-D72 and T45-D48 treatments, respectively (Table 4.7). The interim germination averaged across the seven cultivars and across treatments was 71%, with the lowest and highest values being 42% and 97%, respectively. Normal germination had a lowest value of 55% and a high of 97% with a mean of 76% (Table 4.9). The differences between un-aged seed germination and accelerated normal germinations of treatments T41-D72, T43-D72, and T45-D48 were 11.7%, 14.8% and 23.5%, respectively. The variation in the final germination of all treatments (T41-D72, T43-D72, T45-D48 and control) are illustrated clearly by Figure 4.17. This showed that control was high and can be used to estimate field emergence if field conditions are favourable.

The means of interim and normal germinations of the control treatment were the highest and accelerated ageing interim and normal germinations of T41-D72 and T43-D72 treatments were intermediate with no significant differences between them. Interim and normal germinations for the T45-D48 treatment were the significantly lower than that for the other three treatments.

As the accelerating ageing temperatures increased, accelerated interim and normal germinations, coleoptiles length and coleoptiles dry weight across cultivars reduced significantly, and the number of dead seeds, abnormal seedlings and remaining food reserves increased significantly (Table 4.7 and Appendices 2 and 3). However, the remaining food reserves for Pac 8423 and Nutrifeed did not increase (Tables 4.8 and 4.9).

Generally, mean post-accelerated ageing interim and normal germinations across all cultivars decreased significantly ($P<0.05$) from 70% at T41-D72 and 69 at T43-D72, to 58% at T45-D48, and 76% at T41-D72 and 73 at T43-D72 to 65% at T45-D48, respectively (Table 4.7). Accelerated ageing temperature had a strong effect on germination of cultivars except on seeds of Pac 8421 and Pac 8423. The effect of T41-D72 and T43-D72 accelerating ageing treatments on seed germination were similar, but they were significantly different from T45-D48 where both the interim and final germination percentage was significantly reduced.

Table 4.7: Interim and normal germinations of different sorghum, sudangrass and pearl millet cultivars for control (un-aged seed) and post accelerated ageing treatments (T41D72 T43D72and T45D48) in the laboratory.

	Interim Germination (%) Temperatures (ºC) and Duration (Hours)				Normal Germination (%) Temperatures (ºC) and Duration (Hours)			
Cultivar	Control	T41D72	T43D72	T45D48	Control	T41D72	T43D72	T45D48
Pac 8421	95	96	96	94	96	98	97	94
Pac 8423	97	97	98	97	99	97	97	97
Nutrifeed	90	84	82	86	89	86	83	84
Sugargraze	70	42	35	22	75	59	52	35
Pacific BMR	76	42	43	40	77	50	52	52
Sprint	91	68	70	30	92	75	72	42
Superdan 2	89	64	62	42	91	71	63	49
Mean	87	70	69	58	88	76	73	65
Significance	0.0001	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001
LSD $_{(0.05)}$	10	12	8	11	10	11	7	12

Table 4.8: Remaining food reserves of different sorghum, sudangrass and pearl millet cultivars for control (un-aged seed) and post accelerated ageing treatments (T41D72 T43D72and T45D48) in the laboratory.

	Temperatures (ºC) and Duration (Hours)			
Cultivar	Control	T41D72	T43D72	T45D48
Pac 8421	6.1	7.9	7.2	8.9
Pac 8423	6.0	6.6	5.9	6.1
Nutrifeed	1.7	1.7	1.6	1.8
Sugargraze	8.0	9.7	10.9	11.7
Pacific BMR	9.9	11.4	10.7	12.3
Sprint	2.7	4.4	3.7	5.2
Superdan 2	2.6	3.7	2.9	3.5
Mean	5.3	6.5	6.2	7.1
Significance	0.0001	0.0001	0.0001	0.0001
LSD $_{(0.05)}$	0.7	1.8	1.0	1.4

Table 4.9: Combined (control and post accelerated) interim, normal and remaining food reserves percentages of different sorghum, sudangrass and pearl millet cultivars.

Cultivar	Interim (%)	Normal (%)	Remaining food reserves (mg)
Pac 8421	95	96	8
Pac 8423	97	97	6
Nutrifeed	85	85	2
Sugargraze	42	55	10
Pacific BMR	50	57	11
Sprint	64	70	4
Superdan 2	64	68	3
Mean	71	76	6
Significance	0.0001	0.0001	0.0001
$LSD_{(0.05)}$	5	5	1
Temperature			
T41D72	70	76	6.5
T43D72	69	73	6.2
T45D48	58	65	7.1
Control	87	88	5.3
Significance	0.0001	0.0001	0.0001
Cultivar x Temperature	0.0001	0.0002	0.005

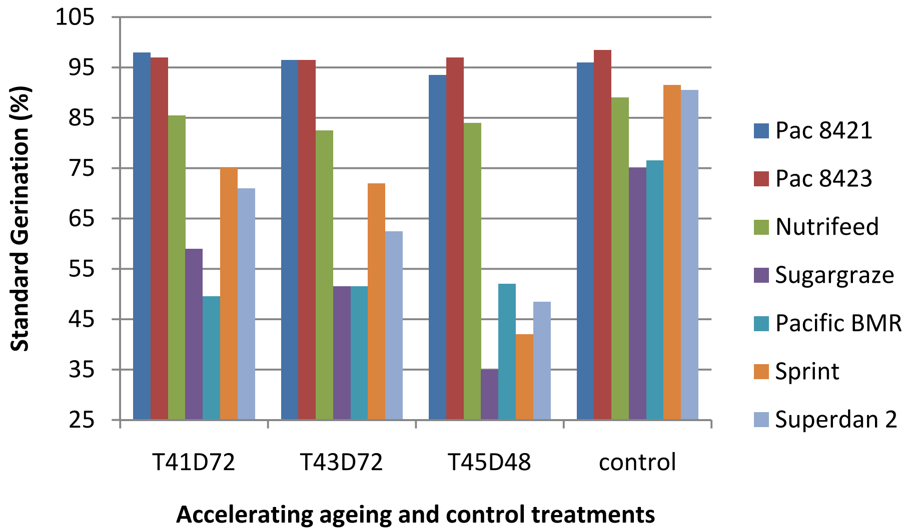

Figure 4.17: The effect of accelerating ageing on normal germination (%) compared with control germination (%).

4.4.2. Field emergence

The field establishment percentages of Nutrifeed, Pac 8421, Pac 8423, Sprint and Superdan 2 for first sowing date were similar, but significantly different from Sugargraze and Pacific BMR which had the lowest emergence rates. For the second sowing, establishment percentages for all the cultivars did not differ significantly. Field emergence for the first sowing date ranged between 77% and 91% with a mean of 85 %, and for the second sowing date, field emergence ranged between 65 and 83% with a mean of 76% (Table 4.10). The field emergence mean for first sowing date was significantly higher than second sowing date. The field emergence of Bettagraze for first and second sowing dates were 86 and 85% respectively. There was no cultivar x sowing date interaction for field emergence.

Table 4.10: Field emergence for first and second sowing dates of different sorghum, sudangrass and pearl millet cultivars.

Cultivar	Sowing Dates	
	December 8	December 21
	Germination %	
Pac 8421	89	73
Pac 8423	86	80
Nutrifeed	88	79
Sugargraze	77	69
Pacific BMR	80	65
Sprint	87	80
Superdan 2	91	83
Mean	85	76
Significance	0.01	NS
LSD $_{(0.05)}$	8	.

4.4.3. Correlation between laboratory germination parameters and field emergence

There was a strong positive correlation between interim control germination and field establishments of first (r = 0.85) and second (r = 0.75) sowing dates, and between normal control germination and field establishments of the first (r = 0.82) and second (r = 0.76) sowing dates. Although field emergence percentage at both sowing dates were positively correlated to the standard germination percentages, the correlation coefficient (r) for first sowing emergence percentage was better than the correlation coefficient (r) of the second sowing date emergence percentage.

The simple correlation coefficients (r values) of interim and normal accelerated ageing germination percentages of T41-D72, T43-D72, and T45-D48, and control with field emergence percentages of the first and second sowing dates were as indicated in Table 4.13. In contrast, the remaining food reserves of T41-D72, T43-D72, T45-D48 and control were negatively correlated to the first and second sowing dates. From the r values (Table 4.13), the interim and final germination counts post-AA and the remaining food reserves of T41-D72, T43-D72 and control treatments showed strong correlation with field seedling establishment. However, the interim and final germination counts post-AA and the remaining food reserves of T45-D48 were poorly correlated with seedling establishment in the field. There were no significant correlations between field emergence for either sowing date and abnormal germination, dead seeds, coleoptiles dry weight per, root dry weight and coleoptile length. The relationship between control final germination and field emergence for the first sowing was strong (Figure 4.18).

The 1000 seed weight of Superdan 2 (15.2 g), Nutrifeed (12.7 g), Pac 8421 (34.1 g), Pac 8423 (29.8 g), Pacific BMR (34.0 g), Sprint (18.9 g), and Sugargraze (32.0 g) had no positive relationship with un-aged laboratory germination.

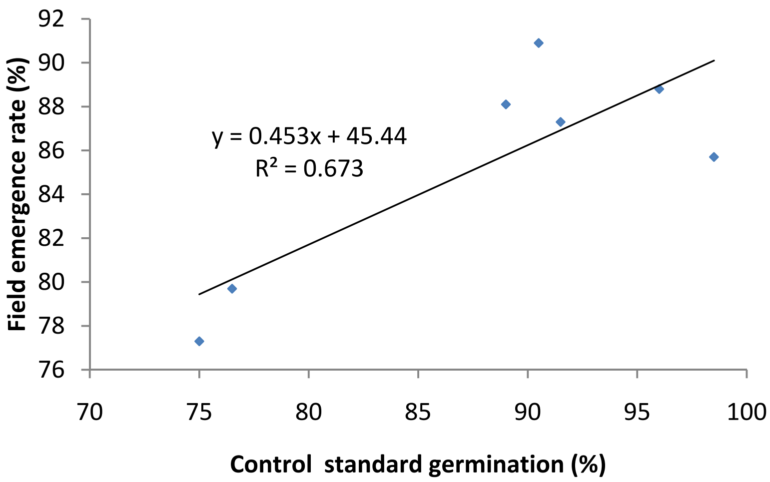

Figure 4.18: Relationship between the control final standard germination and field emergence percentage for first sowing date.

4.4.4. The effect of ageing duration on seed moisture

As the ageing duration increased, seed moisture also increased (Table 4.11). At ageing temperatures and durations of T41-D72, T43-D72 and T45-D48, the mean seed moisture across cultivars were 26.9%, 27.1% and 25.5%, and ranged from 26.3% to 27.7%, 26.5% to 29% and 24.5% to 26.1%, respectively. The seed moisture means of T41-D72 and T43-D72 did not differ significantly, but they were different from the mean of T45-D48 (Table 4.12). However, there were no significant differences between cultivars for seed moisture for each particular accelerating and duration ageing treatment. Also, there was no cultivar x temperature interaction (Table 4.12).

Table 4.11: Seed moisture content of different sorghum, sudangrass and pearl millet cultivars of control (un-aged seed) and post-accelerated ageing treatments (T41-D72, T43-D72, and T45-D48).

	Temperatures (°C) and Duration (Hours)			
Cultivar	Control	T41-D72	T43-D72	T45-D48
	Seed moisture content %			
Pac 8421	12.6	26.3	26.5	25.1
Pac 8423	11.7	27.1	27.0	26.0
Nutrifeed	12.1	27.7	26.8	25.8
Sugargraze	13.3	27.0	29.0	25.5
Pacific BMR	11.3	27.0	26.9	25.2
Sprint	12.1	26.9	26.8	26.1
Superdan 2	13.0	26.5	26.7	24.5
Mean	12.3	26.9	27.1	25.5
Significance	0.0001	NS	NS	NS
LSD $_{(0.05)}$	0.1	.	.	.

Table 4.12: Combined seed moisture content of different sorghum, sudangrass and pearl millet cultivars of post-accelerated ageing treatments.

Cultivar	Seed moisture content (%)
Pac 8421	26.0
Pac 8423	26.7
Nutrifeed	26.8
Sugargraze	27.2
Pacific BMR	26.3
Sprint	26.6
Superdan 2	26.9
Mean	26.5
Significance	NS
Temperature	
T41D72	26.9
T43D72	27.1
T45D48	25.5
Significance	0.0002
Cultivar x Temperature	NS

4.4.5. Fresh un-germinated versus dead seed

Seed that did not germinate within 10 days of the germination test was assessed as dead (that seed which neither was fresh, hard, nor had produced any part of a seedling). This was confirmed by a tetrazolium test where a sample of seed visually assessed as dead did not stain completely. In contrast, viable seed stained completely. (Compare Plate 3.12 with Plate 3.13)

Table 4.13: Simple correlations coefficients for field emergence for two sowing dates against laboratory germination parameters of different sorghum, sudangrass and pearl millet cultivars.

Germination parameters measured	8 December, 2009 sowing date against control or accelerated ageing				21 December, 2009 sowing date against control or accelerated ageing			
	Control	T41D72	T43D72	T45D48	Control	T41D72	T43D72	T45D78
	....				Rvalues...			
Interim germination (%)	0.85*	0.70	0.71	0.48	0.75*	0.59	0.58	0.30
Normal germination (%)	0.82*	0.66	0.60	0.43	0.76*	0.58	0.49	0.26
Abnormal seeds (%)	-0.61	-0.53	0.21	0.53	-0.71	-0.31	0.31	0.60
Dead seeds (%)	-0.84*	-0.65	-0.67	-0.69	-0.70	-0.60	-0.58	-0.46
Dry weight per Coleoptiles (mg)	-0.43	-0.40	-0.40	-0.32	-0.62	-0.53	0.55	-0.43
Dry weight per Root (mg)	-0.56	-0.32	-0.01	-0.54	-0.57	-0.39	-0.30	-0.46
Dry weight per remaining food reserve (mg)	-0.81*	-0.78*	-0.86**	-0.82*	-0.88**	-0.88**	-0.91**	-0.91**
Coleoptiles length (cm)	0.20	0.36	0.38	0.32	-0.12	0.15	0.28	0.14

* Significant at 5% level of probability

** Significant at 1% level of probability

CHAPTER 5 : DISCUSSION

5.1. Forage yield

Yields achieved by the better performing cultivars in both the early and later sowings in this study are generally higher than yields previously reported at the vegetative stage in New Zealand, and this can be attributed to the improvement of cultivars. For example, Gerlach and Cottier (1974) reported yields between about 9,400 and 9,700 kg DM/ha for sudangrass and sorghum *x* sudangrass hybrids, respectively after 77 days. Cottier (1973) reported yields of 6610, 8520, and 8010 kg DM/ha for Japanese millet (*Echinochola crusgalli*), sorghum *x* sudangrass and sudangrass, respectively.

In this study, yields from the later sowing were initially better than those for the earlier sowing. However, re-growth following the 1st harvest was poor as a result of declining autumn temperatures (Table 4.2). The optimum temperature for these crops is > 25 ºC, (Sullivan, 1961) whereas the mean temperature in March 2010 was 15.9 ºC. It is also probable that declining autumn temperatures resulted in reduced photosynthesis and movement of photosythates (Maiti & Soto, 1990). There was also a possibility that the irreversible chlorotic bands (browning) on the leaves due to frost damage (Plate 3.7) would have reduced the photosynthetic area of the plants, and in return reduced the yield as reported by Burns and Wedin (1964). Hence, there was no further accumulaton of dry matter after frost damage. This demostrates that high temperatures and frost free conditions are critical for maximum yield.

In the previous six summer growing seasons (2004/2005 to 2009/2010) in Palmerston North, frost which would have damaged sorghum, sudangrass and pearl millet plants occurred on 12 March, 2005, 14 March, 2006, 2 April, 2007, 10 April, 2008, 3 April, 2009 and 13 March, 2010, respectively (NZMS, nd). Since the Manawatu region, in particular the area surrounding Palmerston North, is likely to experience a first frost anytime starting from the second week of March up to mid-April, sowing should be done in early December to ensure that mid-March or early or mid-April frosts will be avoided or escaped, as sorghum, sudangrass and pearl millet crops would then be harvested or grazed by this time. If earlier sowing is desired appropriate cultivars and/or high vigour seed should be sown because of good ability to withstand adverse conditions and also to ensure good and uniform emergence and establishment.

In this study, yields may have been higher if sowing had been undertaken earlier because declining autumn temperature and frost damage would have been avoided towards the end of the growing season, and high growth rate would have been maintained for a longer period (Causley, 1990). Data from the New Zealand Meterological Services (NZMS,1983) suggests that, generally, soil temperature in the Manawatu region reaches the minimum required for germination of these crops in mid November. For the six years, from 2004 to 2010, the required soil temperatures (16 to 18 ºC) at 10 cm depth were reached on 6 November, 2004, 1 December, 2005, 12 December, 2006, 20 November, 2007, 23 November, 2008 and 8 December, 2009, respectively, thus indicating that sorghum could be sown on these dates (NZMS, nd).

In the case of the 2009/2010 growing season, the average soil temperature for November was below the average long-term temperature. This resulted in delayed sowing from the earlier planned mid-November to early December. Whilst there would be an increased risk of frost with earlier sowing, frosted crops can recover and go on to produce high yields. However, this is dependent on the growth stage of the crop when it is frosted (Causley, 1990). Causley (1990) reported total yields for a sorghum *x* sudan-grass hybrid (cultivar-sudax), which ranged between 21,300 kg/ha from an early November sowing to 11,800 kg/ha from a late December sowing at the Aorangi Research Station, DSIR Grasslands, 15 km west of Palmerston North. These yields were obtained at the flowering stage and hence, they were higher than yields in this study.

The performance of Pac 8423 and Pac 8421, which both carry the brown midrib gene (BMR), was better than that of Pacific BMR, an established and commonly used cultivar in Manawatu, which also carries the brown midrib gene. The mid-rib gene improves the digestibility of the forage, since it decreases the lignin content in the dry matter. However, Miller and Stroup (2004) found that the BMR trait was associated with low vigour and low yield. In contrast, Casler *et al.* (2003) found that yield reductions because of the BMR trait were variable across environments and cultivar specific. This study found similar results. While both Pac 8423 and Pac 8421 performed well, Pac 8423 outperformed Pac 8421, the yield of the second cut of Pac 8421 for the first sowing date reduced significantly due to low growth rate, but the Pac 8423 yield did not drop. The high performance of these cultivars over Pacific BMR can be attributed to cultivar improvement, which has removed the association of low yield and the BMR gene.

In previous comparisons between maize and sorghum in New Zealand, most studies have found that maize produced higher yields, the difference being less in northern areas of the country due to warmer temperatures that promotes sorghum growth (Douglas, 1980). In this study maize was included in the early sowing for comparative purposes. Maize yield at 17,437 kg DM/ha was higher than any of the sorghums. Moreover in this study, the maize yield was accumulated over a longer growing period. Unfortunately, extending the growing period for sorghum in the Manawatu may compromise its quality due to increased fibre content compared to maize fibre content that is offset by highly digestible grains.

Final harvest for the sorghums from the 1st sowing occurred on 22 March whereas the maize plots were harvested on 20 April. The 8 December sowing date is late for maize, even for early maturing hybrids (Wilson *et al*., 1994). As mean growth rates for the best sorghum cultivar (Pac 8423) and maize (P39G12) were similar; 130.1 kg DM/ha/day and 147.6 kg DM/ha/day for P39G12 and Pac8423, respectively (Table 4.4), there is potential to improve cumulative sorghum yields if the growing period can be extended so that the number of grazings/cuttings can be increased before temperatures fall towards the end of the growing season. The growing period can only be increased if the crop is planted as soon as the soil temperature is between 16 to 18 ºC.

It is worth noting that the maize yield (17,437 kg DM/ha) was within 17,151 to 23,330 kg DM/ha and 15,800 to 20,710 kg DM/ha reported by Millner (2002) and Millner *et al*. (2005), respectively. However, it is probable that the maize would have yielded higher than 17,437 kg DM/ha if it had been planted earlier.

In this study, sorghum, sudangrass and pearl millet average total dry matter means (12, 792 and 11, 356 kg DM/ha) for the 1st and 2nd sowing dates were higher than an average yield of turnips (7,400 kg DM/ha) reported by Clark (1995) and Clark *et al*. (1996) in New Zealand (5,000 to 9,500 kg DM/ha) reported by Jacob *et al*. (2004) in Australia.

Sugargraze yields in this study were high. However, this resulted in a higher proportion of stems, thus producing a low leaf/stem ratio.

5.1.1. Tiller density

Nutrifeed tiller density also declined after the 1st harvest, in contrast to all other cultivars. Millet has been found to generally produce less re-growth following cutting or grazing than sorghum (Douglas, 1980). In this study this may have been exacerbated by reduced early growth rate of the millet. Consequently the re-growth of the millet was more exposed to lower temperatures (Table 4.1), and this crop which prefers warmer conditions (Rachie & Majmudar, 1980). There was also a possibility that Nutrifeed had lower food reserves stored in the crown at cutting and less leaf area (photosynthetic area) remained on the cut plants to support re-growth (Fribourg, 1995; Stephenson & Posler, 1984). Therefore, in order to promote high re-growth Beaty *et al.* (1965) suggested that pearl millet needs a residual stubble height of 20 cm rather than 15 cm. This is because 20 cm leaves more area for tiller production than at 15 cm where crowns tend to die with time due to less food reserves to support re-growth. Broyles and Fribourg (1957) also found that re-growth from the higher stubble heights was more vigorous than that from short stubbles.

Tiller density in the sudangrass cultivars was greater than the sorghum *x* sudangrass cultivars, a reflection of the greater tillering ability of sudangrass (Anderson & Guyer, 1986; Cottier, 1973; Gerlach & Cottier, 1974). Tiller density was greater after the 1st harvest for both sowing dates, probably because environmental conditions, particularly optimum temperature, enhanced tiller production (Piggot & Farrell, 1984). In addition, cutting to 15 cm would have greatly increased the light reaching the suppressed tillers below 15 cm. Tiller density for initial growth averaged across cultivars was significantly greater for the first sowing date than for the second sowing date, due to lower temperature at tillering for the first sowing which would have promoted more tillers (Doggett, 1988) (Table 4.2).

5.1.2. Leaf/stem ratio

The mean leaf/stem ratio for the 1st cut for all the cultivars was higher than that for the 2nd cut (Table 4.4), thus indicating that forage quality with more leaf material relative to stems was probably higher for the 1st cut (Elseed *et al.*, 2007). The higher leaf/stem ratio for 1st cut may be because tiller density increased after the 1st cut, thus resulting in increased competition for light, which induced greater stem elongation (Caravetta *et al.*, 1990a). In this study, there was a significant but relatively weak (r = -0.34) negative correlation between tiller density and leaf/stem ratio because of cultivar effect. The decrease of the leaf/stem ratio and an increase in stem proportion may have resulted in reduced forage quality because crude protein is greater in leaves, and leaves are more digestible than stems.

5.1.3. Plant height

In general, the increase in plant height was between 0.7 to 2.7 cm/day. The average increase in plant height of 2.5 cm/day of non-irrigated sorghum plants in Palmerston North reported by Chu and Tillman (1975) was within this range, but was less than the average of an increase in height (5 cm/day) of irrigated plants. This indicates that, as temperatures increase, plant height also increases. Conversely, a gradual decrease in temperature sees a gradual reduction in the increase of plant height and dry matter accumulation per day. This was evident with the re-growth of the second sowing.

In this study, lodging was not observed in any cultivars. Pedersen *et al.* (2005) suggested that BMR cultivars are prone to lodging. This may have been because the cultivars did not head before harvesting. If plants were allowed to head, the heavy ear weights of BMR cultivars may make plants vulnerable to lodging due to reduced lignin content (supportive tissues).

5.1.4. Ear emergence

Ear emergence was only observed in Bettagraze, Pac 8421, Pac 8423 and Sprint, suggesting these cultivars are early maturing. In contrast, heading was not observed in Sugargraze, Nutrifeed, Pacific BMR and Superdan 2 because they are late maturing.

5.1.5. Thermal time

The predicted thermal times (TT) required for the initial growth for sorghum, sudangrass and pearl millet cultivars for both sowing dates to be grazed at 50 cm and 100 cm were similar (Figures 4.3 and 4.5). However, thermal times for re-growth of the second sowing date were greater than thermal times for re-growth of the first sowing date (Figures 4.4 and 4.6). This can be attributted to the low autumn mean temperature in

March 2010 (15.9 ºC), when the re-growth of the second sowing was occuring. Low temperature increases TT requirement (Radhouane, 2008). Furthermore, thermal times for re-growths were greater than initial growths because thermal times for the sprouting stage of the tillers after cutting cultivars were inclusive in this calculation while initial growth only included the TT from emergence to 1st cut. The increase in plant height per each unit of thermal time for both initials of sowing dates and re-growth of the first sowing were similar except regrowth of second sowing that was low because of reduced temperature which resulted in a reduced growth rate.

5.1.6. Relationship between yield, plant height and tiller density

The relationship between height and yield, in this study was strong; as the height increased, the yield also increased (R^2 = 0.69, Figure 4.5). A strong positive correlation between plant height and total biomass yield in sorghum has previously been reported (Brito *et al.*, 2000; Caravetta *et al.*, 1990b; Maiti & Soto, 1990; Taylor *et al.*, 1974). The association between height and yield suggests that height might be used to estimate yield (Piggot, 1989) which would assist farmers with feed budgeting. There was no correlation between dry matter and tiller density observed because different cultivars had different growing strategies such as plant height and plant size. These variations were due to different tiller density for each cultivar.

5.2. Forage quality

5.2.1. Crude protein

The highest crude protein (CP) (18.0%) was found in Nutrifeed (pearl millet). This is most likely because pearl millet is a leafy forage type and the level of CP is greater in leaves than in stems (Ball, 1998; Wall & Ross, 1970). The range of CP (10.3 to 18.0%) across all cultivars assessed was higher than the range of 8% to 14.3% reported by Rachie and Majmudar (1980), but it was similar to the range of 12% to 18% reported by Wall and Ross (1970). Also, it was similar to the concentration of the normal range of desirable herbage for finishing lambs (15 to 18%) and that of mature herbage (13 to 16%) reported by Hodgson and Brookes (1999). The mean of CP content (15.1%) was similar to the CP content (14%) for sorghum reported in Australia by Moss (2009). The level of CP for forage sorghum is dependent on the cultivar grown and management practices, including sowing date and grazing strategy.

Sweet sorghum (Sugargraze) had a lower CP content than the 12% to 18% reported by Wall and Ross, 1970. However, the CP % for Sugargraze was consistent with the observations of Wedin (1970) that in the USA, sweet sorghum is low in CP content, yet high yielding. Regardless, CP contents of all the cultivars assessed in this study were higher than that for maize silage CP (5.4 to 8.2%) reported by de-Ruiter *et al.* (2007) and CP (6.6 to 7.3%) by Millner *et al.* (2005) both in New Zealand. Furthermore, the CP contents of Bettagraze, Nutrifeed, Pac 8421, Pac 8423, Pacific BMR, Sprint and Superdan 2, but not sugargraze were within the CP content range (14.2% to 18.7%) of a summer forage brassica (turnips whole) reported by de-Ruiter *et al.* (2007) and 11 to 24% for turnips leaves reported by Jacob *et al*. (2004), in Australia. However, the CP content of Bettagraze, Nutrifeed, Pac 8421 and Pacific BMR were greater than CP of turnips bulbs (8.1 to 15.7%) reported by de-Ruiter *et al.* (2007).

Undersander and Lane (2001) found that forage sorghum has a higher CP content than maize silage. However, although the CP content was higher than maize, the content for all cultivars was still less than the 19% required for milking cows (Valentine & Kemp, 2007), but it was greater than the 7% required for beef cows (Buxton, 1996). In addition, CP range (10.3% to 18.0%) was similar to the 15% to 18% needed to finish lambs in New Zealand: but it was less than 18% to 20% required for dairy cows as reported by Hodgson and Brookes (1999). This suggests that forage sorghum has sufficient CP for finishing lambs and beef animals, but dairy cows which are raised on these forage sorghum cultivars grown under these conditions will require some other supplements, for example, Lucerne in order to increase the CP in their diet.

The higher concentration of CP observed in this study, compared with that reported by Marsalis *et al*. (2010) (7.1% to 7.6%) can be attributed to the grown cultivars and good soil fertility status which ensured that sufficient nitrogen was available. This resulted in improved nitrogen content within the plants (Moss, 2009). In addition, the timely harvesting (at the vegetative stage) of the forage cultivars also avoided the dilution of the CP content as the yield increased (Snyman & Joubert, 1996).

Reich (2007) commented that BMR cultivars have a higher CP content than non-BMR cultivars. However, in this study, the CP content in some BMR cultivars was similar to the non-BMR cultivars. This can be attributed to the improved yield of BMR cultivars, which resulted in a low protein level (dilution effect).

5.2.2. Metabolisable energy

In general, the metabolisable energy (ME) content of the different cultivars (10.1 to 11.0 MJ/kg DM) in this study, was higher than the 8.5 to 9.3 MJ/kg DM reported by Miller and Stroup (2004) and the 8 to 9.5 MJ/kg DM reported by Moss (2009). This is because lower fibre content increases digestibility. For example, in this study, the means of ADF (35.1%) and NDF (61.5) were less than the means of the ADF (40%) and NDF (68%) reported by Moss (2009). The sorghum, sudangrass and pearl millet ME values in this study were similar to those reported in maize silage (10.3 to 12.4 MJ/kg DM) by de-Ruiter *et al.* (2007) and (10.3 to 11.3 MJ/kg DM) by Millner *et al.* (2005) in New Zealand. The lower fibre content is probably a result of the lower temperature experienced during the growing period which reduces fibre synthesis (Ford *et al*., 1979; Peacock, 1982; Sullivan & Graber, 1947; Wilson *et al*., 1991; Worker & Marble, 1968). However, the ME range of sorghum, sudangrass and pearl millet cultivars (10.1 to 11.0 MJ/kg DM) was less than the ME of whole turnips (11.8 to 12.5 MJ/kg DM) reported by de-Ruiter *et al.* (2007) and (11 to 13 MJ/kg DM) by Clark *et al.* (1996). Using the ME classification described by Stewart and Charton (2006), sorghum, sudangrass and pearl millet have intermediate ME contents because the average value (10.5 MJ/kg DM) in this study, was less than the average of the high quality forage (13 MJ/kg DM) and greater than the average of the low quality forage (8 MJ/kg DM).

Pacific BMR and Pac 8421 had the highest ME contents, which is attributable to the presence of the BMR gene that decreases fibre content (Casler *et al.,* 2003). ME of non-BMR Nutrifeed was as high as Pacific BMR and Pac 8421 because it is a leafy cultivar which results in increased digestibility (Ball, 1998; Chu & Tillman, 1976).

Pac 8423 had low ME compared to the other BMR cultivars due to high ADF and NDF fibre contents, especially ADF (36.5%). The plant height (119.6cm) of this cultivar was greater than Pacific BMR (89.1 cm) and Pac 8421 (106.0 cm). This would have increased fibre content, since height is strongly correlated to fibre content (Buxton & Fales, 1994). In this study, ME was negatively correlated to plant height (Figure 4.15).

ME for non-BMR cultivars (Sugargraze, Sprint, superdan 2, and Bettagraze) was lower than for Pacific BMR, Pac 8421 and Nutrifeed due to a higher fibre content (Table 4.16). Nonetheless, the ME of these cultivars apart from Sugargraze, were within the range for maize reported by de-Ruiter *et al,* (2007) and by Millner *et al.* (2005). In addition, the mean ME (10.5 MJ/kg DM) of all cultivars was similar with the 10 MJ/kg DM targeted by New Zealand dairy farmers for forage silage during summer feed deficits to ensure good milk production (Litherland & Lambert, 2007). These ME levels are greater than the 7 to 9 MJ/kg DM and the 10 MJ/kg DM needed for low production/maintenance feeding of beef animals (Suyama *et al*., 2007).

5.2.3. Soluble sugars and starch

Large differences in soluble sugars and starch were observed between the cultivars due to different genetic potential. Possibly, the greater the leaf area available for interception of radiation for photosynthesis, the higher will be the SSS concentration (Worker and Marble, 1968).

5.2.4. Relationship between agronomic traits and forage quality

The CP content reduced as yield increased because the accumulation of dry matter rate was faster than the accumulation rate of CP, hence there was a dilution effect (Ayub, 2009; Van Soest, 1994). Since CP concentration is greater in leaves than in stems, the increase in plant height also reduced the CP concentration because of decreased leaf and increased stem area (Buxton & Casler 1993; Kilcer *et al*., 2005).

The ME of sorghum forage crops decreased with increase in height because as the plant height increases highly lignified support tissues such as sclerenchyma and xylem are produced. Sclerenchyma and xylem are structural characteristics that reduce forage digestibility (Akin, 1989). In addition, as the plant advanced in age, lignification may have increased (Akin, 1989).

5.3. Seed quality

5.3.1. Germination and seed vigour

The accelerated ageing and control treatments ranked the cultivars by seed vigour as follows: Pac 8421 and Pac 8423 were highest, followed by Nutrifeed, then Sprint and Superdan 2. Sugargraze and Pacific BMR had the lowest seed vigour. Pac 8421 and Pac 8423 had higher seed vigour; hence their post-ageing germination was higher, since they were able to withstand physical stresses (high temperature and relative humidity) better than the lower vigour seed. Therefore, ageing had no effect on the seed germination of Pac 8421 and Pac 8423, since their germination was the same across all ageing treatments (T41-D72, T43-D72 and T45-D48). The seeds of these two cultivars are likely to be able to tolerate adverse field conditions. In contrast the reduction in germination of seeds of Sprint and Superdan 2 showed that they were sensitive to adverse field conditions unlike Pac 8421 and Pac 8423. Pacific BMR and Sugargraze seeds were significantly affected by ageing indicating they were vulnerable to stressful conditions. Also, the control germination of both Pacific BMR and Sugargraze was 76% and 75%, respectively. This low germination under ideal conditions indicates that these two cultivars have low seed vigour that makes them prone to a fast deterioration rate. This problem could be attributed to their genetic potential. Therefore, further research may be needed to determine if these cultivars' low germination is due to inherent low vigour.

As the accelerating ageing temperature increased, the germination percentage was reduced because of enzyme systems that were possibly damaged thus resulting in an increased number of dead seeds and abnormal seedlings (Perl *et al.*, 1978). To be specific, when ageing temperature was increased to T45-D48, germination of Sprint, Superdan 2, Sugargraze and Pacific BMR reduced further significantly. This reduction in germination after ageing seed was the percentage of seed that had low vigour and this indicated the percentage of seed deterioration that had occurred when the seed was exposed to harsh conditions. The higher the percentage of seed with low vigour, the higher the number of dead seeds there will be. The ageing temperature, in this study was more critical than ageing duration in deteriorating the seed, for example, even though seed was aged for longer (72 hours) at lower temperature seed germination did not decline as much as ageing at 45 ºC for 48 hours

The weight of remaining food reserves also increased when ageing temperature increased, probably due to reduced growth rate of the seedlings, which resulted in less food being used to support seedling growth. However, it was observed that the weight of remaining food reserves for Pac 8423 and Nutrifeed did not increase, thus indicating that seedling growth rate of these cultivars was not affected by an increase in ageing temperature. This scenario reflected the negative relationship between remaining food reserves and germination. Cultivar and temperature interactions observed were due to the much lower germination percentage for cultivars with low seed vigour compared to cultivars with high seed vigour.

5.3.2. Field emergence

During the field germination stage of the second sowing, heavy down-pours of rain occurred resulting in some pools of water in the field. Therefore, wet and cold soil conditions were experienced, which probably inflicted stress on the seeds. Because of this, mean seed germination would have been slowed and therefore a lower establishment percentage (76%) was encountered compared to establishment of the first sowing (85%). The low pattern of field emergence for second sowing across all cultivars can be attributed possibly to the excess water (pools of water in some spots within plots) in the field, which damaged the seed and limited air (oxygen) supply in the soil. This may have created anaerobic conditions that led to seed or seedling death (Hampton *et al.,* 1999; Martin, 1986). Also, the cold soil due to excess water could have caused a slow rate of germination that reduced the ability of seed to withstand adverse conditions, this may have resulted in germinating seedlings being attacked by soil fungal and thus the final establishment was reduced (Delouche & Baskin, 1973). Therefore, field emergence of first sowing date was higher than the second sowing date, because the field conditions were slightly better than the conditions of the second sowing date. Field emergences of sorghum, sudangrass and pearl millet took almost 10 days to emerge for the first sowing. A similar emergence time was reported in sorghum by Vanderlip (1993). But the second sowing field emergence was almost 12 days because of watery conditions in some spots within plots that reduced the soil temperature.

Despite mean field emergence for sorghum, sudangrass and pearl millet forage for both sowings being less than 92 % for the maize silage used in this study, and the 96% reported by Aslam *et al.* (1999) in Palmerston North, New Zealand, they were higher than sorghum mean field emergence reported by other workers, for example, 60% by Taylor *et al.* (1974), 60% to 75% by Dogget (1988), 75% by Vanderlip *et al.* (1973), 32% to 60% by Pedersen and Toy (2001), 55% by Radford *et al.* (1989) and 55% by Singh and Dwaliwal (1972). But, they were less than the field emergence of 93% reported by Ibrahim *et al*. (1993). These different findings of sorghum germination by different workers have confirmed the statement by Swanson and Hunter (1936) that sorghum germination shows many discrepancies, due to greater variations that have been attributed to germination conditions (moisture and temperature). For example, Ketterings *et al*. (2007) stated 25 to 30 ºC as being the optimum soil temperature for sorghum species while Gerlach and Cottier (1974) stated 16 to 18 ºC, and Undersander *et al*. (1990) stated 21 ºC. Because of these differences, it is worth stating that the final germination of sorghum is also greatly influenced by germination conditions in addition to cultivars' genetic potential. Therefore, the germination percentages reported by different workers were low because seeds were planted in hotter and drier areas than the Manawatu and different cultivars were used. Therefore, high temperatures and inadequate moisture have been pointed out as the two primary ecological factors that affect germination and emergence of sorghum seed.

5.3.3. Correlation between laboratory germination parameters and field emergence

Un-aged seed germination correlated strongly with seedling establishment in the field, thus indicating that the field conditions were favourable. In particular, field conditions for the first sowing were more favourable than those for second sowing, and hence, the correlation between un-aged seed germination and the first sowing date was greater than second sowing date. Correlation between un-aged seed germination and field emergence was similar to that reported by Yayock *et al.* (1975) who found a correlation for two sowing dates of sorghum of 0.81 and 0.93. Results from this study confirm that un-aged seed germination can be used to predict field emergence if field conditions are favourable. However, in the case of unfavourable field conditions, un-aged seed germination results can over-estimate the actual field emergence (AOSA, 1983; Hampton & TeKrony, 1995; Kulik & Yaklich, 1982).

In this study, accelerated ageing germinations of T41-D72 and T43-D72 also correlated with field emergence, but their r-values were less than the r-values for un-aged seed germination and field emergence. Under adverse conditions, in agreement with Ibrahim *et al*. (1993) and Hampton and TeKrony (1995) T43-D72 can be considered the best accelerating ageing temperature and duration to use to differentiate sorghum seed lots by cultivar. The data for this ageing regime was less variable than the other data but also the standard germination test did not differentiate between Pac 8421, Pac 8423 and Nutrifeed nor did T45-D48 differentiate between Pac 8421 and Nutrifeed.

There was no correlation between coleoptiles length and field emergence. Moreover, coleoptiles length was inherently different between the cultivars used. This suggests that vigour testing using seedling growth rate cannot be used to rank cultivars, unless the objective was to rank seed lots of a specific cultivar (Hampton & TeKrony, 1995).

Also, there was no positive relationship observed between 1000 seed weight and standard germination due to the cultivar effect. This meant that the seed weight of different cultivars cannot be used to predict the germination and vigour of seed. For example, Pacific BMR and Sugargraze were among the cultivars that had high 1000 seed weight, but they had the lowest seed germination and seed vigour. Probably, the positive relationship between 1000 seed weight and standard germination would have been present if the evaluation was among seed lots of a particular cultivar rather than among cultivars of different species (Scott & Hampton, 1985).

5.3.4. The effect of ageing duration on seed moisture

No differences in the moisture content of aged seed within the temperature and ageing treatment were observed, due to uniform and constant absorption of water from the surrounding environment in the ageing inner chambers during the ageing process, and this confirmed the observations of Ibrahim *et al.* (1993). Furthermore, it indicated that ageing procedures were implemented according to the recommendations of Hampton and TeKrony (1995). The moisture range of aged seed was 27% to 29% for T43-D72, which is similar to 29% to 30% reported by Hampton and Tekrony (1995) and 29% to 30% reported by Ibrahim *et al.* (1993). However, the range of moisture of the aged seed 26.3% to 27.7% and 24.5% to 26.1% for T41-D72 and T45-D48, respectively, were lower than the moisture of aged seed reported by Hampton and Tekrony (1995) and

Ibrahim *et al.* (1993). This indicates that these accelerating ageing and duration treatments (T41-D72 and T45-D48) may not stress the seed as much as T43-D72 which may impact on the ability to rank the seed lot by vigour.

Seed moisture of un-aged seed was within 12 to 13% at the end of the storage period between sowing and vigour testing. There may have been some loss of vigour in the nine month gap between sowing and vigour testing. However, given the storage conditions of low moisture and temperature this should have been minimal, if any. This can be confirmed by the findings of Ahmed and Alama (2010) that germination and seed vigour of sorghum is maintained satisfactorily for approximately one year at seed moisture of 12% to 13%, provided storage temperature and relative humidity is 20 ºC and 6%, respectively. At temperatures of -1.1, 10 and 21 ºC, sorghum seed at 10% moisture content have no significant differences in germination, but there are significant differences when seed is stored at 21.1 and 32 °C for one and two years (Bass *et al.*, 1963). Since Bettagraze had higher seed moisture (15.1%) which is outside the safe storage moisture content for sorghum seed, then it is probable that the Bettagraze vigour was likely to be reduced. However, because of the error of pre-drying, no conclusion can be drawn on this. Regardless, it was not included in the data analysis because of the confounding factor of incorrect drying temperature.

5.3.5. Fresh un-germinated versus dead seed

All un-germinated seeds were dead probably due to the harsh environmental conditions the seeds were exposed to resulting in seed deterioration. Hence, they were unable to withstand adverse conditions due to low seed vigour.

CHAPTER 6 : CONCLUSIONS

1. Significant yield differences among cultivars for total yield were observed. The highest yielding group included Pac 8423 (13,953 kg DM/ha), Sugargraze (13,262 kg DM/ha), Bettagraze (12,704 kg DM/ha) and Sprint (12,426 kg DM/ha).

2. There was a strong, positive relationship between yield and plant height.

3. The sowing date had a significant effect on forage yields and crop morphology; later sowing reduced yield, leaf/stem ratio, plant height and tiller density.

4. Crude protein and metabolisable energy were negatively correlated with yield and height. Crude protein and metabolisable energy were strongly and positively correlated.

5. Crude protein was generally high (10.3 to 18.0%), metabolisable energy was intermediate (10.1 to 11.0 MJ/kg DM), and fibre content was generally low [ADF (32.9 to 36.5%) and NDF (57.2 to 65.2%)].

6. Seeds with low vigour had poor field emergence compared to seed with high vigour. This indicated that the establishment percentage is influenced by seed quality and the prevailing sowing conditions.

7. The standard germination test predicted the field emergence for the first sowing date better than second sowing date because the field environment conditions were more favourable for the first sowing than the second sowing. Nevertheless, field conditions for both sowings were good, hence standard germination test gave the better prediction of field emergence than accelerating ageing test (vigour test).

8. Accelerating ageing temperature and ageing duration (43 °C 72 hours) (AA) is the most suitable combination for testing the seed vigour of sorghum, sudangrass, and pearl millet forage cultivars.

9. Forage sorghum and pearl millet are capable of producing early and adequate feed for livestock in the case of feed shortage, since they can be grazed *in situ* much earlier in summer than maize that grows up to the milk line before harvesting.

6.1. Recommended further research

Recommendations for further research are as follows:

a) Determination of the effect of seedbed temperature on seed germination, emergence and early seedling development of different sorghum, sudangrass, and pearl millet cultivars.

b) Evaluation of the effect of animal grazing on the re-growth ability, and assessment of the level of damage caused by trampling of different cultivars.

c) Comparison of the cyanide content of different cultivars of sorghum, sudangrass, and pearl millet cultivars at different plant heights.

REFERENCES

Acquaah, G. (2005). *Principles of crop production: Theory, technique, and technology* (2 ed.). Upper Saddle River, New Jersey, United States of America, Pearson Prentice Hall.

Adams, R. S., McCarty, T. R., & Hutchinson, L. J. (nd). Prevention and control of nitrate toxicity in cattle, Department of Dairy and Animal Science, The Pennsylvania State University, 324 Henning Building University Park, PA 16802. Retrieved on 2 August,2009, from http://www.das.psu.edu/research-extension/dairy/nutrition/pdf/nitrate.pdf

Ahmed, E. E. A., & Alama, S. H. A. (2010). Sorghum (*Sorghum bicolor (L.) Moench.)* seed quality as affected by type and duration of storage. *Agriculture and Biology Journal of North America 1*, 1-8.

Akin, D. E. (1989). Histological and physical factors affecting digestibility of forages. *Agronomy Journal, 81*, 17-25.

Al-Kaisi, M. M., & Yin, X. Y. (2003). Effects of nitrogen rate, irrigation rate, and plant population on corn yield and water use efficiency. *Agronomy Journal, 95*, 1475-1482.

Almekinders, C. J. M., & Louwaars, N. P. (1999). *Farmers' seed production: New approaches and practices*. London: Intermediate Technology Publications.

Amaral, S. R., Lira, M. A., Tabosa, J. N., Santos, M. V. F., Mello, A. C., & Santos, V. F. (2003). Behavior of sweet sorghum lines exposed to water deficit under controlled condition. *Pesquisa Agropecuária Brasileira, 38*, 973-979.

Anderson, B., & Guyer, P. (1986). Summer annual forage grasses, NebGuide, University of Nebraska-Lincoln Extension, G74-171. Retrieved on 5 May, 2010, from http://digitalcommons.unl.edu/extensionhist/1303.

AOSA. (1983). Association of Official Seed Analysts, *Seed Vigour Testing Handbook*, AOSA Contribution No. 32.

Armah-Agyeman, G., Loidand, J., Karow, R., & Bean, B. (2002). Dryland cropping systems: Sudangrass, Oregon State University Extension Services, EM 8793. Retrieved on 5 May, 2010, from http://extension.oregonstate.edu/catalog/pdf/em/em8793-e.pdf

Aslam, T., Choudhary, M. A., & Saggar, S. (1999). Tillage impacts on soil microbial biomass C, N and P, earthworms and agronomy after two years of cropping following permanent pasture in New Zealand. *Soil and Tillage Research, 51*, 103-111.

Assaeed, A. M. (1994). Evaluation of some sweet sorghum varieties under the condition of Central Region, Saudi Arabia. *Annals Agricultural Science, 39*, 649-654.

Ayub, M. (2009). Effects of nitrogen application and harvesting intervals on forage yield and quality of Pearl millet (*Pennisetum americanum* L.). *Pakistan Journal of Life Science, 7*, 185-189.

Ball, D. M. (1998). Summer annual grasses as forage crops in Alabama, Alabama Cooperative Extension System, Circular ANR-134, Agronomy and Soils, Auburn University. Retrieved on 4 June, 2009, from http://www.aces.edu/pubs/docs/A/ANR-0134/.

Barnes, R. F., & Marten, G. C. (1979). Recent developments in predicting forage quality. *Journal of Animal Science, 48*, 1554 -1560.

Barriere, Y., Guillet, C., Goffner, D., Pichon, M., & Martin, B. A. (2003). Genetic variation and breeding strategies for improved cell wall digestibility in annual forage crops. A review. *Animal Research 52*, 193-228.

Bass, L. N., Clark, D. C., & James, E. (1963). Vacuum and inert gas storage of crimson clover and sorghum seeds. *Crop Science, 3*, 425–428.

Bean, B., McCollum, T., Villarreal, B., Blumenthal, J., Robinson, J., Brandon, R., Buttrey, E., VanMeter, R., & Pietsch, D. (2009). Texas Panhandle sweet sorghum silage trial,Texas A & M University System,Texas AgriLife Research and Extension Center. Retrieved on 29 June, 2010, from http://amarillo.tamu.edu/files/2010/11/Forage-Sorghum-2009-Variety-Report-Final.pdf

Beaty, E. R., Smith, Y. C., McCreery, R. A., Ethredge, W. J., & Beasley, K. (1965). Effect of cutting height and frequency on forage production of summer annuals. *Agronomy Journal, 57*, 277-279.

Bertram, J. D., Sneath, R. J., Taylor, K. M., Mills, B. D., McKenzie, R. A., & Reichmann, K. G. (2005). Cyanide (prussic acid) and nitrates in sorghum crops: Queensland, Department of Employment,Economic Development and Innovation, Queensland Primary Industries and Fisheries. Retrievd on 4 June, 2009, from http://www.dpi.qld.gov.au/health/11762.html

Beuerlein, J. E., Fribourg, H. A., & Bell, F. F. (1968). Effects of environment and cutting on the regrowth of a sorghum *x* sudangrass hybrid. *Crop Science, 8*, 152-155.

Black, J. R., Ely, L. O., McCullough, M. E., & Sudweeks, E. M. (1980). Effects of stage of maturity and silage additives upon the yield of gross and digestible energy in sorghum silage. *Journal of Animal Science, 50*, 617-624.

Blum, A. (2005). Drought resistance, water-use efficiency, and yield potential - are they compatible, dissonant, or mutually exclusive?. *Australian journal of agricultural research, 56*, 1159-1168.

Bosley, D. B., Meyer, R. F., Schneekloth, J. P., Schmitz, G. G., & Vigil, M. F. (2005). Northeast Colorado Forage Comparisons, Technical Report, TR05-05, A Cooperative Project of the Cooperative Extension, Department of Soil and Crop Sciences, Colorado State University Fort Collins, Colorado and the USDA-Agricultural Research Service Central Great Plains Experiment Station Akron, Colorado. Retrieved on 29 June, 2009, from www.colostate.edu/dept/aes/Pubs/pdf/tr05-05.pdf

Brar, G. S., & Stewart, B. A. (1994). Crop quality and utilization: Germination under controlled temperature and field emergence of 13 sorghum cultivars. *Crop Science*, 1336-1340.

Brito, A. F., Goncalves, L. C., Rodrigues, J. A. S., Rocha Junior, V. R., Borges, I., & Rodriguez, N. M. (2000). Evaluation of silage from seven sorghum genotypes (Sorghum bicolor (L) Moench). I: Agronomical characteristics. . *Arquivo Brasileiro de Medicina Veterinaria e Zootecnia 52*, 391-396.

Brown, J. (1916). Summer forage crops for Northern Districts. *New Zealand Journal of Agriculture, 13*, 200-204.

Broyles, K. R., & Fribourg, H. S. F. (1957). Nitrogen fertilization and cutting management of sudangrass and millets. *Agronomy Journal, 51*, 277-279.

Burns, J. B., & Wedin, W. F. (1964). Yield and chemical composition of sudangrass and sweet sorghum under three systems of summer management for late fall *in-situ* utilization. *Agronomy Journal, 56*, 457-460.

Busk, P. K., & Moller, B. L. (2002). Dhurrin Synthesis in Sorghum Is Regulated at the Transcriptional Level and Induced by Nitrogen Fertilization in Older Plants1. *Plant Physiology, 129*, 1222-1231.

Buxton, D. R. (1996). Quality-related characteristics of forages as influenced by plant environment and agronomic factors. *Animal Feed Science and Technology, 59*, 37-49.

Buxton, D. R., & Casler, M. D. (1993). Environmental and genetic effects on cell wall compostion and digestibility. In H. G. Jung, D. R. Buxton, R. D. Hatfield & J. Ralph (Eds.), *Forage cell wall structure and digestibility* (pp. 685-714). ASA, Madison, WI.

Buxton, D. R., & Fales, S. L. (1994). Plant environment and quality. In G. C. Fahey, M. Collins, D. R. Mertens & L. E. Moser (Eds.), *Forage Quality, Evaluation, and Utilization* (pp. 155-199). Madison, United States of America: America Society of Agronomy.

Cameron, A. G. (2006). Agnote No: C19 : Forage Sorghum, Department of Primary Industry, Fisheries and Mines, Australia. Retrieved on 4 June, 2009, from http://www.nt.gov.au/d/Content/File/p/Crop/514.pdf

Caravetta, G. J., Cherney, J. H., & Johnson, K. D. (1990a). Within-row spacing influences on diverse sorghum genotypes: I. Morphology. *Agronomy Journal 82*, 206-210.

Caravetta, G. J., Cherney, J. H., & Johnson, K. D. (1990b). Within-row spacing influences on diverse sorghum genotypes: II. Dry matter yield and forage quality. *Agronomy Journal, 82*, 210-215.

Casler, M. D., & Boe, A. R. (2003). Cultivar x environment interactions in switchgrass. *Crop Science, 43*, 2226-2233.

Casler, M. D., Pedersen, J. F., & Undersander, D. J. (2003). Forage yield and economic losses associated with the brown-midrib trait in sudangrass. *Crop Science, 43*, 782-789.

Causley, C. D. (1990). Effect of minimum tillage, sowing rate and sowing time on the yield of a sorghum-sudangrass hybrid in the manawatu, New Zealand. *New Zealand Journal of Agricultural Research 33*, 15-20.

Cerosaletti, P., Ketterings, Q. M., & Kilcer, T. (2002). 2001 Delaware country BMR sorghum sudangrass trial. *What's Cropping Up?, 12*, 1-3.

Chaudhry, A. R., Ghani, A., & Rehman, N. (1990). Variability for fodder yield and itd componentd in sorghum. *Journal of Agriculture Research, 28*, 379-383.

Cherney, J. H., Axtell, J. D., Hassen, M. M., & Anliker, K. S. (1988). Forage quality characterization of a chemically induced brown-midrib mutant in pearl millet. *Crop Science, 28*, 783-787.

Chu, C. P., & Tillman, R. F. (1976). Growth of a sweet sorghum hybrid under two soil moisture regimes in the Manawatu. *New Zealand Journal of Experimental Agriculture, 4*, 351-355.

Clark, D. A. (1995). Summer milk-pasture and crops. *Proceedings of the 47th Ruakura farmers conference* (pp. 10-16). Hamilton, New Zealand: Brebner Print.

Clark, D. A., Howse, S. W., Johnson, R. J., Pearson, A., Penno, J. W., & Thomson, N. A. (1996). Turnips for summer milk production. *Processings of the New Zealand Grassland Association, 57*, 145-150.

Clarke, T., Flinn, P. C., & McGowan, A. A. (1982). Low cost pepsin-cellulose assays for prediction of digestibility of herbage. *Grass and Forage Science, 37*, 147-150.

Collins, M., & Fritz, J. O. (2003). Forage quality. In R. F. Barnes, C. J. Nelson, M. Collins & K. J. Moore (Eds.), *Forages: An introduction to grassland agriculture* (6 ed., Vol. 1, pp. 363-390). Iowa State: A Blackwell Publishing Company.

Copeland, L. O. (1976). Seed and seedling vigour: Principles of seed science and technology (pp. 149-184).

Cottier, K. (1973). Experiments with warm-zone crops for summer greenfeed in the Waikato. *Proceedings of the Agronomy Society of New Zealand, 3*, 25-31.

Cox, E. (1968). Evaluation of climate and its correlation with soil groups, Pp 33-34 in: Soils of New Zealand, Part 1.Soil Bureau Bulletin 26(1).New Zealand Department of Scientific and Industrial Research.

Crush, J. R., & Rowarth, J. S. (2007). The role of C4 grasses in New Zealand pastoral systems. *New Zealand Journal of Agricultural Research, 50*, 125-137.

Cumberland, G. L. B. (1974). Growing and using high yielding crops and coping with drought.1. Summer fodder crops. *Proceedings of the Ruakura farmers' conference*, 113-126.

de-Ruiter, J. M., Dalley, D. E., Hughes, T. P., Fraser, T. J., & Dewhurst, R. J. (2007). Types of supplements:Their nutritive value and use. In P. V. Rattray, I. M. Brookes & A. M. Nicol (Eds.), *Pastures and supplements for grazing animals: New Zealand Society of Animal production , Occasional Publication No 14* (pp.

97-116). Hamilton, New Zealand: New Zealand Society of Animal production (Inc).

Deinum, B., & Dirven, J. G. P. (1975). Climate, nitrogen and grass. 7. Comparison of yield and chemical composition of some temperate and tropical grass species grown at different temperatures. *Netherlands Journal of Agriculture Science, 23*, 69-78.

Delouche, J. C., & Baskin, C. C. (1973). Accelerated ageing techniques for predicing the relative storability of seed lots. *Seed Science and Technology, 1*, 427-452.

Dibble, W. (1915). Crops for silage. *New Zealand Journal Of Agriculture, 10*, 222-226.

Doggett, H. (1988). *Sorghum: Tropical agriculture series* (2 ed.). Harlow, Essex, England: Longman Scietific & Technical.

Don, I. (2003). *International Seed Testing Association (ISTA), Handbook on Seedling Evaluation, Bassersdorf, Switzerland.* (3 ed.).

Douglas, J. (1980). Yield of crops for forage and fodder. In K. R. Drew & P. F. Fennessy (Eds.), *Supplementary feeding: New Zealand Society of Animal Production Occasional Publication No. 7* (pp. 1-47).

Ellison, R. S. (1994). Poisonings in ruminants grazing pasture and fodder crops. *Surveillance :Ruakura Animal Health Laboratory, 21*, 23-26.

Elseed, A. M., Eldaim, N. I. N., & Amasaib, E. O. (2007). Chemical composition and in situ dry matter degradability of stover fractions of five sorghum varieties. *Journal of Applied Sciences Research, 3*, 1141-1145.

Esbo, H. (1980). Seed quality control. *Advances in Research and Technology of seeds, 5*, 9-24.

Evans, W. F., Stickler, F. C., & Laude, H. H. (1961). Sorghum seed germination as affected by moisture and temperature. *Transactions of the Kansas Academy of Science 64*, 210-217.

Fanous, M. A. (1967). Test for drought resistance in pearl millet. *Agronomy Journal, 59*, 337-340.

Farhoomand, M. B., & Wedin, W. F. (1968). Changes in composition of sudangrass and sweet sorghum with maturity. *Agronomy Journal, 60*, 459-463.

Farrar, J. K. (1988). Temperatures and the partitioning and translocations of carbon. Society for Experimental Biology. In S. P. Long & F. I. Woodward (Eds.), *Plants and Temperatures*. Cambridge, UK.

Farré, I., & Faci, J. M. (2006). Comparative response of maize (Zea mays L.) and sorghum (Sorghum bicolor L. Moench) to deficit irrigation in a mediterranean environment. *Agricultural Water Management, 83*, 135-143.

FAO. (2010). Food and Agriculture Organization (FAO), Agricultural statistics. Retrieved on 28 February, 2011, from http://www.fao.org

Fjell, D., Blasi, D., & Towne, G. (1991). Nitrate and prussic acid toxicity in forage :Causes, prevention, and feeding management, Cooperative Extension Service, Kansas State University, Manhattan, MF- 1018, USA. Retrieved on 25 July, 2009, from http://www.ksre.ksu.edu/library/crpsl2/s115.pdf

Ford, C. W., Morrison, I. M., & Wilson, J. R. (1979). Temperature effects on lignin, hemicellulose and cellulose in tropical and temperate grasses. *Australia Journal of Agricultural Research, 30*, 621-633.

Free, H. F., McGill, C. R., Rowarth, J. S., & Hedley, M. J. (2010). The effect of biochars on maize (Zea mays) germination. *New Zealand Journal Of Agricultural Research, 53*, 1-4.

Fribourg, H. A. (1995). Summer annual grasses: Forage In R. F. Barnes (Ed.), (5 ed., Vol. 1): Iowa State University press Ames.

Fulgueira, C. L., Amigot, S. L., Gaggiotti, M., Romero, L. A., & Basilico, J. C. (2007). Forage quality:Techniques for testing. *Fresh Produce, 1*, 121-131.

Fulkerson, W. J., Horadagoda, A., Neal, J. S., & Barchia, I. (2008). Nutritive value of forage species grown in the warm temperate climate of Australia for dairy cows:Herbs and grain crops. *Livestock Science, 114*, 75-83.

Gerlach, J. C. (1974). Climatographs of New Zealand, Ministry of Agriculture and Fisheries Research *Bulletin, 74-1*.

Gerlach, J. C., & Cottier, K. (1974). The use of sorghum as forage crops. *Proceedings of the Agronomy Society of New Zealand, 4*, 83-85.

Gillingham, J. T., Shirer, M. M., Starnes, J. J., Page, N. R., & McClain, E. F. (1969). Relative occurrence of toxic concentrations of cyanide and nitrate in varieties of sudangrass and sorghum-sudangrass hybrids. *Journal of Agronomy 61*, 727-730.

Gorz, H. J., Haag, W. L., Specht, J. E., & Haskins, F. A. (1977). Assay of p-Hydroxybenzaldehyde as a measure of hydrocyanic acid potential. *Crop Science, 17*, 578 -582.

Guinn, G. (1971). Changes in sugar, starch, RNA, protein and lipid-soluble phosphate in leaves of cotton plants at low temperatures. *Crop Science, 11*, 262-265.

Gururanjan, B. (1993). Influence of agrometeorological factors on dry fodder yield of sorghum (*Sorghum bicolor* (L.) Moench). *Forage Research. , 19*, 249 -260.

Halkier, B. A., & Moller, B. L. (1989). Biosynthesis of the cyanogenic glucoside dhurrin in seedlings of sorghum bicolor (L.) Moench and partial purification of the enzyme system involved 1. *Plant Physiology, 90*, 1552-1559.

Hammer, G. L., Vanderlip, R. L., Gibson, G., Wade, L. J., Henzell, R. G., Younger, D. R., Warren, J., & Dale, A. B. (1989). Genotype-by-environment interaction in grain sorghum. II. Effects of temperature and photoperiod on ontogeny. *Crop Science, 29*, 376-384.

Hampton, J. G., Kemp, P. D., & White, J. G. H. (1999). Pasture establishment. In J. White & J. Hodgson (Eds.), *New Zealand Pasture and Crop Science* (pp. 101-115). Victoria, Australia: Oxford University Press.

Hampton, J. G., & TeKrony, D. M. (Eds.). (1995). *Handbook of Vigour Test Methods* (3 ed.): The International Seed Testing Association, Zurich, Switzerland.

Harms, C. L., & Tucker, B. B. (1973). Influence of nitrogen fertilization and other factors on yield, prussic acid, nitrate, and total nitrogen concentrations of sudangarss cultivars. *Agronomy Journal, 65*, 21-26.

Hodgson, J., & Brookes, I. M. (1999). Nutrition of grazing animals. In J. White & J. Hodgson (Eds.), *New Zealand Pasture and Crop Science* (pp. 117-132). Victoria, Australia: Oxford University Press.

Humphreys, L. R. (2005). *Tropical pasture utilization*. Melbourne, Australia: Cambridge University Press.

Hussain, A., Sartaj, A. M., & Bhatti, M. B. (1991). Response of sudangrass to various levels of nitrogen in combination with phosphourus under rainfed conditions. *Pakistan Journal of Agriculture, 12*, 158-164.

Ibrahim, A. E., TeKrony, D. M., & Egli, D. B. (1993). Accelerated ageing techniques for evaluating sorghum seed vigor. *Journal of Seed Technology, 17*, 29-37.

ISTA. (2010). International Rules for Seed Testing (ISTA): International Seed Testing Association (2010 ed.). Bassersdorf, Switzerland.

Jacob, J. L., Ward, G. N., & kearney, G. (2004). Effect of irrigation strategies and nitrogen fertilizer on turnips dry matter yield, water use effiency, nutritive chahracteristics and mineral content in western Victoria. *Australia Journal of Experiemental Agriculture, 44*, 13-26.

Kalton, R. R. (1988). *Overview of the sweet sorghums.* Paper presented at the 43rd Annual Corn and Sorghum Research Conference, Chicago, Washington, December 8-9.

Karlovsky, J. (1966). Sudangrass. *Proceedings of the Ruakura farmers' conference*, 98-101.

Keana, G. P., Kelly, J., Lordan, S., & Kelly, K. (2003). Agronomic factors affecting the yield and quality of forage maize in Ireland: effect of plastic film system and seeding rate. *Grass and Forage Science, 58*, 362-371.

Kemp, P. D., Matthew, C., & Lucas, R. J. (1999). Pastures species and cultivars. In J. White & J. Hodgson (Eds.), *New Zealand Pasture and Crop Science* (pp. 83-99). Victoria, Australia: Oxford University Press.

Ketterings, Q. M., Cherney, J. H., Godwin, G., Kilcer, T. E., Barney, P., & Beer, S. (2007). Nitrogen management of brown midrib sorghum x sudangrass in the northeastern USA. *Agronomy Journal, 99*, 1345-1351.

Ketterings, Q. M., Godwin, G., Cherney, J. H., & Kilcer, T. F. (2005). Potassium managemnet for brown midrib sorghum x sudangrass as replacement for corn silage in the North-eastern USA. *Journal of Agronomy & Crop Science, 191*, 41-46.

Kilcer, T. F., Ketterings, Q. M., Cerosaletti, P., Barney, P., & Cherney, J. H. (2003). Cutting managemnet for brown mid rib sorghum x sudangrass. *What's Cropping Up?, 13*, 4-6.

Kilcer, T. F., Ketterings, Q. M., Cherney, J. H., Cerosaletti, P., & Barney, P. (2005). Optimum stand height for forage brown midrib sorghum x sudangrass in North-eastern USA. *Journal of Agronomy & Crop Science, 191*, 35-40.

Kulik, M. M., & Yaklich, R. W. (1982). Evaluation of vigour test in soybean seeds:Relationship of accelerated ageing, cold, sand bench, and speed of germination tests to field performance. *Crop Science, 22*, 766-770.

Lascano, C. E., Schmidt, A., & Barahona, R. (2001). *Forage quality and the environment.* Paper presented at the XIX International Grasslands Congress Brazilian Society of Animal Husbandry, Piracicaba, Brazil

Leep, R. (2005). Summer annual forage grasses for emergency crops. Michigan State University Forage Information Systems. Retrieved on 29 June, 2010, from http://web1.msue.msu.edu/fis/extension_documents/Summer_Annual_Forages_grasses.

Levitt, J. (1980). *Response of plants to environmental stresses* (Vol. II). New York, NY: Academic Press.

Litherland, A. J., & Lambert, M. G. (2007). Factors affecting the quality of pastures and supplements produced on farms. In P. V. Rattray, I. M. Brookes & A. M. Nicol (Eds.), *Pastures and supplements for grazing animals: New Zealand Society of Animal production , Occasional Publication No 14* (pp. 81-97). Hamilton, New Zealand: New Zealand Society of Animal production (Inc).

Lloveras, J. (1990). Dry matter yield and nutritive value of four summer annual crops in north-west Spain (Galicia). *Grass and Forage Science, 45*, 243-248.

Lonsdale, T. W. (1911). Fodder Crops. *New Zealand Journal of Agriculture, 3*, 386-387.

Ludlow, M. M. (1980). Stress physiology of tropical pasture plants. *Tropical Grasslands, 14*, 136-145.

Ludlow, M. M., Santamaria, J. M., & Fukai, S. (1990). Contribution of osmotic adjustment to grain yield in Sorghum bicolor (L.) Moench under water-limited conditions. II. Water stress after anthesis. *Australia Journal of Agricultural Research, 40*, 67–78.

Lyons, J. M., & Raison, J. K. (1970). Oxidative activity of mitochondria isolated from plant tissue sensitive and resistant to chilling injury. *Plant Physiology, 45*, 386-389.

MAF. (1999). Farmers warned La Niña not over yet, Ministry of Agriculture and Forestry. Retrieved on 29 June, 2009, from http://www.maf.govt.nz/news-resources/news/farmers-warned-la-nina-not-over-yet.

MAF. (2008). Drought recovery, Ministry of Agriculture and Forestry. Retrieved on 2 August, 2009, from www.maf.govt.zn.

MAF. (2009). Regional and national impacts of the 2007–2009 drought, Prepared for MAF Policy by Butcher Partners Ltd. Retrieved on 2 August, 2009, from www.maf.govt.zn.

Maiti, R. K., & Soto, G. G. (1990). Effect of four sowing date environments on growth, development and yield potentials of 15 pearl millet cultivars (*Pennisetum americanum* L Leeke) during autumn-winter seasons in Marin, N.L., Mexico. *Journal of Experimental Botany, 41*, 1609-1618.

Marsalis, M. A. (2006). Forage sorghum production in New Mexico,Guide A-332, Cooperative Extension Services.College of Agriculture and Home Economics, New Mexico State University,USA. Retrieved on 15 April, 2009, from http://www.aces.nmsu.edu/pubs/_a/a-332.pdf.

Marsalis, M. A., Angadi, S. V., & Contreras-Govea, F. E. (2010). Dry matter yield and nutritive value of corn, sweet sorghum, and BMR sweet sorghum at different plant populations and nitrogen rates. *Field Crops Research, 116*, 52-57.

Martin, B. A. (1986). Effects of pre-imbibition of maize (*Zea mays* L) seed in non-aerated water prior to planting. *Plant Physiology, 80*, 23.

Martin, J. H., Leonard, W. H., & Stamp, D. L. (1976). *Principles of field crop production*: Macmillan Publishing Co., Inc., New York

McCormick, S. J. (1971). The effects of sowing date on Maize (Zea mays L) development and yields of silage and grain. *Proceedings of the Agronomy Society of New Zealand, 1*, 51-65.

McDonald, P., Edwards, R. A., Greenhalgh, J. F. D., & Morgan, C. A. (1995). *Animal Nutrition* (5 ed.). Harlow, Essex, England: Longman Scientific & Technical.

Miller, F. R., & Stroup, J. A. (2003). Brown midrib sweet sorghum, sudangrass, and corn: What is the potential? . Paper presented at the 33rd California Alfalfa and Forage Symposium. Retrieved on 20 June, 2009, from http://alfalfa.ucdavis.edu.

Miller, F. R., & Stroup, J. A. (2004). *Growth and management of sorghums for forage production.* Paper presented at the National Alfalfa Symposium, San Diego, Califonia, United States of America. Retrieved on 5 January,2011, from http://ucanr.org/alf_symp/2004/04-148.pdf.

Millner, J.P. (2002). Yield and quality of cereals grown for silage. *Proceedings of the Agronomy Society of New Zealand, 32*, 99-105.

Millner, J. P., Villaver, R., & Hardacre, A. K. (2005). The yield and nutritive value of maize hybrids grown for silage. *New Zealand Journal of Agricultural Research., 48*, 101-108.

Miron, J., Zuckerman, E., Adin, G., Solomon, R., Shoshani, E., Nikbachat, M., Yosef, E., Zenou, A., Weinberg, Z. G., Chen, Y., Halachmi, I., & Ben-Ghedalia, D. (2007). Comparison of two sweet sorghum varieties with corn and the effect of feeding their silages on eating behavior and lactation performance of dairy cows. *Animal Feed Science and Technology, 139*, 23-39.

Mitchell, K. J. (1956). Growth of pasture species under controlled environment.1. Growth at various levels of constant temperature. *New Zealand Journal of Science and Technology, 38*, 203-216.

Mittler, R. (2006). Abiotic stress, the field environment and stress combination. *Trends in Plant Science, 11*, 15-19.

Moot, D. J., Mathhew, C., & Kemp, P. D. (2007). Growth of pastures and supplementary crops. In P. V. Rattray, I. M. Brookes & A. M. Nicol (Eds.), *Pastures and Supplements for Grazing Animals: New Zealand Society of Animal production , Occasional Publication No 14.* (pp. 13-33). Hamilton, New Zealand: New Zealand Society of Animal production (Inc).

Moss, R. (2009). Feed requirements and forage quality: Queenlands Government, Primary Industries and Fisheries. Retrieved on 5 January,2011, from http://www.dpi.qld.gov.au/27_15490.htm

Moyer, J. L., Fritz, J. O., & Higgins, J. J. (2004). Trends in forage yield and nutritive value of hay-type Sorghum spp. *Agronomy Journal, 96*, 1453-1458.

Muldoon, D. K. (1986). The yield, quality and profitability of annual forage, perennial pasture and perennial forage systems under irrigation. *Agricultural Systems, 21*, 201-213.

Nelson, C. J., & Moser, L. E. (1994). Plant factors affecting forage quality. In G. C. Fahey, M. Collins, D. R. Mertens & L. E. Moser (Eds.), *Forage Quality, Evaluation, and Utilization* (pp. 115-142). Madison, United States of America: America Society of Agronomy.

Nijenstein, H., Nydam, J., Don, R., & McGill, C. (2007). *International Seed Testing Association Handbook* (First ed.). Bassersdorf, Switzerland: International Seed Testing Association.

Noller, C. H., & Rhykerd, C. L. (1974). Relationship of nitrogen fertilization and chemical composition of forage to animal health and performance In D. A. Mays (Ed.), *Forage fertilization* (pp. 363-394). ASA, Madison, WI.

Nuwanyakpa, M., Posler, G. L., Bolsen, K. K., & Ilg, H. (1979). Cattlemen's day, yield and quality of six summer annual forages, agricultural experiment station, kansa state university, Manhattan 66506, Report of progress 350. Retrieved on 24 June, 2009, from www.ksre.ksu.edu/library/misc2/ep30.pdf.

NZMS. 1983. New Zealand Meteorological Service (NZMS). Summaries of climatological observations to 1980. New Zealand Metrological Service. Miscellanous Publication 177. Government Printer, Wellington, New Zealand.

NZMS. (nd). New Zealand Meteorological Service (NZMS), monthly reports for daily climatological observations for Palmerston North Grasslands Research Centre (Data from 2004 to 2010).

Oliver, A. L., Grant, R. J., Pedersen, J. F., & O'Rear, J. (2004). Comparison of brown midrib-6 and -18 sweet sorghum with conversion sorghum and corn silage in diets of lactating dairy cows. *Journal of Dairy Science, 87*, 637-644.

Ong, C. K., & Monteith, J. L. (1984). *Response of pearl millet to light and temperature.* Paper presented at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT): Agrometeorology of Sorghum and Millet in the Semi-Arid Tropics:, ICRISAT Center, India, pp. 129-142., Patancheru, India, November 15-20.

OSU. (2003). Seed Biology, Seed Vigor and Vigor Tests, Ohio State University, Department of Horticulture and Crop Science. Retrieved on 5 January, 2011, from http:www.ag.ohio-state.edu.

Pacificseed. (2009). Summer forage agronomy guide 2009/2010. Retrieved on 24 November, 2009, from http://www.pacificseeds.co.nz

Pande, S., Thakur, R. P., Karunakar, R. I., Bandyopadhyay, R., & Reddy, B. V. S. (1994). Development of screening methods and identification of stable resistance to anthracnose in sorghum. *Field Crops Research, 38*, 157-166.

Peacock, J. M. (1982). *Response and Tolerance of Sorghum to Temperature stress:Sorghum in the Eighties.* Paper presented at the International Symposium on Sorghum, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India, pp. 143-159., Patancheru, India, November 2-7.

Peacock, J. M., & Heinrich, G. M. (1984). *Light and temperature responses in sorghum.* Paper presented at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT): Agrometeorology of Sorghum and Millet in the Semi-Arid Tropics:, ICRISAT Center, India, pp. 143-158., Patancheru, India, November 15-20.

Peacock, J. M., & Wilson, G. L. (1984). Sorghum. The physiology of tropical field crops. In P. Goldsworthy & N. M. Fisher (Eds.), (pp. 249 - 279): John Wiley & Sons Ltd.

Pedersen, J. F., & Toy, J. J. (1997). Forage yield, quality, and fertility of sorghum x sudan grass hybrids in A1 and A3 Cytoplasm. *Crop Science, 37*, 1974-1975.

Pedersen, J. F., & Toy, J. J. (2001). Germination, emergence, and yield of 20 plant-color, seed-color near-isogenic lines of grain sorghum. *Crop Science, 41*, 107-110.

Pedersen, J. F., Vogel, K. P., & Funnell, D. L. (2005). Impact of reduced lignin on plant fitness. *Crop Science, 45*, 812-819.

Perl, M., Luria, I., & Germond, H. (1978). Biochemical changes in sorghum seeds affected by accelerated ageing. *Journal of Experimental Botany, 29*, 497-509.

Perry, D. A. (1978). Report of the vigour test committee. Seed Science and Technology. *6*, 159-181.

Perry, D. A. (1987). *Seedlings growth and seedling evaluation: International Seed Testing Association (ISTA): Handbook of Vigour Test Methods*. Zurich, Switzerland: ISTA.

Peterson, G. C., Suksayretrup, K., & Weibel, D. E. (1982). Inheritance of some bloomless and sparse-bloom mutants in sorghum. *Crop Science, 22*, 63-67.

Piggot, G. J. (1989). A comparison of four methods for estimating herbage yield of temperate dairy pastures. *New Zealand Journal Of Agricultural Research, 32*, 121-123.

Piggot, G. J., & Farrell, C. A. (1984). The culture and yield of sorghum for forage and sugar in Northland. *Proceedings of the Agronomy Society of New Zealand, 14*, 105-109.

Ping, J., Zhang, F., Cheng, Q., Du, Z., Lv, X., & Chang, Y. (2005). Performance of one newly developed forage variety Jinco 1 (sorghum/sudangrass) in China. *Asian Journal of Plant Sciences, 4*, 527-529.

Pioneer. (2008). Pioner Technical Insight 801: Bettagraze. Retrievd on 24 November, 2009, from http://www.pioneer.co.nz.

Plucknett, D. L., Younge, C. R., Tzuno, T., Tamimi, Y. H., & Ishizaki, S. H. (1971). Sorghum production in Hawaii. University of Hawii, Agriculture Experimental Station Research Bull. 143.

Porter, K. S., Axtell, J. D., Lechtenberg, V. L., & Colenbrander, V. F. (1978). Phenotype, fiber composition, and invitro dry-matter disapperance of chemically-induced brown midrib (BMR) Mutant of sorghum. *Crop Science, 18*, 205-208.

Posler, G. L., Bolsen, K. K., & Nuwanyakpa, M. Y. (1983). Summer annual forages for livestock production in Kansas, Bulletin 642, Agricultural Experiment Station, Kansas State University. Retrieved on 29 June,2010, from http://www.ksre.ksu.edu/library/crpsl2/sb642.pdf

Priestley, D. A. (1986). *Seed Ageing: implications for Seed Storage and Persistence in the Soil*. Ithaca, United States of America: Comstock.

Rachie, K. O., & Majmudar, J. V. (1980). Pearl Millet. London, United Kingdom: The Pennsylvania State University Press,Pennsylvania, United States of America.

Radford, B. J., Wood, I. M., Beavis, C. H. S., Veerity, A. M., Walsh, P. A., Hazard, W. H. L., Wade, L.J., Spackman, G.B., Hughes, P.J., Robertson, L.N., Page, J.R., & Wollin, A.S. (1989). A survey of the establishment of commercial sorghum and sunflower crops in the Central Highlands of Queensland and analysis of the effects of level and evenness of establishment on grain yield, Occational Publication 43, Australian Institute of Agriculture Science, Brisbane, Australia. Retrieved on 21 November, 2010, from http://www.agris.fao.org.

Radhouane, L. (2008). Autochthonous pearl millet ecotype (*Pennisetum glaucum* L. R. BR) response to different sowing dates in Tunisia. *Sjemenarstvo, 2*, 123-138.

Rahman, M., Fukai, S., & Blamey, F. P. C. (2001). *Forage production and nitrogen uptake of sweet sorghum, grain sorghum and maize as affected by cutting under different nitrogen levels.* Paper presented at the 10th Australian Agronomy Conference., Hobart, Tas, Australia, January 28 – February 1.

Reddy, B. V. S., Reddy, P. S., Bidinger, F., & Blummel, M. (2002). Crop management factors influencing yield and quality of crop residues. Field Crops Research, 84, 57-77

Reich, J. M. (2007). Brown midrib sudangrass hybrids with improved forage quality, World Intellectual Property Organisation. Retrieved on 17 June, 2010, from http://www.wipo.int/pctdb/en/wo.jsp?amp%BIA

Reich, J. M. (2008). Patent application publication, United States,Brown Mid Rib Sudangrass Hybrids CW 1-63-23, Publication No.: US 2008/0098497 A1. Retrieved on 29 June, 2010, from http://www.wikipatents.com/US-Application-20080098497/brown-midrib-sudangrass-hybrid.

Reid, R. L., Clark, B., & Jung, G. E. (1964). Studies with sudangrass II: nutritive evaluation by In-vivo and in-vitro methods. *Agronomy Journal, 56*, 537-542.

Rhodes, P. J. (1977). Summer and early autumn forage yields of maize, sorghum and millets in Nelson and Marlborough. *Proceedings of the Agronomy Society of New Zealand, 7*, 31-35.

Rhykerd, C. L., & Noller, C. H. (1974). The role of nitrogen in forage production. In D. A. Mays (Ed.), *Forage Fertilization* (pp. 416-424). ASA, Madison, WI.

Robert, E. L., & Gurmu, N. M. (1990). Seed vigour and water relations in wheat. *Annals of Applied Biology, 117*, 441-450.

Roos, E. E. (1980). Physiological, biochemical and genetic changes in seed quality during storage. *HortScience, 15*, 781-784.

Rowarth, J. S. (1997). Seed production and management: Temperate: Nutrients and moisture inputs for grass seed yields, Session 25, Lincoln Universtity. Retrieved on 3 January, 2011, from http://www.internationalgrasslands.org/publications/pdfs/1997/III_461.pdf

Sanchez-Diaz, M. F., Hesketh, J. D., & Kramer, P. J. (1972). Wax filament on sorghum leaves as seen with a scanning electron microscope. *Journal of the Arizona-Nevada Academy of Science, 7*, 6 - 7.

Scott, D. J., & Hampton, J. G. (1985). Aspects of seed quality. In M. D. Hare & J. L. Brock (Eds.), *Producing herbage seeds, Grassland Research and practices Series No. 2* (pp. 43-52). Palmerston North: New Zealand Grasslands Association Inc.

Singh, B. R., & Singh, D. P. (1995). Agronomic and physiological responses of sorghum, maize and pearl millet to irrigation. *Field Crops Research, 42*, 57-67.

Singh, N. T., & Dwaliwal, G. S. (1972). Effect of soil temperature on seedling emergence in different crops. *Plant and Soil, 37*, 441- 444.

Snaydon, R. W. (1972). The effect of total water supply, and of frequency of application upon Lucerne II. chemical composition. *Australia Journal of Agricultural Research, 23*, 253.

Snyman, L. D., & Joubert, H. W. (1996). Effect of maturity stage and method of preservation on the yield and quality of sweet sorghum. *Animal Feed Science and Technology, 57*, 63-73.

SNZ. (2009). Statistics New Zealand (SNZ), Agricultural Production Statistics. Retrieved on 20 September, 2010, from http://www.stats.govt.nz.

Sotomayor-Ríos, A., & Pitman, W. D. (Eds.). (2000). *Tropical forage plants: development and use* (1 ed.). Boca Raton, Florida, United States of America: CRC Press LLC

Sparling, G. P., & Schipper, L. A. (2002). Ecological risk assessment:Soil quality at a National Scale in New Zealand. *Journal of Environmental Quality, 31*, 1848-1857.

Staggenborg, S. A., Dhuyvetter, K. C., & Gordon, W. B. (2008). Grain sorghum and corn comparisons: Yield, economic, and environmental responses. *Agronomy Journal, 100*, 1600-1604.

Stephenson, R. J., & Posler, G. L. (1984). Forage yield and regrowth of pearl millet. *Transactions of the Kansas Academy of Science, 87*, 91-97.

Stewart, A., & Charton, D. (2006). *Pastures and forage plants for New Zealand: Grassland research and practices series No. 8.* (3 ed.). Wellington: New Zealand Grassland association, New Zealand Grassland Trust.

Stewart, J. M., & Guinn, G. (1969). Chilling injury and changes in adenosine triphosphate of cotton seedlings. *Plant Physiology, 44*, 605-608.

Sullivan, E. F. (1961). Effect of temperature and phosphorus fertilization on yield and composition of Piper sudangrass. *Agronomy Journal, 53*, 357-358.

Sullivan, J. T., & Graber, R. J. (1947). Chemical composition of pasture plants:With some reference to the dietary needs of grazing animals, Bulletin 489, The Pennsylvania State College, School of Agriculture,Agricultural experiemnt station colleges, Pennysylvanian, United States of America.

Sunaga, Y., Harada, H., & Hatanaka, T. (2005). A simple method for estimating nitrate nitrogen concentrations of standing Sudangrass (Sorghum sudanense (Piper) Stapf) and Sudan-type sorghum (Sorghum bicolor Moench & sudanense) at the heading stage by the nitrate nitrogen concentration of the stem juice and the dry matter ratio. *Grassland Science, 51*, 297-303.

Sunaga, Y., Harada, H., Kawachi, T., & Hatanaka, T. (2008). Management of nitrogen fertilizer application rates based on soil nitrogen fertility with the goal of lowering nitrate nitrogen concentrations in Sudangrass (Sorghum sudanense (Piper) Stapf). *Soil Science and Plant Nutrition, 54*, 543-554.

Suyama, H., Benes, S. E., Robinson, P. H., Getachew, G., Grattan, S. R., & Grieve, C. M. (2007). Biomass yield and nutritional quality of forage species under long-term irrigation with saline-sodic drainage water: Field evaluation. *Animal Feed Science and Technology, 135*, 329-345.

Swanson, A. F., & Hunter, R. (1936). Effect of germination and seed size on sorghum stands. *Journal America Society Agronomy 28*, 997-1004.

Takamitsu, A. (1973). The use of forage sorghum :HCN content in the forage sorghum. *Journal of Japan Glassland Science, 19*, 333-340.

Taylor, A. O. (1977). The use of sorghum in Northland. *New Zealand of Agriculture, 134*, 7-10.

Taylor, A. O., Rowley, J. A., Esson, M. J., Eastin, J. D., & Wallace, R. (1974). Sorghums for conserved feed in Northland. *Proceedings of the Agronomy Society of New Zealand, 4*,74-78.

Tiryaki, I., & Andrews, D. J. (2001). Germination and seedling cold tolerance in sorghum: I. Evaluation of rapid screening methods. . *Agronomy Journal, 93*, 1386-1391.

Ummenhofer, C. U., Gupta, A. S., & England, M. H. (2007). Causes of late Twentieth-Century trends in New Zealand precipitation. *Journal of Climate, 22*, 3-19.

Undersander, D. J., & Lane, W. (2001). Sorghum, sudangrasses, and sorghum-sudangrass hybrids for forage, University of Wisconsin, Extension cooperative. Retrieved on 4 June, 2009, from http://www.uwex.edu/ces/forage/pubs/sorghum.

Undersander, D. J., Smith, H. L., Kaminski, A. R., Kelling, K. A., & Doll, J. D. (1990). Sorghum-forage,Department of Agronomy and Soil Science, College of Agricultural and Life Science and Cooperative Extension, University of Wisconsin-Madison. Retrieved on 4 June, 2009 04, from http:web1.msue.msu.edu

Valentine, I., & Kemp, P. D. (2007). Pastures and supplement resources. In P. V. Rattray, I. M. Brookes & A. M. Nicol (Eds.), *Pastures and Supplements for Grazing Animals: New Zealand Society of Animal production , Occasional Publication No 14* (pp. 3-11). Hamilton, New Zealand: New Zealand Society of Animal production (Inc).

Van Soest, P. J. (1994). *Nutritional ecology of the ruminant* (Second ed.). United States of America: Comstock Publishing.

Van Soest, P. J., Mertens, D. R., & Deinum, B. (1978). Preharvest factors influencing quality of conserved forage. *Journay of Animal Science, 47*, 712-720.

Van Soest, P. J., Robertson, J. B., & Lewis, B. A. (1991). Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of dairy science, 74*, 3583-3597.

Vanderlip, R. L. (1993). How a sorghum plant develops,Kansas State University, Agricultural Experiment Station and Cooperative Extension Service. Retrieved on 18 March, 20011, from http://www.oznet.ksu.edu/library/crpsl2/s3.pdf.

Vanderlip, R. L., Mockel, F. E., & Jan, H. (1973). Evaluation of vigor tests for sorghum seed. *Agronomy Journal, 65*, 486-488.

Vogel, K. P., Haskins, F. A., & Gorz, H. J. (1987). Potential for hydrocyanic acid poisoning of livestock by Indiangrass. *Journal of Range Management, 40*, 506-509.

Waghorn, G. C., Burke, J. L., & Kolver, F. S. (2007). Principles of Feeding Value. In P. V. Rattray, I. M. Brookes & A. M. Nicol (Eds.), *Pastures and Supplements for Grazing Animals: New Zealand Society of Animal production , Occasional Publication No 14* (pp. 35-59). Hamilton, New Zealand: New Zealand Society of Animal production (Inc).

Wall, J. S., & Ross, W. M. (1970). *Sorghum production and utilization – Major feed and food crops in agriculture and food series*. Westport, Connecticut: The AVI Publishing Company Inc.

Walton, P. D. (1983). *Production and management of cultivated forages*. Reston, Virginia, United States of America: Reston Publishing Company Inc.

Watson, S. L., Fjell, D. L., Fritz, J. O., & Blasi, D. A. (1993). Emergency and supplemental forages, Kansas State University Agricultural Experiment Station and Cooperative Extension Service**,** Department of Agronomy, Forage Production, MF-1073. Retrieved on 20 August, 2009, From www.cropsoil.psu.ed/extension/facts.

Wedin, W. F. (1970). Digestible dry matter, crude protein, and dry matter yields of grazing-type sorghum cultivars as affected by harvest frequency. *Agronomy Journal, 62*, 359-363.

Wheeler, J. L., Hedges, D. A., Archer, K. A., & Hamilton, B. A. (1980). Effect of nitrogen, sulphur and phosphorus fertilizer on the production, mineral content and cyanide potential of sweet sorghum. *Australia Journal Experiment of Agriculture and Animal Husbandry, 20*, 330-338.

Wheeler, J. L., Mulcahy, J. L., Walcott, J., & Rapp, G. (1990). Factors affecting the hydrogen cyanide potential of sweet sorghum. *Australian Journal of Agricultural Research, 41*, 1093-1100.

Wheeler, J. L., & Mulchahy, C. (1989). Consequences for animal production of cyanogenesis in forage sorghum & hay-A Review. *Tropical Grasslands, 23*, 193-202.

White, J. G. H., Millner, J., & Moot, D. J. (1999). Cereals. In J. White & J. Hodgson (Eds.), *New Zealand Pasture and Crop Science* (pp. 213-233). Victoria, Australia: Oxford University Press.

Wilkins, R. J. (2000). Forages and their roles in animal systems. In D. I. Givens, E. owen, R. F. E. Axford & H. M. Omed (Eds.), *Forage Evaluation in Ruminant Nutrition* (pp. 1-14). New York, NY, USA: CABI Publishing.

Wilson, D. R., Johnston, J. V., & Salinger, M. J. (1994). Maize production potential and climatic risk in the South Island of New Zealand. *New Zealand Journal of Crop and Horticultural Science 22*, 321-334.

Wilson, J. P., Gates, R. N., & Hanna, W. W. (1991). Effects of rust on yield and digestibility of pearl millet forage. *Phytopath, 81*, 233-236.

Wilson, J. R., Deinum, B., & Engels, F. M. (1991). Temperatures effects on anatomy and digestibility of leaf and stem of tropical and temperate forage species. *Netherlands Journal of Agriculture Science, 39*, 31-48.

Wilson, J. R., & Minson, D. J. (1980). Prospects for improving the digestibility and intake of Tropical grasses. *Tropical Grasslands, 14*, 253-259.

Wilson, J. R., & Ng, T. T. (1975). Influence of water stress on parameters associated with herbage quality of Panicum maximum var. trichoglume. *Australia Journal of Agricultural Research, 26*, 127-136.

Worker, G. F., & Marble, V. L. (1968). Comparison of growth stages of forage sorghum types as to yield and chemical composition. *Agronomy Journal, 60*, 669-671.

Wright, G. C., & Smith, C. G. (1983). Differences between two grain sorghum genotypes in adaptation to droght stress. II. Root water uptake and water use. *Australia Journal of Agricultural Research, 34*, 627-636.

Yayock, J. Y., Jan, H., & Vanderlip, R. L. (1975). Temperature, time, and NH4Cl concentration in vigor testing of sorghum seed. *Agronomy Journal, 67*, 241-242.

Yosef, E., Carmi, A., Nikbachat, M., Zenou, A., Umiel, N., & Miron, J. (2009). Characteristics of tall versus short-type varieties of sweet sorghum grown under two irrigation levels, for summer and subsequent fall harvests, and digestibility by sheep of their silages. *Animal Feed Science and Technology, 152*, 1-11.

Zagrobelny, M., Bak, S., & Moller, B. L. (2008). Cyanogenesis in plants and arthropods. [Review]. *Phytochemistry, 69*, 1457-1468.

Zaychuck, K. S., & Foster-Stubbs, S. (2004). Seed vigour. What Is It? - Agronomy Update 2004 - Agronomy Update , Seed Labs, Canada. Retrieved on 20 July, 2010, from www.2020seedlabs.ca.

Zerbini, E., & Thomas, D. (2003). Opportunities for improvement of nutritive value in sorghum and pearl millet residues in South Asia through genetic enhancemen. *Field Crops Research, 84*, 3-15.

Appendix 1*:* Daily rainfall (mm), maximum temperature (°C), minimum temperature (°C), Soil temperature (°C) and sunshine (hours) for the 2009/2010 sorghum growing season at Palmerston North. Source: AgResearch Grasslands, Palmerston North.

Date	Rain (mm)	Max. Temp (° C)	Min. Temp (° C)	Soil temp (° C)	Sun shine (hours)
1 Dec. 2009	23.8	19.3	11.7	14.2	0.1
2 Dec. 2009	15.4	22.0	12.6	16.4	2.9
3 Dec. 2009	0.0	14.1	9.3	13.9	3.7
4 Dec. 2009	0.2	15.7	8.8	12.1	4.9
5 Dec. 2009	0.4	20.5	10.9	14.2	4.2
6 Dec. 2009	0.6	20.3	12.4	15.8	4.2
7 Dec. 2009	0.0	19.8	12.3	15.2	5.5
8 Dec. 2009	0.0	19.3	7.9	14.9	5.6
9 Dec. 2009	0.0	20.6	12.7	16.2	5.2
10 Dec. 2009	0.0	22.2	12.8	16.3	2.4
11 Dec. 2009	0.0	23.1	12.5	17.4	1.3
12 Dec. 2009	15.0	20.6	13.4	18.0	3.7
13 Dec. 2009	4.0	20.4	12.1	14.7	2.4
14 Dec. 2009	1.4	19.1	11.9	16.4	10.7
15 Dec. 2009	0.8	15.8	7.9	15.2	5.7
16 Dec. 2009	0.0	18.2	4.5	13.4	9.5
17 Dec. 2009	0.0	21.2	9.1	15.4	13.0
18 Dec. 2009	0.0	18.9	12.4	16.7	7.5
19 Dec. 2009	1.0	21.5	13.9	17.6	1.8
20 Dec. 2009	3.2	19.4	10.5	17.4	6.3
21 Dec. 2009	0.6	17.6	8.0	14.9	7.8
22 Dec. 2009	0.0	21.7	4.4	13.8	14.3
23 Dec. 2009	0.0	19.3	6.3	16.2	12.4
24 Dec. 2009	0.0	20.9	10.2	17.1	9.5
25 Dec. 2009	0.0	20.4	10.7	18.1	5.9
26 Dec. 2009	0.0	21.7	14.7	19.0	1.2
27 Dec. 2009	32.0	21.4	14.1	18.5	0.0
28 Dec. 2009	2.4	24.1	14.0	16.9	1.6
29 Dec. 2009	21.6	21.7	16.3	18.8	0.4
30 Dec. 2009	0.0	19.6	9.4	17.0	7.4
31 Dec. 2009	0.0	18.5	6.9	15.0	11.1
Mean	3.9	20.0	10.8	16.0	5.6
Total	122.4	.	.	.	.

Continuation of Appendix 1

1 Jan. 2010	0.0	18.9	12.2	15.8	6.5
2 Jan. 2010	1.4	21.0	13.9	16.6	0.0
3 Jan. 2010	0.0	22.9	17.2	17.2	7.4
4 Jan. 2010	7.0	20.3	12.6	18.5	7.4
5 Jan. 2010	0.2	19.7	10.1	15.9	9.6
6 Jan. 2010	0.0	20.2	7.4	16.0	8.3
7 Jan. 2010	0.0	20.4	14.3	17.2	1.0
8 Jan. 2010	1.4	17.7	12.4	16.7	11.8
9 Jan. 2010	0.0	18.5	11.5	16.4	9.1
10 Jan. 2010	4.0	19.7	11.7	16.3	0.6
11 Jan. 2010	6.0	17.7	11.0	15.7	4.0
12 Jan. 2010	0.2	17.5	6.0	14.1	1.9
13 Jan. 2010	0.0	18.2	8.6	14.7	1.5
14 Jan. 2010	0.0	24.4	7.3	14.8	12.1
15 Jan. 2010	0.0	19.6	14.2	17.6	5.3
16 Jan. 2010	0.2	17.3	13.2	17.7	0.1
17 Jan. 2010	0.0	21.8	9.8	16.0	6.7
18 Jan. 2010	0.0	25.2	14.3	17.8	12.4
19 Jan. 2010	0.0	25.5	12.9	20.3	11.4
20 Jan. 2010	0.0	27.4	15.1	21.3	4.2
21 Jan. 2010	8.4	23.4	16.7	20.8	0.5
22 Jan. 2010	16.8	21.5	15.6	19.6	1.3
23 Jan. 2010	23.2	16.8	14.4	18.4	0.0
24 Jan. 2010	4.0	19.3	14.2	17.6	2.4
25 Jan. 2010	0.0	20.9	14.9	17.6	6.6
26 Jan. 2010	1.8	25.7	16.1	18.7	5.0
27 Jan. 2010	0.0	26.0	15.3	18.9	11.5
28 Jan. 2010	0.0	25.8	13.4	19.2	10.8
29 Jan. 2010	0.0	26.2	16.4	20.0	13.6
30 Jan. 2010	0.0	27.5	15.4	19.9	11.3
31 Jan. 2010	0.4	19.4	15.8	20.3	0.4
Mean	2.4	21.5	13.0	17.7	6.0
Total	75.0	.	.	.	.

Continuation of Appendix 1

1 Feb. 2010	0.0	21.8	16.0	18.3	4.7
2 Feb. 2010	0.0	24.3	16.6	19.0	12.5
3 Feb. 2010	0.0	24.7	16.4	19.5	5.2
4 Feb. 2010	0.0	25.5	15.9	19.8	12.0
5 Feb. 2010	0.0	26.7	12.3	20.4	7.5
6 Feb. 2010	0.0	26.2	11.0	19.7	11.8
7 Feb. 2010	0.0	23.9	14.8	21.3	6.3
8 Feb. 2010	0.0	22.8	13.6	21.0	10.6
9 Feb. 2010	0.0	22.5	10.0	19.5	5.3
10 Feb. 2010	0.0	23.4	11.0	18.7	2.7
11 Feb. 2010	9.4	22.5	15.4	19.3	0.5
12 Feb. 2010	1.0	25.5	16.8	19.4	0.9
13 Feb. 2010	0.2	24.5	17.4	19.0	1.0
14 Feb. 2010	0.2	20.6	15.6	18.6	1.4
15 Feb. 2010	0.4	23.4	14.8	18.0	2.5
16 Feb. 2010	0.0	23.9	14.6	17.4	3.4
17 Feb. 2010	11.2	20.9	17.3	19.6	0.0
18 Feb. 2010	3.6	27.1	17.8	19.7	5.6
19 Feb. 2010	0.4	19.9	9.9	18.2	1.1
20 Feb. 2010	0.0	21.7	8.1	15.6	6.2
21 Feb. 2010	0.0	22.6	10.1	16.5	5.8
22 Feb. 2010	0.0	22.8	14.6	18.3	10.4
23 Feb. 2010	0.0	23.9	11.9	18.6	11.3
24 Feb. 2010	0.0	29.9	11.6	18.6	6.0
25 Feb. 2010	8.0	21.7	15.4	18.4	2.1
26 Feb. 2010	0.8	20.8	13.5	18.4	8.2
27 Feb. 2010	0.0	25.6	9.1	16.2	12.6
28 Feb. 2010	0.0	22.8	11.7	19.0	7.6
Mean	1.3	23.6	13.7	18.8	5.9
Total	35.2	.	.	.	.

Continuation of Appendix 1

1 March. 2010	0.0	24.0	11.8	19.1	9.1
2 March. 2010	4.8	21.7	15.5	19.6	0.2
3 March. 2010	0.0	20.6	13.9	17.6	2.2
4 March. 2010	0.0	22.0	12.1	16.1	10.5
5 March. 2010	0.0	26.9	13.5	17.0	11.5
6 March. 2010	1.6	21.5	14.2	19.0	7.4
7 March. 2010	0.0	19.8	13.6	17.0	2.9
8 March. 2010	0.0	20.9	11.2	17.5	5.3
9 March. 2010	0.0	22.2	11.6	16.6	7.8
10 March. 2010	0.0	25.9	13.6	17.4	11.3
11 March. 2010	1.8	19.1	13.8	19.5	0.8
12 March. 2010	2.2	18.7	6.6	16.1	2.9
13 March. 2010	0.0	18.6	2.2	12.0	3.6
14 March. 2010	0.0	22.6	9.9	14.9	9.1
15 March. 2010	0.0	21.1	12.8	17.6	6.5
16 March. 2010	0.0	20.1	13.2	17.8	4.4
17 March. 2010	1.8	16.2	5.7	16.6	5.0
18 March. 2010	0.0	17.6	0.5	11.0	1.5
19 March. 2010	1.0	17.5	13.5	15.3	0.0
20 March. 2010	0.0	21.6	12.0	15.7	3.1
21 March. 2010	0.0	19.8	15.5	17.3	0.3
22 March. 2010	0.0	22.6	15.5	16.8	1.4
23 March. 2010	19.6	19.4	10.7	16.0	7.7
24 March. 2010	7.6	22.0	10.4	14.4	2.5
25 March. 2010	0.0	17.4	11.9	13.8	3.6
26 March. 2010	0.0	19.7	11.5	15.1	2.6
27 March. 2010	0.2	20.7	12.7	15.9	2.8
28 March. 2010	0.0	16.7	12.2	16.6	0.0
29 March. 2010	0.0	19.1	9.6	12.3	10.1
30 March. 2010	0.0	22.1	7.3	13.7	8.7
31 March. 2010	0.0	21.5	6.1	13.0	10.9
Mean	1.3	20.6	11.1	16.1	5.0
Total	40.6	.	.	.	.

Appendix 2: Abnormal percentage and dead seed of different sorghum, sudangrass and pearl millet cultivars for control (un-aged seed) and post accelerated ageing treatments (T41D72 T43D72and T45D48) in the laboratory.

Cultivar	Temperatures (°C) and Duration (Hours)				Temperatures (°C) and Duration (Hours)			
	control	T41D72	T43D72	T45D48	control	T41D72	T43D72	T45D48
	Abnormal (%)				Dead seed (%)			
Pac 8421	2.0	1.0	1.0	1.0	2.5	1.0	2.5	1.0
Pac 8423	0.5	1.5	2.0	1.5	1.0	1.5	1.5	5.5
Nutrifeed	7.0	4.5	6.5	9.5	4.0	10.0	13.5	6.5
Sugargraze	7.0	8.0	4.0	2.5	18.0	33.0	42.5	62.5
Pacific BMR	12.0	4.5	4.5	5.5	11.5	46.0	44.0	42.5
Sprint	2.5	3.0	4.0	16.0	6.0	22.0	19.0	42.0
Superdan 2	4.0	5.5	8.0	22.5	5.5	23.5	29.5	29.0
Mean	5.0	4.0	4.3	8.4	6.9	19.6	21.8	27
Significance	NS	NS	NS	0.0001	0.0006	0.0001	0.0001	0.0001
LSD $_{(0.05)}$	8.1	.	.	6.1	6.9	9.5	11.8	10.4

Appendix 3: Coleoptile dry matter weight (mg/seedling), root dry matter weight (mg/seedling) and coleoptile Length (cm) of different sorghum , sudangrass and pearl millet cultivars for control (un-aged seed) and post accelerated ageing treatments (T41D72 T43D72 and T45D48) in the laboratory.

Cultivar	Temperatures (°C) and Duration (Hours)				Temperatures (°C) and Duration (Hours)				Temperatures (°C) and Duration (Hours)			
	control	T41D72	T43D72	T45D48	control	T41D72	T43D72	T45D48	control	T41D72	T43D72	T45D48
	Coleoptile dry matter weight (mg/seedling)				Root dry matter weight (mg/seedling)				Coleoptile Length (cm)			
Pac 8421	11.4	10.5	10.8	9.0	2.5	2.4	2.6	2.1	14.4	13.7	13.2	12.8
Pac 8423	9.4	9.7	10.1	9.6	2.8	2.5	2.3	2.3	11.5	13.4	14.2	13.1
Nutrifeed	4.1	4.0	4.2	4.4	1.4	1.3	1.4	1.5	10.2	9.9	10.1	9.3
Sugargraze	9.1	8.5	8.6	7.6	2.4	1.9	1.9	2.2	11.1	8.9	9.2	8.0
Pacific BMR	9.5	8.3	9.1	7.3	2.5	1.8	2.1	1.8	10.7	10.5	10.9	9.9
Sprint	5.8	4.8	5.3	4.4	1.7	1.3	1.6	1.7	11.8	10.5	10.4	9.3
Superdan 2	5.1	4.6	5.1	4.3	1.3	0.9	1.1	1.1	10.4	9.9	10.5	9.0
Mean	7.8	7.2	7.6	6.8	2.1	1.7	1.8	1.8	11.5	11.0	11.2	10.2
Significance	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.04	0.003	0.0001	0.0001	0.0001
$LSD_{(0.05)}$	0.7	0.9	0.5	1.1	0.3	0.3	0.3	0.8	2.0	1.3	1.4	1.5