MONTANE SOUTH AFRICAN GRASSLANDS AS A NEW PLANTING DESIGN FORM IN URBAN GREENSPACE

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ABSTRACT

The aims of this study were to develop communities of South African montane grassland species as a new planting design form in urban parks and green spaces. The uniqueness on the canopy texture and structure additionally the attractiveness produced from colorful flowers, from spring, summer and autumn potentially give strong design impact. To develop the community for use in urban greenspace three series of experiment were conducted to investigate time of sowing, growth performance, winter hardiness, competition in communities and appearance. Most of the species show good emergence and growth performance when sowing seeds directly in the field between March and May. Pre-germination treatments did speed up germination post sowing in the field but do not result in a significant increase of emergence percentage compared sown directly. Studies on species hardiness during extreme cold winter in 2010/2011 on different types and depth of media (sand 70 mm, sand 140 mm and soil 70 mm) found that increase in depth of mulch decrease the survival of the species on sand. Increased seedling mortality was due to lower root zone temperatures in the deeper sand with ambient temperatures as low as -8.7 °C. Most of the species sown in soil shows a better survival than sown in sand. Greater soil wetness in soil was less hostile to overwintering survival than was the lower temperatures associated with the sand treatments. Evergreen species such as *Dierama robustum, Berkheya multijuga,* and *Senecio macrospermus* overwintered well and *Gladiolus saundersii* is one of the hardiest species in this experiment. In the competition experiment, forbs species were the most productive in producing biomass and % cover in every community. *Berkheya purpurea* is a highly productive species and dominant in the first and second year of this study and greatly affected the production of biomass and canopy coverage in the communities it was present in. The communities with forbs species in combination produced 50% cover faster approximately 50 days after spring cutting in the second year. The geophytes species had much less influence on the biomass and % cover in the community, at least in the first two years. Even though *Kniphofia uvaria* also able to produce high biomass but does not greatly increases % cover due to the canopy structure being more open. However, the combination of species with different canopy layers is a very effective spatial arrangement for naturalistic design. High germination percentage as well as good growth in the first and second years of study showed that most species are able to survive and flower well in the UK. Most of forbs from low canopy species flower early in the season on the first and second years while geophytes species with slow growth, medium and tall canopy flowering from mid-season until a late season. Based on the results of these studies it appears that South African montane grassland have good potential to be used as a new planting design in UK urban greenspace

DECLARATION

No portion of this work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or institute of learning.

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CHAPTER 1: INTRODUCTION

1.1 Background

Changing perceptions of nature have influenced landscape professionals to develop urban landscape involving the use of naturalistic ecological design (Lovejoy, 1998; Oudolf and Gerritsen, 2003; Dunnett and Hitchmough, 2004). Among designers there is increasing interest in naturalistic planting design, as evidenced by the form of major new parks such as the Olympic Park in London. It is still uncertain as to how members of the public feel about this type of planting, although providing it is colourful enough there is increasing evidence of growing support (Jorgensen, 2004).

Research into the selection of non-native species for cultivation as sown naturalistic urban planting started at the University of Sheffield over 12 years ago by Hitchmough (2004) and Dunnett (2004). This approach is elaborated in `The Dynamic Landscape: Design, Ecology and Management of naturalistic urban planting’ (Dunnett and Hitchmough, 2004). Planting based on ecological concepts using species well fitted to the local environment to create semi-natural vegetation can reduce management costs and create attractive urban landscape. To achieve a strong aesthetic impact over a long season a combination of native and exotic species is often needed, particularly in countries with a very small native flora. The combination of species must fulfill both the aesthetic and functional needs of a landscape. The colour of the flowers and the texture of the leaves and inflorescence in total are important ingredients. For these species to co-exist at low maintenance, and yet still produce dramatic flowering displays, control of initial plant density is important as is understanding of species’ growth requirements, their adaptability and phenology.

Climate change is increasingly having an impact on these ideas. If implemented on a very large scale naturalistic planting can make some contribution to reducing the CO_2 emissions behind global warming, but also provides an opportunity to use attractive species from other countries which were previously not usable. Increasing temperature during the United Kingdom winter makes species from Southern Africa far more viable for naturalistic planting design in Britain. Rapid development in the last 30 years and global warming has encouraged the planning and development of new urban landscape areas focused towards nature in cities. Landscape development with the concept of naturalistic style has increased and become popular across Europe (Ozguner et al.,2007). The revolution of urbanization in the 19th century and the explosive growth of urban areas in the 20th century have created an increased of alienation between people and the natural world (Ozguner et al.,2007). A new perception of nature has become apparent and the creation of more natural landscapes in urban areas has increased as a way of providing support for the process that supports the natural environment (Kendle and Forbes, 1997). The idea of naturalistic designed landscapes was originally conceptualised in the UK in the 18th century with the English Landscape Garden and is further developed in the 19th century on a smaller, more urban scale as the “Wild Garden” by William Robinson (Robinson and Darke, 2009). This concept has spread throughout northern Europe and North America, although it is interpreted very differently within different countries. In North America, the approach has been to use largely native species; in Europe, both native and non- native species have been used, depending on the ecological and cultural context (Hitchmough and Dunnett, 2004). There is sometimes a major tension between these contrasting positions (Robinson and Darke, 2009). Intentional or unintentional naturalisation of species in the UK goes back > 5,000 years. There has been an increase in this since the 1500s because of world trade: some alien plants come from agriculture and forestry, some from gardens. In Britain, non-native plants play an important role in gardens, in part because the native flora is very small, and this limits the effects that can be created. Activities such as cultivating exotic plants, designing plantings of these species in domestic gardens and visiting other people’s gardens are major recreational activities, particularly between spring and autumn. The combination of native and exotic species in urban parks and meadows allow more dramatic colour impacts to be produced for longer (Hitchmough and Woudstra, 1999).

Since its discovery by Europeans in the C17th, South Africa has held much interest for European horticulture (Culver, 2001). Initially this was limited to the winter rainfall, Mediterranean geophytes associated with the Western Cape, but by the mid C19th interest had extended to the high altitude, summer rainfall grasslands of the Eastern Cape and Qua Zulu Natal (Cunningham and Davis, 1997; Culver, 2001; Clivia Society, 2003). These latter grasslands are dominated by the C4 grass *Themeda triandra*, but contain a highly diverse range of forbs and geophytes >3500 species, (Pooley, 2005), adapted to cold to very cold winters and a frequent (often annual) cycle of spring burning (Mucina, and Rutherford, 2006). There are clear signs of growing public interest in this flora, as evidenced by increasing cultivation in nurseries (Merrick, 2009) in the UK. The increasingly mild winters of the past 20 years have transformed perceptions of these species from being fringe semi-hardies prone to winter kill, to reliable plants.

1.1.1 Naturalistic planting design approach

Naturalistic planting design was created based on the natural and ecological concept based upon the use of natural features and suitability of species to grow in the new environment. The natural concept is more of the landscape appearance created. Natural planting design is a basis of how combining species with their wild character as the existence as a form in nature (Oudolf and Kingsbury, 2005).

Ecological is a dynamic concept. The ecological concept is involved from the beginning with the design process. It is started with the selection of plants, until the development of naturalistic planting species is existing in the park. Choosing a suitable species to new environments and can growth well is not as easy as expected. An understanding of the original environment and explore how these species grow naturally in their habitats will give a strong good idea in creating a stable species combination.

A stable species combination with the good establishment in an artificial ecosystem in park will involve low input cost of maintenance. Plants selection play as the important role in naturalistic planting design. To have the appearance and ecological impact in planting design South African grassland species with a huge of temperatures range in Montane South African grassland, is a home of thousand flowering plants can make a better form and aesthetics for naturalistic planting design in UK greenspace.

1.1.2 Climate Change in the UK in relation to climate of South Africa grassland.

The surrounding sea has a major influence on the UK, producing a climate that changes from day to day. In general in the UK, the summer is cooler than those on the European continent and winter are milder (Pearce, 1998). Due to the high latitude, at altitudes exceeding 400 m, climate in UK is typically cold and cloudy for much of the year. Annual rainfall typically varies from 400 to 1,500 mm pa. The eastern UK is generally drier, all year round in comparison to other areas, and colder in winter, as it is closer to continental Europe, and hence caught up in high pressure systems in winter.

On the high altitude plateau that forms much of South Africa (SA) much of this country is classified as a temperate climate (Schulze, 1997). The rainfall may vary spatially from 400-2500 mm per year, with the eastern half of SA experiencing rain only in summer and the Western largely only in winter. Mucina and Rutherford (2006) document the climate and vegetation of South Africa, Lesotho and Swaziland show that the coldest periods in the Grassland biome is June to August. Fog is found and often long lasting on the upper slopes of the Escarpment and Sea ward scarps. The biome has high lighting flash densities encouraging grass fires during the winter dry season. The range of mean annual temperature varies from 4˚C to 14.7˚C per year. In some area like the Drakensberg, Lesotho and the Stormberg Plateau the mean temperature can go much lower than 0 ^{o}C during the winter month. The lowest recorded temperatures at an official meteorological station are -18.6 ˚C at Buffelsfontein in the Eastern Cape (*South African Weather Service*, 2011). Growing season temperatures in relation to the UK are shown in table 1.1.

Table 1.1 Comparison of Sheffield air temperature and precipitation in June and August 2010 with historical data (2001-2010) for 5 South African stations that approximate to the natural distribution of the plant species used in this study.

Location	June (December in SA)				August (February in SA)			
	T	**TM**	**Tm**	**PP**	**T**	**TM**	**Tm**	**PP**
Sheffield, UK	15.6	20.1	11.0	41.6	15.5	19.3	11.7	44.8
Barkly East	17.4	26.9	9.7	60.3	17.6	27.4	10.9	75.4
Maseru	23.3	28.8	14.4	24.3	22.2	27.8	14.9	49.4
Pretoria	21.0	28.5	15.5	131.0	20.7	27.9	15.5	89.2
Bloemfontein	22.3	31.3	13.2	66.0	22.0	30.3	14.5	71.9
Queenstown	19.9	30.1	13.8	41.5	20.3	30.1	15.0	44.3

T - Average monthly temperature (°C)
TM - Average maximum monthly temperature (°C)
Tm - Average minimum monthly temperature (°C)
PP - Total precipitation (mm)

The grassland biome (Latitude 25^{o} to 33^{o}S) is located in areas on the high central plateau of South Africa, and the inland areas of KwaZuluNatal and the Eastern Cape. It occupies about 24% of SA surface area. The grassland is rich with plant species totaling 3,788 species (Mucina and Rutherford, 2006). The structural of grasslands are simple and strongly dominated with Redgrass (*Themeda triandra*) and other C4 grasses. The canopy cover depends on soil moisture availability and mean annual rainfall (Mucina and Rautherford, 2006). Besides tussock grasses, the inter-tussock space contains many summer and autumn flowering forbs for example, *Agapanthus, Berkheya, Crocosmia, Diascia, Dierama, Gladiolus, Hesperantha, Kniphofia, Moraea, Osteospermum, Phygelius* and *Watsonia*. Mediteranean *Agapanthus (A. africanus, and A. praecox)* were some of the first SA species to arrive in Europe during the Dutch Colonisation of Cape of Good Hope in the seventeenth century (Culver, 2001). The 17th and 18th century was climatically cold compared today. Therefore, most of the species introduced throughout Europe during that time could not survive winter frosts in Europe during that period and could only be cultivated under glass.

Figure 1.1 South African montane grassland dominated by tussock grasses and inter-tussock space containing flowering forbs.

Expeditions during the late 19th and early 20th century further north in the high altitude areas started to yield more cold hardy species, for example in *Agapanthus, A. campanulatus*. Interest in South African plants increased as a result and many of the nurseries in the UK produced many *Agapanthus* and *Kniphofia* cultivars at this time. Today species like *Kniphofia* spp., *Agapanthus* spp. *Crocosmia* spp. and *Dierama* spp are cultivated and planted in a traditional groups or blocks of a single species. Interest in South African species from the high altitude above 1500m-3000 m grasslands of the Eastern Cape and Drakensberg for use in naturalistic planting in the UK was initiated by Hitchmough in 2004 (Hitchmough, 2010).

1.1.3 Overall aim of the research

To develop communities of summer rainfall South African forbs, geophytes and grasses as a new planting design form for 21st century urban public and commercial-landscapes.

1.1.4 Research questions

- Is it possible to develop South African grassland species as new planting design under UK climate?
- What criteria should be considered when selecting SA plants for naturalistic planting? Can communities of SA species be established by field sowing?
- What effect do sowing mulch characteristics have on emergence, establishment and longer term survival?
- Are South African plant communities able to survive winter cold and wetness?
- How long to communities of SA species typically look attractive?

1.1.5 Research objectives

The objectives of the study are

- To investigate the effect of sowing time and seed pre-treatment on the synchronous germination of species in sown communities
- To investigate relative growth rate of component species with different times of sowing and seed pre-treatment
- To investigate the effects of air filled porosity of different sowing substrates on the survival of difficult species of summer rainfall species in response to summer wetness and winter wetness in combination with cold winters.
- To investigate the effects of height of the foliage canopy of a range of forbs, grasses and geophytes on competition with multispecies sown communities.

- To investigate the effect of different ratios of species with different canopy heights on short to medium term community development, individual species mortality and floral performance.

1.5 Research activities

A series of experiments were conducted to develop South African grassland species as a new planting design form in British green spaces. Three main experiments were initiated to achieve the aim and objectives of this study (Figure 1.2). The first study looked at achieving uniform establishment of key species **(Chapter 3).** This was followed by studies on growth and survival of species sensitive to wetness condition **(Chapter 4)**, and thirdly, studies on the effect of competition between species of different potential productivity or canopy height on individual plant survival, community structure and appearance **(Chapter 5)** have been conducted**.**

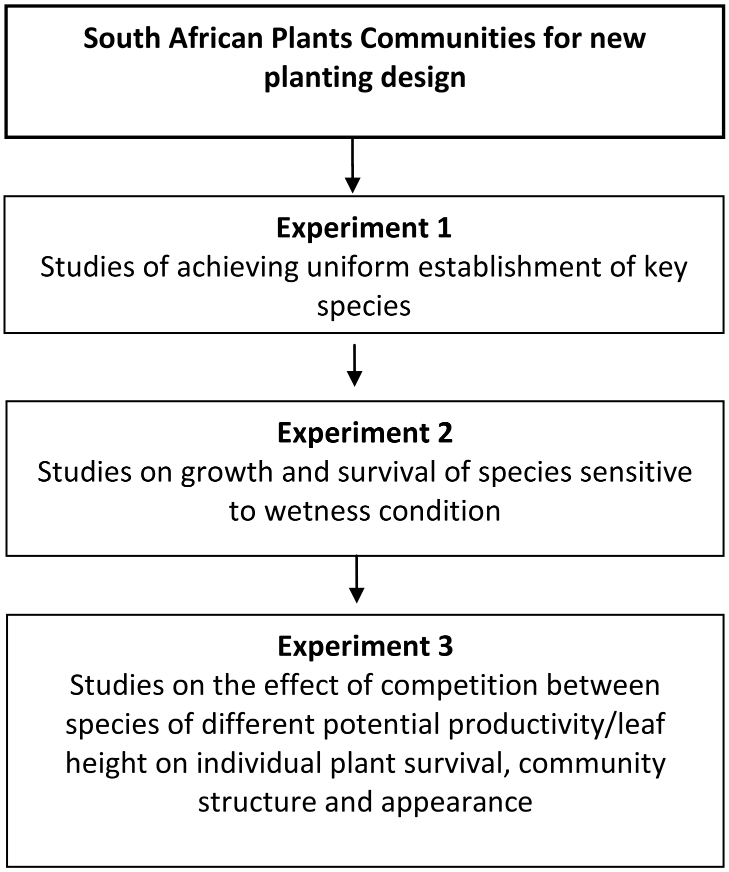


Figure 1.2 The scope of the study highlighting key areas of experimentation

CHAPTER 2: GERMINATION, ESTABLISHMENT AND COMPETITION IN SOWN PLANT COMMUNITIES

2.1 Factors affecting seedling establishment

The meaning of germination is clarified by Bewley and Black (1994), germination begins with water uptake by the seed (imbibition) and ends with the start of elongation by the embryonic axis, usually the radicle. Expansion of seed size as it imbibes water is the beginning with the germination process. Seed coats soften and rupture, and the radicle emerges first from the seed. Desai (2004) defines germination as an emergence of the embryo from the seed by starting a variety of anabolic and catabolic activities, including respiration, protein synthesis and mobilization of food reserves after it has absorbed water.

This germination process according to Bewley and Black (1994) can be divided into three phases (Figure 2.1). The first phase is the process of imbibition (water uptake) and this occurs in seeds that are both dormant or non-dormant. The second phase is where a reduction on water uptake and metabolic major events take place in preparation for the emergence of the radicle in non-dormant and dormant seeds (Bradford, 1990). While the third phase during the germination process is radicle elongation together with an increase in the water uptake (Manz et al., 2005). The radicle elongation process is identified as the end in the seed germination process. The duration for each phase is dependent upon the properties of each seed of sown, for example how species effects seed coat, seed size and water uptake.

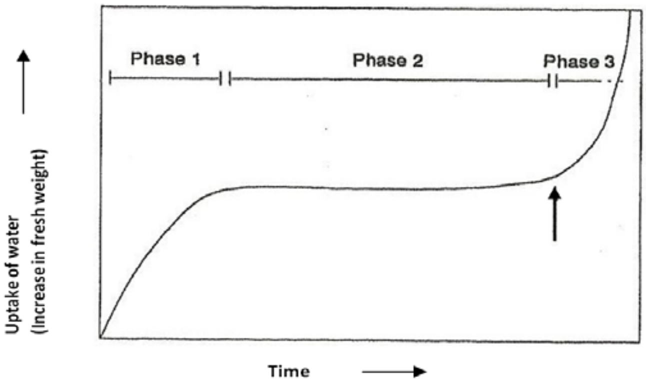


Figure 2.1 Triphasic pattern of water uptake in germination process (adapted from Bewley and Black, 1994) Arrow marks the time of radicle protrusion.

After completion of the germination process the seed emergence process starts. The process of hypocotyl and epicotyl emergence from the surface of soil or sowing medium was categorized by Chong et al. (2002) as epigeous and hypogeous. Epigeous pattern is where the cotyledons raised aboveground and the seedling forms a hypocotyl hook that pushes through the soil. The hook will open to create straight seedling when it reaches the light. The other pattern is hypogeous in which the cotyledons remain underground and the stem (epicotyl) emerges aboveground (Chong et al., 2002). Time to seed germination among species is varied and controlled by ecological and evolutionary origins. According to Baskin and Baskin (2001), what controls the time of seed to germinate can be determined from information on seed, environmental condition in habitat and interaction between these two factors from time to seed maturation and germination.

In research work that involves sowing seeds directly, understanding of seed germination ecology is very important. Baskin and Baskin (2001) outline the best method of conducting research on seed germination ecology is to break the problem into a series of questions:

- When do seeds mature?
- When are they dispersed?
- What is the dormancy state of seeds at the time of maturation and at dispersal?
- What are the environmental conditions in the habitat between time of maturation and germination?
- What environmental conditions are required to break dormancy and to induce it?
- What conditions are required to promote germination of non-dormant seeds?

2.1.1 Intrinsic factors affecting germination and emergence

2.1.1.1 Seed quality

The success of sowing seed directly in the favourable field is completely dependent upon the quality of seed used. Suppliers of seeds of agricultural and other species subject to national seed quality legislation are obliged to ensure seed purity of species and variety supplied (Beavis et al., 1999; George, 2009). Ability of seed to germinate and seed vigor is an intrinsic factor that are essential in the success of direct seeding cultivation in developing plant communities. A quality seed is dependent on several things: seed age, seed storage condition, seed production condition, including the degree of fungal pathogens in wet conditions, insect predation, degree of pollination and others (Bewley and Black, 1994; Desai, 2004; Pieta-Filho, and Ellis, 1991).

Quality seed production starts from the formation at the plants. According to Bewley and Black, (1994), response to environmental stress in seed production is different and complex. Stress such as lack of water(Crocker and Barton, 1953), or the temperature being too low or too high (Grime, 1977) will affect seed production, with a reduction in the number and quality of seeds (Bornscheuer et al., 1993). However, sometimes it will also benefit to the quality of seeds produced during that time. Experience of plants gone through different stress conditions will produce a generation of seeds that are resistant to such conditions (Bewley and Black, 1994; Aaron et al., 1993).

The vigor of an individual seed is the ability of seed to produce normal seedling. The process of cell division and cell enlargement of seeds it can be disrupted due to water and heat stress (Kranner et al., 2010). High temperatures above 30 °C will reduce the grain filing period in wheat (Wrigley et al., 1994). Reducing the weight of the seed when mature can affect the quality of seeds produced on tomato (Demir and Ellis, 1992) and soybean (Keigley and Mullen, 1986).

2.1.1.2 Seed size and uniformity

Seed size is an important parameter to influences germination and emergence of the species. Large seeds can give an advantage to certain species to germinate in a wide range of environments. The greater seed weight is determined to have finer storage reserves, which can increase the seed vigor (Powell, 1988). Seed size significantly influences seedling establishment and survival in the competition (Coomes and Grubb, 2003; Turnbull et al., 1999). Large seed size is also much more favourable in terms of having food reserve for seedling to survive (Bonfil, 1998) and low soil moisture (Rey et al., 2004 and Baker, 1972).

As mention by Grubb (1977), all stages in the regeneration cycle are potentially important including production of viable seed, to the maintenance of species richness in plant communities. Production of limited amount of seed will affect the succession of species establishment in the communities (Turnbull et al., 2000). Germination, growth and biomass production in plant communities is influenced by seed size (Egli, 1998). Sowing of the mixed seed of a species may result in non-uniform density of seedlings, which may lead to heterogeneity in the vigor and size of the seedlings (Gunaga and Vasudeva, 2011).

2.1.1.3 Seed dormancy

In sowing seed directly in the field, seed dormancy is an important factor to take into consideration. There are different opinions in classifying types of seed dormancy. A dormant seed (Baskin and Baskin, 2004) is said to be one that does not have the capacity to germinate in a specified period of time under any combination of normal physical environmental factors (temperature, light/dark, etc.) that otherwise is favourable for its germination. Bewley (1997), by contrast defined dormancy as the failure of an intact viable seed to complete germination under favourable conditions. In the case of morphological dormancy, delay of germination (dormancy) is due to the requirement for a period of embryo growth and radicle emergence after the mature seed has been dispersed (Sanchez, 2004). A non-dormant seed (or other germination unit), on the other hand, is one that has the capacity to germinate over the widest range of normal physical environmental factors (temperature, light/dark, etc.) possible for the genotype. A non-dormant seed will not germinate, of course, unless a certain combination of physical environmental factors (temperature, light/dark, etc.) (Bewley and Black, 1994).

The non dormant seed that does not germinate because of the absence of one or more of these factors is said to be in a state of quiescence [enforced dormancy of Harper (1977) and pseudodormancy of [Hilhorst and Karssen (1992), Koornneef and Karssen (1994)]. Quiescence is included under ecodormancy of Lang et al. (1985). The seed will germinate when the appropriate set of environmental conditions is within its range of requirements for radicle emergence, providing it has not entered secondary dormancy (Bewley and Black, 1994). Use of the species in producing naturalistic planting design usually exceeds 5-10 species in the community. Each species has a different time to germinate. A lot of studies have been done to overcome seed dormancy factors for induced germination in sowing practice. Many pre-treatments have been successfully used to break dormancy, acid, hot water and mechanical scarification have been found suitable in species (Khurana and Singh, 2001) with impermeable seed coats. Many temperate species require exposure to a period of low temperatures to germinate.

The selection of species with non-dormant seed is a priority in crop cultivation, where, non-uniform germination can disrupt establishment of designed communities by species that germinated earlier and will establish faster and eliminate the slow species.

2.1.1.4 Overcoming these intrinsic limitations to germination in practise

Methods of sowing a seed mix for urban green space potentially involves many species and seeds with different germination performance and dormancy. In storage condition, seeds develop the dormancy when it dries out. Post harvest, many temperate forbs develop some type of physical and physiological dormancy (Baskin and Baskin, 1988; Bewley, 1997). A lot of studies and methodology of seed pre-germination treatment have been developed to improve and overcome dormancy such as winter chilling situ, chilling in a fridge, mechanical abrasion and hormone treatment (Luna et al., 2008). Although using plant hormones have a very good effect, the cost of preparation is too high in comparison with 3 other mechanical treatments.

Chilling in the laboratory can break the dormancy of many seeds. Imbibed seeds exposed to low temperatures breaks dormancy allowing germination to occur (Slade and Causton, 1979; Hitchmough et al., 2000). Quick and uniform germination of seed can be achieved by pre-sowing treatments which improves germination rate, uniformity of germination and total germination percentage (Parera and Cantliffe, 1994). In crop production under unfavourable environmental conditions, rapid seed germination and stand establishment are critical factors (Nejad and Farahmand, 2012). Pre-sowing treatment will improve seed performance under adverse environmental conditions (Ashraf and Foolad, 2005).

2.1.2 Extrinsic factors affecting germination and emergence

2.1.2.1 Temperature

Suitable conditions for germination often reflect those experienced in the habitat of a species (Baskin and Baskin, 1998). Temperature has a major influence on what can germinate when and how fast. The species that live in temperate areas and at high altitudes are able to germinate at low temperatures. Whereas species which originate from tropical areas in the lowlands need at least 20 °C in order to germinate. The germination of South African species in their habitat are also heavily influenced by temperature. South Africa grassland species of C4 grasses do not germinate when the temperature daily mean is below 25 °C (O’Connor and Bredenkamp, 1997).

During germination and the early establishment phase, seeds and seedlings are extremely susceptible to physiological stress, mechanical damage and infection. When a seed is sown in agriculture, horticulture, or restoration ecology works in the field, the key factor that controls initial germination and emergence is the avoidance of severe moisture stress (Fay and Schultz , 2001: Hitchmough and Innes, 2007). Hitchmough (2003) has shown that by maintaining sowings at close to field capacity, a wide range of species can be reliably established in landscape sowings. Temperature plays a key role in determining when an imbibed seed is able to germinate and species requirements are strongly influenced by the geographic region from where the plants originate. In a study of *Watsonia* species, Ascough et al. (2007) found that species from winter- rainfall areas germinated optimally within a temperature range of 10 – 20 °C. However species which originated from summer -rainfall region had the best germination rate at temperatures between 15- 25 °C. Species widely distributed across summer and winter rainfall zones such as *Watsonia pillansii* could germinate across the range from 10 to 30 °C (Ascough, et al., 2007). These responses are however very problematic for sown plant communities, when sowing must be undertaken at the same point in time.

Germination and seedling emergence is influenced by many factors, but of particular importance are: seed quality (Alderson, 1987), seed dormancy (Baskin and Baskin, 2001), pre-sowing treatments/requirements (Khan, 2010), water stress (Hegarty, 1978), temperature (Thompson and Grime, 1983), light (Fenner and Thompson, 2005), and predation/pathogens (Kirkpatrick and Bazzaz, 1979; Wilby and Brown, 2001). Temperature has a major influence on what can germinate, when (Baskin et al., 1995), and how fast (Baskin and Baskin, 1988). Because plant traits are often shaped by the conditions in their habitats (Grubb, 1977), species that grow in temperate, high latitude climates and at high altitudes in lower latitudes, are often able to germinate at low temperatures (Shimono and Kudo, 2005). Some of these species may be subject to imposed thermo-dormancy at higher temperatures. Temperature requirements for germination are typically higher for species of lower latitudes or altitudes (Baskin and Baskin, 2001). Photosynthetic pathway has an effect on emergence, many C4 grasses do not germinate until daily mean temperature is >25 °C (O’Connor and Bredenkamp, 1997). C3 grasses such as *Festuca* and *Merxmuellera*, are typically able to germinate at 15 °C or lower (Palazzo and Brar, 1997). Temperature requirements for germination affect the time of year a species can emerge at, and hence the capacity of the seedlings to avoid exposure to severe stress and or high levels of competition. Ascough et al., (2007) found that *Watsonia* species from winter-rainfall areas germinated optimally at 10-20 °C, whilst summer rainfall species showed optimal germination at 15-25 °C. Species widely distributed across summer and winter rainfall zones such as *Watsonia pillansii* could germinate across the range from 10 to 30 °C (Ascough et al. 2007). Beyond the minimum temperature threshold for germination, the main effect of increasing temperature (until inhibitory levels are reached), is to increase the rate of germination (Garcia-Huidorbro, et al., 1982). Mean maximum germination is rarely reduced or increased within the range acceptable for germination (Baskin and Baskin, 2004; Karlsson and Milberg, 2007).

2.1.2.2 Water

Seed germination and seedling emergence is influenced by several factors: seed quality, pre-sowing treatment, germination conditions such as water, temperature, germination media, light and pathogens. Water is the catalyst factor that causes the beginning with the germination process (Bradford, 1990). Water uptake by the seed in the process of imbibition normally requires 2 to 3 times the weight of the seed. Seeds can only germinate when sufficient water is available, and they have intimate contact of the soil. Movement of water from the substrate to the seed is also influenced by several factors (Bannister, 1976). The difference in water potential between seed and soil is one of the factors that influence the rate of water movement from soil to seed (Bewley and Black, 1994).

Imbibition can take place in some species in a humid atmosphere (Kavak and Eser, 2009) but in many cases, germination requires seed to be in contact with the water phase around soil particles (Harper and Benton, 1966). Suitable moisture conditions for germination often reflect those experienced in a species habitat (Baskin and Baskin, 1998). Once germination commences, avoidance of severe moisture stress is the critical factor in maximizing emergence, both in the habitat and when sown in restoration ecology or horticultural practice (Keddy and Constabel, 1986; Hitchmough et al., 2003). Fay and Schultz (2009) found that emergence increased with North American prairie forbs when exposed to longer watering intervals, but this appears to be due to an anaerobic germination environment. Noe and Zedler (2000) and Hitchmough et al., (2003) report maximum emergence in a wide range of wild occurring species as soil moisture stress decreased. Where soil moisture stress is minimal, temperature is often the critical factor affecting how many seedlings are present to a point in time.

In the development of semi-natural vegetation, water management is crucial. It starts with the selection of a suitable sowing medium for maintaining optimal moisture content and also keeps adequate water resources for seeds to germinate and seedling establishment. The early seedling stage is the most critical stage of water requirement. The growth of plants will be retarded due to inhibition of cell elongation by water limitation (Nieman, 1965).

2.1.2.3 Light

Light is an extremely important factor for releasing seeds from dormancy (Bewley and Black 1994). Light requirements is dependent upon the species sown. There are species that require light to germinate, and some species that need dark to germinate (Grime et al., 1981; Baskin and Baskin, 1988). This occurs due to where seeds were produced. *Portulaca oleracea* differed in germination percentage when alternately exposed to red and far-red light (Gutterman and Porath, 1975). Meanwhile, seed from plants exposed to far-red light did not germinate in darkness (Gutterman, 1974; Baskin and Baskin, 2001). The explanation of how light affects some seeds and causes them to be in a state of readiness for germination and yet prevents other seeds if necessary for germinating is highly complex. Suffice it to say that it is mainly the light's effect upon a plant pigment called phytochrome within the seed. This relates to the type of light which the seed receives. As a generalisation, light in the red wave length usually promotes germination whereas blue-light inhibits it (Batty, 1989).

2.1.2.4 Effect of sowing practice on these factors

Naturalistic planting design often involves the sowing of more than five species within a densely populated area. Standard seedling targets per square metre typically range from about 50 to 100 plants (Hitchmough, 2004).

Direct sowing of seeds is potentially an effective way to create semi-natural vegetation in urban green space. This method is increasingly widely adopted (Hitchmough, 2004) being used at the London Olympic Park, and at several Royal Horticultural Society Gardens. Used to develop perennial and annual meadow in the Olympic Park (Neal and Hopkins, 2013) where over 300 kg of seeds were sown. The selection of this cultivation method is based on advantages such as being cost-effective during preparation of the planting materials, significant impact of naturalistic, time saving and easy maintenance. There are also disadvantaged such as seed dormancy, the design skills required to make seed mixtures and post-sowing maintenance (Dunnet and Hitchmough, 2004). Direct sowing requires good planning and accurate forecasts. Sowing seeds directly requires a suitable environment in terms of temperature and moisture.

i) Sowing time

Failure to determine the right time to sow the seeds will produce unsatisfactory results (Green and Ivins, 1985; McDonald et al., 1983). Timing of emergence of component species is extremely important in multi-species sowings, as it also is in natural systems (Wilson and Gerry, 1995; Hitchmough et al., 2003). In restoration ecology timing of sowing is often closely related at the time when the soil moisture content is optimum, however in urban work irrigation is often used to increase emergence, and sowing at the right temperature for germination becomes more of a focus. Timing of sowing is most sensibly driven by the combination of temperatures required for emergence, and the dormancy status of species sown. Species such as North American prairie plants that often requiring moist chilling, are best sown in winter whereas species not requiring this treatment establish well from spring sowing (Walck, 2011). In mixed sowings species that emerge after the quicker species are more likely to be shaded out and eliminated by the earlier establishing incumbent (Quintana et al., 2004).

ii) Sowing depth

Among the factors determining the depth of sowing are seed size, speed of germination and soil type. Each species used in the plant communities will have different characteristics. The determination of the optimum depth for all species used for the cultivation of processed products is very important to get a uniform and sustainable growth of plant communities.

Sowing depth determination often depends upon the size among the species of seeds used (Li et al., 2006). Large seeds sometimes germinate better in the nursery more than in small seeds because they contain more food reserves (Bennet, 2004). The nursery seedbed surface is often made to a depth of 10-20 mm, however Aslam (1984), revealed that optimum germination for large seed like sunflower occurred when planted at 7.5 cm depth due to . reliable soil moisture at this planting depth. Soil near to surface is exposed to evaporation by wind and high temperature (Harper and Benton, 1966), however some small seeded species require light for germination and emergence (Hitchmough et al. 2011). Deeper burial of seeds increases the thermal time for seed to emergence and decrease germinability (Harris et al., 1987). Planting seeds at suitable depth to give the seeds a chance to absorb water from the surrounding before the media that surrounds it dry. Seeds require about 50% of the weight to germinate, therefore, the compaction of the surface after sowing the seed is also important to get good contact to the media and enable seed to absorb large amounts of wate. Medium type used also affects the determination of the sowing depth. The light planting mediums such as sand dry over the surface quickly.

As mixed sowings are normally broadcast sown, depth is much less controllable, and practices such as raking mean that different sized seed is always distributed across a depth gradient from the surface to 25-40 mm deep.

iii) Type of substrate

Sowing seeds directly in the field conventionally requires good seedbed preparation. Among the characteristics of a good seedbed is to have good drainage; other characteristics include the ability to retain moisture, a suitable pH and free from weed fragments and weed seeds. Site preparation process usually includes soil cultivation, removing impurities, levelling the ground and spraying herbicides. If the original soil in that area has excellent soil properties, the seeds can be sown directly after two weeks of spraying pesticide.

When preparing a site for the naturalistic planting project, one of the main components to analyze is soil texture and structure. Soil is one of the most limiting factors in healthy growth of plants. Once the physical characteristics of soil such as bulk density, water-holding capacity, air filled porosity, pH, nutrients content determines (Craul, 1992; Ingram et al., 1993), then the correct plants to use in given site conditions can be selected (Özgüner et al., 2007). In agricultural and horticultural practice optimalising soil productivity is seen as key, however when dealing with ecologically based vegetation such as meadows and prairies, low productivity is more desirable, so the critical issues become moisture holding capacity and root penetrability. Urban waste soils are often very interesting in that they are highly heterogeneous and create very interesting vegetation, unlike highly fertile soils.

iv) Use of sowing mulch to control weeds

The main problem in sowing directly in the field is the competition of seedling and weeds. The use of a 75-100mm layer of weed seed bank free material as a planting medium for making seedbed also functions as sowing mulch (Hitchmough and Fleur, 2006). A range of materials can be used for this purpose depending on local availability and cost, plus the nature of their physical properties in relation to the intended vegetation. Sharp sand is a widely available and effective material, but so can various grades of crushed brick and organic green waste.

v) Rolling after sowing

The process of germination in the sowing medium depends on the efficiency of the imbibition process. The seed needs to have good contact with soil particles. The germination of seeds is uneven when the imbibitions process is not effectively facilitated.

In the cultivation process, rolling is a secondary soil cultivation process. In a big area rolling usually was done by using corrugated roller (Starcevich and Sharma, 2011) or footprint for the small area. Loosened plough soil is pressed against the non-plough soil to ensuring water from lower pass through to the upper layers. Rolling the soil surface after sowing can influence better germination of seed, especially for small seeds to germinate (Musec, 2006). Roll after sowing firms and levels the surface and create a good seed and soil contact for germination. The water uptake process in seeds will increase by reducing the volume of non-capillaries of the soil and increase capillary rise of water by rolling on the soil surface. The heterogeneous nature of the soil surface provide widely different condition for seeds to germinate. Seeds with a specific germination requirement will be germinated with different numbers and proportions and established by the sort of micro-environment in which seed dispersed on to soil surfaces (Harper, 1965). In naturalistic planting, sowing seed directly with a combination of different species and seed size need to increase a good seed and soil contact for all seeds to have same chances to increase the water uptake during the germination process.

vi) Irrigation post sowing

In a naturalistic planting design, sharp sand is often used as mulch and as a sowing medium (Hitchmough, 2008). The ability of these materials to hold water is also very important determinant of the frequency of watering to get good emergence. Sowing seed on the surface of coarse sand requires watering every one to two days as sand has much lower water capacity than soil (Handreck and Black (2005).

The optimal moisture content can be provided through watering based on visual and touch inspection of media or by fixing the moisture sensor in the field (Fieldhouse and Hitchmough, 2004). If the medium is irrigated too frequently, the new seedlings will be damaged due to anaerobic conditions (Allen et al., 1998).

2.2 Competition in plant communities

2.2.1 Plant growth rate

Plant growth rate refers to the increase in dry weight of plants over a known period of time. Increase in dry weight is strongly associated with an increase in plant size (Fitter and Hay, 2001). Historically people have more interest on selecting species with fast growth rate, than slower growing counterparts used when plants are mixed in a community. Fast growing species have higher rates of carbon exchange producing roots and leaves faster. Whilst it is true that high growth rate species in sown communities help to overcome weed competition within the community, they also tend to eliminate the slower growing species that are sown with them, leading to a decline in diversity and visual interest. Competition within communities must therefore also be taken into account in order to produce a stable and functional community. High plant growth rates are most likely to be desirable or even essential when dealing with highly productive moist soils, where low productivity species will never be particularly stable due to the excess nutrients and water driving ongoing invasion of weedy species (Dunnet and Hitchmough, 2004)

2.2.1.1 Relative growth rate

Relative growth rate has been used as a means of categorizing, particularly for seedlings, the potential of different species to compete for resources (Grime and Hunt, 1975; Grime et al., 2007). Small seeded species typically have higher growth rates (Turnbull et al., 2008) and tend to be more ephemeral species associated with more open habitats. Long lived, large seeded, clone forming geophyte species associated with productive *Themeda triandra* tussock grasslands, such as *Dierama* (Mucina and Rutherford, 2006), have particularly slow seedling growth. Lunt (1997), found seedling geophyte survival in closed *Themeda* grasslands in Australia depended on the extent of stored carbohydrates in their seeds.

Species that germinate quickly in favorable environments normally have a high relative growth rate (Shipley, 1989). In Gross's study (Gross, 1984) she identified the effect of seed size and growth form on seedling establishment of monocarpic perennial plants. She found that the relative growth rates of seedlings were generally inversely related to seed size, with small seeded species having faster relative growth rates than large. Similar trends have been noted by Turnbull (2008). Ultimately establishment success depends on the interplay between plant traits characteristics such as emergence time, seedling growth form, and relative growth rate, and in some cases these factors will be influenced by seed size (Gross, 1984b; Rey, 2004).

2.2.2 Competition in sown communities

Naturalistic planting in designed landscapes inevitably causes severe competition between individual herbaceous plants. This is because plants are often planted or sown much closer together than in conventional planting. As a result whether all are the same or different species, plants will be subject to different growth rates and growth forms. It is these differences in plant size, growth rate and architecture that lead to what is known as competitive asymmetry; the capacity of one plant to compete more effectively for resources and particularly light than other plants (Schwinning and Weiner, 1998). Grime (1979) states that plant competition in early and adult stages refer to the tendency of neighbouring plants to utilize the same quantum of light, nutrient, water and volume of space. There has been a huge amount of work trying to understand the mechanics of competiton in plant communities over the past 30 years. Two of the leading thinkers on this are Grime and Tilman, although they come at this problem from different directions, and hence have generated competing theories, which others have tried to reconcile (Crane, 2005)

Plant Strategy Theory or CSR Theory (Table 2.1) is the basis for the development of naturalistic plant community (Grime, 1979). Two environmental factors can inhibit the growth and survival of potentially dominant aggressive species; i) Stress; often defined as a shortfall or excess of resources vital to physiological processes, for example, extreme temperature, heavy shade, drought and low nutrient availability, ii) Disturbance this involves the destruction or damage of plant tissue and biomass by physical damage of plants e.g. cultivation and grazing.

Table 2.1 Combinations of environmental stress and disturbance resulting in three basic plant response strategies (from Grime, 2001).

		Intensity of stress	
		Low	High
Intensity of disturbance	Low	Competitors (C-strategists)	Stress-tolerators (S-strategists
	High	Disturbance-tolerators (R-strategists	Uninhabitable

The timing of the developmental stages in aerial plant parts has significant survival value in competitive situations among species (Harris, 1977). Phenological studies of SA grassland species in relation to development of aerial parts of mono-cultural plant communities and the relationship of this with relative growth rate have been studied by Richardson (unpublished) in Sheffield. The results of these field trials indicate that different plant affect competitive potential differently across time. Fast growing species will initially be competitive dominants, however very slow growing species that also accumulate biomass may eventually displace these species. Further study on these species is required and how there varying growth rates can be accommodated in sown communities. Consideration of their differences in growth rate and biomass productivity must be given before combining the species in designed plant communities (Sayuti and Hitchmough, 2013). In the short term competition for resources in communities will allow fast growing species to eliminate slow growing species, unless the abundance of the former is reduced. Competition also has positive effects however; in high density sowings, sown species compete more effectively against weedy species (Hitchmough and De La Fleur, 2006).

Each species has a different growth rate and different patterns of growth, which influence the outcome of competition. In developing sown or planted multi species communities, species must be listed according to growth rates, flowering period, size at maturity in order to develop a community that when formed has a good appearance and functions effectively (Hitchmough, 2004). Developing naturalistic plant communities is based on understanding the growth cycles and other competitive characteristics of the plant species used, as well as the decorative characteristics that are more widely used within professional horticulture.

2.2.2.1 Competition for water

In habitats in which light is abundant and soil resources very limited, availability of water below ground is very important in determining competition. Where water and nutrients are abundant and light limiting, then above ground competition is more important in this context than root competition (Wilson and Tilman, 1993). Weiner (1988) also reported that the competition for light is considered to be primary because of plants grow bigger and crowded in fertile soil. Where water and nutrients are not abundant, the opposite tends to be the case (Casper and Jackson, 1997). This view is strongly supported by many of the previous studies that below ground competition intensity increased as productivity levels decreased (Putz and Canham 1992, Wilson, 1993, Wilson and Tilman, 1993).

Competition for water starts when seedlings emerge and increase their size and compete with adjacent surviving seedlings. As mentioned by Schwinning and Weiner (1998) the hypotheses of competition for water is based on the principle that each unit of biomass is equal in its contribution to water uptake. It is expected that competition for water is size asymmetric and correlated with plants water potential. In that case, this might occur when larger plants maintain lower tissue of water potentials and open the stomata longer thereby increasing transpiration (Schwinning and Weiner, 1998). According to Casper and Jackson

(1997) water uptake is driven by plant transpiration and is a function of water movement to the root, maximum rate of transpiration (Schulze, 1994). In the mechanics of root interactions in belowground competition, the degree of competition increases as effective water diffusion increase (Baldwin, 1976). The competition is dependent on the capacity of roots to avoid other roots that are absorbing water and the amount of soil moisture available (Friedman and Orshan, 1974).

Among herbaceous plants Vila and Sardan (1999) and Silvertown (2012) have studied how varying the moisture regime influences patterns of dominance and change in vegetation. In the grassland biome of South Africa, change and turnover of tufted perennials is depended on the rainfall regime. The increased frequency of drought-related mortality therefore, has the potential for rapid compositional change (O'Connor and Bredenkamp, 1997). Araya (2011) found that fynbos niche segregation in the Western Cape of South Africa occurs along soil-moisture gradients. Studies on plants in an English meadow by Silvertown (1999) also revealed that plant community segregated influence by hydrological gradient.

Availability of water in the soil varies with the gradient and the environment in terms of whether it is in shade or an open area. Shading can reduce near-ground solar radiation and decrease the temperature and evaporative rates from plants and soil (Breshears et al., 1998). A couple of study on seedling growth in herb communities suggested that increased use of water by herbs did not have a negative effect on growth probably because of decreasing evaporation from the soil surface counterbalanced water loss through the herbs canopies (Vila and Sardan, 1999). Low evaporation under canopies allow competition for available water. In plant communities, the depth of root systems and efficiency of absorbing water (Archibold, 1995) will influence the degree of competition for water. William and Hobbs (1989) demonstrated that shrubs species namely *Baccharis pilularis* unable to establish under annual grasses because of root failure to reach soil moisture below the depth of the grass roots.

2.2.2.2 Competition for soil nutrients

Competition for nutrients is a major factor that structures plant communities. Competition between species will be increased when the nutrient availability in soil is lower (Tilman and Grace,1990), however Grime (2002, 1979) interprets these responses in a diametrically opposite manner, that competition increases as nutrients increase. Grimes interpretation makes more intuitive sense as on nutrient rich soils biodiversity is intrinsically low because plant biomass is high leading to competitive asymmetry (Weiner and Thomas, 1986) and the elimination of slower growing species by larger. On highly infertile soils there is rarely enough biomass for marked competitive asymmetry to be a powerful factor.

The fertility of soil in urban areas varies considerably. In general it is, due to intentional and unintentional eutrophication, generally more fertile than the soils in the natural habitats of many wild occurring plants, although it may be less fertile than agricultural land and typically has relatively poor structure. Most plant do of course produce more biomass more quickly when planted on soil more fertile compared to a natural landscape (Bullock and Gregory, 2009). Soil nutrients are normally distributed heterogeneously and supplied episodically (Cadwell et al., 1996). Nutrient uptake will increase per unit root length when plants grow on nutrient rich soil (Fransen et al., 2001). As result competition will increase under more fertile soils. In communities of species as opposed to agricultural and horticultural monocultures, increasing fertility is therefore typically a problem for the maintenance of diversity.

The intensity of competition for nutrients is increased by the degree of nutrient availability in the soil (Buckland and Grime, 2000). Heterogeneous pattern of renewal nutrient in soil can affect the mode of competition. Competition below ground often reduces plant biomass more than aboveground competition (Wilson, 1988). High density plants in semi natural vegetation show increased competition because the root density belowground is higher than in crops. Competition for all nutrients will increase as root length and density increases (Barber, 1984). Sand and Mulligan (1990) reported finer roots are less competitive and will be able to absorb nutrients at the lower nutrient concentration. The rooting pattern will change according to uncertainties of nutrient supply (Schwinning and Weiner, 1998). As reported by Caldwell and Richards (1989) local root density tends to match small-scale variability in resource levels and species respond differently to the different patterns of spatial and temporal variation (Crick and Grime, 1987; McConnaughay and Bazzaz, 1992; Grime, 1994). Moreover, the response of roots to exploit the heterogeneous distribution of soil resources potentially will modify competitive asymmetry (Casper and Cahill, 1996). For example, Aerts (1999) reported that high-nutrients habitats were dominated by fast-growing perennials with a tall stature and have high turnover rates of leaves roots. Fast growing species with a rapid growth rate tends to eliminate of small seedling, slow grow and give a shading effect on the lower species. In these situations the typical response to additional nutrients will be individual species will become dominant and potentially able to eliminate the others species (Tilman and Grace, 1990). According to Grime (1979), the highly competitive species will suppress other species at higher nutrients levels. The situation causes a decline in species richness. Many studies on species richness in relation to availability of nutrient leves (Pausus and Austin, 2001) revealed that species richness decline along the resource gradient as nutrient concentration decrease (Grime, 1973; Austin and Smith, 1989; Pausas and Carreras, 1995; Vetaas, 1997).

2.2.2.3 Competition for light

Each species in a community has a slightly different shoot, leaf morphology and growth habit to its neighbours. Although many species share broadly similar patterns, for example in SA grassland species, a basal fan of erect leaves is a very common architecture. As vegetation becomes taller and more productive, taller individuals intercept more of the light (Grime, 2001). Species with lower leafage are likely to be competitively disadvantaged, particularly on productive soils, leading to seedling death, a phenomenon known as self thinning (van der Werf et al., 1995). Capacity to compete for light between species in the communities depends upon the capacity to employ stored and newly produced photo-synthates to fuel stem growth and shoot elongation. Grime (1979) showed how in closed herbaceous vegetation, difference in stature may have critical impacts on survival. Differences in height are associated with large changes in the light intensity, direction, and quality of radiation and the ability of a seedling or established plant to compete successfully for light. Hautier, et al., (2009) has shown that competition for light is a major mechanism of loss of diversity in plant communities. Because water and nutrient availability in soil have a major impact on how much growth is produced, these factors have a major impact on competition for light. It has been shown that the spatial arrangement of leaf layers, with relatively more leaf area in the top-layers of the canopy, may also be an important determinant of the competitive ability for light interception (Grime, 1979; Spitters and Aerts, 1983; Mitchley, 1988; Barnes et al., 1990; Aerts et al., 1990).

In planting design there has been increasing research into how to create vegetation to avoid competition for light eliminating individual species. It is possible to create herbaceous vegetation composed of multiple layers of species “stacked” on top of one another. Typically this entails a low growing, spring flowering shade tolerant understory layer , a mid-canopy late spring to summer flowering layer and a taller mid-summer to autumn flowering layer (Ahmad and Hitchmough 2007). Complex layered structures are set up to maximize the resource utilization within the vegetation to whilst restricting invasive weedy species from outside; simultaneously maximizing the duration of flowering, to maximize opportunities for wildlife, and in particular invertebrates biodiversity (Hitchmough, 2008).

The combination of high and low canopy species provide interesting and suitable image concept to develop naturalistically. However, the aesthetics of the physical characteristics of the plant used to provide an attractive image should also be balanced with competition for light when the plant matures (Hitchmough, 2010). In mixed communities, species have different growth rates, and competition is subject to size asymmetry. The larger plants can reduce the light levels require by smaller species (Parker and Muller, 1982). Small species were thinned under shading of adult species and seedling under shading become smaller compared to the exposed seedlings (Vila and Sardan, 1999). In ecological based planting factors that influence competitive interactions such as light will affect how the practitioners make informed decisions about the outcome of competition among the plants they wish to use (Hitchmough, 2010).

CHAPTER 3: EFFECT OF SOWING TIME AND GERMINATION PRE-TREATMENT ON EMERGENCE AND BIOMASS PRODUCTION OF SOUTH AFRICAN SPECIES IN THE FIRST GROWING SEASON.

3.1 Introduction

Increasing acceptance of naturalistic planting design in urban green space has enhanced the use of species diversity in plant communities. The development of semi-natural grassland and meadow in urban green space is a significant outcome from the naturalistic planting design. South African grassland species are among the exotic species that have been used in UK landscape planting, but next to nothing is known of their germination, emergence and growth characteristics when sown in the field. For these species combine in a mix of semi-natural grassland communities in urban greenspace basic information on the rates of germination and early growth of these species should be studied. Previous research (Maguire, 1962) has suggested that South African species can be split into their three groups on the basis of different rate of speed germination 1) Rapid; 2) Medium; 3) Slow. Germination and growth rate are the very important factors to discover before use the species in a seed mix. This is to obtain uniform growth and prevent early competition between species that could result in species with the slow growth rates being eliminated by those with faster growth rates.

The timing of species emergence is important both in natural systems (Meyer and Kitchen, 1994) and in multi-species sowings (Hitchmough et al., 2003). Given equivalent initial growth rates, species that emerge later than other species are more likely to be shaded and outcompeted by earlier establishing species (Grubb, 1977; Quintana et al., 2004). Understanding the effect of temperature on days to emergence is particularly important in sown, multi-species plant communities, when sowing must generally be undertaken on the same day (Turner et al., 2006; Hitchmough et al., 2004). Determination of the most appropriate time for sowing is vital if successful vegetation is to be created (Pywell et al., 2003; Jinks et al., 2006).

This experiment explored how time of sowing and pre-treatments (pre-germination in the laboratory prior to sowing) influenced the time taken for emergence and the subsequent production of biomass. This study was undertaken on 22 species of SA grassland species

3.1.1 Objectives

The specific objectives of this study were:

1) To determine the effect of sowing time on percentage of field emergence and plant size after one growing season on a range of species.
2) To determine the effect of pre-sowing treatment in combination with sowing time on field emergence and plant size.
3) To evaluate the growth performance and vegetative phenology of the species across the experiment.

3.2 Materials and methods

This experiment was conducted under field experiment conditions at Sheffield Botanic Garden for a period of 10 months. The experiment consisted of two factors and two treatments in combination. It is involved a factorial design with two key factors; i) time of sowing and; ii) pre-sowing treatment. The experiment involved 22 species x 4 treatment combinations x 4 replications (Table 3.1).

Although the target of the seedling for each mini-plot was the same, the number of seed sown in each species varied. The different is because of different percentage of germination in field performance from preliminary studies and also the availability of seed supplied. The reason for having the target was to try to have approximately similar densities of species across the experiment.

Table 3.1 South African grassland species used in the study

Species	**Speed germination groups**	**Target plants**	**Actual seed sown/mini-plot**
Berkheya purpurea	Rapid	10	20
Diascia integerrima	Rapid	10	20
Eragrostis curvula	Rapid	10	20
Galtonia candicans	Rapid	10	20
Gazania linearis	Rapid	10	35
Helichrysum aureum	Rapid	10	50
Helichrysum pallidum	Rapid	10	35
Agapanthus campanulatus	Intermediate	10	20
Agapanthus inapertus	Intermediate	10	20
Aloe boylei	Intermediate	10	20
Crocosmia masonorum	Intermediate	10	25
Gladiolus papilio	Intermediate	10	30
Hesperantha coccinea	Intermediate	10	20
Kniphofia triangularis	Intermediate	10	35
Moraea huttonii	Intermediate	10	25
Tritonia drakensbergensis	Intermediate	10	20
Watsonia latifola	Intermediate	10	35
Watsonia pillansii	Intermediate	10	20
Dierama latifolium	Slow	10	25
Dierama pulcherrimum	Slow	10	25
Gladiolus oppositiflorus	Slow	10	14
Watsonia pulchrum	Slow	10	35

3.2.1 Pre-germination treatment

In the pre-germination (indicated by +) treatment, intermediate and slow germination rate species were pre sown as shown in figure 3.1 in an attempt to ensure that emergence took place at approximately the same time as fast emerging species. Pre-germination studies had previously been applied to many of the species by an MA student (Richardson 2009) and had proved useful in synchronising emergence across species with very different germination rates. In the (-) treatment, seed of all species was sown in the field on the same day (16th March 2010) without pre-treatment. The pre-sowing treatments involved pre-germination on moist filter paper in a growth cabinet at 20/10 °C, followed by removal and sowing in the field according to the schedule shown in figure 3.1. The procedures for the pre-treatment were as follows:

- Two layers of filter paper (Whatman No.1 900 mm) were placed in a Petri dish.
- In each Petri dish, the filter paper was moistened with 5 ml of de-ionised water.
- Seeds from each species of intermediate and slow germination groups were sealed with parafilm to maintain the moisture content.
- The petri dishes were placed in a growth cabinet at 20/10 °C for a 16 hour per day by florescent lamps. They were rotated and re-randomised once a week to reduce locational bias within the cabinet.

In the field, each of the species was sown in a mini-plot (150 mm x150 mm) with four replicates. A simple frame had been made from the exterior plywood (9 mm) with 150 mm square cut-outs to prevent seeds mixing during sowing time. Seeds were scattered on top of the mini-plot on sharp sand (size range 0.06 – 2.0 mm) and then pressed it to give a maximum contact with sand. A layer of horticulture grit was used as 5-10 mm deep mulch on the top of each mini-plot to keep the surface of sand moist, to maximize germination success.

3.2.2 Data collection

The number of seedlings that had emerged within each small plot was recorded in June and August 2010 and used to estimate the percentage of seed emergence in all species (Table 3.2). The number of seedlings in each mini-plot was counted in every two-week interval to get the percentage of emergence on individual species along the observation period. Percentage emergence was calculated from the number of seed sown.

Table 3.2 Activities and timescale for data collection in this experiment

Treatments		Type of data	Activities	Time
March	(-)	Emergence	Field emergence (Counts -%)	June August
	(+)			
May	(-)			
	(+)			
March	(-)	Growth rate	Dry weight Relative growth rate	1st harvest- June 2nd harvest- September
	(+)			
May	(-)			1st harvest- August 2nd harvest- November
	(+)			

The seedlings were harvested at 60 days after emergence (1^{st} June 2010 for March sowing and 1^{st} August 2010 for May sowing) in the field and then 90 days after the first harvest. A harvesting procedure was developed to cope with highly variable seedling emergence and seedlings of very different sizes within an individual plot seedling cohort, and also to ensure that some seedlings were available for harvest at the end of the summer. A harvesting procedure was developed to cope with highly variable seedling emergence and different sized seedlings within quadrat seedling cohorts, and to ensure that seedlings were available for the final harvest. The procedure for harvesting at 60 days was as follows;

- <3 seedlings, no harvest from that particular quadrat.
- 4 to 7 seedlings, harvest one average sized seedling, if 8-11 seedlings harvest 2 seedlings, a large and a small one.
- >12-15 seedlings, harvest 3 seedlings (small, medium and large).

This process resulted in a minimum of 3 seedlings for RGR and dry weight analysis for each species at each harvesting time.

Each of the sampled seedlings from all species were cut off at a ground level and the cut biomass of each individual seedling placed into individual coded envelopes. Samples were dried at ambient temperatures (15-25°C) within a laboratory before being transferred to the oven at 80°C for five days. Mean dry weights for the time period in question were then used to compare the effect of pre-treatment and sowing time on the growth rate of the sown species. The harvesting data was then used to generate the growth rate data for individual species during the establishment.

Seedlings were harvested 60 and 150 days after emergence. Harvesting of seedlings sown in March commenced on 1st June 2010, with the second harvest on 1st September 2010. May sown seedlings were harvested on 1st August 2010, and 1st November 2010. Relative growth rate was calculated using the formula of Hunt (2003);

$$\text{Relative growth rate} = \frac{\ln(W_2) - \ln(W_1)}{t_2 - t_1}$$

W_1 = above ground weight 60 days after emergence

W_2 = above ground weight 150 days after emergence

t_1 = number of days at first harvest

t_2 = number of days at second harvest

3.2.3 Statistical analysis

Statistical analysis was undertaken using SPSS version 16 for windows. Data was initially explored through a variety of statistical approaches, both parametric and non-parametric. This included transformation (log e for weight data, and arcsine square root for percentage data to improve the properties of the data sets for parametric analysis, namely distributional characteristics and homogeneity of variance (Zar, 1999). Even after transformation the data was significantly non-normally distributed, and variance was far from homogenous ($P<0.05$). As a result following discussion with a statistician a decision was made to use non parametric means of analysis. The Mann-Whitney *U*-test was used for in place of t-test for paired comparisons.

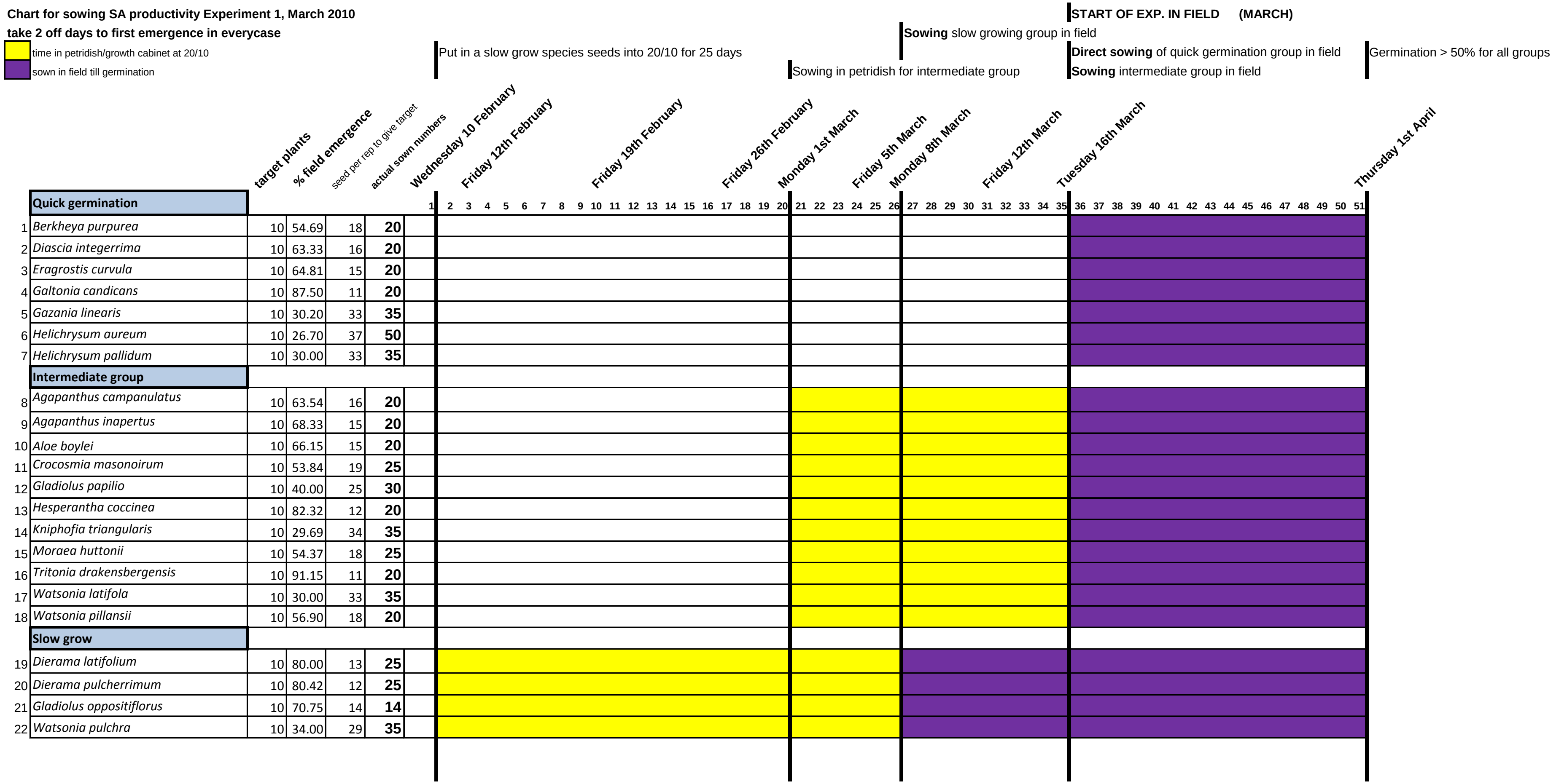


Chart for sowing SA productivity Experiment 1, March 2010

take 2 off days to first emergence in everycase

🟨 time in petridish/growth cabinet at 20/10

🟪 sown in field till germination

Put in a slow grow species seeds into 20/10 for 25 days

Sowing in petridish for intermediate group

Sowing slow growing group in field

START OF EXP. IN FIELD (MARCH)

Direct sowing of quick germination group in field

Sowing intermediate group in field

Germination > 50% for all groups

		target plants	% field emergence	seed per rep to give target	actual sown numbers	1–20	21–26	27–35	36–51
	Quick germination								
1	*Berkheya purpurea*	10	54.69	18	**20**				🟪
2	*Diascia integerrima*	10	63.33	16	**20**				🟪
3	*Eragrostis curvula*	10	64.81	15	**20**				🟪
4	*Galtonia candicans*	10	87.50	11	**20**				🟪
5	*Gazania linearis*	10	30.20	33	**35**				🟪
6	*Helichrysum aureum*	10	26.70	37	**50**				🟪
7	*Helichrysum pallidum*	10	30.00	33	**35**				🟪
	Intermediate group								
8	*Agapanthus campanulatus*	10	63.54	16	**20**		🟨	🟨	🟪
9	*Agapanthus inapertus*	10	68.33	15	**20**		🟨	🟨	🟪
10	*Aloe boylei*	10	66.15	15	**20**		🟨	🟨	🟪
11	*Crocosmia masonoirum*	10	53.84	19	**25**		🟨	🟨	🟪
12	*Gladiolus papilio*	10	40.00	25	**30**		🟨	🟨	🟪
13	*Hesperantha coccinea*	10	82.32	12	**20**		🟨	🟨	🟪
14	*Kniphofia triangularis*	10	29.69	34	**35**		🟨	🟨	🟪
15	*Moraea huttonii*	10	54.37	18	**25**		🟨	🟨	🟪
16	*Tritonia drakensbergensis*	10	91.15	11	**20**		🟨	🟨	🟪
17	*Watsonia latifola*	10	30.00	33	**35**		🟨	🟨	🟪
18	*Watsonia pillansii*	10	56.90	18	**20**		🟨	🟨	🟪
	Slow grow								
19	*Dierama latifolium*	10	80.00	13	**25**	🟨	🟨	🟪	🟪
20	*Dierama pulcherrimum*	10	80.42	12	**25**	🟨	🟨	🟪	🟪
21	*Gladiolus oppositiflorus*	10	70.75	14	**14**	🟨	🟨	🟪	🟪
22	*Watsonia pulchra*	10	34.00	29	**35**	🟨	🟨	🟪	🟪

Figure 3.1 Chart for sowing South African grassland species on the same day and across a staggered time period. Species was sown base on actual seed numbers for each replicate. Slow growing species was sown on 8th March while rapid and intermediate species was directly sown in field on 16th March 2010.

3.3 Results

3.3.1 Effect of time of sowing on seedling emergence and establishment of species in June and August 2010.

There were highly significant different in the percentage emergence of all species (p<0.01 Mann-Whitney U-test) when sowing in March as compared to sown in May (Figure 3.2). All species sown in March had the highest rate of emergence (above 40%) at two different date of assessment namely in June and August 2010.

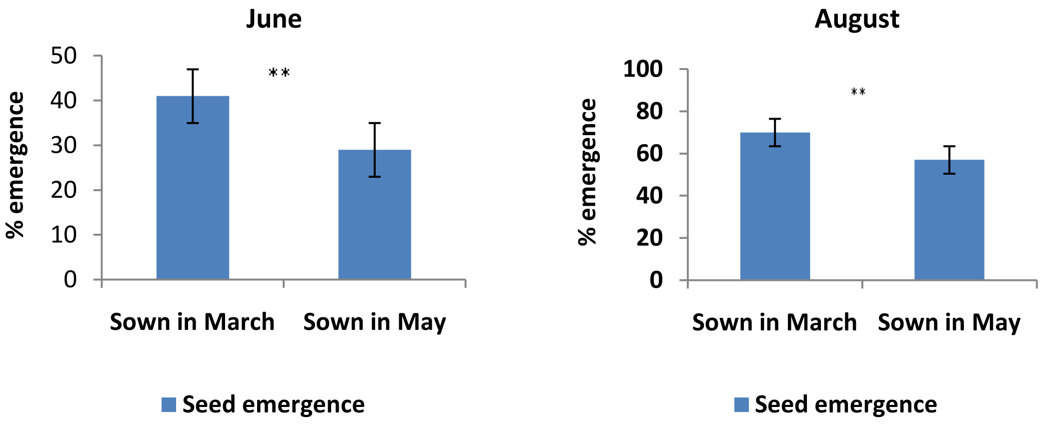


Figure 3.2 Effect of sowing time on % emergence of species by June and August 2010. Significant differences (Mann-Whitney U-test) between sowing in March and May are indicated by; * P=0.05; ** P=0.01; ns, not significant. Error bars represent 1 S.E.M.

3.3.2 Effect of pre-germination treatments versus sowing seed directly into the experiment on seedling emergence and establishment of species in June and August 2010.

There were significantly differences (p<0.01) between species in pre-germination treatments as compared to sown directly at the June assessment. In August, these comparisons were not significantly different. Results also show that the pre-germination treatment gives the highest percentage on the seed emergence at both of assessment times (Figure 3.3).

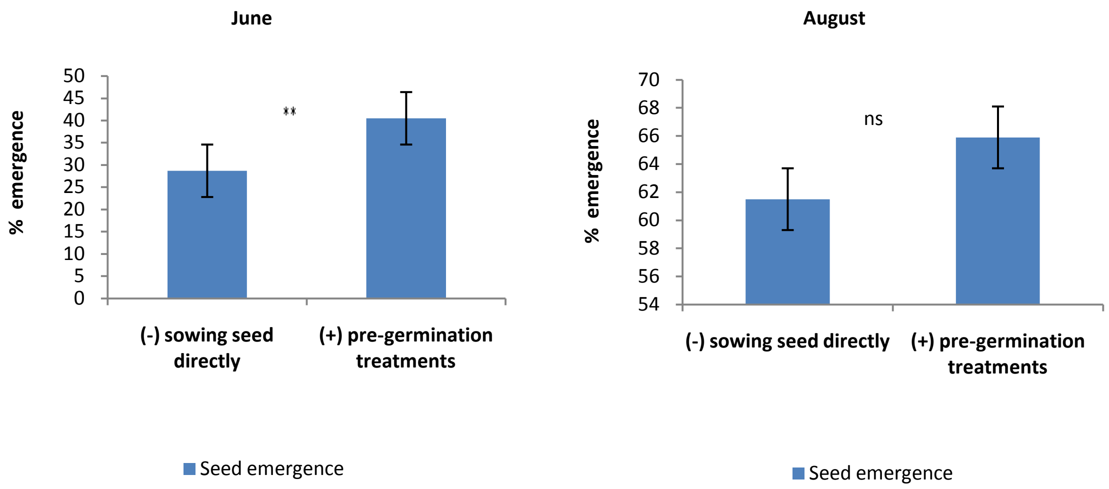


Figure 3.3 Effect of pre-germination treatments and sowing seed directly on % emergence of species by June and August 2010. Significant differences (Mann-Whitney U-test) between sowing in March and May are indicated by; * P=0.05; ** P=0.01; ns, not significant. Error bars represent 1 S.E.M.

3.3.3 Effect of sowing time and sowing treatment on emergence of species in different rate of germination groupings

Data for all species was pooled and divided according to three groups based on speed germination rate namely quick, intermediate and slow (Figure 3.4). The result of the analysis of data for the months of June and August is shown in figure 3.4. The quick germination group does not show any significant difference, while emergence was significantly higher in the intermediate (P=0.01) and slow germination groups (P=0.05, Mann-Whitney *U*-test) when was sown in March compared to May.

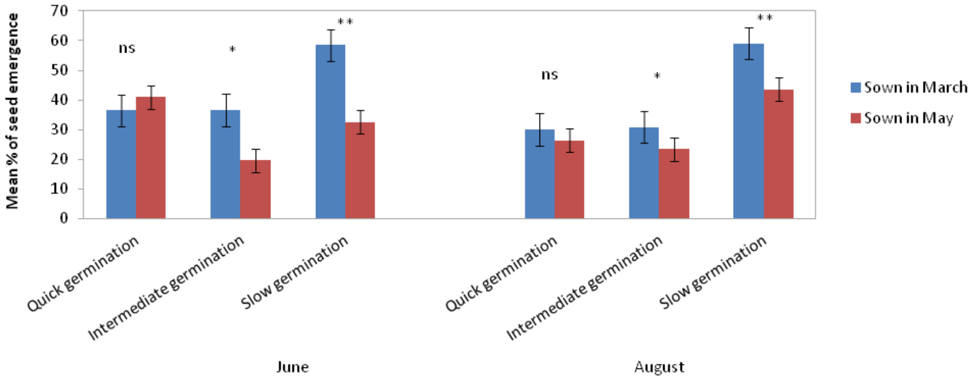


Figure 3.4 Effect of sowing date on mean percentage seed emergence of species as pooled speed of germination groups. Bars with significant differences (Mann-Whitney U-test) between treatments are indicated by; * P=0.05; ** P=0.01; ns, not significant.

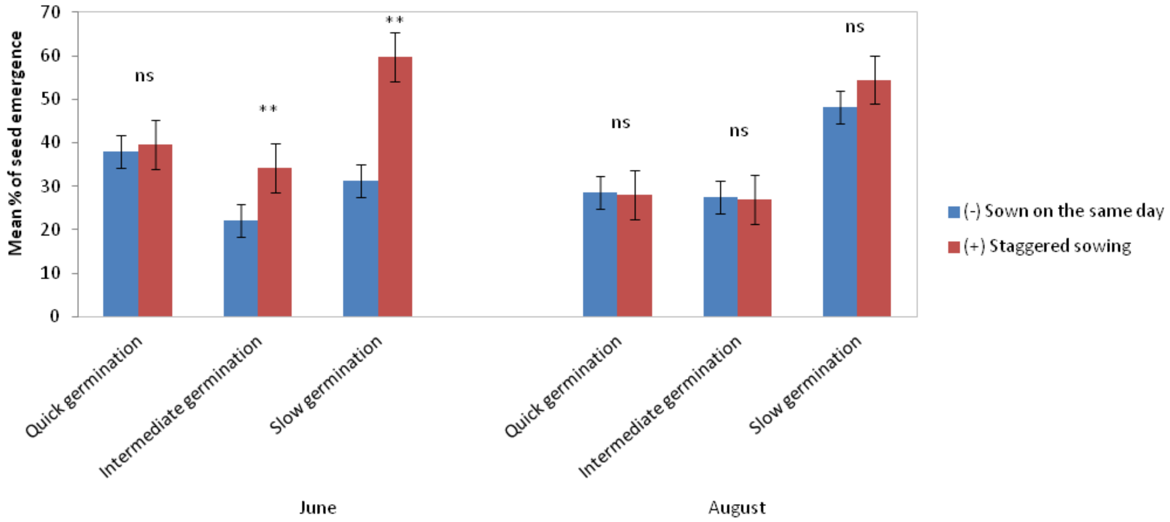


Figure 3.5 Effect of sowing directly and pre-germination treatment on mean percentage of seed emergence of species pooled across speed of germination groups. Bars with significant differences (Mann-Whitney U-test) between treatments are indicated by; * P=0.05; ** P=0.01; ns, not significant.

Pre-germination significantly increased emergence (P=0.01, Mann-Whitney *U*-test) in June for the intermediate and slow groups of species (Figure 3.5). However, analysis data for August does not show any significant difference on a mean percentage of seed emergences among all the three groups.

3.3.4 Effect of time of sowing on seedling emergence and establishment of each species in June and August 2010.

Statistical analysis for individual species (paired comparisons using the Mann Whitney test) showed that percentage of emergence in most of the species tested (14 of the 22 species, see Figure 3.6) was not significantly different at the June assessment date, when sown in March or May. However, *Eragrotis curvula*, *Agapanthus campanulatus, Kniphofia triangularis*, *Moraea huttonii, Watsonia pulchra* and *Dierama pulcherrimum* showed significant differences (P<0.05, Mann-Whitney *U*-test) in percentage seed emergence when sowing in March and May respectively. Sowing in March, even when not statistically different (P>0.05) typically resulted in a higher percentage emergence compared to sowing in May.

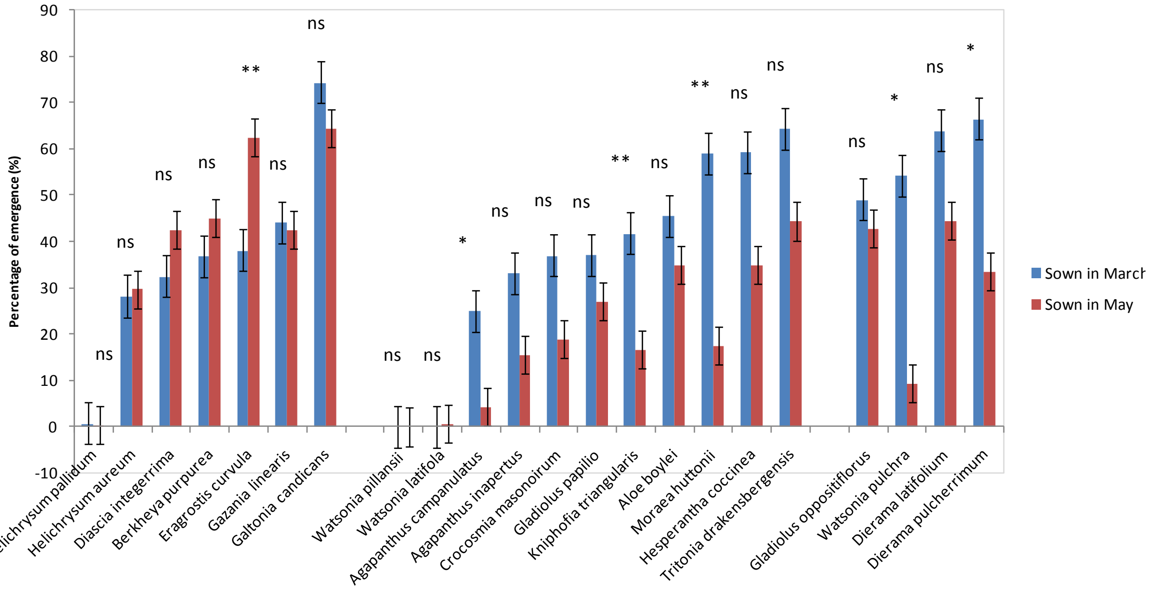


Figure 3.6 Effect of sowing time on % emergence of species by June 2010. Significant differences (Mann-Whitney U-test) between sowing in March and May for each species are indicated by; * P=0.05; ** P=0.01; ns = not significant.

Figure 3.7 shows the percentage of seed emergence in August 2010. Sowing in March showed higher percentage seedling emergence-establishment compared with sowing in May. Species such as *Gazania linearis*, *Crocosmia masonoirum*, *Kniphofia triangularis*, *Morea huttonii*, *Watsonia pulchra*, and *Dierama pulcherrimum* showed significantly higher emergence (<P=0.05, Mann-Whitney *U*-test) when sown in March and assessed in August.

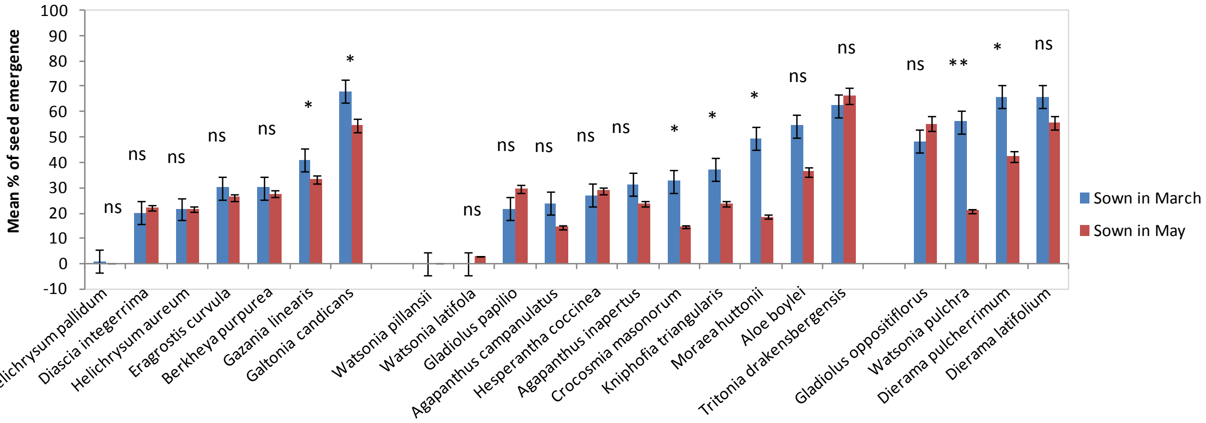


Figure 3.7 Effect of sowing time on % emergence of species by August 2010. Significant differences (Mann-Whitney U-test) between sowing in March and May for each species are indicated by; * P=0.05; ** P=0.01; ns, not significant.

3.3.5 Summary of results of each species

3.3.5.1 Fast germinating species

i) *Galtonia candicans and so on……*

The emergence of *Galtonia candicans* started after 15 days when sown in May (Figure 3.8A). Sowing seeds in March delayed seed emergence but gave higher mean emergence at day 75.

ii) *Helichrysum aureum*

Maximum emergence (approximately 45%) of *H.aureum* occurred in the May sowing. Seed emergence showed a sharp increase from day 15 to day 60 and in the March sowing between day 45 to day 90 (Figure 3.8B).

iii) *Diascia integerima*

As shown in figure (3.8C), the highest percentage of seed emergence (approximately 50%) of *Diascia integerima* was achieved when seed was sown directly in March. The percentages of seed emergence start to rise 15 days after sowing and dropped after 45 days when sowing in May. The percentage of emergence declined after 75 days for March sows and 45 days for May sowing.

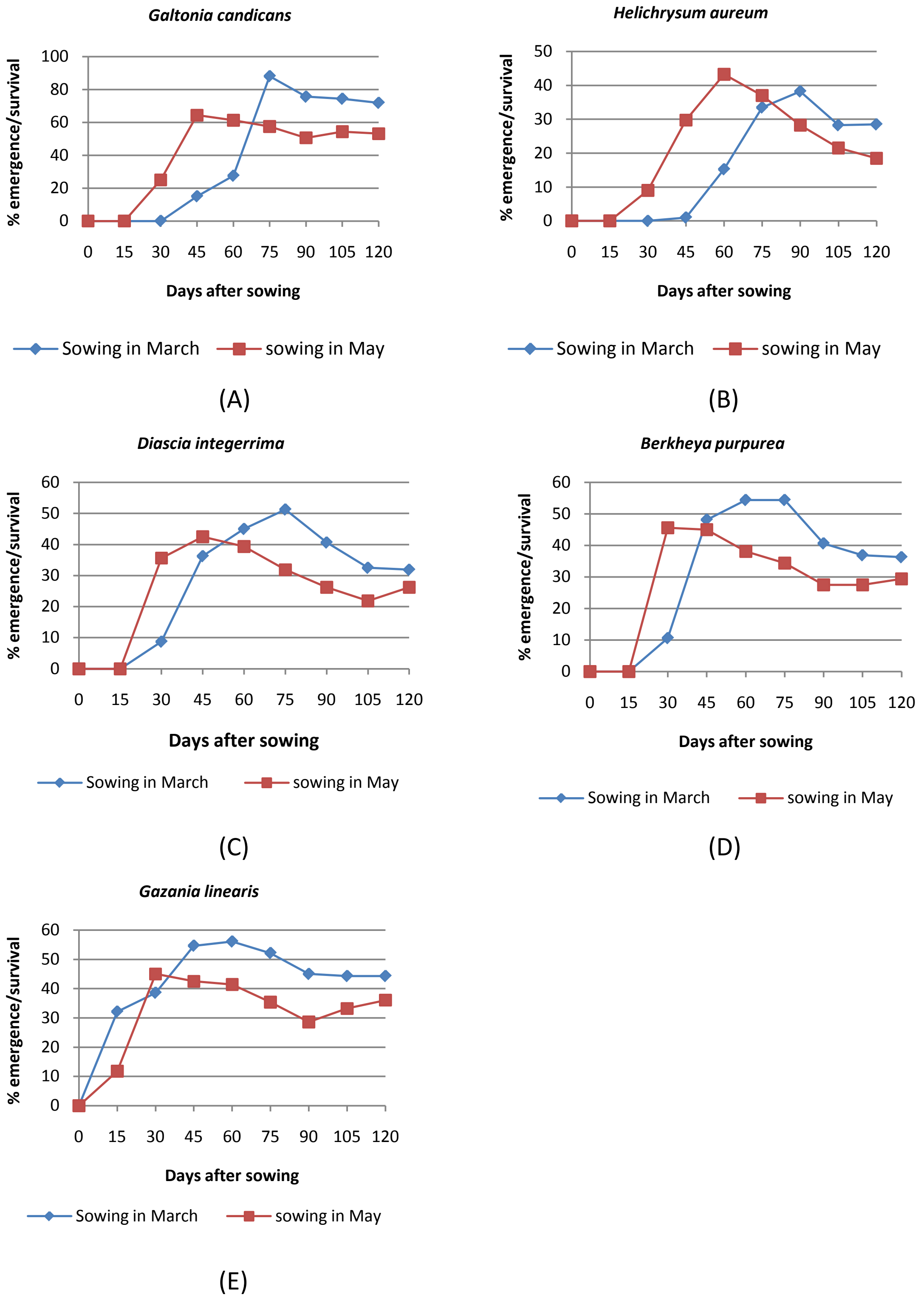
iv) *Berkheya purpurea*

Maximum seed emergence (approximately 55%) of *Berkheya purpurea* was achieved after 60 days when the seed was sown in March. A steady increase in percentage seed emergence happened 15 days after sowing in March and May (Figure 3.8D).

v) *Gazania linearis*

Percentage seed emergence of *G. linearis* increased rapidly for both times of sowing within 30 days after sowing. The maximum percentage of seed emergence was achieved by 60 days (approximately 55%) when sowing in March, while sowing in May gave a maximum

45% seed emergence 30 days after sowing. Emergence of *G.lineris* declined 60 to 120 days after sowing in March and 75 to 120 days after sowing in May (Figure 3.8E).



(A)

(B)

(C)

(D)

(E)

Figure 3.8 Effect of time of sowing on percentage of seed emergence and survival of each species by days after sowing

vi) *Helichrysum pallidum*

Emergence of *H.pallidum* was very low (Figure 3.9F), the maximum percentage emergence achieved only 0.7 % when sown in March and 0% at 60 days after sowing when sown in May.

vii) *Eragrotis curvula*

Sowing seed at different time has a marked effect on the percentage of seed emergence of *E.curvula* (Figure 3.9G). Species sown in May gave the maximum percentage of seed emergence (approximately 70%) as compared to sowing in March (approximately 55%). The seed emergence increased sharply 15 days after sowing when sowing in May but was stretched out over a much longer period when sown in March .

3.3.5.2 Medium speed emerging species

i) *Aloe boylei*

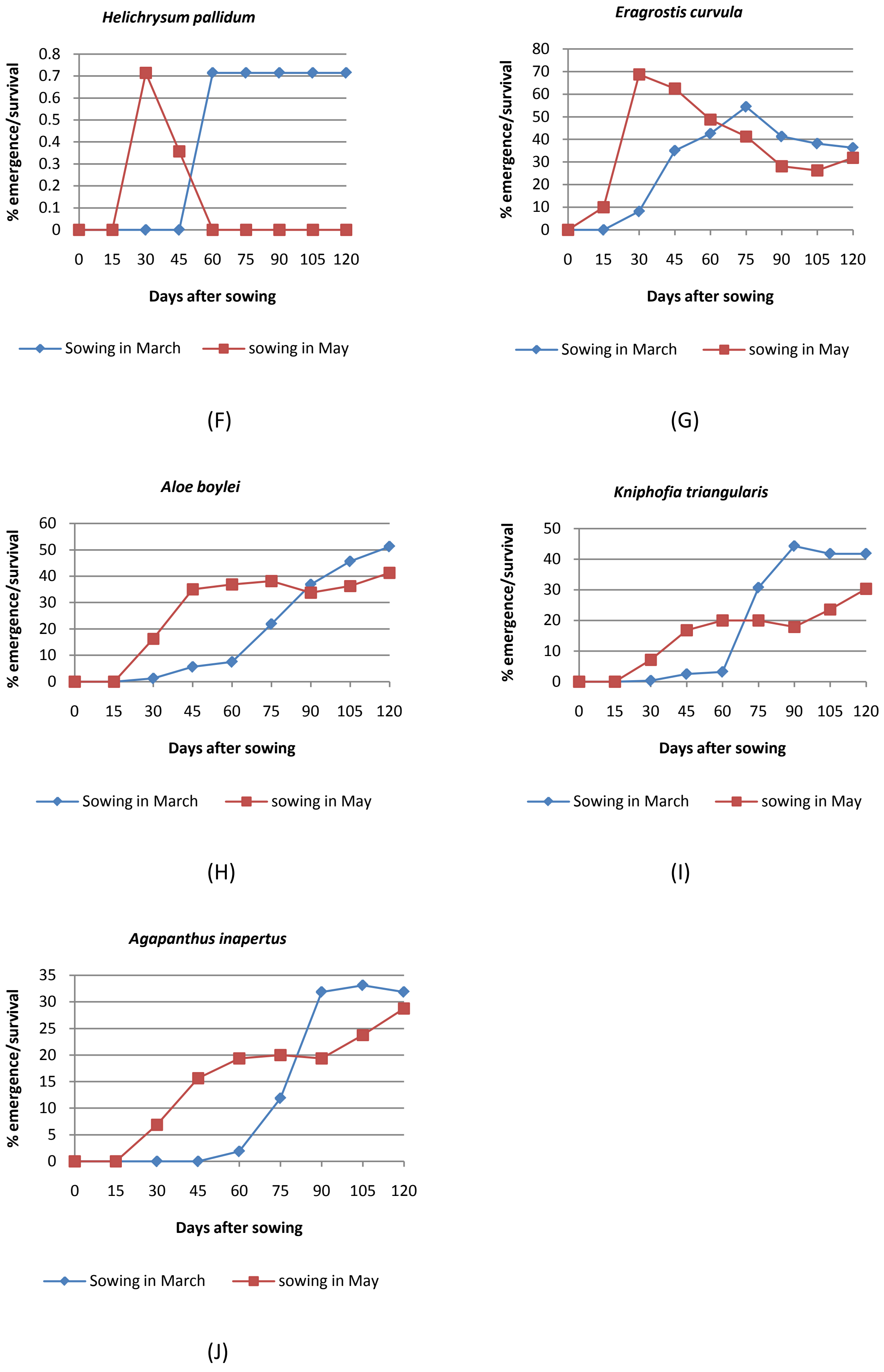
The percentages of seed emergence curves of *A .boylei* show the same pattern in both treatments (Figure 3.9H). Sowing seed in May achieved the higher percentage of seed emergence (approximately 20% greater).

ii) *Kniphofia triangularis*

Maximum seed emergence was achieved at 90 days when sowing in March. A sigmoid pattern of emergence of *K.triangularis* occurred in both treatments. *Kniphofia triangularis* seed emergence was 15 days earlier when sowing in May (Figure 3.9I) but sowing seed in March gave substantially higher total seed emergence.

iii) *Agapanthus inapertus*

Agapanthus inapertus sown in March took a long time to germinate as compared to sowing in May. Ultimately sowing in March gave the highest percentage emergence (Figure 3.9J).



(F) (G)

(H) (I)

(J)

Figure 3.9 Effect of time of sowing on percentage of seed emergence and survival of each species by days after sowing

vi) *Gladiolus papilio*

There was little effect of time of sowing (Figure 3.10K) on emergence characteristics of *G.papilio* seeds.

vii) *Hesperantha coccinea*

The percentage of emergence of *H.coccinea* was very high. As it can be seen from the figure (Figure 3.10L), the best emergence of approximately 75% was associated with sowing in March.

viii) *Agapanthus campanulatus*

Agapanthus campanulatus achieved maximum percentage seed emergence (approximately 25%) in 90 days after sowing in March (Figure 3.10M).

ix) *Watsonia latifolia*

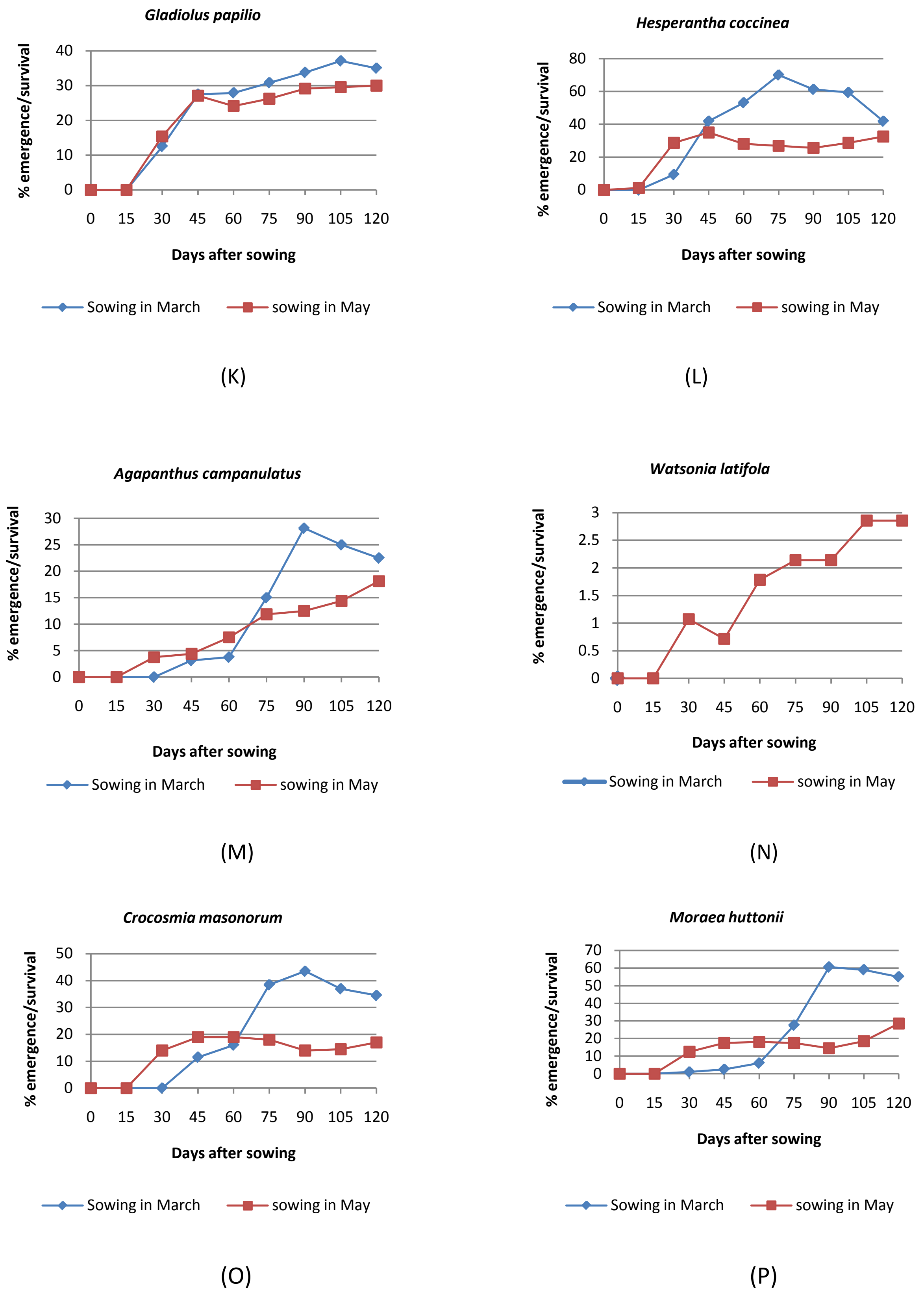
The emergence of *W.latifolia* was very low. Only seed sown in May emerged, to give approximately 2.8% of emergence (Figure 3.10N).

x) *Crocosmia masoniorum*

Percentage of emergence was ultimately considerably higher when sown in March (Figure 3.10 O).

xi) *Morea huttonii*

As shown in figure (3.10 P), the highest emergence (approximately 60%) of *M .huttonii* seed was achieved from a March sowing. Sowing seed in May shows an increase of emergence rate but substantially lower total emergence.



(K) (L)

(M) (N)

(O) (P)

Figure 3.10 Effect of time of sowing on percentage of seed emergence and survival of each species by days after sowing

x) *Tritonia drakensbergensis*

The rate of germination is was initially more rapid when May sown but ultimately emergence was the same (Figure 3.11Q).

3.3.5.3 Slow emerging species

3.3.5.18 *Watsonia pulchra*

This species had slightly more rapid germination when sown in March and also substantially higher total emergence (Figure 3.11R).

3.3.5.19 *Gladiolus oppositiflorus*

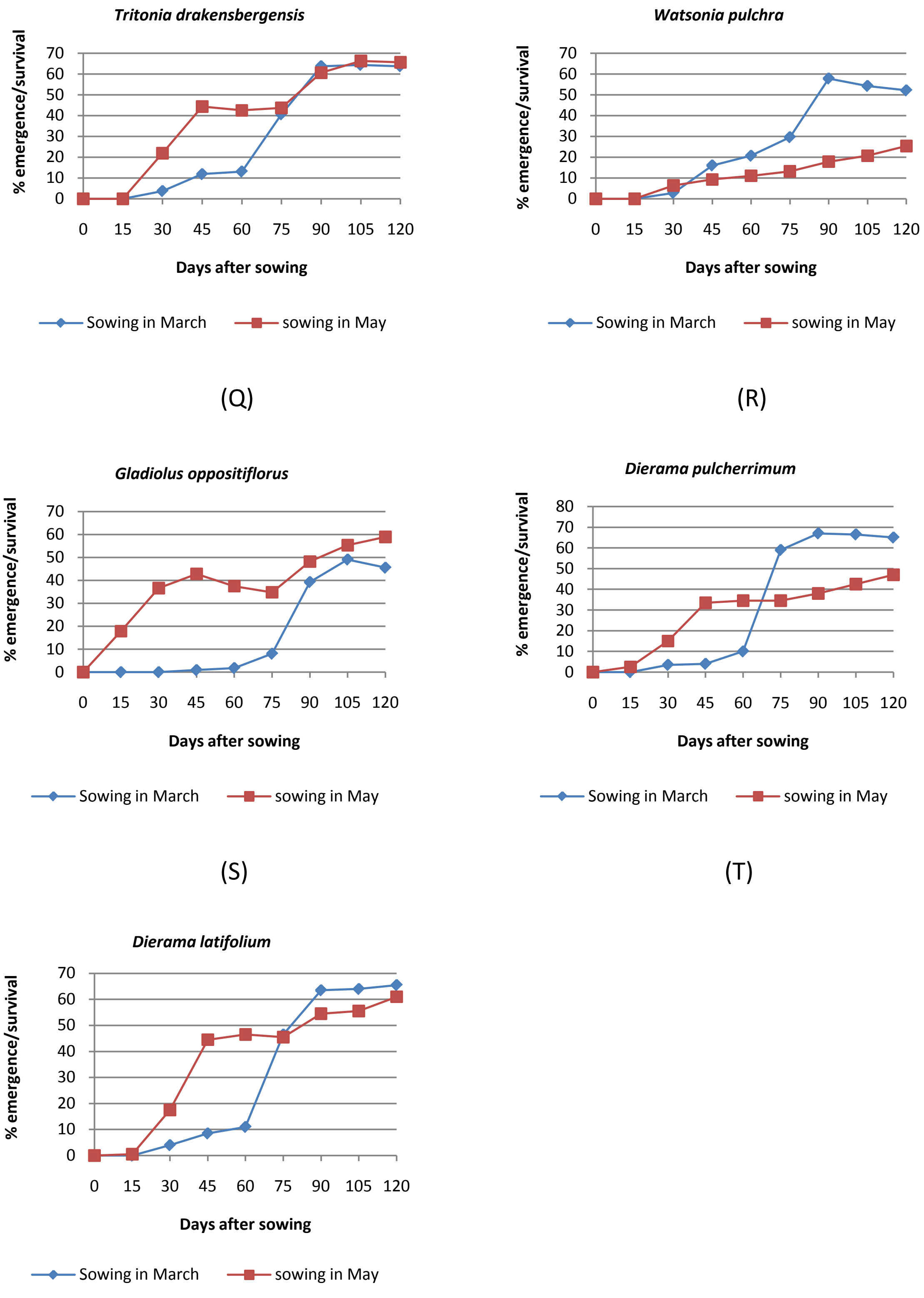
This species also showed a much higher initial emergence rate when sown in May, but ultimately total emergence was very similar from both sowing dates (Figure 3.11S).

3.3.5.20 *Dierama pulcherrimum*

Sowing in March results in an initially low emergence rate but by 75 days total emergence has exceeded the May sow, and this pattern continues to day 120 (Figure 3.11T).

3.3.5.21 *Dierama latifolium*

Final total emergence for this species was very similar for March and May sown. As with *D. pulcherrimum*, there is a little emergence until after 75 days and then a spike of emergence (Figure 3.11U).



(Q)

(R)

(S)

(T)

(U)

Figure 3.11 Effect of time of sowing on percentage of seed emergence and survival of each species by days after sowing

3.3.6 Effect of sowing seed directly and pre-germination treatment on seedling emergence and establishment by June and August 2010.

The effect of pre-germination treatment and sowing seed directly for all species shows a significantly different (p<0.05) at the June assessment. The percentage of seed emergence in August for all species did not show a significant different between treatment. A bar chart also showed that the staggered sowing period gave the higher percentage of seed emergence compared sown all species directly into the field.

Sowing species directly into the field experiment compared with pre-germination in a growth cabinet prior to sowing into the field experiment did not have a significant effect on 16 of the species tested (Figure 3.12). Three species such as *Gladiolus papilio*, *Tritonia drakensbergensis* and *Gladiolus oppositiflorus* showed significantly improved seed emergence with the pre-germination treatment (P<0.05, Mann-Whitney *U*-test). Three species, *Helichrysum pallidum*, *Watsonia latifolia* and W*atsonia pilliansii* showed very low seed emergence (close to 0%). By August however, there was no significant differences in terms of percentage emergence/establishment of species sown directly into the experiment and those pre-germinated for periods of time prior to sowing into the experiment (see Figure 3.13).

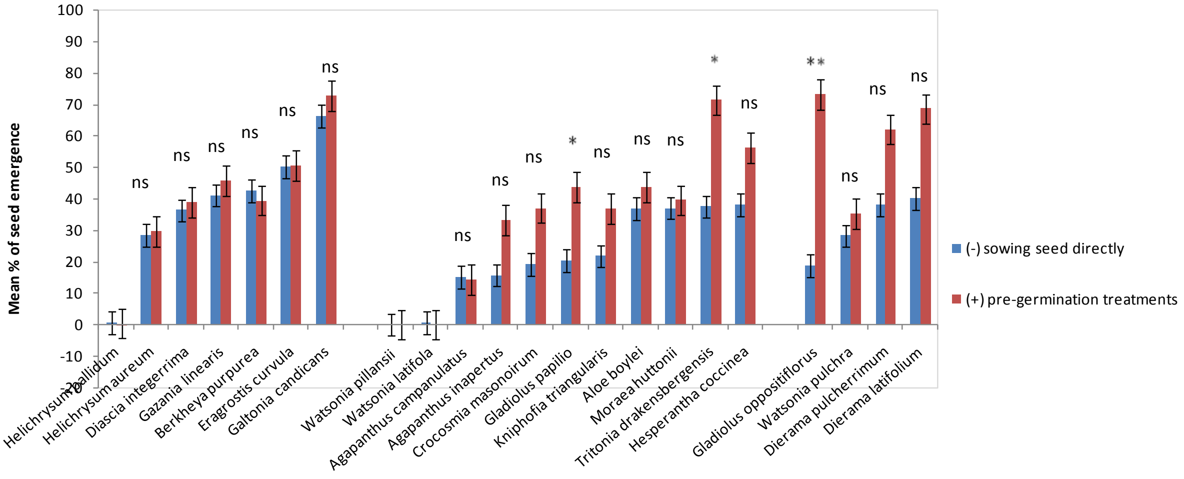


Figure 3.12 Effect of sowing time on % emergence of species by June 2010. Significant differences (Mann-Whitney U-test) between sowing in March and May for each species are indicated by; * P=0.05; ** P=0.01; ns, not significant.

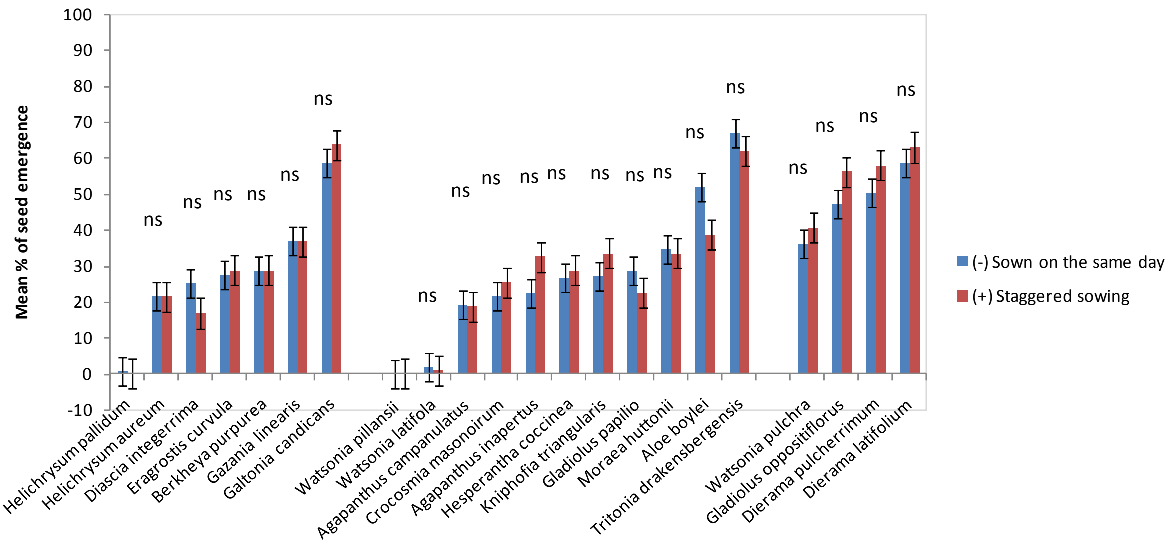


Figure 3.13 Effect of sowing time on % emergence of species by August 2010. Significant differences (Mann-Whitney U-test) between sowing in March and May for each species are indicated by; * P=0.05; ** P=0.01; ns, not significant.

3.3.7 Effect of sowing time on biomass of species by 60 days after emergence.

The figure (3.14) shows a significant difference between the mean total dry weights of the species at day 60 after emergence. There was a highly significant difference (p = 0.01) on aboveground species dry weight when seeds were sown in March and May. Sowing seeds in May show rapid growth with higher dry weight as compared sown in March.

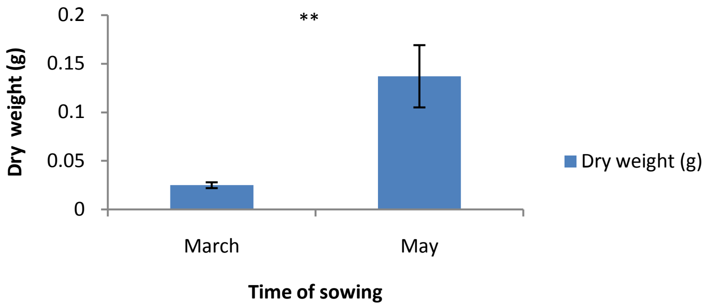


Figure 3.14 Effect of sowing time on biomass of species by 60 days after emergence. Significant differences (Mann-Whitney U-test) between sowing in March and May for species are indicated by; * P=0.05; ** P=0.01; ns = not significant.

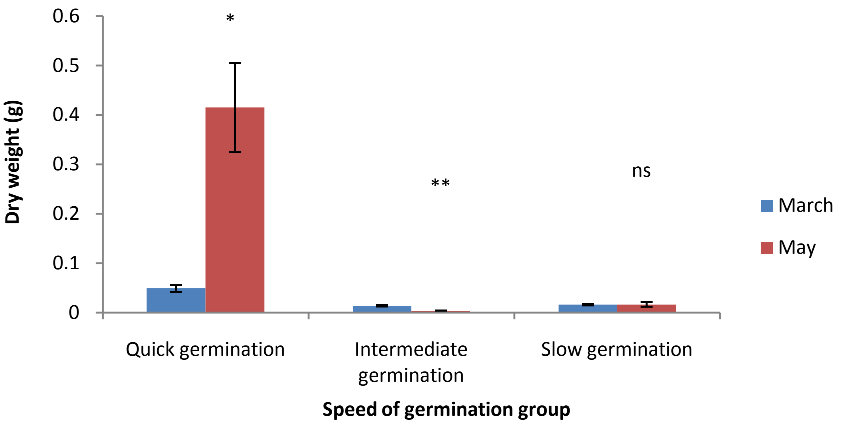
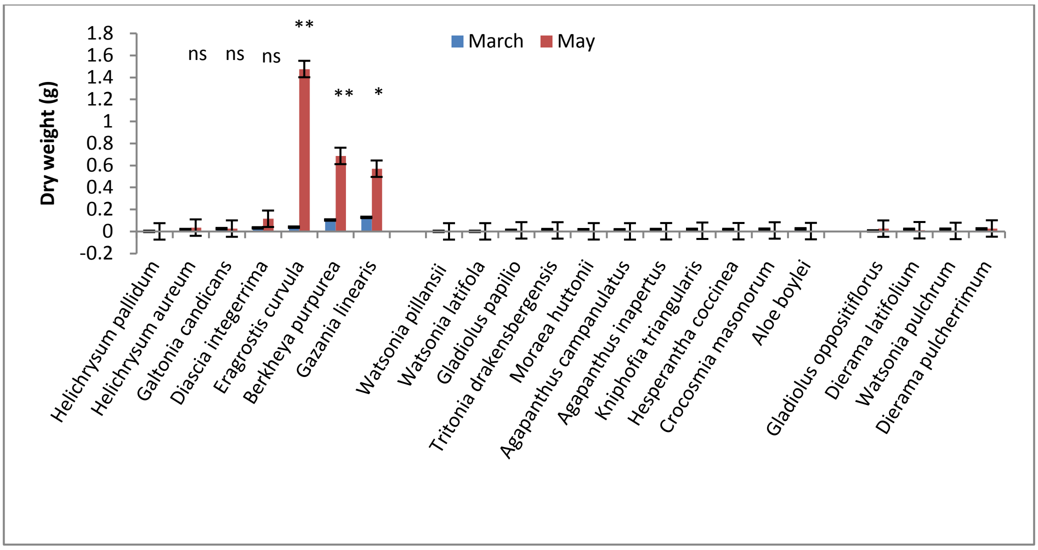


Figure 3.15 Effect of sowing date on biomass of species in 60 days after emergence as pooled as speed of germination groups. Bars labelled with significant differences (Mann-Whitney U-test) between treatment for each groups are indicated by; * P=0.05; ** P=0.01; ns, not significant.

Species in the rapid germination group give the higher rates of aboveground dry weight when May rather than March (p = 0.05) sown. Medium rate germination group species do the same however; species with slow speed germination did not show any significant difference (Figure 3.15).



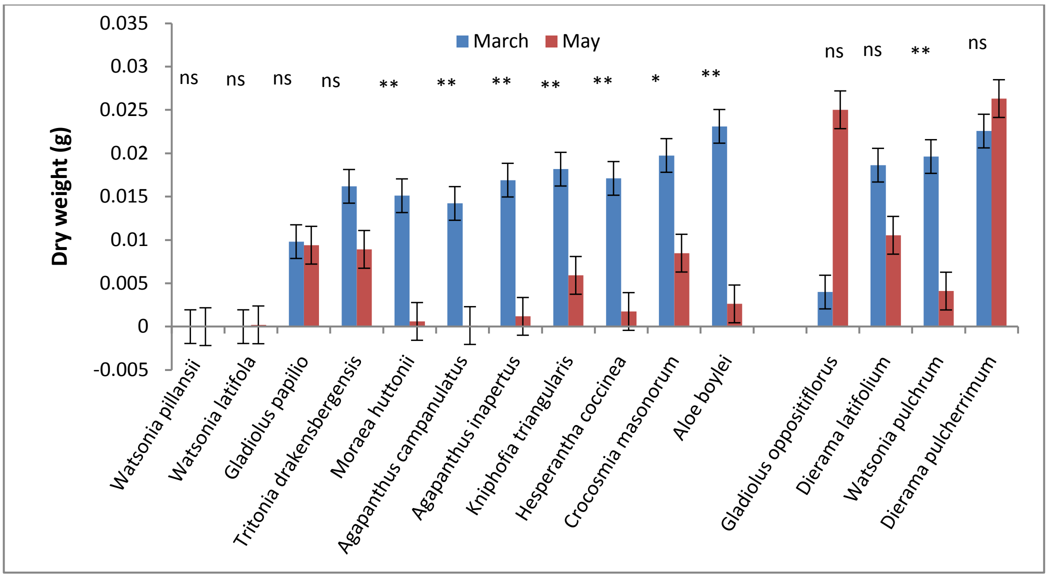


Figure 3.16 Effect of sowing time on biomass of each species by 60 days after emergence. Significant differences (Mann-Whitney U-test) between sowing in March and May for species are indicated by; * P=0.05; ** P=0.01; ns = not significant.

Sowing seeds in March and May have different effects on the aboveground dry weight of each species tested. Results from figure (3.16) indicate that species with rapid germination like *Eragrotis curvula*, *Gazania linearis* and *Berkheya purpurea* showed highly significant differences on aboveground dry weight when seeds were sown in May as compared to March. Species in the medium speed germination group such as *Morea huttonii*, *Agapanthus campanulatus*, *Agapanthus inapertus*, *Kniphofia triangularis*, *Hesperantha coccinea*, *Crocosmia masoniorum*, and *Aloe boylei* showed a significant difference (p=0.05) and highly significant differences (p=0.01) between treatments 60 days after emergence. Although the mean aboveground dry weight of the slow-speed germination group had no significant difference between treatments, but data analysed on each species showed highly significant difference on aboveground dry weight of *Watsonia pulchra* at 60 days after emergence. The other species did not show any significant differences between treatments.

3.3.8 Effect of pre-germination treatment and sowing seed directly on biomass by 60 days after emergence.

As shown in the figure (3.17) the pre-germination treatment affected mean aboveground dry weight species. Species treated with the pre-germination treatment before sowing showed a significant increase in aboveground dry weight as compared to species that were sown directly into the plots (Figure 3.17).

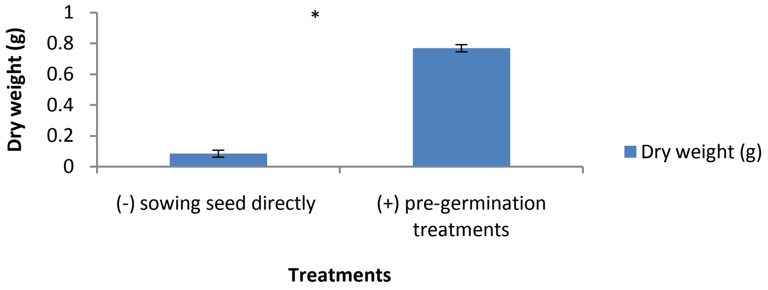


Figure 3.17 Effect of sowing seed directly and pre-germination treatments on biomass of species by 60 days after emergence. Significant differences (Mann-Whitney U-test) between sowing seed directly and pre-germination treatments are indicated by; * P=0.05; ** P=0.01; ns, not significant. Error bars represent 1 S.E.M.

3.3.8.1 Dry weight 60 days after emergence

Dry weight data for sowing seed directly and pre-germination treatments was pooled. As shown in figure (3.18), the biomass of species with pre-germination treatment was significantly higher (p=0.05) at 60 days after emergence. Pre-germination treatment also had a significant and highly significant effect on the above ground dry weight across speed of germination groups. The Mann Whitney U-test found that dry weight were not statistically different between sowing seed directly and pre-germination treatment in the rapid germination group 60 days after emergence (Figure 3.18).

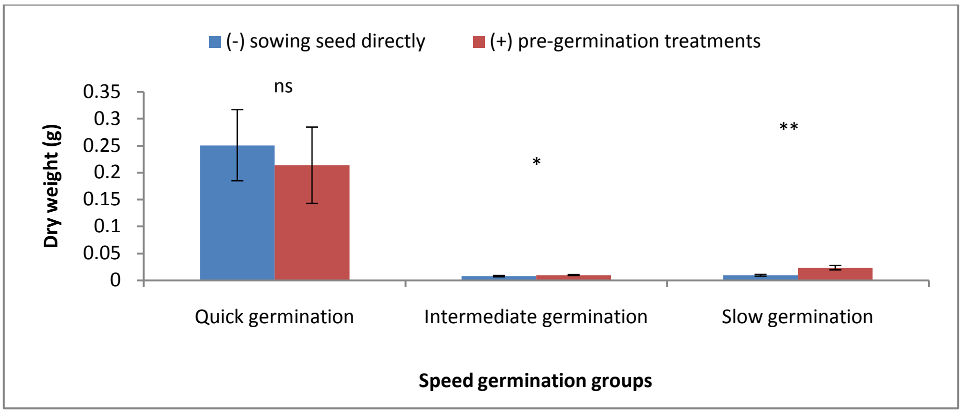
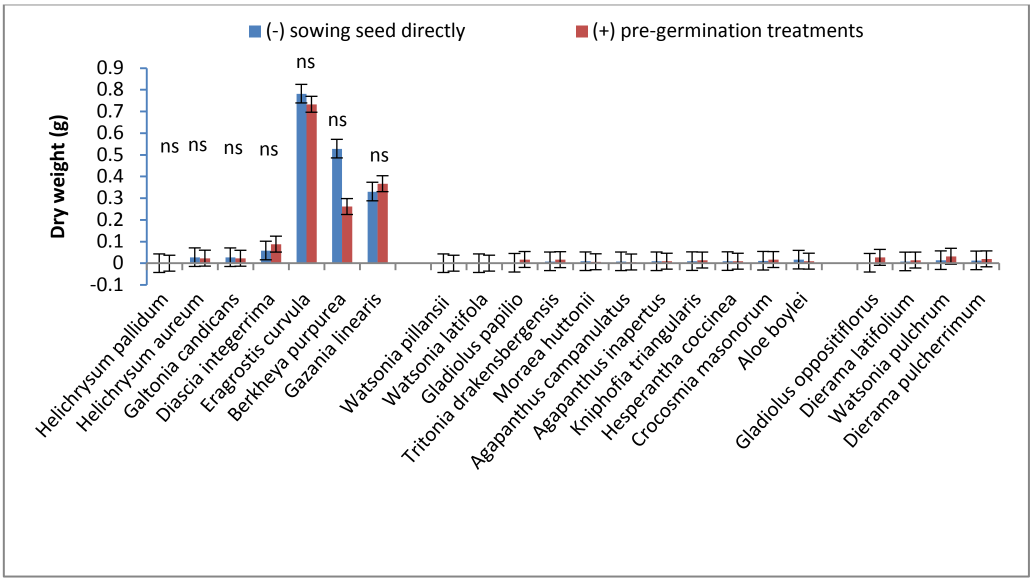


Figure 3.18 Effect of sowing seed directly and pre-germination treatments on biomass of species by 60 days as pooled across speed germination groups. Bars with significant differences (Mann-Whitney U-test) are indicated by; * P=0.05; ** P=0.01; ns, not significant.

3.3.8.2 Dry weight of each species

Pre germination treatment only significantly (Figure 3.19, *Gladiolus papilio* (p<0.005) and *Dierama latifolium* (p<0.01) when analysed at the species level.



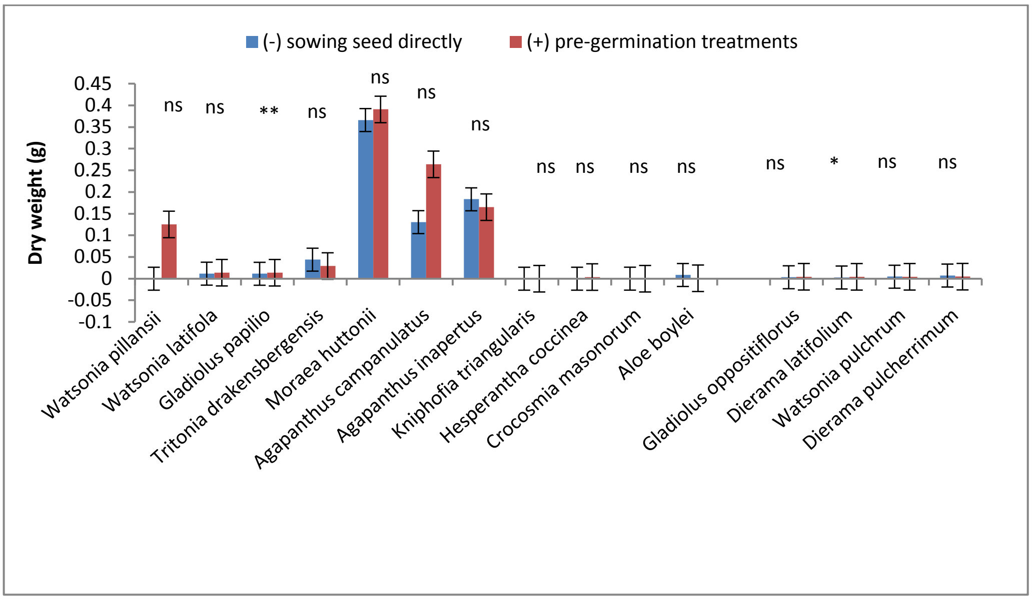


Figure 3.19 Effect of sowing seed directly and pre-germination treatments on biomass of species by 60 days after emergence. Significant differences (Mann-Whitney U-test) are indicated by; * P=0.05; ** P=0.01; ns, not significant. Error bars represent 1 S.E.M.

3.3.9 Effect of sowing time on biomass of species 150 days after emergence

3.3.9.1 Effects on species in speed of germination groups

As shown in figure (3.20), the greatest mean dry weight was achieved when species were sown in March (p=0.01 Mann Whitney U-test) rather than May.

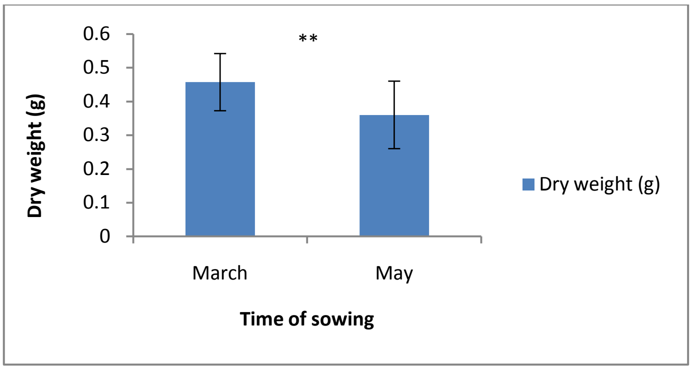


Figure 3.20 Effect of sowing time on mean biomass of species by 150 days after emergence. Significant differences (Mann-Whitney U-test) are indicated by; * P=0.05; ** P=0.01; ns = not significant.

Within speed germination treatment groups, the largest dry weight was recorded for rapid germination group (Figure 3.21). All speed germination groups was highly significantly difference (p<0.01, Mann Whitney U-test) between sowing in March and May. Only the rapid germination group had higher dry weight when sown in May.

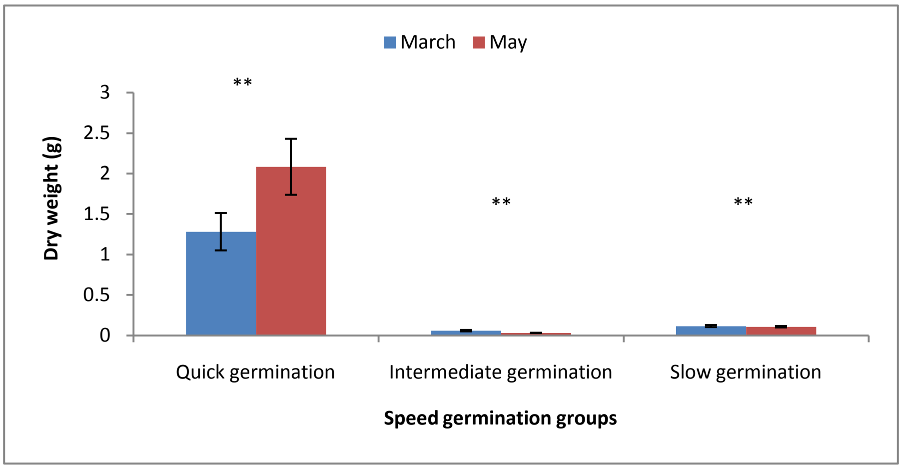


Figure 3.21 Effect of sowing date on biomass of species in 150 days after emergence as pooled as speed of germination groups. Bars labelled with significant differences (Mann-Whitney U-test) are indicated by; * P=0.05; ** P=0.01; ns, not significant.

3.3.9.2 Dry weight of individual species 150 days after emergence

The Mann Whitney U-test indicated that *Diascia integerrima*, *Agapanthus campanulatus*, *Morea huttonii*, *Gladiolus papilio*, *Hesperantha coccinea*, *Tritonia drakensbergensis*, *Kniphofia triangularis*, *Crocosmia masonoirum*, *Gladiolus oppositiflorus*, *Watsonia pulchra*, *Dierama latifolium* and *Dierama pulcherrimum* dry weight was significantly affected by sowing time (Figure 3.22).

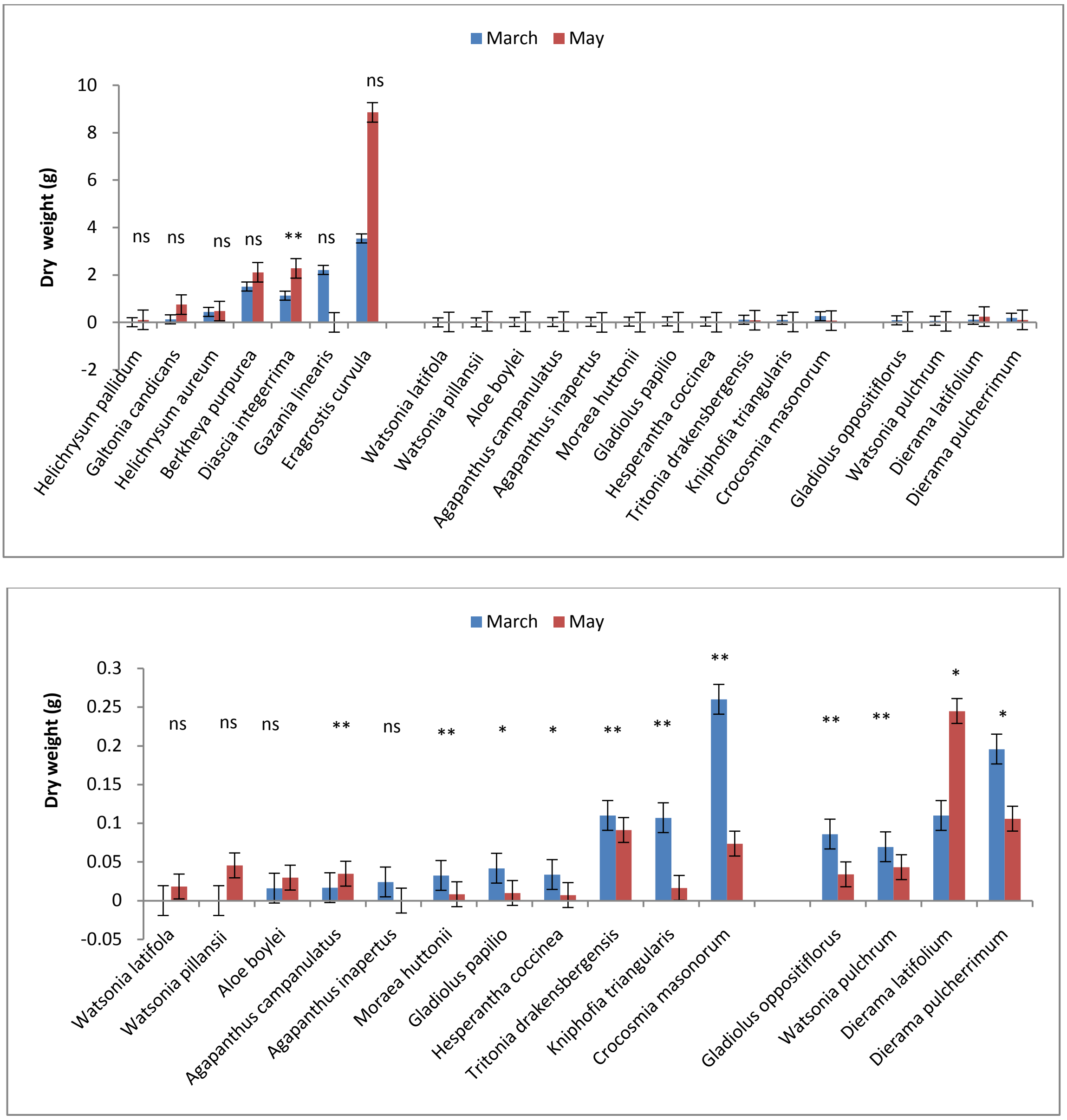


Figure 3.22 Effect of sowing time on biomass of each species by 150 days after emergence. Significant differences (Mann-Whitney U-test) between sowing in March and May for species are indicated by; * P=0.05; ** P=0.01; ns = not significant.

3.3.10 Effect of sowing seed directly and pre-germination treatments on biomass of species by 150 days after emergence.

At the final harvest 150 days post emergence there were highly significant difference (p=0.01) in above ground dry weight (Figure 3.23) in response to the treatments.

As shown in figure (3.24), when dry weight was pooled as speed of germination groups, only the Intermediate speed of germination group showed highly significant difference between treatments.

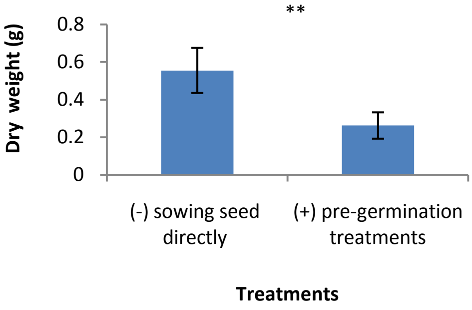


Figure 3.23 Effect of sowing seed directly and pre-germination treatments on biomass of species by 150 days after emergence. Significant differences (Mann-Whitney U-test) between sowing seed directly and pre-germination treatments are indicated by; * P=0.05; ** P=0.01; ns, not significant. Error bars represent 1 S.E.M.

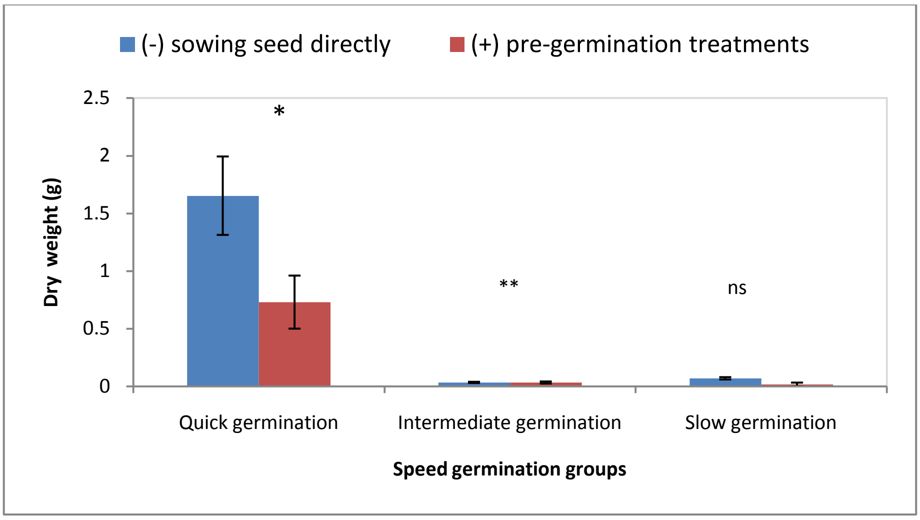
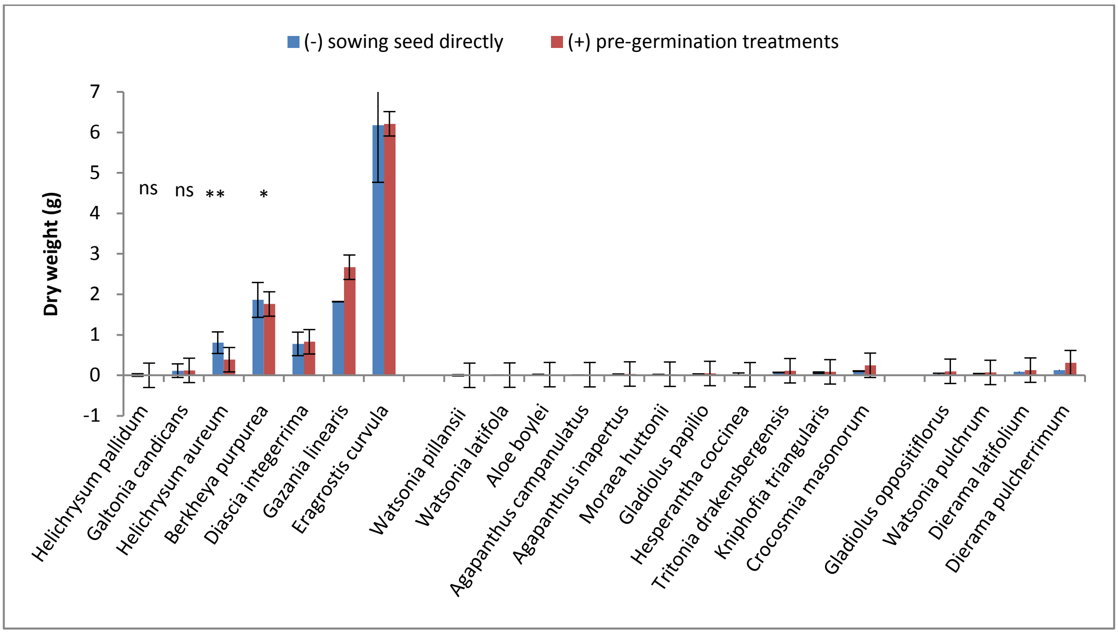


Figure 3.24 Effect of sowing seed directly and pre-germination treatments on biomass of species after 150 days as pooled across speed germination groups. Bars labelled with significant differences (Mann-Whitney U-test) between treatment for each groups are indicated by; * P=0.05; ** P=0.01; ns, not significant.

3.3.10.1 Effect of Pre-treatment after 150 days on individual species

Three species show significant differences between treatments (Figure 3.25); *Helichrysum aureum, Berkheya purpurea* and *Hesperantha coccinea.*



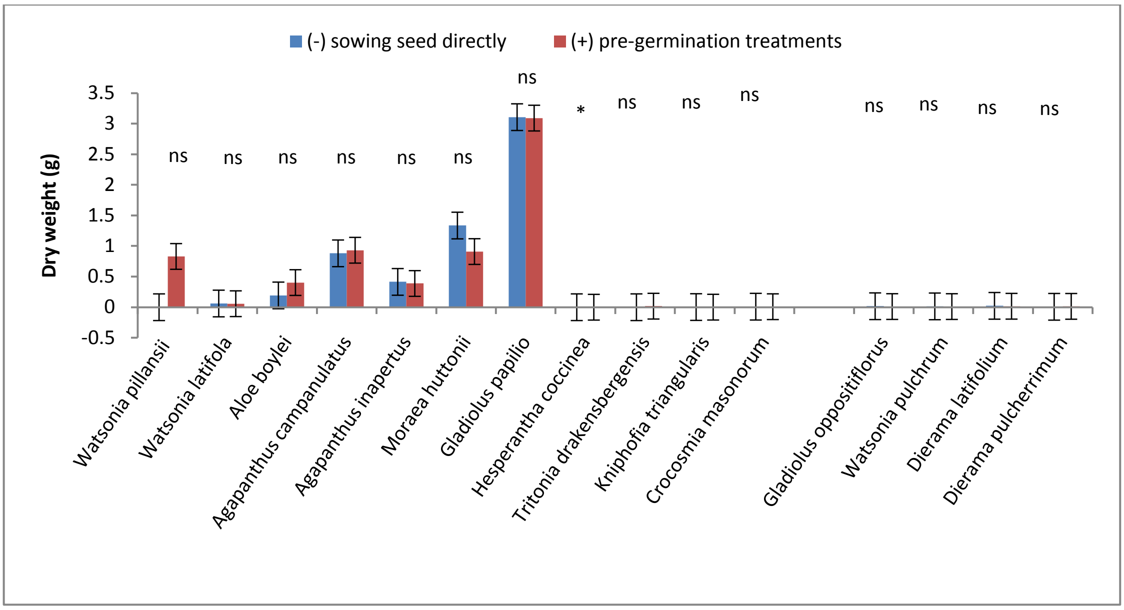


Figure 3.25 Effect of sowing seed directly and pre-germination treatments on biomass of species by 150 days after emergence. Significant differences (Mann-Whitney U-test) between sowing seed directly and pre-germination treatments are indicated by; * P=0.05; ** P=0.01; ns, not significant. Error bars represent 1 S.E.M.

3.3.11 Relative growth rate

As shown in figure 3.26, the relative growth rate of species was significantly higher for May rather than March sowings.

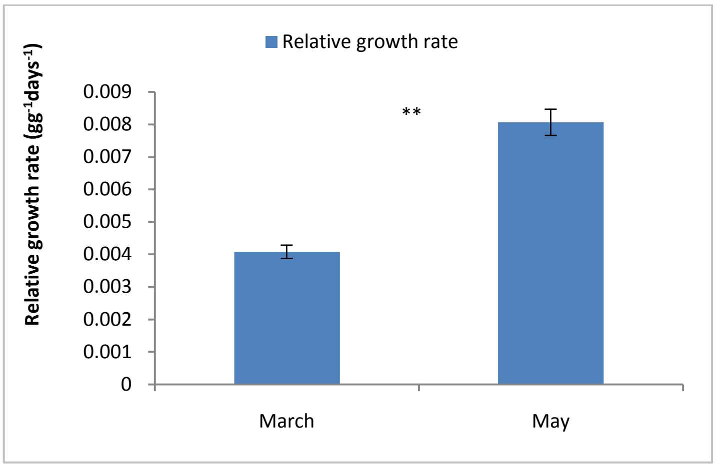


Figure 3.26 Effect of sowing time on relative growth rate of species 150 days after emergence. Significant differences (Mann-Whitney U-test) are indicated by; * P=0.05; ** P=0.01; ns = not significant.

There were very significant differences between the pre-treatment/ sowing directly in the field treatments on average relative growth rate on pooled sowing date data (Figure 3.27).

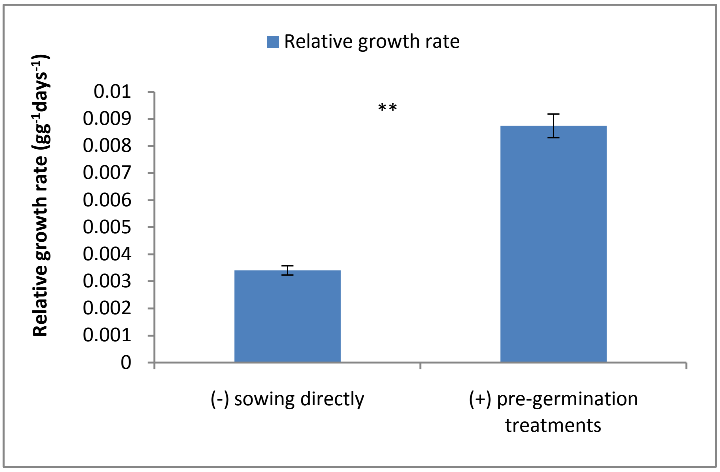


Figure 3.27 Effect of sowing seed directly and pre-germination treatments on relative growth rate of species by 150 days after emergence. Significant differences (Mann-Whitney U-test) are indicated by; * P=0.05; ** P=0.01; ns, not significant. Error bars represent 1 S.E.M.

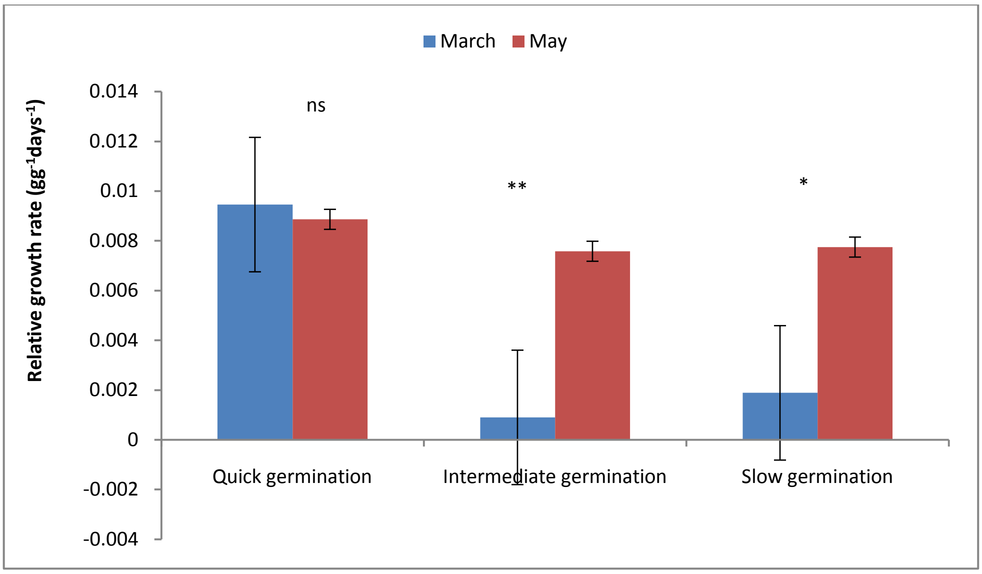


Figure 3.28 Effect of sowing date on relative growth rate of species as pooled as speed of germination groups. Bars labelled with significant differences (Mann-Whitney U-test) between treatment for each groups are indicated by; * P=0.05; ** P=0.01; ns, not significant.

As species pooled as speed germination groups, relative growth rate was typically higher when seeds were sown in May. Only species in the medium speed germination group showed a significant difference (p = 0.01) when sown in May as compared to March (Figure 3.28).

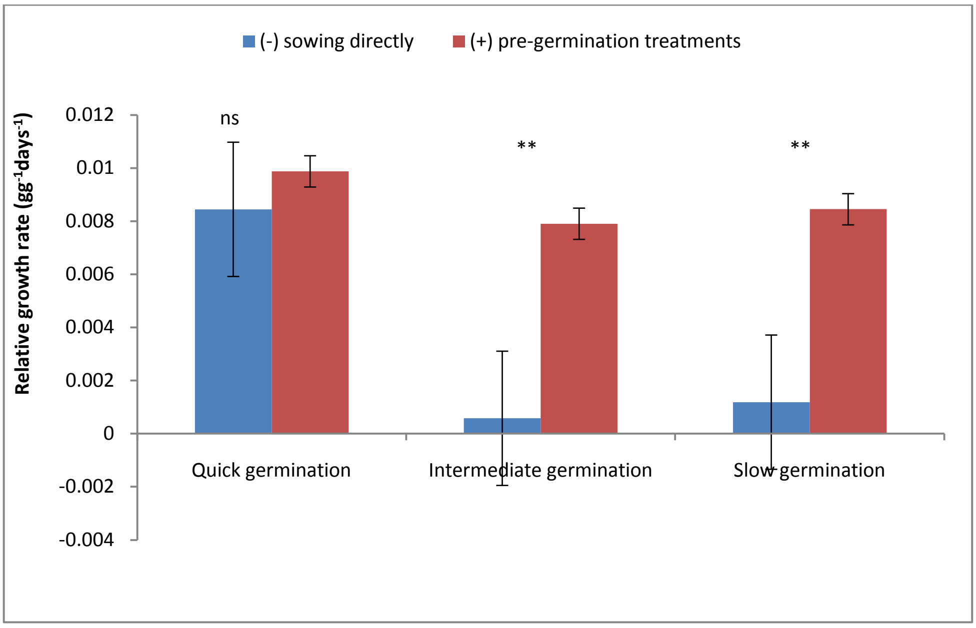


Figure 3.29 Effect of sowing seed directly and pre-germination treatments on relative growth rate of species as pooled across speed germination groups. Bars labelled with significant differences (Mann-Whitney U-test) are indicated by; * P=0.05; ** P=0.01; ns, not significant.

The effect of pre-treatment on relative growth rate of species in pooled speed germination group is different at 150 days after emergence, with a significant difference in the medium and slow group (Figure 3.29).

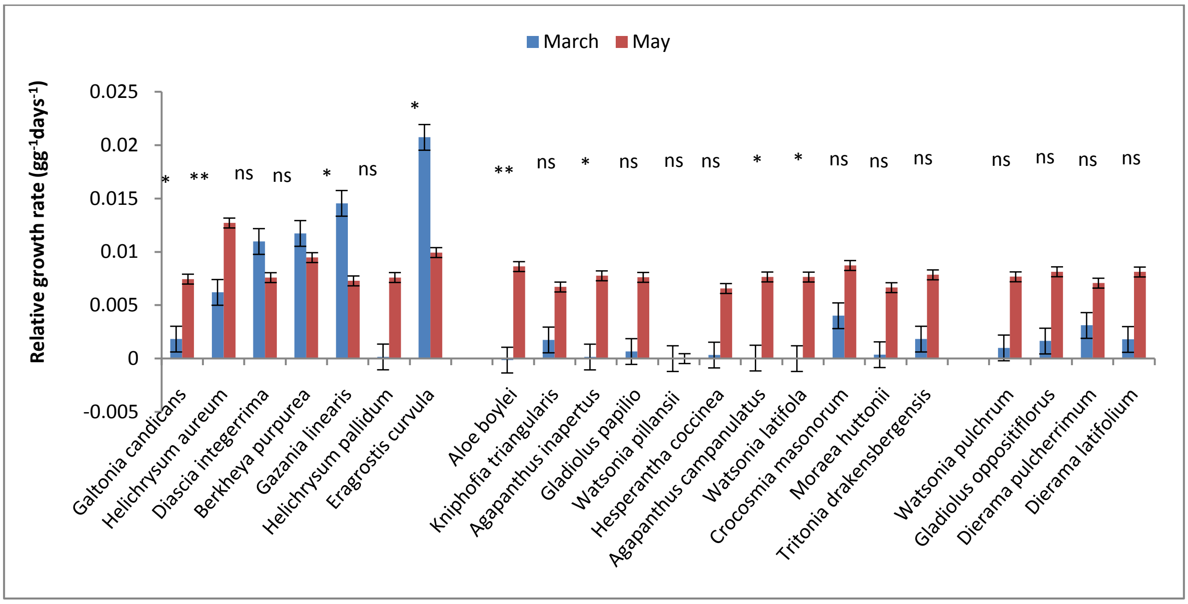


Figure 3.30 Effect of sowing time on relative growth rate of each species by 150 days after emergence. Significant differences (Mann-Whitney U-test) between sowing in March and May for species are indicated by; * P=0.05; ** P=0.01; ns = not significant.

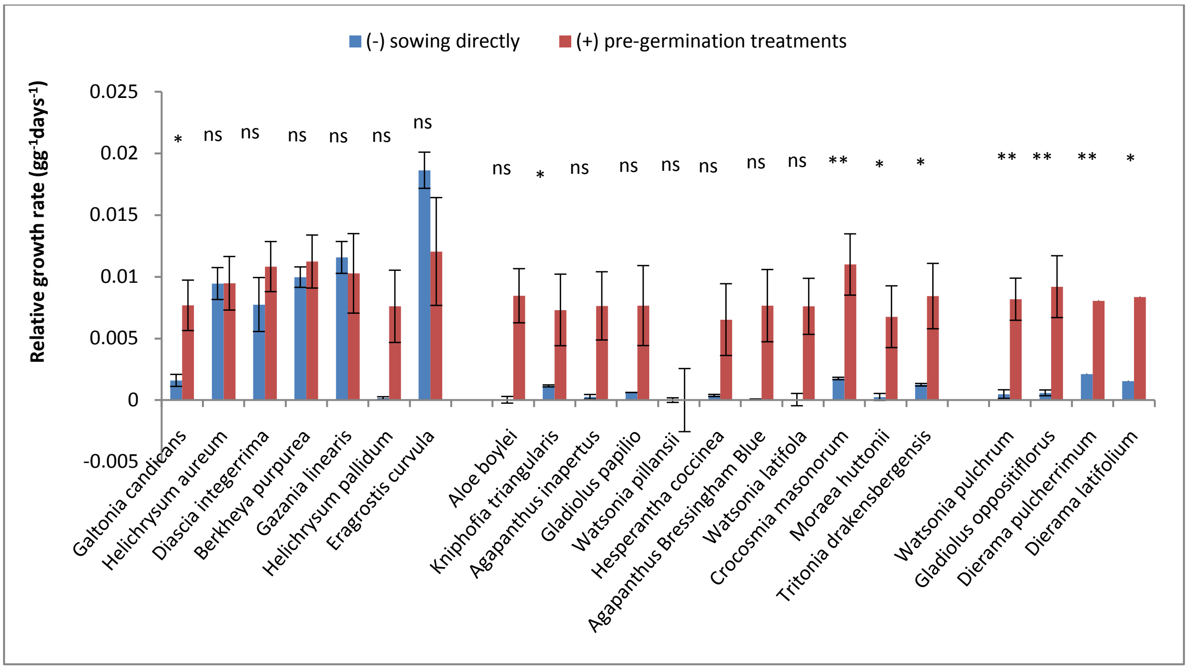


Figure 3.31 Effect of sowing seed directly and pre-germination treatments on relative growth rate of each species by 150 days after emergence. Significant differences (Mann-Whitney U-test) between sowing seed directly and pre-germination treatments are indicated by; * P=0.05; ** P=0.01; ns, not significant. Error bars represent 1 S.E.M.

Figure 3.30 shows that sowing time had a significant effect on relative growth rate for some species in the rapid germination group (*Galtonia candicans*, *Helichrysum aureum*, *Gazania lineris*, *Eragrotis curvula*) and in the medium group (*Aloe boylei* and *Agapanthus inapertus*).

Pre-germination treatment showed a significant effect on relative growth rate at 150 days after emergence with all of the slow germinating species (*Watsonia pulchra*, *Gladiolus oppositiflorus*, *Dierama pulcherrimum*, *Dierama latifolium*). Species in the medium speed germination group such as *Kniphofia triangularis*, *Crocosmia masonoirum*, *Tritonia drakensbergensis* and *Morea huttonii* also showed significant and highly significant differences in response to pre-germination treatments (Figure 3.31).

3.4 Discussion

In this study, there are three main questions to deal with : when is the most appropriate time for sowing? Did the pre-sowing treatment influence emergence and establishment? How did the species respond to the treatments in terms of growth? These are discussed under three topics, sowing time and seed emergence, pre-sowing treatment and biomass and relative growth rate:

3.4.1 Sowing time and seed emergence

Overall, sowing seed in the early spring gave an advantage to many species for early establishment and good grow the. It was shown in figure 3.2, sown in March gives the high percentage of emergence compared to sow in May. The same effect can also be observed from the results based on speed of germination group. Sowing seed in March had a significant positive effect on emergence of medium and slow germination species (Figure 3.4). High percentage of emergence leads to many seedlings established. Most species sown in May (Figure 3.8-3.11) have high germination rate at the beginning, but the number of surviving seedling decreased by August. This situation may be due to sowing seed in May causes new seedlings to be exposed to high evaporation rates during the summer, leading to higher mortality than in earlier sowing. Most of the species used for this study are geophytes that have slow germination and growth rate compare to forbs species. The slow germination and growth rate making it more susceptible to desiccation during periods of high evaporation.

Almost all geophyte species in June assessment shows sown in March gave a high percentage of seed emergences, although only five species that showed significant differences with sown in May (Figure 3.6). Species that showed good germination in May were *Gladiolus papilio*, *Hesperantha coccinea*, *Tritonia drakensbergensis* and *Gladiolus oppositiflorus*. This situation may be due to these species experiencing late germination and thus avoided the high evaporation phase. Loss of moisture on the surface of the sowing media has a major negative impact on the process of seed germination and establishment. According to Bewley and Black (1994), there are three phases in the germination of seeds. The three phases are completely dependent on the moisture content in the soil. If the medium used suffers from dryness it will affect the process of seed germination. Speed of germination is also dependent on moisture content surrounding seeds. Each species experiences different germination times. Some of the fast-growing species such as *Helichrysum aureum*, *Diascia integerrima*, *Berkheya purpurea* and *Eragrotis curvula* gave high percentage emergence in May (Figure 3.6). Moisture and temperature seemed to be optimal for these species when sown in May.

3.4.2 Pre-sowing treatment

Each species have a different germination rates. Pre-sowing treatment was expected to help accelerate and increase the rate of species field emergence in medium and slow germination species. As a whole, results shows that South African grassland species responded to pre-germination treatment, with highly significant differences compared to species that were sown directly. Sown seed with pre-germination treatment provides a high percentage of seed emergence in June assessment. But the effect of this treatment disappeared by the time assessment was done in August (Figure 3.3). This may be due to most of the intermediate and slow germination species sown directly increasing their germination percentage in summer, and hence catching up. Pre-germination treatment is most beneficial to the species with medium and slow germination rate (Figure 3.4). Pre-germination treatment accelerates the speed of germination but overall germination performance still dependent on seed quality of the sown species and the degree of moisture stress. Species sown directly in field will germinate when temperature and moisture is suitable for the species to germinate. Some species do not give a positive response to the pre-germination treatment. *Gladiolus papilio*, *Morea huttonii Aloe boylei and Tritonia drakensbergensis* emergence without pre-sowing treatment was higher than species with pre-germination treatment even though was not significantly different (Figure 3.13).

Overall it can be concluded here that by later in the growing season the pre-germination treatments do not help much in improving the percentage emergence of all species treated. Only a few species showed a significant response to the pre germination treatment. Sowing directly does not show much difference in terms of performance of seed emergence and is much easier to conduct in practice.

3.4.3 Biomass and relative growth rate (RGR)

3.4.3.1 Biomass

In general, data taken after 60 days of germination showed that species sown in May gives higher aboveground dry weight. This might be expected due to May sowings experiencing higher temperatures for the species to grow well. The rapid germination group dominated the high dry weights of species sown in May (Figure 3.15). The situation is different for the species from the medium and slow germinating species where sowing in March results in higher dry weights than sowing in May This situation may be due to May sowings of these species being adversely affected by the high temperature (20-25 °C) in May than may have delayed germination. After 150 days, species sown in March generally had higher dry weights compare to May. This was due to a larger percentage of the 150 days coinciding with suitable conditions for growth, that the May sowing where harvesting was done at the beginning at the winter. The temperature is already dropped in the early autumn, and weak solar activity caused the species growth rate was decreased. This situation did not affect the fast growing species which were more able to respond to the light and suitable temperature.

Overall, pre-germination treatment had a significant impact on dry weight after 60 days post germination. This condition greatly affects the species from the medium and slow groups at the early stage. Pre-treatment effectively lengthens the growth period leading to significant differences between two treatment on the intermediate and slow species group (Figure 3.18). The effect is more on slow growing species but only one species showed significant differences of the treatment when analyzed individually.

Treatment effects do not appear on aboveground dry weight at the second harvesting for slow speed germination group. After 150 days, the dry weight of species from the slow germination group was not significantly affected by pre-treatment. Even though the intermediate group shows significant differences between treatments but only one species (*Hesperantha coccinea*) showed the significant different between treatment (Figure 3.25). From the results, it can be suggested that pre-germination treatment did not affect biomass production in the longer term. Overall pre-germination treatment methods only provide benefits to only a few species that have very slow germination. Stoffella (1992) also reported that pre-germinated seeds resulted in minimal differences in subsequent seedling root morphology as compared with non treated or primed seeds. Priming seeds resulted in similar taproot growth rates and a smaller root mass than non treated seeds. Pre-germinating or priming seeds caused no beneficial or deleterious effect in seedling root morphology.

Sowing seed directly is a simple and desirable method rather than the complications of pre-germination treatments. Overall, sowing seed directly produced more biomass compare to sowing with the pre germination treatment due to the rapid biomass production from fast growing species like *Berkheya purpurea* and *Helichrysum aureum*. However, only two species (*Moraea huttonii* and *Gladiolus papilio*) from the intermediate group shows the higher aboveground dry weight when sowing directly (Figure 3.25). The rest of intermediate and slow germination species shows slightly lower biomass when sowing directly but not significant differences with pre-germinated seeds after 150 days of emergence. Most of the geophytes species sown in this experiment are probably much slower growing in the first growing season compared to the habitat in the South Africa. The slow-growing rate suggests that these species are currently temperature limited in the UK.

3.4.3.2 Relative growth rate

Relative growth rate can be used to determine the number of seeds to be sown and species composition used in multi-species plant communities to avoid fast growing species from eliminating slow growing species. Nearly all species had higher growth rates when sown in

May when solar radiation and air temperatures were higher, and RGR's may have been greater still had the study been carried out in South Africa, leading to different ranking order. Despite the typically montane habitats of the species in this study, those with the most northern distributions (*A. inapertus, W. latifolia*, and *W. pulchra)* were likely to have been most poorly fitted to the climate of experimental site. It is very low relative growth rate when sown in March as compare to May (Figure 3.30). This is supported by horticultural experience in Britain, where both *Watsonia* species are slow and difficult to cultivate outdoors. Seedlings of *Agapanthus inapertus* are also slow. A few species had slower RGR when sown in May, for example *H. coccinea*, but given that this is a riparian species this probably is due to the greater moisture stress associated with the later sowing time. Despite the trend for higher relative growth rates from the later sowing date, in terms of individual RGR this only differed significantly between the two sowing dates for eight species.

Pre-germination treatment also helps to increase the dry weight of the species from the medium and slow groups. Over 50% of the species of both groups experienced a significant improvement in response to pre-germination treatment of the species, especially species from the slow germination group, the extra number of growing days seem to be important.

3.5 Conclusion

This study has shown that the time of sowing is the important factor for pre-sowing planning before sowing seeds directly in a field. Sowing seeds at the right times will increase the percentage of emergence and enhance growth performance of the species. Temperature played an important role for seed to germinate and seedling establishment when seed was sown at different times (March and May). High temperature and drought in summer 2010 was affected the establishment of seedling sown in May. Although most of the species in May showed high percentage seed emergence at the early stage, the number of seedling dropped due to hot weather in June and July 2010.

The hypothesis that pre-germination treatment can increase the germination rate and fasten the germination to achieve 50% emergence was largely restricted to the intermediate and slow germination group and significant differences had mainly disappeared after 150 days post emergence.

The main findings of this research are as follow:

- Late sowing in spring generally gives the higher percentage of emergence but reduced seedling establishment or survival subject to high temperature during summer.
- Sowing seed in March showed the highest seedling establishment because of long growing window.
- Overall, pre-germination treatment did not greatly assist seed emergence compared to sowing directly.
- Pre-germination treatment influence of relative growth rate was largely restricted to geophytes from the slow germinating groups.

CHAPTER 4: EFFECT OF SOWING MULCHES DEPTH AND TYPE ON SURVIVAL OF SOWN SOUTH AFRICAN SPECIES.

4.1 Introduction

Prior to 2009, preliminary studies have been undertaken in the Department of Landscape, University of Sheffield on over 100 species of montane South African grassland species as part of ongoing MA research to characterize these species under the UK climate. All of the Montane South African grassland species have evolved to grow in a climate with high summer rainfall with essentially dry, but very cold winters. In these environments, nocturnal minima can be severe; Buffelsfontein, a station at approximately 1700 m in the Molteno district of the Eastern Cape, has registered lows of -18.6 °C (South African Weather Service, 2011).

Capacity to survive winter temperatures is clearly an important consideration for plant species for use in plant communities in UK urban greenspace. Unlike in their habitat, in Britain South African species need to tolerate both cold and wetness in winter. The experience gained from in some cases over a century of growing many of the key summer rainfall grassland genera in gardens, is this combination of being wet and cold effectively in practice, reduces the capacity to tolerate temperatures that are obviously tolerated without damage in South Africa.

A major environmental constraint limiting growth, development and distribution of plants in temperate climate is by freezing. Plant growth in cold temperature has evolved the mechanisms to increase their ability to tolerate freezing temperature following exposure to a period of low but non-freezing temperature (Xin and Browse, 2000; Stitt and Hurry, 2002). The process of plants adapted to the period of low but non-freezing temperature is called cold acclimation (Levitt, 1980). As mentioned by Thomashow (1999) in a cold acclimation review that plant (Arabidopsis) can control their expression of a regulon of cold-induced genes that increase plant freezing tolerance. In a practical application where freezing temperature are major factor limiting the geographical location suitable for growing crop and horticulture plants, new breeding of cold tolerance plant is one of the potential strategies. However in landscape planting, new plants introduced into cold environmental condition also need to go through the process of cold acclimation. In a naturalistic planting design plants are directly exposed to frost and snow in winter. Exposure to frost can cause the water in plant cells to freeze and damage the cell wall. The plants will become limp, blackened and distorted by frost-damaged. The morning sun also can cause the plants defrost quickly and rupturing their cell walls. Evergreen plant leaves will turn brown and shoot become translucent appearance. Lack of moisture when soil becomes frozen also can damage a hardy plants and tough evergreens. The plants will die when roots unable to take water in a frozen soil (Tranquillini, 1982).

Much of the garden based literature (Rolfe, 2006) has made this connection between cold tolerance and winter wetness in summer rainfall South African species. This has led to widespread assumptions that by keeping summer rainfall South African species drier in winter their cold tolerance will be increased. In gardening practice this might be achieved by growing plants in pots and placing them out of the rain in winter, or by covering the ground with material that intercept and deflect rain. As these approaches to increasing cold tolerance in South African species have no capacity to be employed in urban greenspace practice. We wanted to look at whether there were ways in which we could increase soil dryness. Since sowing mulches (a layer of weed seed free material approximately 75mm deep) are applied to the surface to facilitate establishment by sowing, and these are often formed of very free draining material such as coarse sand, these provided an opportunity to explore their effect on cold tolerance of South African species.

Conversely it is known (Ingram and Thomas, 2010) that cold injury can be protected from to some degree through watering plants before a soil freezing. Adequate water in soil will assist in absorbing heat and reradiating heat. Elevated temperature around plants during freezing will help to avoid cold damage to plants. Using mulch can help reduce loss of soil moisture, reducing heat retention below the mulch but increasing the cold experienced above the mulch. Too much watering or rainfall to the soil may become too saturated and may damage root systems. Increase of soil wetness, water logging and flooding during winter throughout the UK will increase incidence root damage and reduce tree stability (Broadmeadow, 2002). According to Drew (1983), the concentration of oxygen in soil water may decline slowly when temperature become low. The plants rooting zone is subject to anaerobic condition or oxygen concentrations ranging from fully air-saturated to anaerobic.

The overall aim of this study was to compare the effect of different depths of substrate on the survival over winter of South African grassland species. We hypothesised that South African grassland species tolerance of winter cold would be increased by growing in substrates that are drier and more highly oxygenated in winter.

4.1.1 Objectives

The specific objectives of this study were:

- To evaluate the effect of sowing mulch type and depth on establishment.
- To determine the effect of sowing mulch type and depth on mortality during the growing season
- To determine the effect of sowing mulch type and depth on mortality during winter

4.11 Species selection

Based on a MA student (Richardson, 2009) field germination and growth rate study in 2008/2009, plus Hitchmough's (unpublished data) four years of experience of growth of these species in pots, 19 Montane South African grassland species were identified as particularly sensitive to excessive soil wetness, leading to observed mortality either in summer or in winter (Table 4.1). Seed was obtained from a home germplasm collection in 2008 and 2009 and purchased seed from Silverhill Seeds in South Africa. All seed were dry stored in a fridge at approximately 4 °C to minimize loss of germinability.

Table 4.1 Selected Montane South African Grassland species sensitive to wetness based on experience in cultivation.

Species	Typical degree of winter wetness in habitat [a]	Typical degree of winter coldness in habitat [b]	Level of sensitive to wetness
Watsonia marlothii	*xxx*	*x*	insensitive
Berkheya multijuga	*xx*	*xxx*	sensitive
Bulbine abysinnica	*xx*	*xx*	sensitive
Dierama reynoldsii	*xx*	*xx*	sensitive
Dierama robustum	*xx*	*xxx*	sensitive
Gladiolus saundersii	*xx*	*xxx*	sensitive
Haphlocarpha scaposa	*xx*	*xx*	sensitive
Senecio macrospermus	*xx*	*xxx*	sensitive
Watsonia confusa	*xx*	*xx*	sensitive
Watsonia densiflora	*xx*	*x*	sensitive
Watsonia latifolia	*xx*	*xx*	sensitive
Watsonia lepida	*xx*	*xx*	sensitive
Watsonia strubeniae	*xx*	*x*	sensitive
Aloe cooperi	*x*	*x*	not sensitive
Bulbine narcissifolia	*x*	*xx*	-
Gladiolus abbysinicus	*x*	-	-
Helichrysum nudiflorum	*x*	*xx*	sensitive
Watsonia pulchrum	*x*	*x*	sensitive
Aloe boylei	-	*xx*	less sensitive

[a] Wetness: *xxx* - wet, *x* - dry; [b] Coldness: *xxx* - very cold, *x* - less cold

4.2 Materials and methods

The experiment examined the depth of sowing mulch on survival and mortality of South African grassland species under summer and winter conditions.. Sharp sand was used as a standard sowing mulch treatment with 70 mm and 140 mm depths. John inners No. 1 compost (70 mm depth) was used to replicate the soil surface for the controls whilst providing initially weed seed free conditions (Table 4.2). John Innes was chosen because of its substantial mineral soil component was likely to have similar thermal and other physical properties to the existing site topsoil (Figure 4.1). The experiment was conducted at the Sheffield Botanical Garden. These experiments consist of three treatments as follows:

Table 4.2 Types of sowing mulch with the different depth as experimental treatments

Types of sowing mulch	Depth of mulch
Sharp sand	70 mm
Sharp sand	140 mm
Soil (John Innes No 1)	70 mm

A total of 19 species were sown into each treatment involving a randomized block design with four replicates of each treatment giving rise to a total of 12 main plots (1.0 m x 1.20 m in size per plot). Each plot is subdivided into 19 subplots (150 mm x 150 mm) into which seeds of a single species were sown. Species in each plot were randomly arranged.

Species used in the experiment were drawn from the three different speed germination rate groups (Rapid, Intermediate and slow). Intermediate and slow germination species were pre-sown as discussed in Chapter 3. The pre-germination treatment was to ensure emergence took place at approximately the same time as fast emerging species. Seed of all species were sown into the plots on 13th May 2010. The number of seeds used was dependent on the germination percentage of each species recorded in the previous germination study (Chapter 3). The calculation of the number of seeds is based on laboratory and field germination percentage, and the number of seedlings required per subplot. Even though the number of seed per replicate was calculated, the number of seed sown also depended on availability of seeds for each species. Calculation of seeds and the sowing schedule can be seen in figure 4.4. A staggered sowing approach was adopted to try and obtain germination of all species at approximately the same time, in order to have as even an age structure as possible for assessing cold tolerance. An additional three species of *Crinum bulbispermum*, *Crinum macowanii* and *Scadoxus puniceus* were planted into the experiment in summer. This is because the seed of these species arrived late from SA.

The same sowing and irrigation practice described in chapter 3 was applied to this experiment. The plots were irrigated at two-day intervals where no significant rain occurred within a four-day period. At the early stage of seedling growth, each subplot was covered by fruit net on the structure made using bamboo canes to prevent fox digging in the sand bed at night (Figure 4.2).

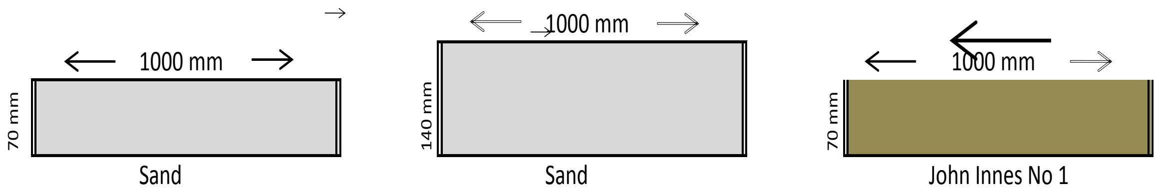


Figure 4.1 Illustration of different depth and type of media used in this experiment.

Figure 4.2 Experimental sites at the Sheffield Botanical Garden, Clarkehouse Road, Sheffield United Kingdom. Picture was taken on 23rd September 2010.

4.2.1 Data Collection

4.2.1.1 New seedlings present

The emergence was monitored every week and recorded as new seedling present in every month for each species until October 2010. Observations were made throughout the growing season on any species that showed signs of damage or die back.

4.2.1.2 Survival and mortality over winter

Based on the number of seedlings present in October 2010, seedling survival and mortality was calculated in June 2011 to assess mortality of the species over winter 2010-11. Observations were recorded in February 2011 on likely mortality.

4.2.1.3 Temperature and moisture recorded

Substrate moisture content was recorded everyday in two weeks started 3rd June 2010 until 17th June 2010 using DELTA-T moisture prob. Temperatures at the soil surface were recorded in 2011 using max-min thermometers. Minimum temperatures at the surface and at 50 mm in the substrates were also recorded in winter 2011/2012 using Tinytag Plus 2 (dual channel temperature recorder) data loggers. There are three data loggers with two probes, and each was placed in a different medium. The probes were placed on the surface and buried at 50 mm depth. Data reading was set to take minimum and maximum temperature every 30 minutes. Temperature data was downloaded each month to ensure the data logger was always working (Figure 4.3)

Figure 4.3 Data downloaded every month from TinyTag data logger in experimental plot.

4.2.1.4 Media characteristics

Procedures were undertaken in the laboratory to characterize the substrates used in the study. The soil test was done using methods to be employed when investigating plant substrates and aggregate-type drainage materials used at roof-greening sites (FLL guidelines for green roof) (Landschaftsbau, 2002). Details of the laboratory procedure are attached in the appendices. The bulk density of each type of media and soil underneath was calculated after sample saturated air dry 12 hours and oven dry under 80 °C in 24 hours. Bulk density, water holding capacity and air fill porosity was determined based on the mean of three samples. Calculation of Air filled Porosity used Handreck and Black (1989) formula:

V= volume of sample in cubic centimeters
M1= Weigh of sample after sampling
M2= Dry weigh of sample after oven drying
Volume of water in sample = M1 – M2 (mL)
Volume of solids = M2/2.65 (mL)

$$\text{Air filled porosity} = \frac{V - M2/2.65 - (M1 - M2)}{V} \times 100 \text{ volume \%}$$

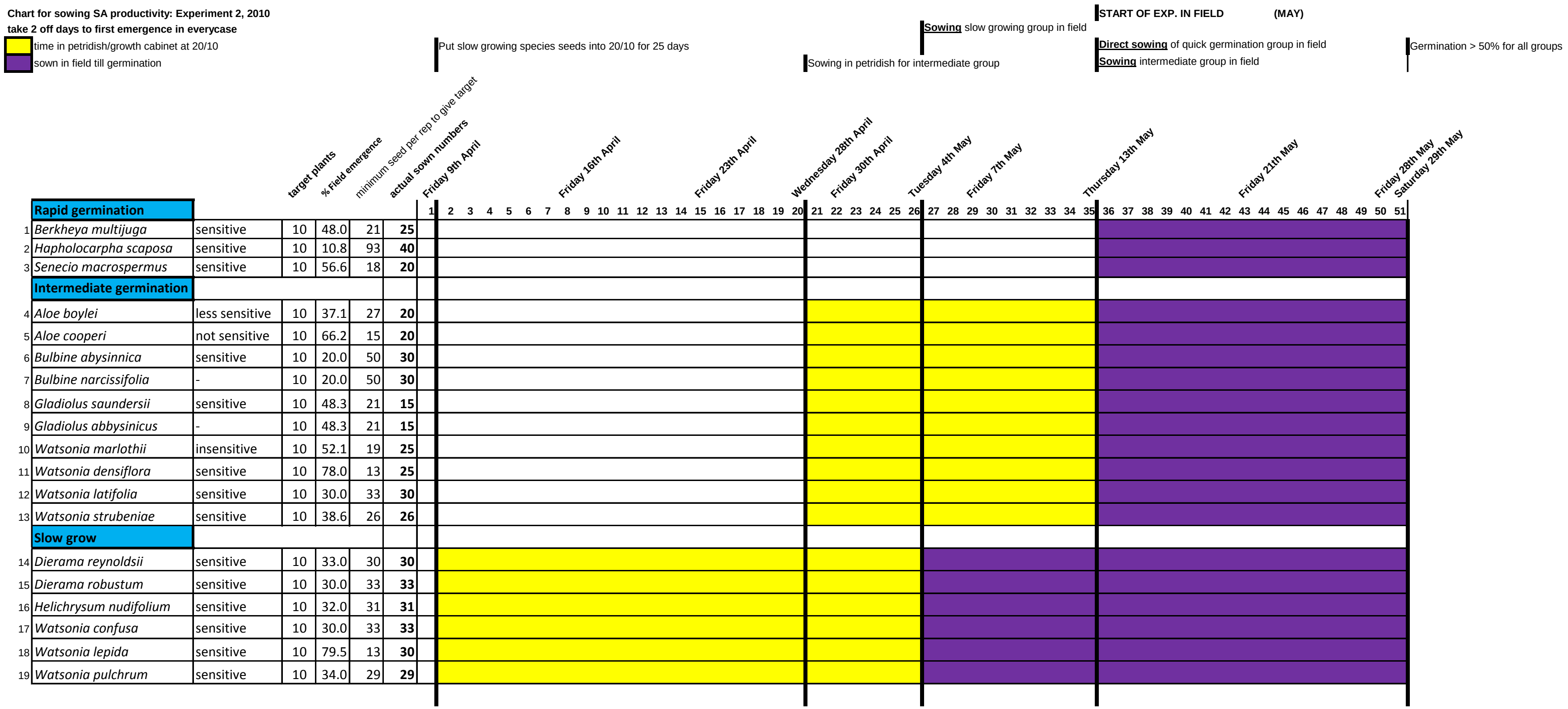


Chart for sowing SA productivity: Experiment 2, 2010

take 2 off days to first emergence in everycase

🟨 time in petridish/growth cabinet at 20/10

🟪 sown in field till germination

Put slow growing species seeds into 20/10 for 25 days

Sowing in petridish for intermediate group

Sowing slow growing group in field

START OF EXP. IN FIELD **(MAY)**

Direct sowing of quick germination group in field

Sowing intermediate group in field

Germination > 50% for all groups

			target plants	% Field emergence	minimum seed per rep to give target	actual sown numbers	1–20	21–26	27–35	36–51
	Rapid germination									
1	*Berkheya multijuga*	sensitive	10	48.0	21	**25**				🟪
2	*Hapholocarpha scaposa*	sensitive	10	10.8	93	**40**				🟪
3	*Senecio macrospermus*	sensitive	10	56.6	18	**20**				🟪
	Intermediate germination									
4	*Aloe boylei*	less sensitive	10	37.1	27	**20**		🟨	🟨	🟪
5	*Aloe cooperi*	not sensitive	10	66.2	15	**20**		🟨	🟨	🟪
6	*Bulbine abysinnica*	sensitive	10	20.0	50	**30**		🟨	🟨	🟪
7	*Bulbine narcissifolia*	-	10	20.0	50	**30**		🟨	🟨	🟪
8	*Gladiolus saundersii*	sensitive	10	48.3	21	**15**		🟨	🟨	🟪
9	*Gladiolus abbysinicus*	-	10	48.3	21	**15**		🟨	🟨	🟪
10	*Watsonia marlothii*	insensitive	10	52.1	19	**25**		🟨	🟨	🟪
11	*Watsonia densiflora*	sensitive	10	78.0	13	**25**		🟨	🟨	🟪
12	*Watsonia latifolia*	sensitive	10	30.0	33	**30**		🟨	🟨	🟪
13	*Watsonia strubeniae*	sensitive	10	38.6	26	**26**		🟨	🟨	🟪
	Slow grow									
14	*Dierama reynoldsii*	sensitive	10	33.0	30	**30**	🟨	🟨	🟪	🟪
15	*Dierama robustum*	sensitive	10	30.0	33	**33**	🟨	🟨	🟪	🟪
16	*Helichrysum nudifolium*	sensitive	10	32.0	31	**31**	🟨	🟨	🟪	🟪
17	*Watsonia confusa*	sensitive	10	30.0	33	**33**	🟨	🟨	🟪	🟪
18	*Watsonia lepida*	sensitive	10	79.5	13	**30**	🟨	🟨	🟪	🟪
19	*Watsonia pulchrum*	sensitive	10	34.0	29	**29**	🟨	🟨	🟪	🟪

Figure 4.4 Chart for sowing South African grassland species on the same day and across a staggered time period. Species was sown based on seed target numbers for each replicate. Slow growing species was sown on 4th May while rapid and intermediate species was directly sown in field on 13th May 2010.

4.2.2 Statistical analysis

Due to the problems with data distribution and homogeneity, even after transformation, 2-way statistical analysis was performed using non-parametric tests. Statistical analysis was undertaken using SPSS version 19 for windows. Mann-Whitney test was used for in place of t-test for paired comparisons. This test was used to compare the significant differences between treatments. The Kruskal-Wallis test was used to compare the significant differences among the treatments at a significant level at $p<0.05$. Suffix subscript letters were used to indicate of statistically significant differences in figures, and tables produce in the chapter.

4.3 Results

4.3.1 Weather background data in 2010/2011 growing season.

The table below shows the statistics of weather conditions during the growing season in 2010 and 2011 recorded by the Western Park Weather Station. The weather station is located approximately 800 m from the experimental plot. Based on the weather data, the average temperature recorded in May was >10 °C. The temperature is above the suitable level for the seed to germinate. It continued to rise until the end of August with an average of 17.1 °C and then decrease in following month. The highest temperature recorded in 2010 was in May (27.7 °C), while the coldest temperature recorded was in December (-8.7 °C).

The lowest rainfall received happened in May, with 19.8 mm while November was the wettest month recorded (111.3 mm). According to the 2010 annual weather summary released by the Western Park Weather Station (unpublished), November was a month of extremes and many respects a true record breaker. The lowest minimum temperature (-7.2 °C) ever recorded since recorded began in 1882.

Table 4.3 Sheffield weather statistics in 2010/2011 recorded by Weston Park Weather Station, Sheffield.

Month	Air temperature (^{0}C)			Precipitation (mm)	Sunshine (hours)
	Highest	Lowest	Average		
April	19.9	1.2	9.3	25.4	171.8
May	27.7	0.0	11.0	19.8	187.9
June	26.8	6.5	15.6	41.6	214.2
July	26.0	9.8	17.1	67.3	142.2
August	23.1	6.3	15.5	44.8	172.9
September	21.8	4.9	14.2	71.0	131.5
October	17.5	0.2	10.3	67.8	116.8
November	17.3	-7.2	5.1	111.3	70.2
December	8.0	-8.7	0.3	22.7	51.4
January	12.7	-3.5	4.1	48.8	56.6
February	14.1	-1.1	6.4	100.4	49.4
March	17.6	-1.7	7.0	11.2	135.7

4.3.2 Physical characteristics of substrates

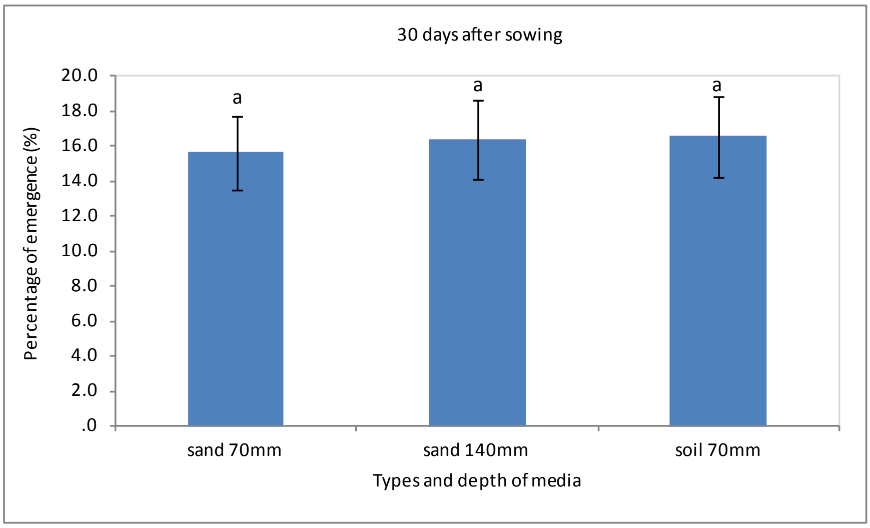
The bulk density of sand is slightly higher than compost (John Innes No 1) and soil. Soil had the lowest bulk density (0.9 g/cm^3) due to being rich in organic matter (Handreck and Black, 1989). Sand has the lowest water holding capacity (10.8%) while compost and soil reach approximately 37.5% and 45.9% respectively. The repeated watering for permeability test shows that sand with the high pore space was the faster infiltration which is 0.042 cm/s (Table 4.4).

Table 4.4 Physical characteristics of two substrates used and soil underneath

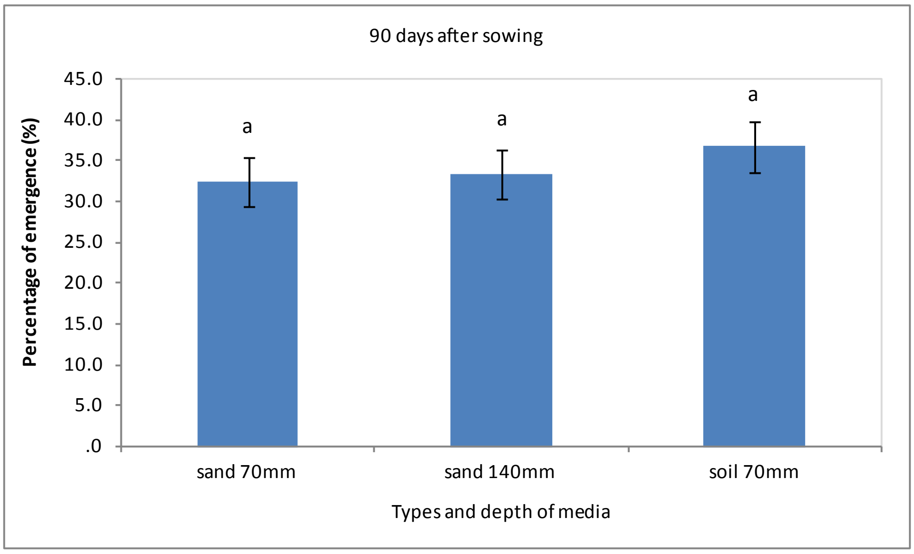
	Sharp sand	John Innes No.1	Soil
Bulk density (g/cm^3)	1.5	1.0	0.9
Water holding capacity (%)	10.8	37.5	45.9
Air filled porosity (%)	21.0	17.8	14.0
Permeability (cm/s)	0.042	0.01	0.003

4.3.3 Different depth and type of media

The results show no significant differences between the treatments as mean of all species in response to different depth and type of media (Figure 4.5). The legend on the left side of this graphic is not clear; replace, this will be the case with all of them like this



(a)



(b)

Figure 4.5 Effect of different depth and types of media on field emergence of montane South African grassland species at 30 and 90 days after emergence. Bars labelled with same letters are not significantly different at P=0.05 (Kruskal-Walis test, pairwise Mann-Whitney U-test). Error bars represent 1 S.E.M.

4.3.4 Effect of different depth and type of media on field emergence of individual species 30 and 90 days after emergence.

4.3.4.1 Different depth and type of media

The only species that showed a significant difference between treatments were *Bulbine abysinnica* and *Watsonia lepida*. At 30 days *Watsonia lepida* emergence was significantly higher (P<=0.05) when sown in sand. *Bulbine abysinnica* showed the opposite trend. As shown in Table (4.5) most of the geophytes species emerged late compared to forbs species. Geophytes ultimately after 90 days, typically had higher emergence. Two species, *Watsonia latifolia* and *Helichrysum nudifolium* did not emerge.

Table 4.5 Effect of different depths and type of media on field emergence on individual species 30 and 90 days after emergence. *P*-values refer to the differences on percentage of emergence between different depth and types of media on each species.

	Percentage emergence at 30 days after sowing						Percentage emergence at 90 days after sowing						*P* -value for 30 days	*P* -value for 90 days
	Sand 70 mm		Sand 140 mm		Soil 70 mm		Sand 70 mm		Sand 140 mm		Soil 70 mm			
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE		
Quick germination														
Berkheya multijuga	37.00	11.12	45.00	7.54	48.00	3.26	13.00	10.37	20.00	9.09	15.00	4.77	0.823ns	0.575ns
Senecio macrospermus	62.50	14.21	71.25	9.65	73.75	2.39	58.75	12.97	56.25	13.59	65.00	6.12	0.938ns	0.910ns
Haphlocarpha scaposa	14.00	4.69	11.50	3.75	22.75	4.49	20.00	5.86	19.37	3.28	23.12	3.73	0.144ns	0.776ns
Intermediate														
Bulbine abysinnica	0.00	0.00	0.00	0	1.50	0.866	0.83	0.83	5.83	1.59	9.16	2.84	0.111ns	0.032*
Watsonia densiflora	34.00	4.16	34.00	8.08	28.00	10.58	63.00	13.79	63.00	13.4	78.00	6.63	0.787ns	0.688ns
Watsonia latifolia ^{a}	-		-		-		-	-	-	-	-	-	-	-
Watsonia strubeniae	18.25	3.25	26.75	6.88	26.00	7.33	76.92	7.19	79.80	3.64	78.84	4	0.571ns	0.811ns
Gladiolus saundersii	24.75	4.97	26.75	5.51	23.50	2.02	30.00	8.81	28.33	5.69	23.33	3.33	0.854ns	0.726ns
Watsonia marlothii	10.00	3.46	12.00	2.3	12.00	3.65	39.00	10.87	50.00	9.3	51.00	7.72	0.908ns	0.488ns
Aloe cooperi	17.50	7.50	12.50	4.33	18.75	8.51	35.00	6.77	27.50	13.14	40.00	12.07	0.763ns	0.585ns
Bulbine narassiflora	0.00	0.00	0.75	0.75	0.00	0	8.33	2.15	4.17	2.09	3.33	1.36	0.368ns	0.204ns
Gladiolus abbysinicus	1.75	1.75	1.75	1.75	0.00	0	23.33	5.77	15.00	5.69	26.67	11.86	0.577ns	0.738ns
Aloe boylei	0.00	0.00	0.00	0	1.25	1.25	30.00	12.24	47.50	6.61	50.00	6.45	0.368ns	0.426ns
Slow														
Dierama robustum	11.25	3.75	16.50	4.33	4.50	0.87	50.00	7.26	47.72	7.56	58.33	9.69	0.086ns	0.624ns
Watsonia confusa	24.00	3.67	21.00	2.12	24.75	2.25	44.69	6.47	54.54	8.74	57.57	3.27	0.519ns	0.365ns
Watsonia pulchrum	16.50	3.79	14.00	0	19.25	4.4	41.37	7.83	31.03	3.72	33.62	5.14	0.496ns	0.508ns
Watsonia lepida	21.75	3.81	15.25	2.83	10.00	1.73	36.67	7.57	36.67	8.05	31.67	7.01	0.045*	0.691ns
Dierama reynoldsii	3.25	2.35	2.25	0.75	0.75	0.75	44.17	13.96	45.83	11.08	56.66	10.97	0.453ns	0.787ns
Helichrysum nudifolium ^{a}	-		-		-	-	-	-	-	-	-	-	-	-

Significant differences between different depth and media on each species (Kruskal-Wallis test and Mann Whitney U-test for pair comparison) are indicated by: * P=0.05; ns, not significant.

4.3.5 Effect of different depth and type of media on mortality of montane South African grassland before winter 2010/2011.

4.3.5.1 Different types of media

As shown in (Figure 4.6), there is no significant difference between sand and soil in general on the percentage of mortality before winter 2010/2011.

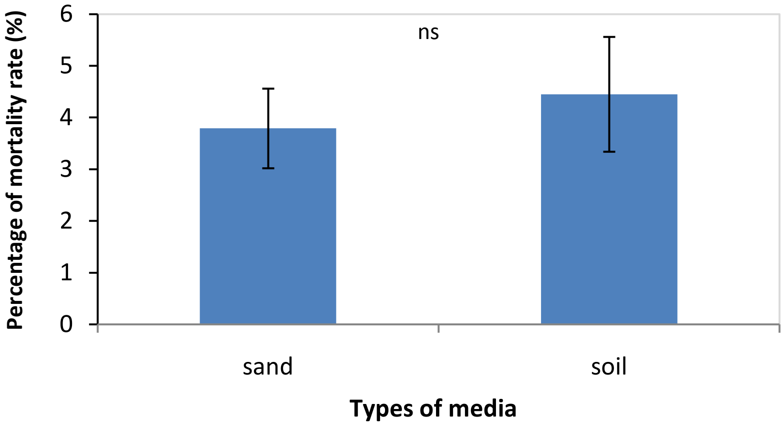


Figure 4.6 Effect of different types of media on % mortality of South Africa grassland species before winter 2010/2011. Significant differences (Mann-Whitney U-test) between sand and soil are indicated by; **P<=0.01. Error bars represent 1 S.E.M.

4.3.5.2 Different depth and types of media

The mortality rate was not significantly different across different depth and type of media combinations (Figure 4.7). Even though there were no significant differences between treatments, but sand 140 mm and soil 70 mm shows the high percentage of mortality as compare to sand with 70 mm depth.

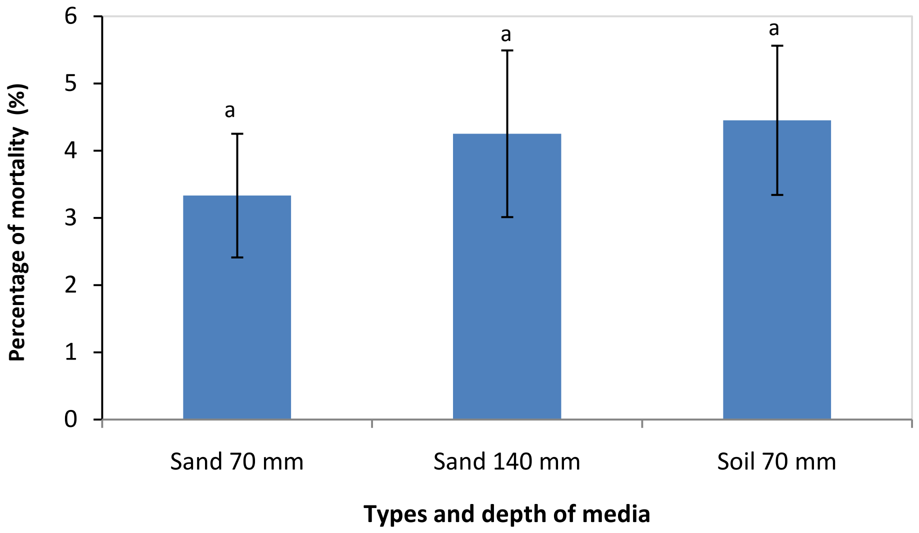


Figure 4.7 Effect of different depth and types of media on % mortality of South Africa grassland species before winter 2010/2011. Bars labelled with different letters are significantly different at P=0.05 (Kruskal-Walis test, pairwise Mann-Whitney U-test). Error bars represent 1 S.E.M.

4.3.6 Effect of different depth and types of media on mortality of individual species over winter 2010/2011.

4.3.6.1 Different depth and types of media

Most species were not significantly different in mortality between sand and soil, although as a general trend more species died on 70 mm soil (Table 4.6).

The numbers of species that died before winter was higher on soil with a nominal 70 mm depth. *Dierama reynoldsii*, *Gladiolus saundersii*, *Watsonia confusa* and *Watsonia pulchrum* were the only species showing a significant difference across the treatments. The data on three species such as *Crinum macowanii*, *Crinum bulbispermum* and *Scadoxus puniceus* shows high percentage of mortality before winter. *Dierama reynoldsii* and *Watsonia pulchrum* showed better survival on sand and *Gladiolus saundersii* and *Watsonia confusa* on soil (Table 4.6).

Table 4.6 Effect of different depth and types of media on % mortality of South Africa grassland species before winter 2010/2011. *P*-values refer to the difference between percentage of mortality of each species on a different depth and types of media.

	Percentage of mortality before winter 2010/2011 (%)						*P* -value
	Sand 70 mm		Sand 140 mm		Soil 70 mm		
Species	Mean	SE	Mean	SE	Mean	SE	
Aloe boylei	1.25	1.25	1.25	1.25	0.00	0.00	0.577ns
Aloe cooperi	0.00	0.00	0.00	0.00	1.25	1.25	0.368ns
Berkheya multijuga	0.00	0.00	12.00	8.48	0.00	0.00	0.113ns
Bulbine abysinnica	0.00	0.00	0.00	0.00	0.00	0.00	1.000ns
Bulbine narcissifolia	0.84	0.84	0.00	0.00	0.84	0.84	0.577ns
Crinum bulbispermum	14.29	5.83	0.00	0.00	14.29	10.10	0.146ns
Crinum macowanii	0.00	0.00	21.43	17.00	10.72	6.84	0.267ns
Dierama reynoldsii	0.00 ^{b}	0.00	0.00 ^{b}	0.00	11.67 ^{a}	7.39	0.027*
Dierama robustum	0.00	0.00	0.00	0.00	0.76	0.76	0.368
Gladiolus abbysinicus	0.00	0.00	0.00	0.00	0.00	0.00	1.000ns
Gladiolus saundersii	8.33 ^{ab}	5.00	16.67 ^{a}	6.38	0.00 ^{b}	0.00	0.048*
Haphlocarpha scaposa	2.50	1.77	0.00	0.00	0.00	0.00	0.113ns
Helichrysum nudifolium[*]	-		-		-		-
Senecio macrospermus	1.25	1.25	0.00	0.00	0.00	0.00	0.368ns
Scadoxus puniceus	22.14	14.30	23.34	13.47	28.33	9.57	0.939ns
Watsonia confusa	0.00 ^{a}	0.00	7.58 ^{b}	4.01	5.31 ^{b}	1.45	0.047*
Watsonia densiflora	1.00	1.00	2.00	2.00	0.00	0.00	0.573ns
Watsonia latifolia[*]	-		-		-		-
Watsonia lepida	10.00	4.30	3.33	1.35	8.34	8.33	0.445ns
Watsonia marlothii	0.00	0.00	3.00	1.91	8.00	8.00	0.358ns
Watsonia pulchrum	7.76 a	3.26	0.00 b	0.00	2.59 ab	2.58	0.035*
Watsonia strubeniae	3.85	2.17	2.89	1.84	5.77	1.92	0.680ns

[*] *not germinate at all*

Significant differences (Kruskal-Wallis test and Mann-Whitney U-test for pair comparison) between different depth and types of media are indicated by; *P<=0.05; ns, not significant.

4.3.7 Effect of different depth and type of media on survival rate of montane South African grassland overwinter 2010/2011.

4.3.7.1 Different types of media

The results indicate that seedlings in the soil treatment had highly significantly greater survival than those sown in sand (Figure 4.8).

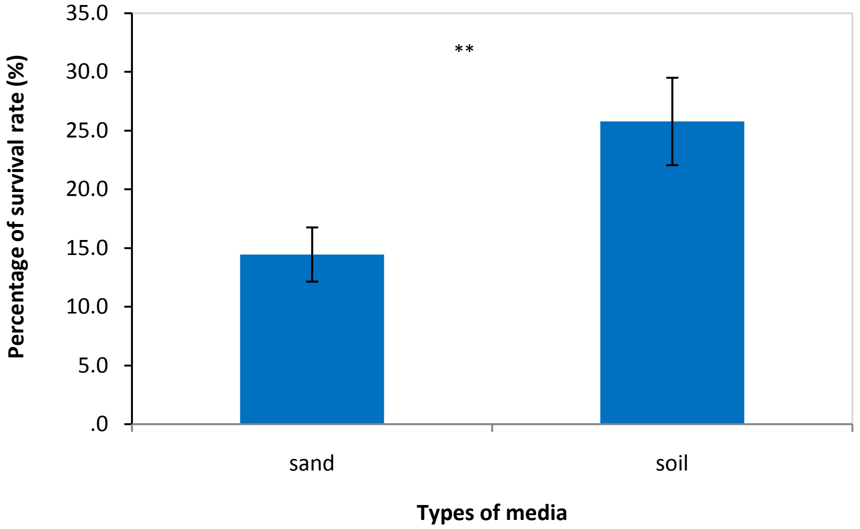


Figure 4.8 Effect of different types of media on % survival of South Africa grassland species overwinter 2010/2011. Significant differences (Mann-Whitney U-test) between sand and soil are indicated by; **P<=0.01. Error bars represent 1 S.E.M.

4.3.7.2 Different depth and types of media

The survival rate was significantly different across different depth and type of media combinations. Species sown on soil with a nominal 70 mm depth gave the higher survival rate as compared to 70 mm and 140 mm sand. However, species survival rate on 70 mm soil was not significantly different with 70 mm sand. Survival rate in 140 mm sand was significantly different to 70 mm soil but not with 70 mm sand (Figure 4.9).

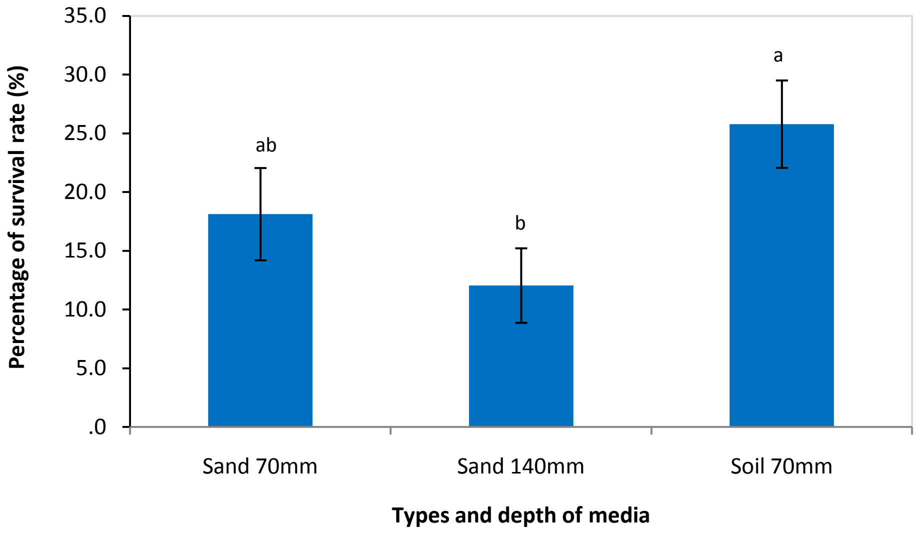


Figure 4.9 Effect of different depth and types of media on % survival of South Africa grassland species overwinter 2010/2011. Bars labelled with different letters are significantly different at P=0.05 (Kruskal-Walis test, pairwise Mann-Whitney U-test). Error bars represent 1 S.E.M.

4.3.8 Effect of different depth and types of media on survival of individual species over winter 2010/2011.

4.3.8.1 Different depth and types of media

Most species were not significantly different in survival between sand and soil, although as a general trend more species survived on soil compared to sand (Table 4.7).

The number of species surviving over winter was greatest on soil. *Bulbine narcissifolia* was the only species showing a significant difference across the treatments. The data does however reveal differences in cold tolerance, with *W. strubeniae G. abysinnicus*, *A. boylei* and *A. cooperi* showing zero survival in all treatments, suggesting they are the least cold tolerant species. The next least cold tolerant are all Watsonia; *W. confusa*, *W. marlothii*, and *W. lepida*.

Table 4.7 Effect of different depth and types of media on % survival of South Africa grassland species overwinter 2010/2011. *P*-values refer to the difference between percentage of survival of each species on a different depth and types of media.

	Percentage of survival after winter 2010/2011 (%)						
	Sand 70 mm		Sand 140 mm		Soil 70 mm		*P* -value
Species	Mean	SE	Mean	SE	Mean	SE	
Aloe boylei	0.00	0.00	0.00	0.00	0.00	0.00	1.00ns
Aloe cooperi	0.00	0.00	0.00	0.00	0.00	0.00	1.00ns
Berkheya multijuga	36.36	23.76	25.00	25.00	52.23	21.59	0.637ns
Bulbine abysinnica	0.00	0.00	0.00	0.00	17.50	11.81	0.113ns
Bulbine narcissifolia	12.50 ^{a}	7.27	0.00 ^{b}	0.00	68.75 ^{a}	23.66	0.048*
Crinum bulbispermum	20.00	20.00	0.00	0.00	43.93	17.62	0.119ns
Crinum macowanii	0.00	0.00	0.00	0.00	30.21	20.65	0.113ns
Dierama reynoldsii	9.15	3.28	1.32	1.31	25.76	4.33	0.101ns
Dierama robustum	63.14	16.22	36.82	9.52	70.13	11.12	0.219ns
Gladiolus abbysinicus	0.00	0.00	0.00	0.00	0.00	0.00	0.00ns
Gladiolus saundersii	85.00	9.57	100.00	0.00	75.00	14.43	0.241ns
Haphlocarpha lyrata	34.71	13.86	17.50	17.50	43.87	14.63	0.624ns
Helichrysum nudifolium *	-	-	-	-	-	-	-
Senecio macrospermus	58.78	13.95	56.49	7.83	52.99	4.19	0.967ns
Scadoxus puniceus	0.00	0.00	0.00	0.00	0.00	0.00	1.00ns
Watsonia confusa	0.00	0.00	0.00	0.00	1.47	1.47	0.368ns
Watsonia densiflora	15.21	3.99	3.75	3.75	20.89	7.79	0.124ns
Watsonia latifolia *	-	-	-	-	-	-	-
Watsonia lepida	2.50	2.50	0.00	0.00	2.78	2.77	0.573ns
Watsonia marlothii	0.00	0.00	0.00	0.00	1.79	1.78	0.368ns
Watsonia pulchrum	0.00	0.00	0.00	0.00	8.33	8.33	0.368ns
Watsonia strubeniae	0.00	0.00	0.00	0.00	0.00	0.00	1.00ns

* *not germinate at all*

Significant differences (Kruskal-Wallis test and Mann-Whitney U-test for pair comparison) between different depth and types of media are indicated by; *P<=0.05; ns, not significant.

4.3.9 Coldest temperature recorded on the surface and sub-surface in 2011-12

The winter of 2011/2012 proved to be the coldest winter for over three decades in many parts of the UK and provided an opportunity to investigate the climate of the substrates in greater detail. The coldest temperature was recorded on 4th Feb 2012. At 50 mm depth the soil temperature on this night was approximately 0.4 °C, compared with -1.4 °C in the sand (Figure 4.10). The temperature at the surface was substantially colder above sand than above soil (see Figure 4.10). As a comparison, the minimum air temperature recorded at Western Park Weather Station, Sheffield, at 1.2 m above ground on the same day was -5 °C (Figure 4.11).

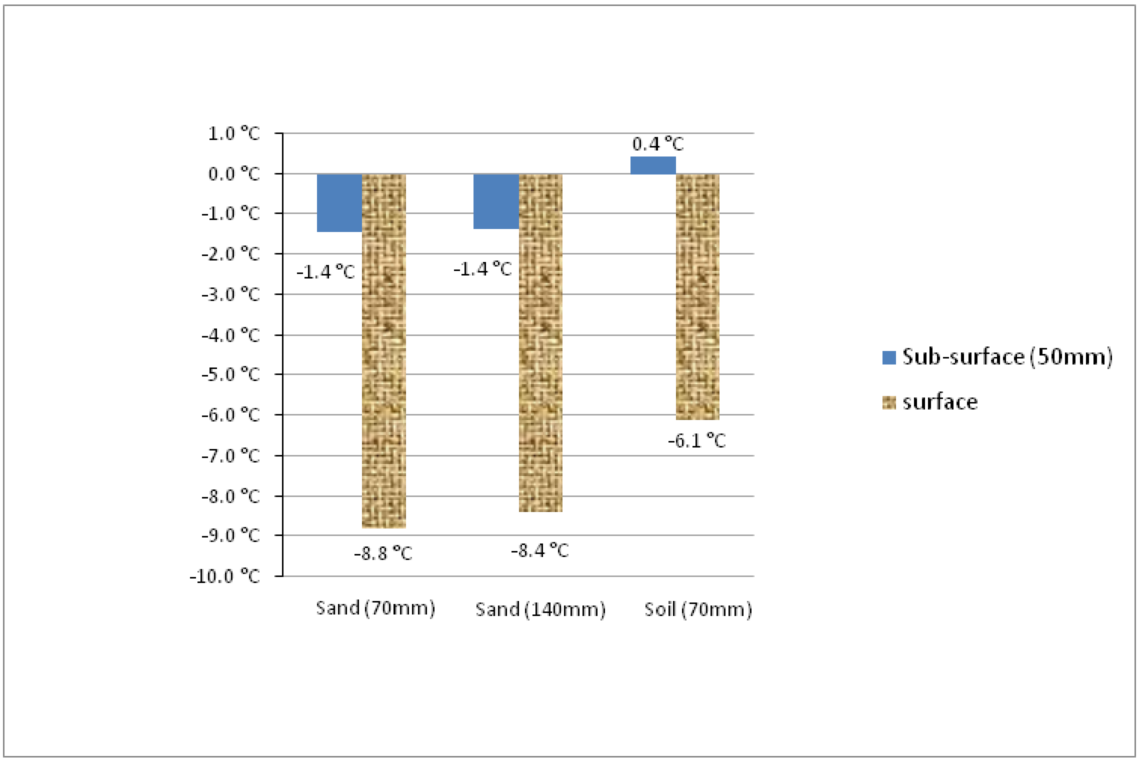


Figure 4.10 Minimum temperature across different type of medium and depth on the coldest night in 2012 (4th Feb; 8.00 am)

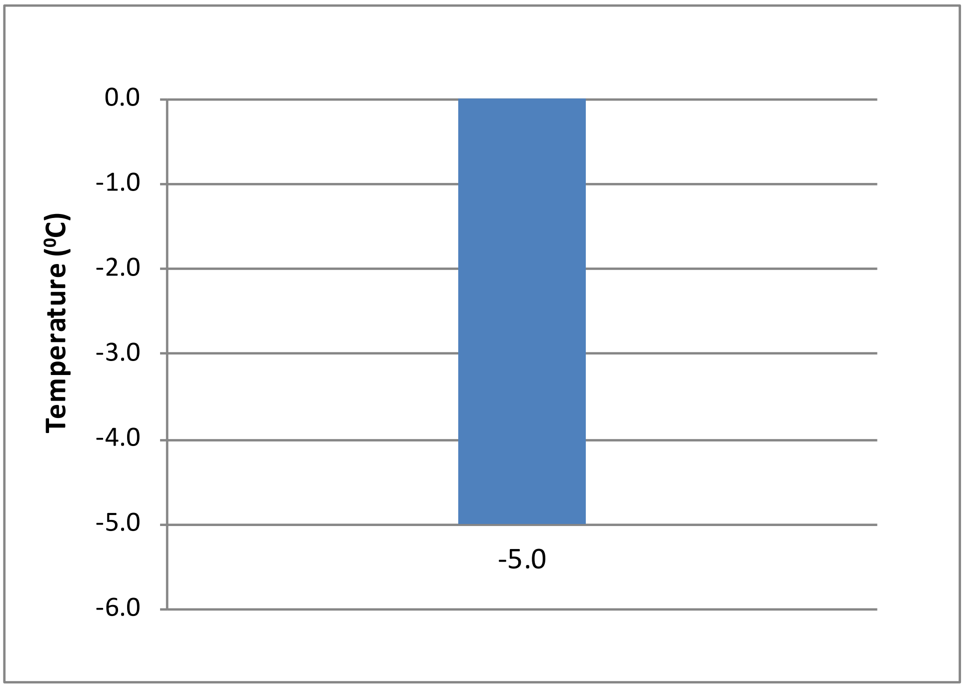


Figure 4.11 Minimum air temperature recorded on 4th February 2012 by Weston Park Weather Station, Sheffield.

4.4 Discussion

4.4.1 Field emergence

The adequate water and suitable temperature when sown on 13th May 2010 helped almost all species produce a good emergence rate at the end of observation. Rising temperatures could also increase appropriate temperature near the surface of the planting medium. This is reflected in Table 4.8 where the temperature is at a high level at a depth of 10 to 20 mm. Frequency of rainfall after sowing in May and June helped germination performance for all species. Frequency of rainfall after sowing in May and June helped germination performance for all species. The total amount of precipitation was not particularly high, but the high frequency was enough to maintain the surface moisture. Table 4.3 shows the most significant increase in the amount of rainfall was received around 60 days after sowing. Total rainfall received increased from 19.8 mm to 67.3 mm. The irrigation also has done manually to remain the medium surface moisture always at the optimum condition for germination.

Table 4.8 Sub surface temperature recorded using digital thermometer at 2.00 pm

Date	Sand (70 mm)		Sand (140 mm)		Soil (70 mm)	
	10 mm	20 mm	10 mm	20 mm	10 mm	20 mm
03/06/2010	29.98	28.28	29.55	27.93	30.25	27.83
05/06/2010	30.20	28.98	29.83	28.15	29.25	27.18
06/06/2010	19.83	19.58	19.80	19.38	19.65	18.98
10/06/2010	13.05	13.15	12.93	13.10	13.08	13.20
11/06/2010	23.45	21.53	23.35	21.48	24.05	20.10
12/06/2010	24.43	22.93	24.08	22.55	24.03	21.00
17/06/2012	30.38	27.50	30.18	27.48	31.60	27.98
18/06/2010	17.38	17.40	17.18	17.18	17.38	17.20
21/06/2010	26.03	25.68	26.08	25.73	26.35	25.28

Most of the species tested did not show a significant difference in emergence in response to the depth and type of media. In the species that did show a response, these had disappeared after 90 days (Table 4.5). Only two species had emergence below 10%; *Bulbine* *abysinnica* and *Bulbine narcissifolia.* The seeds of these species used in this study were produced on a field station in the previous year, and quality appears to have been lower, as particularly in the case of *H. nudifolium*. Almost all *Watsonia spp*. showed high emergence (except *Watsonia latifolia)*. It seems likely that the seed batch of this latter species supplied from South Africa was old and non-viable.

Species that had rapid growth, such as *Senecio macrospermus* and *Berkheya multijuga,* showed a decline (approximately 50%) in seedling numbers 90 days after emergence (Table 4.5). This situation happened as far as can be seen due to competition for space. The first seedlings to emergence retained their competitive advantage to access light and eliminated smaller seedling in the subplots leading to self-thinning. Apart from competition for space, reduction of the number of seedlings *Senecio macrospermus* was also due to an unknown fungal pathogen that affected this species. It can be seen yellowing and wilting of plant leaves even at flowering time (Figure 4.12). The high frequency of rain at the end of May, coupled with watering appeared to pathogen attack. The primary root may have been disrupted due to anaerobic conditions when high moisture surrounded the root zone (Isaac, 1991). The hairy leaf and stem of *S. macrospermus* also is capable of capturing high humidity on the leaf surface that cause fungal infection on the surface and cause the plants to wither and die after suffering severe damage.

Figure 4.12 *Senecio macrospermus* affected by fungal pathogens in wet conditions. Picture taken 10th June 2011.

4.4.2 Survival of species in winter 2010-11.

Seedling survival was markedly lower in the 140 mm depth sand treatment (Figure 4.8).

The results of the study showed that, as expected by increasing the depths of the mulch it was reduced moisture in a medium during winter. Increase depth in sand was made the sand drier with more air filled pore space (Table 4.4). The proportion of water in the sand is lower than the soil. The disparities in particle sizes between the underlying soil and the coarse sand mulch restrict the capacity of heat transfer from the relatively warm soil beneath the sand above, that is losing its heat to the atmosphere as nocturnal temperatures decline. Hence the surface of the sand is substantially colder at night than the soil, in which case the reduced particle size disparities allow for heat to be conducted to the surface across the course of the night to replace that lost and hence to prevent the surface temperature dropping as low as that of the sand.

The loss of moisture in soil, and in sand in particularly (since its initial moisture holding capacity is much lower, see table 4.4) reduces the thermal conductivity of the soil.. Soil in a wet condition cools more slowly at night because of more efficient heat transfer through the moisture phase (Craul, 1992). These processes led to the temperature differentials between soil and sand surface in this experiment of approximately 2°C, and also differentials of a similar magnitude at 50 mm depth.

Mortality of many species before winter 2010/2011 is not significantly different between sand and soil (Figure 4.6). Only 4 species (*Dierama reynoldsii*, *Gladiolus saundersii*, *Watsonia confusa* and *Watsonia pulchrum*), which showed a significant difference between the type of media and different media thickness (Table 4.6). *Dierama reynoldsii* showed high mortality in soil, which is 11.67 % suggested that this species was not as tolerant to the high moisture content as the other species. While *Gladiolus saundersii* have higher mortality (16.67 %) at 140 mm sand, this may be due to the root zone near the sand surface being affected by drought condition due to the sand surface with high on AFP (21%) was dries quickly when hot days during spring and summer. High percentage mortality for *Crinum bulbispermum*, *Crinum macowanii* and *Scadoxus puniceus* is caused by digging activity by foxes at night.

The most important factor determining whether species survive is temperature during winter. Almost 70% of the species survive in the soil compared to sand. Soil retained its high water-holding capacity of 45.9% (Table 4.4) over winter. Although almost all species planted in soil had higher survival than sand with different depths, this was not the case with *Gladiolus saundersii*. This species showed 100% survival even in 140 mm, suggesting that its corms are particularly tolerant of cold. The less moisture, the lower the temperature drops (Leong, et al., 1998). This situation can be seen in the sand to a depth of 140 mm showed only 7 species was survived the over winter. The higher air filled porosity in sand, which is 21% (Table 4.4) compared to soil and low air filled capacity of 10.8% cause the moisture in the sand with a high thickness will cause the root zone to become quickly dry and can drop to -2°C (Figure 4.10). Root exposure at temperatures above -2 °C over 5 days (Leach, et al., 1997) can cause cell death and roots are susceptible during spring and summer.

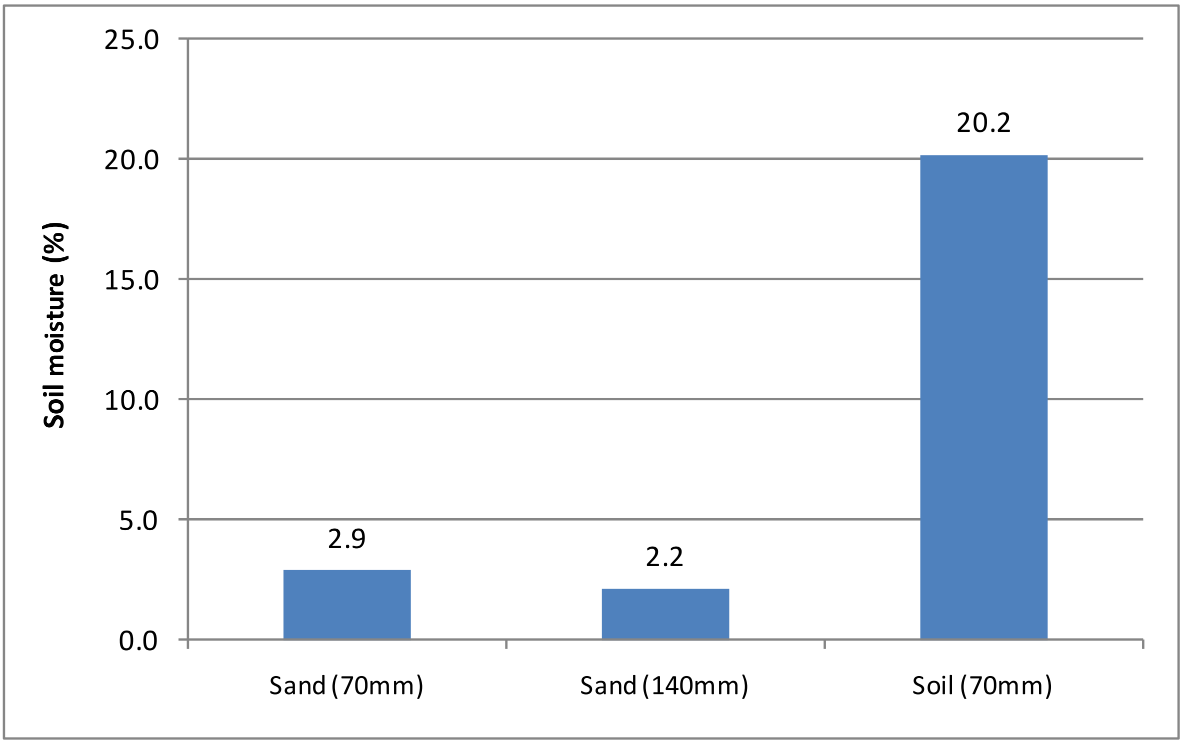


Figure 4.13 Average *in situ* soil moisture content of different mulch types and depth at approximately 50mm depth. Data was taken using Delta-T probe at 10.00 am everyday in 2 weeks in June 2010.

Other species that survived over winter were *Bulbine narassiflora*, *Crinum macowanii*, *Berkheya multijuga*, *Haplocarpha lyrata, Watsonia densiflora*. Differences in temperature beween soil and sand at a depth of 50 mm of around 2°C allow many species to survive in soil. Evergreen species like *Dierama robustum*, *Berkheya multijuga* and *Senecio macrospermus* also affected by extreme cold temperatures during the winter 2010/2011. *Berkheya* and *Senecio* also suffered loss of leaves due to exposure to temperatures of -8.7 °C recorded in December. Table 4.9 provides written observation's of how species were affected over winter 2010/2011. *Dierama robustum* showed good performance as an evergreen species, but also demonstrated its lowest percentage of survival in 140 mm sand.

Because the plants were small by the commencement of winter, the rhizomes etc., of species like the Aloes were inevitably sat close to the surface and hence experienced very low temps; if the same temps were experience by older bigger plants only part of the roots would be damaged to the same degree.

This experiment highlighted species with high survivorship in different substrates and different depth of mulch are *Gladiolus saundersii*, *Berkheya multijuga*, *Haplocarpha scaposa*, *Senecio macrospermus* and *Dierama robustum.* The survival response of species has clarified how the nature of the soil surface and the different temperatures generated by this, is important for South African grassland species, especially in the first year after sowing, when underground storage organs are very close to the surface. With species that were sown on sand with a depth of 140 mm, only 6 species survived, compared to 9 species on 70 mm sand and 13 species on soil. This shows how differences of only 1-2 °C in nocturnal surface and subsurface temperatures make a huge difference to the survival percentage of species.

Table 4.9 Written observation on foliage condition after winter 2010/2011. The observation was made in 12th February 2011.

Species	**Foliage retention after winter 2010/2011**		
	Sand 70 mm	**Sand 140 mm**	**Soil 70 mm**
Aloe boylei	Complete dissapear	Complete dissapear	20% Complete retention 80% Complete dissapear
Aloe cooperi	Complete retention	Complete dissapear	Complete dissapear
Berkheya multijuga	Green	100% retention	Green
Bulbine abysinnica	Complete dissapear	Complete dissapear	Complete dissapear
Bulbine narcissifolia	Complete dissapear	Complete dissapear	Green + 90% dissapear
Crinum macowanii	Complete dissapear	Complete dissapear	Complete dissapear
Crinum bulbispermum	Complete dissapear	Complete dissapear	Complete dissapear
Dierama reynoldsii	50% green & 50% retention	50% green & 50% retention	50% green
Dierama robustum	Green	Green, some foliage kill	Green
Gladiolus saundersii	Complete retention	Complete retention	Complete dissapear
Gladiolus abbysinicus	Complete dissapear	Complete dissapear	Complete retention
Haphlocarpha lyrata	Complete dissapear	50% retention	Complete retention
Helichrysum nudifolium	Complete dissapear	Complete dissapear	Complete dissapear
Scadoxus puniceus	Complete dissapear	Complete dissapear	Complete dissapear
Senecio macrospermus	Green & retained silvery	Green + 80% retention	Green & retained silvery
Watsonia confusa	Complete retention	Complete retention	Complete retention
Watsonia densiflora	Complete retention	Complete retention	Complete retention
Watsonia latifolia	Complete dissapear	Complete dissapear	Complete dissapear
Watsonia lepida	Complete retention	Complete retention	Complete retention
Watsonia marlothii	Complete retention	Complete retention	20% green
Watsonia pulchrum	Complete retention	Complete retention	Complete retention
Watsonia strubeniae	Complete retention	Complete retention	Complete retention

4.5 Conclusion

The hypothesis for this study was that species tolerance to winter cold is increased when growing in substrates that are drier and more highly oxygenated in winter is not supported. In this study survival of SA grassland species, and especially geophytic species was strongly linked to a substrate that was wetter in winter, but which also had improved thermal properties in terms of restricting sub zero temperatures within and above these materials. A different picture might have emerged had the soil on the site had much lower drainage capacity, and had winter rainfall been greater than was experienced in 2010-11. Species such as *D. reynoldsii* performed relatively well in the study in soil, however in wetter climates such as Northern Ireland (Dunlop, unpublished) it is reported to be sensitive to soil wetness.

Soil bulk density is relatively low on an experimental plot (0.9 g/cm^3). This situation may be due to high organic content. According to Hendreck and Black, 2005, high organic matter in the soil compared mineral decreases bulk density. This is shown in table 4.4 where the AFP for the soil is relatively high at 14%. This shows the condition of the soil at the site is still in good condition for plant growth allowing a lot of species to benefit from relatively higher temperatures despite the soil wetness to survive. Although the evidence from previous studies was that *Watsonia* are sensitive to high moisture content, they generally survived better in soil despite this because of higher temperatures. Using *Watsonia* sp. in design plant community must take into account the soil moisture gradient for planting site and the physical characteristics of the soil.

Freezing temperature is the main factors causing many species died especially during winter. Extreme winter and extreme temperatures (-8.7 °C) cause many species die where the root zone is below freezing except for a few species of evergreens like *Dierama robustum, Berkheya multijuga, Senecio macrospermus*. *Gladiolus saundersii* is one of the hardiest species in this experiment, and has good potential for use as a result.

CHAPTER 5: EFFECT OF COMPETITION BETWEEN SPECIES OF DIFFERENT FOLIAGE CANOPY HEIGHT AND POTENTIAL PRODUCTIVITY ON COMMUNITY STRUCTURE AND APPEARANCE.

5.1 Introduction

A herbaceous plant community with multiple canopy layers is a new approach to naturalistic planting design. The longer term dynamic of multiple layer plant communities consisting of shade tolerant lower layers and shade intolerant upper layers have been studied by Hitchmough (2004); and Ahmad and Hitchmough (2007). These studies used native UK woodland understory species and North American prairie species. According to Price (2012) these planting arrangements inspired her work with Nigel Dunnet at the Olympic Park garden.

The same method was also used in this study to answer the question of how to incorporate South African montane grassland species with different morphology and growth rate to create a stable, sustainable designed community. The difference between this study and that of Ahmad (2007) is that the forbs, geophytes and grass in the South African grass community are largely believed to be shade intolerant, including the species in the lowest, ground layer. The experiment described in this chapter was established as the main experiment in these studies, and was sown on 13th April 2011 to provide two growing seasons of data and test the visual and functional success of sown communities of SA species. The experiment investigated the effect of different proportions of species with low, medium and tall foliage canopies on the growth, development and survival of individual species. It also determined the effect of community structure on community productivity and appearance. The experiment incorporated understanding of establishment and survival gained from experiment 1 and 2 and involved a large range of species sown in the seed mixture. The seeds used were mainly produced in summer 2010 from container-grown material grown from seed since 2006, for use in this experiment.

The provisional research hypothesis is that in mixed communities, the establishment and survival of the species with the lowest leaf canopies will be inversely proportional to the percentage of species with taller foliage. The study will look at the effect of life form, i.e. grasses, geophytes and forbs as sub-components within this.

5.1.1 Objectives

The specific objectives of this study were:

1) To investigate the emergence of 30 species when sown in mixture
2) To investigate the effect of different proportions of species with low, medium and tall foliage canopies on cover values in year 1 and 2.
3) To investigate the effect of 9 plant communities derived from different ratios of low medium and tall foliage on the biomass production and phenology of species in year 2.
4) To investigate the effect of these communities on survival of species in community in years 1-2.
5) To determine the effect of community structure on community actual productivity and appearance in year 2.

5.1.2 Species selection

Based on experiment 1 and 2 as well as information from field observations and the availability of seeds, a total of 30 species of South African montane grassland with different canopy heights were selected to be used in this study. Each canopy group consisted of 10 species with different combinations of geophytes, forbs and grass. Species that were not available from home produced seed were purchased from Jelitto Seeds, Germany and Silverhill Seeds, Cape Town. All seeds were stored in the refrigerator at a temperature of 4°C before use to avoid loss of seed viability. Selected species was listed as in Table 5.1 below:

Table 5.1 South African grassland species used in the experiment, within the three canopy height groupings (Hillard 1977; Hillard and Burtt, 1991; Goldblatt and De Vos 1999; Goldblatt, et al., 2004; Goldblatt, 1986; Codd 2005; Snoeijer 2004; Van Wyk and Smith 2005; Mucina and Rutherford, 2006).

Species	Family	Distribution	Habitat	Example of community type (from Mucina and Rutherford, 2006)	Altitudinal range in SA (m)	Seed weight (mg)	Origin of population used in study
Low (<300 mm)							
Diascia integerrima	Scrophulariaceae	Eastern Cape, KwaZulu-Natal, and Free State	Open grassland and rocky slopes	Southern Drakensberg Highland Grassland (Gd 4)	1220 - 3000	0.1	Silverhill unknown
Diascia tugelensis	Scrophulariaceae	KwaZulu-Natal, Lesotho	Often in moist rocky sites	uKhahlamba Basalt Grassland (Gd 7)	1800 to 3355	0.2	Sentinel Peak KZN
Eucomis bicolor	Hyacinthaceae	Kwazulu-Natal, Eastern Cape, Free State	Grassland, forest, swamps and along river banks,	Northern Drakensberg Highland Grassland (Gd5)	to 2745	4.0	Silverhill unknown
Gazania linearis	Asteraceae	Widely distributed, Eastern Cape to KZN	Open grassland and rocky slopes	Stormberg Plateau Grassland (Gd 3)	0 - 3050	1.6	Cultivated, Jelitto
Geum capense	Rosaceae	Eastern Cape, Kwazulu-Natal	Wet alpine grassland and bogs	Amathole montane grassland (Gd1)	765 to 3290	3.5	Naudes Nek Eastern Cape
Haplocarpha lyrata	Asteraceae	Western Cape	Open grassland and rocky slopes	Amathole montane grassland (Gd1)	200 to 1500	0.3	Sentinel Peak KZN
Helichrysum aureum	Asteraceae	Eastern Cape to Mpumalanga	Open grassland and rocky slopes	uKhahlamba Basalt Grassland (Gd 7)	0 - 2170	0.2	Silverhill. unknown
Merwilla plumbea	Hyacinthaceae	Eastern Cape to Mpumalanga	sunny slopes, rocky hills, cliffs and ledges,	Lesotho Highland Basalt Grassland (Gd 8)	0 - 2170	4.2	Bloemfontein
Kniphofia hirsuta	Asphodelaceaea	Drakensberg	to damp cliff faces, rocky slopes or streams	Lesotho Highland Basalt Grassland (Gd 8)	to 2622	3.2	Jelitto seeds
Tritonia drakensbergensis	Iridaceae	Northern Eastern Cape .	Moist grassland and cliffs	Lesotho Highland Basalt Grassland (Gd 8)	1100 - 2300	4.0	Silverhill, unknown

Low canopy species

Diascia integerrima

Diascia tugelensis

Eucomis bicolor

Gazania lineris

Geum capense

Haplocarpha lyrata

Helichrysum aureum

Kniphofia hirsuta

Merwilla plumbea

Tritonia drakensbergensis

Species	**Family**	**Distribution**	**Habitat**	**Example of community type (from Mucina and Rutherford, 2006)**	**Altitudinal range in SA (m)**	**Seed weight (mg)**	**Origin of population used in study**
Medium (300 - 600 mm)							
Agapanthus inapertus	Agapanthaceae	Mpumalanga	Grassland, moist soil	Lydenburg Montane Grassland (Gm 18)	500- 1800	4.1	Cultivated
Berkheya purpurea	Asteraceae	Eastern Cape	Open grassland and rocky slopes	uKhahlamba Basalt Grassland (Gd7)	1525 -3050	3.8	Cultivated, Jelitto
Diascia rigescens	Scrophulariaceae	Eastern Cape, Kwazulu Natal	Damp places on grassy mountain slopes, often among rocks or in full sun at forest margins	Amathole montane grassland (Gd 1)	305 to 1675	0.7	Moonstone Mountain Eastern Cape
Dierama mossii	Iridaceae	KwaZulu-Natal	Summer-rainfall region in grassland	Amathole montane grassland (Gd 1)	to 1525	9.9	Cultivated
Gladiolus saundersii	Iridaceae	KwaZulu-Natal, Eastern Cape, Free State	Grows in summer on rocky outcrops, scree slopes and other exposed habitats in dry spots that are seasonally wet	Lesotho Highland Basalt Grassland (Gd 8)	to 2745	3.3	Silverhill
Kniphofia ritualis	Asphodeliaceae	KwaZulu-Natal, Eastern Cape, Free State	Wet mountain slopes, shallow soil on rock.	uKhahlamba Basalt Grassland (Gd 7)	to 3100	2.3	Silverhill
Kniphofia triangularis	Asphodeliaceae	Eastern Cape to KZN	Grassland, moist to wet.	Lesotho Highland Basalt Grassland (Gd 8)	1000 - 2000	2.1	Cultivated
Themeda triandra	Poaceae	Northern Cape, Eastern Cape, Western Cape, Free State, Mpumalanga, Limpopo	Widespread in grassland	Very widespread, many biomes	2 to 2500	5.6	Barkley East Eastern Cape
Watsonia galpinii	Iridaceae	Eastern Cape, Western Cape	Found in wet sites along streams		3000	4.7	Silverhill
Watsonia pillansii ex Bolus	Iridaceae	Eastern Western Cape to KZN	Open grassland and rocky slopes	Drakensberg Foothill Moist Grassland (Gs 10)	50 - 1800	6.1	Cultivated

Medium canopy species


Agapanthus inapertus


Berkheya purpurea


Diascia rigescens


Dierama mossii


Gladiolus saundersii


Kniphofia ritualis


Kniphofia triangularis


Watsonia galpinii


Watsonia pilliansii


Themeda triandra

Species	Family	Distribution	Habitat	Example of community type (from Mucina and Rutherford, 2006)	Altitudinal range in SA (m)	Seed weight (mg)	Origin of population used in study
Tall (>600 mm)							
Crinum macowanii	Amaryllidaceaea	KwaZulu-Natal, Mpumalanga	Hill slope, marsh/swamp/wetland, river/stream bank, mountain peak	Amthole Montane Grassland (Gd 1) but also other grassland habitats	200 to 1650		Silverhill
Crocosmia masoniorum	Iridaceae	Engcobo district, Eastern Cape.	Shaded, wet rock ledges and faces	Drakensberg Foothill Moist Grassland (Gs 10)	>1000	2.7	Cultivated, Jelitto
Dierama pulcherrimum	Iridaceae	Eastern Cape	Grassland, moist	Amthole Montane Grassland (Gd 1)	900 - 1700	13.7	Cultivated, Jelitto
Galtonia candicans	Hyacinthaceae	Eastern Cape to Mpumalanga	Grassland and margins of scrub, moist	Eastern Free State Sandy Grassland (Gm 4)	1350 - 2150	7.2	Cultivated, Jelitto
Gladiolus geardii	Iridaceae		Moist sandstone slopes	Fynbos-grassland transitions		2.5	B &T seeds
Gladiolus dalenii	Iridaceae	Kwazulu-Natal, Free state, Limpopo, Gauteng, Eastern Cape	Open grassland, woodland and scrub and in rocky areas, often among rocks along streams,	uKhahlamba Basalt Grassland (Gd 7)	5 to 2600	5.3	various
Gladiolus oppositiflorus	Iridaceae	Eastern Cape	Open grassland and rocky slopes	Southern Drakensberg Highland Grassland (Gd 4)	100 - 2500	10.0	Silverhill, unknown
Gladiolus papilio	Iridaceae	Eastern Cape Northwards	Moist grassland, seeps and marshes	Eastern Free State Sandy Grassland (Gm 4)	300 – 2500	5.1	Cultivated
Kniphofia uvaria	Asphodeliaceae	Eastern Cape, Western Cape	Seeps, marshes and streams on sandstone slopes	Very widespread, both in dry and wet sites	15 to 2285	1.4	Thomas River Eastern Cape
Moraea spathulata	Iridaceae	Eastern Cape, KwaZulu Natal, Mpumalanga, Free State	Grows in open grassland/at edge of forest/thickets/ Often among rocks	Amathole montane grassland (Gd 1) but also other grassland biomes	30 to 2745	4.0	Silverhill

Tall canopy species


Crinum macowanii


Crocosmia masonoirum


Dierama pulcherrimum


Galtonia candicans


Gladiolus dalenii


Gladiolus geardii


Gladiolus oppositiflorus


Gladiolus papilio ruby

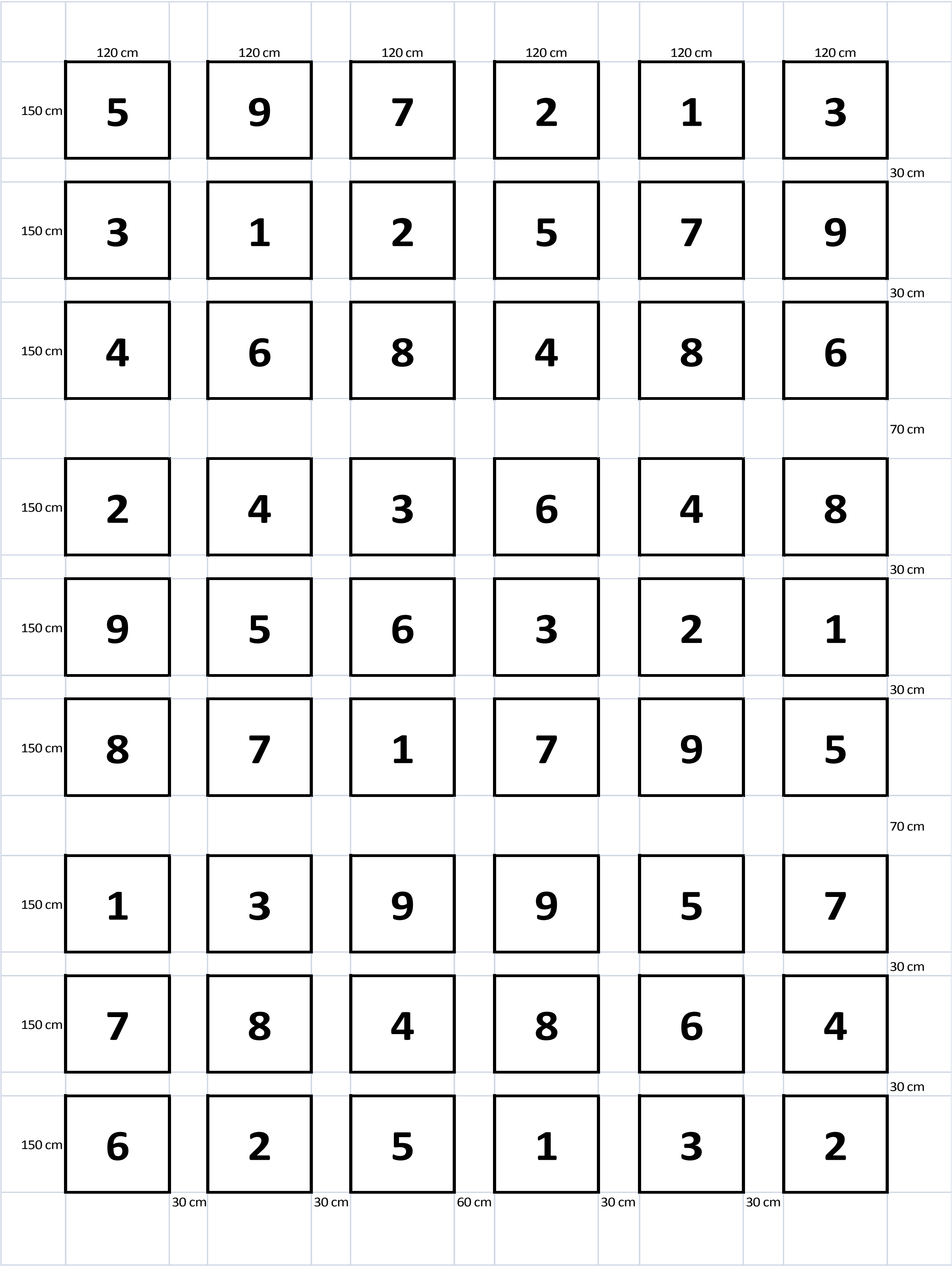

Kniphofia uvaria


Moraea spathulata

5.2 Materials and methods

This experiment was conducted on a research plot in the nursery at Sheffield Botanical Garden (53.3720° N, 1.4981° W), Sheffield, United Kingdom. During site preparation in February 2011, the soil surface was cultivated to a depth of 150 mm to 300 mm using a Kubota mechanical soil cultivator. The soil surface then levelled manually using garden rakes. Weeds and other vegetation in the plots were sprayed prior to cultivation using a glyphosate herbicide and in some cases removed manually.

The experimental layout involved a factorial block experiment with 6 main blocks subdivided into 9 subplots (54 subplots in total). Each block represented a replicate (6) and the 9 subplots represented treatments. The non completely random, directed blocking approached used in this experiment was based on statistical advice to reduce shade effects from the tree and hedges near the plots. This was achieved by having all of the 9 treatments present in each row parallel with the hedge. Illustrative layout of the experiment is shown in the figure 5.1 below: Each subplot was surrounded by a wood edging board (100 x 25mm tanalised timber) and the cross paths between plots were covered by Sarlon Weed mat to provide easy access and control of weeds. Sharp sand was used as a 75mm deep sowing mulch to prevent weed seed germination from within the underlying soil from competing with sown seedlings. Sand spreading was completed ready for sowing in April 2011.



5	9	7	2	1	3
3	1	2	5	7	9
4	6	8	4	8	6
2	4	3	6	4	8
9	5	6	3	2	1
8	7	1	7	9	5
1	3	9	9	5	7
7	8	4	8	6	4
6	2	5	1	3	2

Figure 5.1 Arrangement of plots in the competition experiment. Numbers represent community types from 1 to 9.

The overall target density of seedlings 1m^2 was 100 plants. This is the total of all seedlings present and was chosen as a compromise between not requiring too much seed and not having very small numbers of individuals of individual species when a species is present at a very low ratio overall. For example in community 4 (Table 5.2), low species are present at 14.25% of the target plant density per m^2, and given that there are 10 species in each canopy height grouping this means the target density allows for 1 plant of each low species. If the sowing target was say 50, this would not be possible (Table 5.3).

The seeds for each treatment sub-plot was mixed with a compost sowing carrier to obtain uniform seed distribution and to easily identify that the distribution was indeed uniform from the different colour of compost and sand sowing mulch. Raking was used to distribute the seeds evenly into the sowing mulch. Wire mesh was placed on the top of each plot to avoid seedbed surface digging by foxes at night. Slug and snail poison with active ingredient metaldehyde was used with the rate is about 40 pellets/m^2 every two weeks until the end of May to reduce the risk of seedling loss from this source prior to the first seedling count. Where no significant rain (>8mm) occurred within a 4 day period, plots were irrigated at 2 days intervals to return the sand to field capacity. Weeding in each plots was done manually especially at the early stage of seed emergence as sand sometimes contains weed weeds. Further monitoring was done around the plots once a month to prevent slug and snail damage in humid weather conditions.

Seed sowing was completed on 14th April 2011. 60 days post sowing, counting of seedling emergence was initiated to determine the number of seedlings in a permanent quadrat (size 80 cm x 120 cm) in the centre of each treatment subplot. As the number of seedlings actually present post sowing is dependent on what germinates and emerges, a sufficient number of seedlings for each treatment combination to meet the individual species target needed to be identified. Species that had more seedlings than target were thinned post count and species that had insufficient had seedlings added to the plots (Table 5.4). Because seed supply was limited some species (*Diascia rigescens*, *Gladiolus saundersii*, *Gladiolus oppositiflorus* and *Crocosmia masonoirum*) were planted using vegetative plant in September 2011.

Table 5.2 Proportion of tall, medium and low species in the community types used in this experiment

Community	Community composition by foliage height group
Community 1	Tall: 100%, Medium 0%, Low: 0%
Community 2	Tall:0%, Medium: 100%, Low: 0%
Community 3	Tall:0%, Medium: 0%, Low: 100%
Community 4	Tall: 57%, Medium 28.5%, Low: 14.25%
Community 5	Tall: 14.25%, Medium 57%, Low: 28.5%
Community 6	Tall: 28.5%, Medium 14.25%, Low: 57%
Community 7	Tall: 33%, Medium 0%, Low: 66%
Community 8	Tall: 33%, Medium 66%, Low: 0%
Community 9	Tall: 0%, Medium 33%, Low: 66%

Table 5.3 Actual seed sown (g) for each species per treatment community in each plot (1.8m^2)

Species	Number of seeds/g	Approximately seed weight sown/1.8 m^2																	
		T1 (100%T)		T2 (100%M)		T3 (100%L)		T4 (57%T:28.5%M: 14.25%L)		T5 (14.25%T:57%M: 28.5%L)		T6 (28.5%T:14.25%M :57%L)		T7 (33%T:66%L)		T8 (33%T:66%M)		T9 (33%M:66%L)	
		S/P	MF	S/P	MF	S/P	MF	S/P	MF	S/P	MF	S/P	MF	S/P	MF	S/P	MF	S/P	MF
Low canopy (L)																			
Diascia integerrima	7142					0.005	(1)	0.0004	(3)	0.001	(2.7)	0.003	(2)	0.005	(1.5)			0.005	(1.5)
Diascia tugelensis	5714					0.011	(1)	0.0009	(3)	0.003	(2.7)	0.006	(2)	0.011	(1.5)			0.011	(1.5)
Geum capense	288					0.114	(1)	0.0095	(3)	0.032	(2.7)	0.063	(2)	0.114	(1.5)			0.114	(1.5)
Gazania lineris	645					0.051	(1)	0.0042	(3)	0.014	(2.7)	0.028	(2)	0.051	(1.5)			0.051	(1.5)
Haplocarpha lyrata	3846					0.019	(1)	0.0016	(3)	0.005	(2.7)	0.010	(2)	0.019	(1.5)			0.019	(1.5)
Helichrysum aureum	4211					0.021	(1)	0.0018	(3)	0.006	(2.7)	0.012	(2)	0.021	(1.5)			0.021	(1.5)
Merwilla plumbea	238					0.252	(1)	0.0210	(3)	0.070	(2.7)	0.140	(2)	0.252	(1.5)			0.252	(1.5)
Kniphofia hirsuta	308					0.130	(1)	0.0108	(3)	0.036	(2.7)	0.072	(2)	0.130	(1.5)			0.130	(1.5)
Tritonia drakensbergensis	250					0.180	(1)	0.0150	(3)	0.050	(2.7)	0.100	(2)	0.180	(1.5)			0.180	(1.5)
Eucomis bicolor																			
Medium canopy (M)																			
Berkheya purpurea	263			0.137	(1)			0.029	(2.7)	0.076	(2)	0.023	(3)			0.137	(1.5)	0.137	(2.5)
Diascia rigescens	1379			0.033	(1)			0.007	(2.7)	0.018	(2)	0.005	(3)			0.033	(1.5)	0.033	(2.5)
Dierama mossii	101			0.255	(1)			0.053	(2.7)	0.141	(2)	0.042	(3)			0.255	(1.5)	0.255	(2.5)
Themeda triandra	180			0.167	(1)			0.060	(2.7)	0.159	(2)	0.048	(3)			0.286	(1.5)	0.286	(2.5)
Kniphofia triangularis	476			0.084	(1)			0.018	(2.7)	0.047	(2)	0.014	(3)			0.084	(1.5)	0.084	(2.5)
Gladiolus saundersii	302			0.149	(1)			0.031	(2.7)	0.083	(2)	0.025	(3)			0.149	(1.5)	0.149	(2.5)
Kniphofia ritualis/albomontana																			
Agapanthus inapertus	241			0.249	(1)			0.052	(2.7)	0.138	(2)	0.041	(3)			0.249	(1.5)	0.249	(2.5)
Watsonia pillansii ex wisley	163			0.276	(1)			0.058	(2.7)	0.153	(2)	0.046	(3)			0.276	(1.5)	0.276	(2.5)
Watsonia galpinii	215			0.209	(1)			0.044	(2.7)	0.116	(2)	0.035	(3)			0.209	(1.5)	0.209	(2.5)
Tall canopy (T)																			
Crinum macowanii																			
Crocosmia masoniorum																			
Dierama pulcherrimum	73	0.616	(1)					0.381	(2)	0.103	(3)	0.171	(2.7)	0.616	(2.5)	0.616	(2.5)		
Galtonia candicans	139	0.185	(1)					0.114	(2)	0.031	(3)	0.051	(2.7)	0.185	(2.5)	0.185	(2.5)		
Gladiolus geardii	400	0.113	(1)					0.069	(2)	0.019	(3)	0.031	(2.7)	0.113	(2.5)	0.113	(2.5)		
Gladiolus dalenii	187	0.193	(1)					0.119	(2)	0.032	(3)	0.053	(2.7)	0.193	(2.5)	0.193	(2.5)		
Gladiolus oppositiflorus	100	0.360	(1)					0.222	(2)	0.060	(3)	0.100	(2.7)	0.360	(2.5)	0.360	(2.5)		
Gladiolus papilio ruby	198	0.260	(1)					0.160	(2)	0.043	(3)	0.072	(2.7)	0.260	(2.5)	0.260	(2.5)		
Kniphofia uvaria	714	0.126	(1)					0.078	(2)	0.021	(3)	0.035	(2.7)	0.126	(2.5)	0.126	(2.5)		
Morea spathulata	250	0.240	(1)					0.148	(2)	0.040	(3)	0.067	(2.7)	0.240	(2.5)	0.240	(2.5)		

S/P= seed weight (g)/plot; MF=Multiplier factor (as shown in brackets), Multiflier factor used to increase the number of seeds sown to avoid species that have a low ratio does not reach the target species per quadrate when sown. High percentage of species will be multiplied by the smallest multiples; eg. community 4 Tall 57% multiplied by 2, Medium 28.5% (2.7) and Low 14.25% (3)

Table 5.4 Actual seedling target number for each species per 1.0m^2 quadrat

Species	Ratio in 1m^2	Targeted seedling per quadrate /1.0 m^2																	
		T1 (100%T)		T2 (100%M)		T3 (100%L)		T4 (57%T:28.5%M: 14.25%L)		T5 (14.25%T:57%M: 28.5%L)		T6 (28.5%T:14.25%M :57%L)		T7 (33%T:66%L)		T8 (33%T:66%M)		T9 (33%M:66%L)	
		SP	TS	SP	TS	SP	TS	SP	TS	SP	TS	SP	TS	SP	TS	SP	TS	SP	TS
Low canopy (L)																			
Diascia integerrima	10					4	(7)	4	(2)	10	(3)	6	(4)	2	(5)			9	(5)
Diascia tugelensis	10					4	(7)	3	(2)	3	(3)	0	(4)	7	(5)			6	(5)
Geum capense	10					8	(7)	4	(2)	7	(3)	7	(4)	5	(5)			6	(5)
Gazania lineris	10					3	(7)	1	(2)	4	(3)	9	(4)	7	(5)			4	(5)
Haplocarpha lyrata	10					1	(7)	1	(2)	3	(3)	2	(4)	1	(5)			2	(5)
Helichrysum aureum	10					7	(7)	14	(2)	17	(3)	12	(4)	18	(5)			18	(5)
Merwilla plumbea	10					8	(7)	7	(2)	9	(3)	5	(4)	4	(5)			5	(5)
Kniphofia hirsuta	10					10	(7)	5	(2)	6	(3)	8	(4)	6	(5)			6	(5)
Tritonia drakensbergensis	10					12	(7)	13	(2)	10	(3)	13	(4)	7	(5)			14	(5)
Eucomis bicolor	10					7	(7)	7	(2)	3	(3)	4	(4)	5	(5)			5	(5)
Medium canopy (M)																			
Berkheya purpurea	10			2	(7)			3	(3)	9	(4)	2	(2)			6	(5)	6	(3)
Diascia rigescens	10			4	(7)			3	(3)	3	(4)	1	(2)			4	(5)	3	(3)
Dierama mossii	10			8	(7)			8	(3)	11	(4)	6	(2)			8	(5)	8	(3)
Themeda triandra	10			14	(7)			11	(3)	16	(4)	10	(2)			19	(5)	12	(3)
Kniphofia triangularis	10			10	(7)			12	(3)	14	(4)	14	(2)			16	(5)	6	(3)
Gladiolus saundersii	10			7	(7)			3	(3)	4	(4)	2	(2)			5	(5)	5	(3)
Kniphofia ritualis/albomontana	10			7	(7)			3	(3)	4	(4)	2	(2)			5	(5)	5	(3)
Agapanthus inapertus	10			10	(7)			10	(3)	11	(4)	6	(2)			12	(5)	7	(3)
Watsonia pillansii ex wisley	10			11	(7)			9	(3)	9	(4)	7	(2)			8	(5)	8	(3)
Watsonia galpinii	10			8	(7)			12	(3)	7	(4)	12	(2)			10	(5)	7	(3)
Tall canopy (T)																			
Crinum macowanii	10	7	(7)					4	(4)	2	(2)	3	(3)	3	(3)	3	(3)		
Crocosmia masoniorum	10	7	(7)					4	(4)	2	(2)	3	(3)	3	(3)	3	(3)		
Dierama pulcherrimum	10	12	(7)					12	(4)	5	(2)	6	(3)	7	(3)	6	(3)		
Galtonia candicans	10	8	(7)					8	(4)	6	(2)	4	(3)	8	(3)	9	(3)		
Gladiolus geardii	10	11	(7)					5	(4)	3	(2)	4	(3)	5	(3)	4	(3)		
Gladiolus dalenii	10	7	(7)					5	(4)	3	(2)	4	(3)	5	(3)	4	(3)		
Gladiolus oppositiflorus	10	7	(7)					6	(4)	3	(2)	4	(3)	5	(3)	4	(3)		
Gladiolus papilio ruby	10	7	(7)					5	(4)	3	(2)	4	(3)	5	(3)	4	(3)		
Kniphofia uvaria	10	17	(7)					12	(4)	8	(2)	11	(3)	10	(3)	7	(3)		
Morea spathulata	10	24	(7)					10	(4)	10	(2)	11	(3)	14	(3)	8	(3)		

SP= number of seedling present/species; TS=Target number of seedling-as shown in brackets.

The whole experiment was covered with two layers of fleece during winter 2011/2012 in order to minimise the risk of mortality and decrease the number of species present in the communities (Figure 5.3). Tiny Tag recording probes were installed to monitor minimum temperature beneath the fleece. The fleece was taken off on 13th March 2012 at the end of winter. All plant were cut to 50 mm aboveground using hedge trimmer at the early spring (3rd April 2012) to make all species at the same level in competition in terms of above ground photosynthetic tissue at the beginning of second growing season. An overall view of the experimental plots in shown in Figure (5.2)

Figure 5.2 Experimental plots at the Sheffield Botanical Garden, Sheffield, United Kingdom; (a) Compost was mixed with seeds as a carrier, (b) Overall views of treatment plots after sowing

Figure 5.3 The experimental plots covered by fleece in winter 2011/2012

5.2.1 Data collection

A permanent quadrat (1200 x 800mm) was established for data collection within each treatment plot. Within each quadrat, seedling numbers for emergence cover value and biomass data were collected. The numbers of seedlings of each species in each quadrat was counted in June 2011 (60 days after sowing). Cover values were taken from August 2011 until October 2011 at approximately two weeks intervals. In the second growing season (2012) cover values were estimated from April 2012 until June 2012 to make a comparison with the first growing season. Flowering and reproductive phenology was recorded for all species in the second season (2012). Photographs of the experiment were taken from the same position and angle throughout the year.

At the end of second growing season (October 2012), all plants in quadrats were harvested by cutting at ground level with scissors. Each species above ground biomass was carefully placed into coded envelopes (one plant per envelope) and dried it at an ambient temperature in a sealed glasshouse before being transferred into the laboratory oven. The envelopes were placed in the oven at 70^0C for 2 days until the samples were completely dry. Samples were weighed using a digital balance and the numbers of samples were used as count data for the number of plants present in quadrat.

5.2.2 Statistical analysis

Following extensive discussions with a statistician at the University of Sheffield, ANOVA analysis was chosen as the method to apply to all of the data. Specialised modelling was considered too tricky to interpret for this data. Secondly transformations such as a square root or log were considered as alternatives but on the whole they caused as many problems as they solved with the data. Where there were few plants p/a modelling was considered but this did not prove any better than the straight forward ANOVA. Non-parametric approaches were not considered as it does not allow adjustment for the different original number of plants sown or planted.

5.3 Results

5.3.1 Field emergence of South African species 60 days post sowing

Table 5.5 shows approximately 80% of species tested did not show any significant differences in the percentage of field emergence across the 9 different communities within the experiment. Only 8 species showed a significant difference between communities; *Haplocarpha scaposa*, *Helichrysum aureum, Gazania linearis* and *Diascia integerrima, Dierama mossii, Watsonia spp., Dierama pulcherrimum* and *Kniphofia uvaria. Galtonia candicans* showed the highest emergence of all sown species (55.02%); *Haplocarpha scaposa* showed the lowest emergence of 4.6%.

Medium canopy species typically showed high emergence compared to others canopy groups, with most of the species achieving >20% mean emergence across communities. Emergence values for *Watsonia* and *Gladiolus* are the mean for each genus, due to the difficulty of distinguishing the species at the seedlings stage.

Table 5.5 Percentage field emergence of South African grassland species across different community 60 days post sowing in 2011

Species	Percentage of emergence (%) Community 1	2	3	4	5	6	7	8	9	Mean	P-value
Low											
Diascia integerrima			46.75^{a}	23.00^{b}	28.4^{b}	22.5^{b}	25.00^{b}		27.31^{b}	28.83	0.003 **
Diascia tugelensis			9.72^{a}	21.00^{a}	14.07^{a}	10.00^{a}	13.89^{a}		16.67^{a}	14.23	0.101 ns
Geum capense			30.05^{a}	32.00^{a}	31.91^{a}	24.29^{a}	23.94^{a}		24.44^{a}	27.77	0.399 ns
Gazania linearis			9.17^{c}	12.00^{bc}	25.12^{ab}	27.50^{a}	30.56^{a}		28.01^{a}	22.06	0.0001 **
Haplocarpha scaposa			5.32^{ab}	3.21^{b}	7.10^{a}	4.58^{ab}	3.94^{ab}		3.47^{ab}	4.60	0.034 *
Helichrysum aureum			27.03^{ab}	38.00^{a}	24.20^{ab}	19.17^{b}	19.63^{b}		20.74^{b}	24.80	0.002 **
Merwilla plumbea			9.72^{a}	24.00^{a}	21.84^{a}	20.93^{a}	18.38^{a}		20.94^{a}	19.30	0.115 ns
Kniphofia hirsuta			42.50^{a}	38.00^{a}	25.59^{a}	26.53^{a}	33.75^{a}		24.43^{a}	31.80	0.067 ns
Tritonia drakensbergensis			46.67^{a}	57.00^{a}	37.04^{a}	30.00^{a}	35.19^{a}		33.70^{a}	39.93	0.056 ns
Medium											
Berkheya purpurea		26.39^{a}		20.00^{a}	27.92^{a}	20.37^{a}		25.50^{a}	25.56^{a}	24.29	0.367 ns
Diascia rigescens		18.75^{a}		33.00^{a}	24.07^{a}	35.42^{a}		21.90^{a}	24.36^{a}	26.25	0.112 ns
Dierama mossii		40.19^{ab}		62.00^{a}	27.42^{b}	47.96^{ab}		40.83^{ab}	29.56^{b}	41.33	0.001 **
Themeda triandra		48.88^{a}		49.00^{a}	42.88^{a}	44.07^{a}		38.56^{a}	36.17^{a}	43.26	0.054 ns
Kniphofia triangularis		32.92^{a}		30.00^{a}	48.39^{a}	29.53^{a}		33.79^{a}	22.80^{a}	32.91	0.490 ns
Agapanthus inapertus		36.94^{a}		37.00^{a}	28.75^{a}	26.67^{a}		27.60^{a}	29.33^{a}	31.05	0.203 ns
$^{\#}$*Watsonia spp.* (*W. pilliansii, W. galpinii*)		38.33^{a}		33.00^{ab}	25.00^{ab}	33.7^{ab}		22.52^{b}	22.44^{b}	29.17	0.006 **
Tall											
Dierama pulcherrimum	42.59^{a}			23.00^{a}	37.78^{a}	20.67^{a}	42.22^{a}	22.22^{a}		31.41	0.046 *
Galtonia candicans	58.97^{a}			58.00^{a}	62.22^{a}	44.33^{a}	49.00^{a}	57.60^{a}		55.02	0.163 ns
$^{\#}$*Gladiolus spp.* (*G. geardii, G. dalenii, G. Papilio, G. Oppositiflorus*)	36.60^{a}			27.00^{a}	37.76^{a}	35.19^{a}	32.10^{a}	32.30^{a}		33.49	0.826 ns
Kniphofia uvaria	25.74^{a}			12.00^{b}	17.78^{ab}	20.63^{ab}	15.11^{ab}	10.80^{b}		17.01	0.018 *
Morea spathulata	41.95^{a}			41.00^{a}	45.56^{a}	33.50^{a}	43.00^{a}	38.00^{a}		40.50	0.684 ns

$^{\#}$It was not possible to really distinguish between seedlings of these species-hence estimated are `pooled ‘

5.3.2 Mortality in 2012 of individual species across communities

As shown in a Table 5.6, mean seedling mortality of individual species varied substantially between species, but only one species (*Gladiolus geardii;* Tukey HSD ($p<0.05$)) showed significant differences in mortality across the communities. The species with the highest mortality were in declining order (*Galtonia candicans*, *Crinum macowanii*, *Gladiolus geardii, Gladiolus saundersii, Diascia integerrima* and *Gladiolus papilio*). The species with the lowest mortality were in ascending order (*Dierama mossii*, *Watsonia spp* and *Kniphofia uvaria*).

Table 5.6 Effect of community on individual species mortality in 2012. Values represent individuals present in 2012 as a percentage of those present at the final count in 2011.

Percentage of mortality (%)

Species	**Community**									Mean	P-value
	1	2	3	4	5	6	7	8	9		
Low canopy											
Diascia integerrima			41.11 a	16.67 a	44.44 a	61.11 a	83.33 a		50.00 a	49.44	0.159 ^{ns}
Diascia tugelensis			7.5 a	0.00 a	8.33 a	0.00 a	10.00 a		4.17 a	5.00	0.519 ^{ns}
Geum capense			3.33 a	0.00 a	0.00 a	0.00 a	16.67 a		9.72 a	4.95	0.152 ^{ns}
Gazania lineris			11.9 a	0.00 a	0.00 a	5.56 a	16.67 a		16.67 a	8.47	0.780 ^{ns}
Haplocarpha lyrata			0.00 a	0.00 a	8.33 a	0.00 a	19.44 a		0.00 a	4.63	0.165 ^{ns}
Helichrysum aureum			4.17 a	0.00 a	0.00 a	4.17 a	5.56 a		18.33 a	5.37	0.074 ^{ns}
Merwilla plumbea			8.33 a	0.00 a	8.33 a	0.00 a	0.00 a		25.00 a	6.94	0.281 ^{ns}
Kniphofia hirsuta			0.00 a	0.00 a	0.00 a	0.00 a	4.17 a		8.33 a	2.08	0.532 ^{ns}
Tritonia drakensbergensis			0.00 a	16.67 a	11.11 a	0.00 a	0.00 a		0.00 a	4.63	0.254 ^{ns}
Eucomis bicolor			17.78 a	16.67 a	0.00 a	8.33 a	0.00 a		22.22 a	10.83	0.615 ^{ns}
Medium canopy											
Berkheya purpurea		0.00 a		11.11 a	4.17 a	16.67 a		3.33 a	0.00 a	5.88	0.685 ^{ns}
Diascia rigescens		11.11 a		22.22 a	16.67 a	16.67 a		3.33 a	0.00 a	11.67	0.784 ^{ns}
Dierama mossii		2.78 a		0.00 a	0.00 a	0.00 a		0.00 a	0.00 a	0.46	0.435 ^{ns}
Themeda triandra		5.56 a		5.56 a	0.00 a	25.00 a		3.33 a	0.00 a	6.58	0.238 ^{ns}
Kniphofia triangularis		25.20 a		5.56 a	22.22 a	41.67 a		19.17 a	11.11 a	20.82	0.548 ^{ns}
Gladiolus saundersii		70.83 a		44.44 a	33.33 a	41.67 a		47.22 a	69.44 a	51.16	0.460 ^{ns}
Kniphofia ritualis		10.71 a		16.67 a	18.06 a	25.00 a		13.53 a	7.63 a	15.27	0.854 ^{ns}
Agapanthus inapertus		0.00 a		8.33 a	0.00 a	0.00 a		0.00 a	0.00 a	1.39	0.435 ^{ns}
Watsonia pillansii & *galpinii*		5.04 a		0.00 a	0.00 a	0.00 a		0.00 a	0.00 a	0.84	0.151 ^{ns}
Tall canopy											
Crinum macowanii	54.17 a			94.44 a	58.33 a	66.67 a	91.67 a	83.33 a		74.77	0.202 ^{ns}
Crocosmia masoniorum	0.00 a			16.67 a	8.33 a	0.00 a	0.00 a	0.00 a		4.17	0.230 ^{ns}
Dierama pulcherrimum	16.67 a			0.00 a	0.00 a	0.00 a	0.00 a	0.00 a		2.78	0.435 ^{ns}
Galtonia candicans	50.99 a			70.83 a	75.00 a	88.89 a	88.89 a	88.89 a		77.25	0.158 ^{ns}
Gladiolus geardii	12.50 b			60.00 ab	83.33 a	88.88 a	30.55 b	25.00 b		50.04	0.0001 **
Gladiolus dalenii	13.33 a			17.50 a	13.38 a	16.67 a	16.67 a	33.33 a		18.48	0.847 ^{ns}
Gladiolus oppositiflorus	17.78 a			41.67 a	16.67 a	66.67 a	47.22 a	41.67 a		38.61	0.248 ^{ns}
Gladiolus papilio ruby	29.17 a			56.94 a	58.33 a	44.44 a	38.89 a	47.22 a		45.83	0.544 ^{ns}
Kniphofia uvaria	0.00 a			0.00 a	0.00 a	0.00 a	0.00 a	0.00 a		0.00	0.00 ^{ns}
Morea spathulata	4.76 a			8.33 a	8.33 a	11.11 a	25.00 a	11.11 a		11.44	0.870 ^{ns}

5.3.3 Cover value of all communities in 2011 and 2012.

Foliage cover value (for all species) was recorded from August 2011 until October 2011 at two weeks intervals. The Tukey HSD ANOVA analysis shown in Table 5.7 showed highly significant differences in cover values between communities, although very often this was restricted to Community 1 versus the rest only. Cover values in Community 1 (100% tall foliage) was much lower throughout, and only reached 39.50% cover value at the end of observation period in 2011 whilst the rest of the communities showed >80% of cover value.

In a year 2 after the spring maintenance cutting, shows a different trend of cover value between communities. Community 6 in May and community 7 in April have the highest cover values at this date. However, at the end of May and early June 2012 the cover values are only significantly different between Community 1 and all of the other communities.

5.3.4 Days to reach 50% cover in 2011 and in 2012.

Figure 5.4 shows 50% cover value was not achieved in both 2011 and 2012 in the tall community (Community 1). With the exception of Community 1, cover value closure rates were similar for all communities, as might be expected given the sharing of many of the low and medium canopy species in these communities (Figure 5.4). Most of the communities reached the 50% cover value faster in the second years (within approximately 50 days after spring cutting)(Figure 5.4).

Table 5.7 Cover value of all communities in 2011 and in 2012

Plant canopy propotion	% Cover value							
	Year 1				Year 2			
	25/08/2011	15/09/2011	30/09/2011	18/10/2011	28/04/2012	18/05/2012	29/05/2012	10/06/2012
Community 1: Tall: 100%, Medium 0%, Low: 0%	7.33 ^{b}	18.83 ^{b}	37.32 ^{b}	39.50 ^{b}	8.86 ^{c}	14.21 ^{c}	21.91 ^{b}	31.86 ^{b}
Community 2: Tall:0%, Medium: 100%, Low: 0%	50.66 ^{a}	77.17 ^{a}	87.02 ^{a}	84.57 ^{a}	16.56 ^{bc}	24.96 ^{bc}	50.31 ^{a}	70.80 ^{a}
Community 3: Tall:0%, Medium: 0%, Low: 100%	63.50 ^{a}	82.08 ^{a}	89.63 ^{a}	85.97 ^{a}	26.44 ^{ab}	36.18 ^{ab}	53.04 ^{a}	68.19 ^{a}
Community 4: Tall: 57%, Medium 28.5%, Low: 14.25%	39.00 ^{a}	75.31 ^{a}	84.88 ^{a}	86.72 ^{a}	23.76 ^{ab}	36.74 ^{ab}	57.28 ^{a}	73.83 ^{a}
Community 5: Tall: 14.25%, Medium 57%, Low: 28.5%	51.83 ^{a}	77.93 ^{a}	86.57 ^{a}	88.58 ^{a}	25.06 ^{ab}	33.50 ^{ab}	56.85 ^{a}	75.97 ^{a}
Community 6: Tall: 28.5%, Medium 14.25%, Low: 57%	60.83 ^{a}	84.38 ^{a}	91.52 ^{a}	92.70 ^{a}	29.49 ^{ab}	43.05 ^{a}	67.86 ^{a}	80.08 ^{a}
Community 7: Tall: 33%, Medium 0%, Low: 66%	53.50 ^{a}	75.75 ^{a}	86.12 ^{a}	84.87 ^{a}	31.47 ^{a}	39.15 ^{ab}	57.22 ^{a}	70.23 ^{a}
Community 8: Tall: 33%, Medium 66%, Low: 0%	42.00 ^{a}	74.07 ^{a}	83.35 ^{a}	86.72 ^{a}	18.13 ^{abc}	27.47 ^{abc}	52.83 ^{a}	71.85 ^{a}
Community 9: Tall: 0%, Medium 33%, Low: 66%	60.50 ^{a}	77.93 ^{a}	86.57 ^{a}	88.58 ^{a}	29.86 ^{ab}	41.98 ^{ab}	72.01 ^{a}	82.43 ^{a}
P values for cover value within column	0.0001**	0.0001**	0.0001**	0.0001**	0.0001**	0.0001**	0.0001**	0.0001**

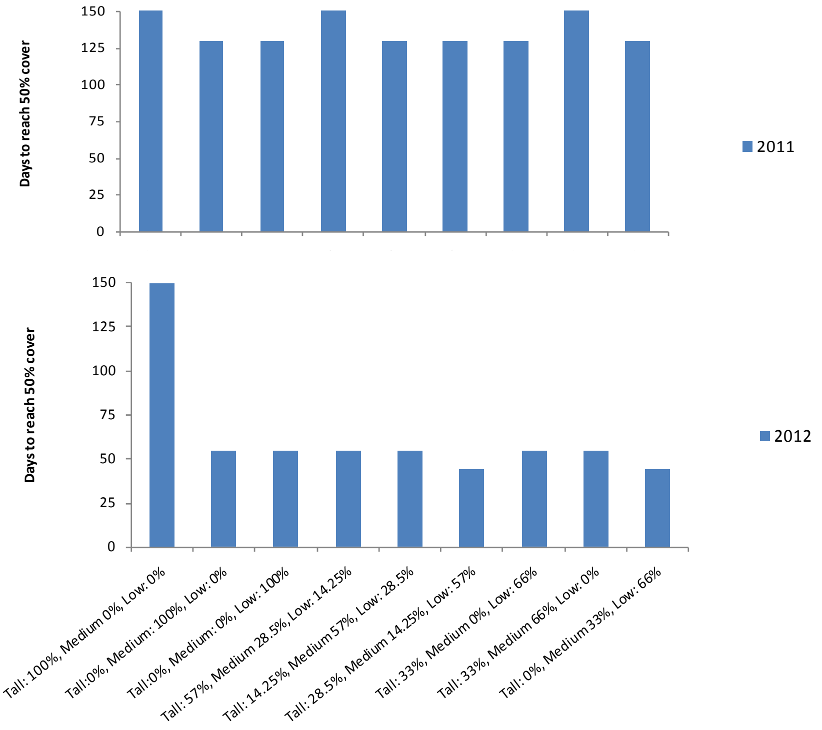


Figure 5.4 Days to reach 50% cover across all community recorded in 2011 and 2012.

5.3.4 Biomass of species across communities in 2012

5.3.4.1 Total biomass

Table 5.8 shows various effect of sowing seed of South African grassland in communities on total biomass. Six of the species namely *Diascia integerrima*, *Geum capense*, *Haplocarpha scaposa*, *Kniphofia hirsuta*, *Tritonia drakensbergensis* and *Eucomis bicolour* in a low canopy group showed a significant and highly significant difference across the different community where these species were present.

The results of multi comparison analysis on total biomass show that 60% of species from a medium canopy have significant and highly significant differences when species are sown in a different community. Other's species such as *Diascia rigescens*, *Dierama mossii* and *Gladiolus saundersii* did not show any significant differences in total biomass of each species between community.

Results in Table 5.8 also indicated that 70% species in a tall canopy group was significant and highly significant differences on total biomass across different communities.. Others species in a tall canopy group like *Crinum macowanii*, *Dierama pulcherrimum* and *Gladiolus papilio* does not show any significantly different across community.

Mean total biomass of all species shows that *Berkheya purpurea*, *Kniphofia uvaria* and *Themeda triandra* are the species most likely to produce higher mean total biomass compared to other species.

Table 5.8 Total biomass of individual species analysed across the experimental communities in September 2012

Total biomass for each species in communties (g)

Species	**Community**									Mean	**P-value**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		
Low											
Diascia integerrima			14.73 ^{a}	1.10 ^{b}	2.90 ^{b}	1.75 ^{b}	0.13 ^{b}		0.85 ^{b}	3.78	0.0001**
Diascia tugelensis			80.90 ^{a}	53.39 ^{a}	37.79 ^{a}	89.03 ^{a}	87.64 ^{a}		63.73 ^{a}	68.75	0.710ns
Geum capense			13.30 ^{a}	4.72 ^{b}	1.89 ^{b}	5.18 ^{b}	5.32 ^{b}		5.56 ^{b}	5.99	0.003**
Gazania linearis			20.81 ^{a}	11.03 ^{a}	22.58 ^{a}	43.95 ^{a}	60.59 ^{a}		56.02 ^{a}	35.83	0.359ns
Haplocarpha scaposa			112.03 ^{a}	9.35 ^{b}	73.68 ^{ab}	67.71 ^{ab}	37.15 ^{ab}		22.89 ^{b}	53.80	0.021*
Helichrysum aureum			10.87 ^{a}	41.56 ^{a}	36.59 ^{a}	111.34 ^{a}	24.90 ^{a}		53.42 ^{a}	46.45	0.064ns
Merwillia plumbea			0.06 ^{a}	0.03 ^{a}	0.04 ^{a}	0.04 ^{a}	0.09 ^{a}		0.06 ^{a}	0.05	0.770ns
Kniphofia hirsuta			33.66 ^{a}	9.48 ^{b}	6.37 ^{b}	28.65 ^{ab}	21.47 ^{ab}		9.83 ^{a}	18.24	0.004**
Tritonia drakensbergensis			11.32 ^{a}	1.88 ^{b}	2.06 ^{b}	2.91 ^{b}	2.94 ^{b}		2.29 ^{b}	3.90	0.002**
Eucomis bicolor			0.48 ^{ab}	0.13 ^{b}	0.16 ^{b}	0.19 ^{b}	0.63 ^{a}		0.22 ^{ab}	0.30	0.005**
Medium											
Berkheya purpurea		631.73 ^{a}		230.29 ^{ab}	278.74 ^{ab}	91.42 ^{b}		395.88 ^{ab}	199.89 ^{b}	304.65	0.011*
Diascia rigesens		47.93 ^{a}		20.06 ^{a}	10.23 ^{a}	15.49 ^{a}		9.76 ^{a}	14.14 ^{a}	19.60	0.420ns
Dierama mosii		6.17 ^{a}		10.46 ^{a}	7.14 ^{a}	2.55 ^{a}		8.84 ^{a}	4.55 ^{a}	6.62	0.258ns
Themeda triandra		166.12 ^{a}		120.10 ^{ab}	105.47 ^{ab}	33.46 ^{b}		160.08 ^{a}	92.19 ^{ab}	112.90	0.0001**
Kniphofia triangularis		8.43 ^{ab}		8.20 ^{ab}	3.55 ^{b}	2.36 ^{b}		13.45 ^{a}	7.76 ^{ab}	7.29	0.032*
Gladiolus saundersii		0.19 ^{a}		0.29 ^{a}	0.30 ^{a}	0.08 ^{a}		0.40 ^{a}	0.05 ^{a}	0.22	0.172ns
Kniphofia ritualis		40.66 ^{a}		7.79 ^{b}	12.83 ^{ab}	15.45 ^{ab}		13.53 ^{ab}	7.63 ^{b}	16.32	0.042*
Agapanthus inapertus		0.57 ^{a}		0.13 ^{b}	0.29 ^{ab}	0.12 ^{b}		0.29 ^{ab}	0.19 ^{ab}	0.27	0.041*
Watsonia spp (Watsonia pilliansii &Watsonia galpinii)		24.99 ^{b}		14.23 ^{ab}	13.11 ^{ab}	6.97 ^{b}		16.05 ^{ab}	11.44 ^{ab}	14.47	0.013*
Tall											
Crinum macowanii	0.48 ^{a}			0.09 ^{a}	0.15 ^{a}	0.45 ^{a}	0.08 ^{a}	0.02 ^{a}		0.21	0.205ns
Crocosmia masonoirum	10.49 ^{a}			2.89 ^{a}	2.19 ^{b}	2.71 ^{b}	1.86 ^{b}	2.48 ^{b}		3.77	0.0001**
Dierama pulcherrimum	9.12 ^{a}			13.00 ^{a}	4.09 ^{a}	6.81 ^{a}	10.56 ^{a}	8.17 ^{a}		8.63	0.357ns
Galtonia candican	21.36 ^{a}			4.18 ^{b}	4.35 ^{b}	1.18 ^{b}	1.29 ^{b}	1.65 ^{b}		5.67	0.0001**
Gladiolus geardii	2.41 ^{a}			0.65 ^{ab}	0.13 ^{b}	0.05 ^{b}	1.23 ^{ab}	1.44 ^{ab}		0.99	0.014*
Gladiolus dalenii	13.78 ^{a}			9.10 ^{a}	6.29 ^{a}	5.48 ^{a}	14.02 ^{a}	8.93 ^{a}		9.60	0.872*
Gladiolus oppositiflorus	3.34 ^{a}			1.27 ^{ab}	1.10 ^{ab}	0.69 ^{b}	0.43 ^{b}	0.11 ^{b}		1.16	0.009**
Gladiolus papilio	1.56 ^{a}			1.32 ^{a}	1.49 ^{a}	1.22 ^{a}	0.53 ^{a}	0.59 ^{a}		1.12	0.932ns
Kniphofia uvaria	449.01 ^{a}			92.40 ^{b}	61.44 ^{b}	93.65 ^{b}	85.75 ^{b}	115.77 ^{b}		149.67	0.0001**
Morea spathulata	3.38 ^{a}			1.13 ^{b}	0.43 ^{b}	0.74 ^{b}	1.94 ^{ab}	0.68 ^{b}		1.38	0.002**

5.3.4.2 Effect of different communities and number of species present on species biomass

There are three different responses of species on the effect of different communities and number of species on mean biomass. Table 5.9 showed that species from low canopy layer, such as *Haplocarpha scaposa* (22.48g), *Helichrysum aureum* (17.87g) and *Diascia tugelensis* (16.80g) had the highest mean biomass when compare to other species at the same canopy height. All of these species shows dominant biomass production in this group. Meanwhile, other species such as *Merwillia plumbea* (0.03g) and *Eucomis bicolor* (0.08g) had a smallest mean biomass compared to other species. Only two species from the low canopy layer showed highly significant differences (P<0.01) when compared on mean biomass across communities. *Diascia integerrima* and *Tritonia drakensbergensis* show significantly different mean biomass across communities. The highest mean biomass produced by *Diascia integerrima* was in community 3 (5.90g) and the lowest in community 7 (0.13g)(tall and low mix). Both of the larger and smaller mean were very significant different across (P <0.01). Communities (4, 5, 6, 7 and 9) did not show any significant differences between them. *Tritonia drakensbergensis* also produced high biomass in community 3 (1.55g), not significantly different (P<0.05) to the biomass of this species in community 4 and 6. Meanwhile, community 3 had very significant difference (P <0.05) compared with community 7 and 9. The lowest mean biomass of this species was in Community 7.

In the medium canopy layer, the *Berkheya purpurea* and *Themeda triandra* are the two dominant species producing mean biomasses of 102.08g and 38.91g respectively in the community 2. Species such as *Diascia rigescens*, *Kniphofia ritualis*, *Watsonia* spp. (*W.pilliansii* and *W.galpinii*) and *Kniphofia triangularis* produced moderate mean biomass. *Gladiolus saundersii* and *Agapanthus inapertus* are two species that gave the lowest mean biomass in the second year after sowing. However, the mean biomass for all species in the medium canopy height did not show any significant differences between the community in which medium canopy species were represented (P <0.05) (Table 5.9).

In the tall canopy layer, two species showed a significant differences (P <0.05) between the different communities in which these species were represented. *Kniphofia uvaria* and

Galtonia candicans. *Kniphofia uvaria* showed the highest mean biomass (54.83g) in communities 1 and highly significantly different (P <0.01) compared with other communities. Community 4,5,6,7 and 8 do not show a significant difference between them. *Galtonia candicans* gave the highest mean biomass (9.74g) compared to other communities but was not significant differences with community 4, 5, 7 and 8. The lowest mean biomass of *Galtonia candicans* (0.58g) is shown in community 6 (Table 5.9). *Kniphofia uvaria* is the dominant species in this group with the highest average mean biomass of 25.43g (Table 5.9). Species that have the lowest mean biomass (<1.0g) in this group include *Crinum macowanii*, *Morea spathulata*, *Gladiolus geardii* and *Gladiolus papilio* (Table 5.9).

Table 5.9 Individual species biomass across the experimental communities

Total mean biomass for each species in communties (g)

Species	**Community**									Mean	**P-value**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		
Low											
Diascia integerrima			5.90 ^{a}	1.10 ^{b}	1.84 ^{b}	1.13 ^{b}	0.13 ^{b}		0.85 ^{b}	1.82	0.001**
Diascia tugelensis			15.16 ^{a}	19.97 ^{a}	12.32 ^{a}	21.17 ^{a}	19.34 ^{a}		12.85 ^{a}	16.80	0.792 ns
Geum capense			3.86 ^{a}	3.01 ^{a}	1.01 ^{a}	1.55 ^{a}	1.63 ^{a}		1.59 ^{a}	2.11	0.05 ns
Gazania linearis			6.09 ^{a}	5.51 ^{a}	7.22 ^{a}	18.15 ^{a}	10.10 ^{a}		11.81 ^{a}	9.81	0.61 ns
Haplocarpha scaposa			29.74 ^{a}	8.45 ^{a}	39.66 ^{a}	18.36 ^{a}	24.77 ^{a}		13.88 a	22.48	0.316 ns
Helichrysum aureum			21.05 ^{a}	20.78 ^{a}	18.48 ^{a}	26.36 ^{a}	5.94 ^{a}		14.61 ^{a}	17.87	0.147ns
Merwillia plumbea			0.02 ^{a}	0.03 ^{a}	0.026 ^{a}	0.03 ^{a}	0.028 ^{a}		0.02 ^{a}	0.03	0.994ns
Kniphofia hirsuta			4.56 ^{a}	3.71 ^{a}	1.82 ^{a}	5.02 ^{a}	3.29 ^{a}		2.21 ^{a}	3.44	0.095ns
Tritonia drakensbergensis			1.55 ^{a}	0.79 ^{ab}	0.64 ^{b}	0.79 ^{ab}	0.59 ^{b}		0.71 ^{b}	4.49	0.009**
Eucomis bicolor			0.12 ^{a}	0.10 ^{a}	0.15 ^{a}	0.07 ^{a}	0.14 ^{a}		0.08 ^{a}	0.11	0.472ns
Medium											
Berkheya purpurea		102.08 ^{a}		77.34 ^{a}	71.49 ^{a}	43.06 ^{a}		91.75 ^{a}	66.63 ^{a}	75.39	0.282 ns
Diascia rigesens		8.93 ^{a}		7.35 ^{a}	3.77 ^{a}	7.75 ^{a}		8.56 ^{a}	9.43 ^{a}	7.63	0.860ns
Dierama mosii		0.95 ^{a}		1.60 ^{a}	1.12 ^{a}	0.76 ^{a}		1.37 ^{a}	1.60 ^{a}	1.23	0.447ns
Themeda triandra		38.91 ^{a}		41.03 ^{a}	26.03 ^{a}	17.67 ^{a}		34.50 ^{a}	28.32 ^{a}	31.07	0.120 ns
Kniphofia triangularis		1.80 ^{a}		2.30 ^{a}	0.95 a	1.31 ^{a}		2.19 ^{a}	2.57 ^{a}	1.85	0.136 ns
Gladiolus saundersii		0.10 ^{a}		0.23 ^{a}	0.16 ^{a}	0.08 ^{a}		0.21 ^{a}	0.05 ^{a}	0.14	0.118ns
Kniphofia ritualis		6.81 ^{a}		2.97 ^{a}	5.03 ^{a}	12.50 ^{a}		5.06 ^{a}	3.16 ^{a}	5.92	0.583 ns
Agapanthus inapertus		0.08 ^{a}		0.04 a	0.05 ^{a}	0.05 ^{a}		0.05 ^{a}	0.04 ^{a}	0.05	0.170 ns
Watsonia spp (Watsonia pilliansii &Watsonia galpinii)		2.55 ^{a}		1.92 ^{a}	1.61 ^{a}	1.20 ^{a}		1.91 ^{a}	1.64 ^{a}	1.81	0.331 ns
Tall											
Crinum macowanii	0.20 ^{a}			0.09 ^{a}	0.15 ^{a}	0.35 ^{a}	0.08 ^{a}	0.02 ^{a}		0.15	0.552 ns
Crocosmia masonoirum	1.60 ^{a}			1.15 ^{a}	1.11 ^{a}	2.71 ^{a}	1.40 ^{a}	0.85 ^{a}		1.47	0.267 ns
Dierama pulcherrimum	1.95 ^{a}			2.20 ^{a}	1.89 ^{a}	2.30 ^{a}	2.47 ^{a}	2.00 ^{a}		2.14	0.952 ns
Galtonia candican	9.74 ^{a}			2.02 ^{ab}	4.35 ^{ab}	0.58 ^{b}	1.30 ^{ab}	1.65 ^{ab}		3.27	0.045*
Gladiolus geardii	0.51 ^{a}			0.28 ^{a}	0.13 ^{a}	0.05 ^{a}	0.72 ^{a}	0.69 ^{a}		0.40	0.083 ns
Gladiolus dalenii	3.01 ^{a}			2.12 ^{a}	2.03 ^{a}	3.24 ^{a}	4.14 ^{a}	3.19 ^{a}		2.96	0.897 ns
Gladiolus oppositiflorus	1.32 ^{a}			0.89 ^{a}	0.39 ^{a}	0.28 ^{a}	0.55 ^{a}	0.11 ^{a}		0.59	0.060 ns
Gladiolus papilio	0.57 ^{a}			1.33 ^{a}	0.77 ^{a}	0.60 ^{a}	0.32 ^{a}	0.34 ^{a}		0.66	0.815 ns
Kniphofia uvaria	54.83 ^{a}			15.49 ^{b}	20.50 ^{b}	20.61 ^{b}	17.41 ^{b}	23.75 ^{b}		25.43	0.002**
Morea spathulata	0.43 ^{a}			0.28 ^{a}	0.19 ^{a}	0.30 ^{a}	0.46 ^{a}	0.23 ^{a}		0.32	0.163 ns

5.3.4.3 Effect of canopy height grouping on mean biomass of different species.

i) One canopy layer only communities (Communities, 1-3)

Haplocarpha scaposa is the most dominant biomass species in the low canopy layer group. It produces the highest mean biomass 29.74g and is followed by *Helichrysum aureum* (21.05g) (Table 5.10). Meanwhile *Helichrysum aureum* mean biomass was not significantly different from *Diascia tugelensis* but was significantly different from *Diascia integerrima, Geum capense, Gazania linearis* and *Kniphofia hirsuta* (Table 5.10). Other species such as *Eucomis bicolor, Merwillia plumbea* and *Tritonia drakensbergensis* give the lowest mean biomass for in this community and highly significant differences with the three dominant species from this group like *Haplocarpha scaposa, Helichrysum aureum* and *Diascia tugelensis.*

Berkheya purpurea was the most dominant species in the medium canopy height. It has the highest mean biomass (102.08g), highly significantly different (P <0.01) when compared to other species. The second highest of the mean biomass contributors in this group is *Themeda triandra* (38.91g) and also have significant differences from other species (P<0.05) Tukey HSD. The lowest biomasses in this group are *Gladiolus saundersii and Agapanthus inapertus* (Table 5.10).

Species in the tall canopy layer showed a highly significant difference (P <0.001) between species across the communities. *Kniphofia uvaria* is the dominant species in mean biomass production in this group. It produces the highest mean biomass of 54.83g, with the other nine species having a mean biomass of <10g, and that did not differ statistically across the experimental communities (Table 5.10). Average mean biomass between the three canopy height groups of one canopy layer only in communities shows that the medium canopy group has the highest average biomass (18.02g) compared with low (8.81g) and 7.42g for tall canopy group (Table 5.10). Average mean biomass in community 2 was heavily influenced by *Berkheya purpurea*, a dominant species with the highest mean biomass produced in the second year.

ii) Two canopy layer experimental communities (Communities, 7-9)

Table 5.10 shows the effect of adding extra canopy layers on mean biomass of species. All species in community 7, 8 and 9 showed highly significant differences (P<0.001) in the mean biomass of individual species within the experimental communities. *Haplocarpha scaposa* remained the dominant species in the low canopy group. However, the mean biomass of *H. scaposa* was decreased by approximately 45% (24.77g to 13.89g) when were sown together with different species from the medium canopy layer. Low canopy species responsed differently in community. *Haplocarpha scaposa*, *Diascia tugelensis* and *Gazania linearis* were the main contributor to biomass in community 7 while *Helichrysum aureum*, in addition to *Haplocarpha scaposa*, *Diascia tugelensis* and *Gazania linearis* made a large contribution to biomass in community 9. All of these species still produced high mean biomass, even when sown with a potentially more dominant species such as *Kniphofia uvaria* and *Berkheya purpurea*. *Kniphofia uvaria* and *Berkheya purpurea* was not affected by added additional numbers of species to a community. Both species are dominant with higher mean biomass in their respective communities (Table 5.10).

All the species in with one extra canopy layer communities show a significant difference between species within communities (P<0.05;P<0.01). The average mean biomass of the three communities 7, 8 and 9 shows that community 8 and 9 biomass was influenced by *Berkheya purpurea*. Both communities show similar average mean biomass namely 9.39g for community 8 and 9.02g in community 9 (Table 5.10). Without *Berkheya purpurea* in community 7, the average mean biomass was only 4.71g even though *Kniphofia uvaria* as among the high producers of mean biomass is present in this community.

iii) Two extra canopy layer experimental communities (Communities, 4-6)

There was no major difference in mean biomass of species from low canopy layer when were sown in a community with 20 species with a different canopy layer. Species such as *Haplocarpha scaposa*, *Helichrysum aureum*, *Diascia tugelensis* and *Gazania linearis* remain as the largest contributor of mean biomass from a low canopy group. Species like *Berkheya purpurea, Themeda triandra* (medium canopy layer) and *Kniphofia, uvaria* (Tall canopy layer) are still as dominant producers of mean biomass even when other species are present. In community 6, the mean biomass of *B.purpurea* slightly decreases to 43.06g and was not significantly different compared to *Diascia tugelensis* (21.17g), *Helichrysum aureum* (26.36g) and *Kniphofia uvaria* (20.61g). Average of mean biomass of species within community in community 4,5 and 6 (7.73 g, 7.75 g and 7.13 g) was not affected with different proportion of canopy types (Table 5.10).

Table 5.10 Individual species mean biomass within the experimental communities

Mean biomass of individual species within community (g)

Species	Community								
	1	2	3	4	5	6	7	8	9
Low									
Diascia integerrima			5.90 ^{cd}	1.10 ^{c}	1.84 ^{c}	1.13 ^{c}	0.13 ^{d}		0.85 ^{c}
Diascia tugelensis			15.16 ^{bc}	19.97 ^{bc}	12.32 ^{bc}	21.17 ^{abc}	19.34 ^{ab}		12.85 ^{bc}
Geum capense			3.86 ^{cd}	3.01 ^{c}	1.01 ^{c}	1.55 ^{c}	1.63 ^{d}		1.59 ^{c}
Gazania linearis			6.09 ^{cd}	5.51 ^{c}	7.22 ^{bc}	18.15 ^{bc}	10.10 ^{abcd}		11.81 ^{bc}
Haplocarpha scaposa			29.74 ^{a}	8.45 ^{c}	39.66 ^{ab}	18.36 ^{bc}	24.77 ^{a}		13.89 ^{bc}
Helichrysum aureum			21.05 ^{ab}	20.78 ^{bc}	18.48 ^{bc}	26.36 ^{ab}	5.94 ^{bcd}		14.61 ^{bc}
Merwilla plumbea			0.02 ^{d}	0.03 ^{c}	0.03 ^{c}	0.03 ^{c}	0.03 ^{d}		0.02 ^{c}
Kniphofia hirsuta			4.56 ^{cd}	3.71 ^{c}	1.82 ^{c}	5.02 ^{bc}	3.29 ^{cd}		2.21 ^{c}
Tritonia drakensbergensis			1.55 ^{d}	0.80 ^{c}	0.64 ^{c}	0.79 ^{c}	0.59 ^{d}		0.71 ^{c}
Eucomis bicolor			0.12 ^{d}	0.10 ^{c}	0.15 ^{c}	0.07 ^{c}	0.14 ^{d}		0.08 ^{c}
Medium									
Berkheya purpurea		102.08 ^{a}		77.34 ^{a}	71.49 ^{a}	43.06 ^{a}		91.75 ^{a}	66.63 ^{a}
Diascia rigescens		8.93 ^{c}		7.35 ^{c}	3.77 ^{c}	7.75 ^{bc}		8.56 ^{c}	9.43 ^{bc}
Dierama mossii		0.95 ^{c}		1.60 ^{c}	1.12 ^{c}	0.76 ^{c}		1.37 ^{c}	0.89 ^{c}
Themeda triandra		38.91 ^{b}		41.03 ^{b}	26.03 ^{bc}	17.67 ^{bc}		34.50 ^{b}	28.32 ^{b}
Kniphofia triangularis		1.80 ^{c}		2.30 ^{c}	0.95 ^{c}	1.31 ^{c}		2.19 ^{c}	2.57 ^{c}
Gladiolus saundersii		0.10 ^{c}		0.23 ^{c}	0.16 ^{c}	0.08 ^{c}		0.21 ^{c}	0.05 ^{c}
Kniphofia ritualis		6.81 ^{c}		2.97 ^{c}	5.03 ^{c}	12.50 ^{bc}		5.06 ^{c}	3.16 ^{c}
Agapanthus inapertus		0.08 ^{c}		0.04 ^{c}	0.05 ^{c}	0.05 ^{c}		0.05 ^{c}	0.04 ^{c}
Watsonia spp		2.54 ^{c}		1.92 ^{c}	1.61 ^{c}	1.20 ^{c}		1.91 ^{c}	1.64 ^{c}
Tall									
Crinum macowanii	0.21 ^{b}			0.09 ^{c}	0.15 ^{c}	0.35 ^{c}	0.08 ^{d}	0.02 ^{c}	
Crocosmia masonoirum	1.60 ^{b}			1.15 ^{c}	1.11 ^{c}	1.40 ^{c}	0.77 ^{d}	0.85 ^{c}	
Dierama pulcherrimum	1.95 ^{b}			2.20 ^{c}	1.89 ^{c}	2.30 ^{bc}	2.47 ^{cd}	2.00 ^{c}	
Galtonia candicans	9.74 ^{b}			2.02 ^{c}	4.35 ^{c}	0.59 ^{c}	1.30 ^{d}	1.65 ^{c}	
Gladiolus geardii	0.51 ^{b}			0.28 ^{c}	0.13 ^{c}	0.05 ^{c}	0.72 ^{d}	0.69 ^{c}	
Gladiolus dalenii	3.01 ^{b}			2.12 ^{c}	2.03 ^{c}	3.24 ^{bc}	4.14 ^{cd}	3.19 ^{c}	
Gladiolus oppositiflorus	1.32 ^{b}			0.90 ^{c}	0.39 ^{c}	0.28 ^{c}	0.55 ^{d}	0.11 ^{c}	
Gladiolus papilio ruby	0.57 ^{b}			1.33 ^{c}	0.77 ^{c}	0.60 ^{c}	0.32 ^{d}	0.34 ^{c}	
Kniphofia uvaria	54.83 ^{a}			15.49 ^{bc}	20.50 ^{bc}	20.61 ^{abc}	17.41 ^{abc}	23.75 ^{b}	
Morea spathulata	0.43 ^{b}			0.28 ^{c}	0.19 ^{c}	0.30 ^{c}	0.46 ^{d}	0.23 ^{c}	
Mean	7.42	18.02	8.81	7.73	7.75	7.13	4.71	9.39	9.02
P-value	0.0001**	0.0001**	0.0001**	0.0001**	0.0001**	0.0001**	0.0001**	0.0001**	0.0001**

5.4 Discussion

5.4.1 Growth productivity of the species in year 2

A study examining aspects of achieving emergence and quantifying growth rate in monoculture has previously been discussed in Chapter 3. In experiment 3, this same performance was not found on *Diascia integerrima* when planted in non-monocultural conditions in conjunction with other species such as medium and tall canopy layers. However, mean biomass of *D. Integerrima* was higher (5.90g) if planted together with species from the same canopy layer (Table 5.10). In Experiment 1, *Gazania linearis* and *Helichrysum aureum* produced high mean biomass (Table 5.11) and both species also did this in experiment 3 in multi-species communities. (Table 5.7).

Berkheya purpurea is a species that had the highest mean biomass and high relative growth of forbs when grown in monoculture (Table 5.11). This species maintains this competitive growth performance in Experiment 3 when growing in mixed communities. Other species that performed similarly in both experiments are *Galtonia candicans, Crocosmia masoniorum, Tritonia drakensbergensis* and *Kniphofia triangularis*. These species produce mid range mean biomass in experiment 3. *Agapanthus inapertus* had slow growth and low mean biomass in the monoculture experiment and also in the mixed communities in Experiment 3, where even in the second year it was able to survive even though it was heavily shaded by other, taller species.

Table 5.11 Effect of time of sowing on mean standing biomass of individual plants of each species at the end of a 150 days post sowing growth window. Data summary from Experiment 1,under monocultural conditions. Significant differences (P=0.05, Mann-Whitney *U*-test) are indicated by asterisks.

Species	Seed weight	Standing biomass seed sown in March (g)	Standing biomass seed sown in May (g)
Diascia integerrima	0.14	1.309 *	0.242 *
Helichrysum aureum	0.24	0.592	1.019
Eragrostis curvula	0.34	2.973 *	9.393 *
Helichrysum pallidum	0.39	0.014	-
Hesperantha coccinea	0.85	0.05	0.06
Gazania linearis	1.55	1.577	2.061
Aloe ecklonis	2	0.015	0.018
Kniphofia triangularis	2.1	0.105 *	0.028 *
Agapanthus campanulatus	3.63	0.067	0.051
Berkheya purpurea	3.8	1.166 *	2.560 *
Moraea huttonii	4	0.031	0.011
Tritonia drakensbergensis	4	0.098	0.043
Agapanthus inapertus	4.14	0.026	0.017
Gladiolus papilio	5.05	0.042	0.02
Crocosmia masoniorum	5.2	0.167	0.041
Watsonia latifolia	6	-	0.004
Watsonia pulchra	6	0.051 *	0.014 *
Ornithogalum candicans	7.19	0.073	0.157
Dierama latifolium	9.95	0.102	0.073
Gladiolus oppositiflorus	10	0.043 *	0.016 *
Dierama pulcherrimum	13.69	0.142	0.113

5.4.2 Survival/mortality of species across communities in year 2

Survival/mortality will influence a total biomass produced by the individual species in the community and affects the appearance and structural composition of designed vegetation. The assumption at the outset of the study was that the highest mortality would be demonstrated in the low canopy species because these would be least able to escape the shade generated by taller species. Mean mortality (for all species in each layer) was as follows: low = 10.23%, medium 12.67 %, and tall 32.34%. It seems that over the two years of this experiment, this individual species characteristic were more important in terms of mortality than foliage canopy characteristics. Table 5.6 shows that *Diascia integerrima* experienced the highest mortality (49.44%) when compared with the other low canopy species. This high mortality reduced the total biomass of this species (< 5g) in all communities in which it was represented. This performance was in contrast to Experiment 1, in which *Diascia integerrima* had low mortality and high mean biomass and also relative growth rate compared to other species. Mortality was associated with the winter-spring period at the commencement of the second year. A possible explanation for this might be that the cover of fleece during the winter to avoid winter frost, created humid conditions that lead to the loss of *Diascia integerrima* due to fungal organisms. Alternatively, given the sensitivity of this species to wet soil, it may simply have been a response to the unusually wet year of 2012, in association with pots with poorer than average drainage.

As can be seen from the Table 5.6, within the medium height canopy *Gladiolus saundersii* showed the highest average of mortality (51.16%) resulted in a very low total biomass of <1.0g. This species is, like *D. integerrima*, often associated with dry rocky grasslands, and may have suffered damage from either winter or spring wetness. During the course of the study it has often shown signs of fungal root rots when cultivated in pots, a sign of high sensitivity to wet composts. Other species also showed relatively high mortality in this group for example Kniphofia triangularis,

Because there were no significant differences between communities for all species within the medium canopy layer group in terms of mortality during year 2, this again suggests that one and a half growing seasons is insufficient for the taller species to develop sufficiently to start to shade lower species. These effects are anticipated to be more powerful in the future.

In this study, the species that had the highest mortality were those from tall canopy layer such as *Crinum macowanii* (74.77%), *Galtonia candicans* (77.25%) and *Gladiolus geardii* (50.04%). This result may be explained by the attractiveness of *Crinum macowanii* foliage to slug grazing, and this may also be the case with, *Galtonia candicans*. As a winter green and not very cold tolerant summer-winter transition species *Gladiolus geardii* showed signs of foliage damage in the cold winter of 2011-12, even under the fleece.

5.4.3 Total biomass of the communities and of individual species in these

Actual community productivity is influenced by the total of each species are cultivated. It is closely related to the quantity of each species in each community created. However, not all species are significantly different on total biomass across the community. Some species are not significantly different even though it was planted in small proportion compared to the big proportion. This situation occurs in species such as *Diascia tugelensis*, *Gazania linearis*, *Helichrysum aureum* and *Merwillia plumbea*. The observed on *Diascia tugelensis* found that the productivity of this species was higher is related to the way of this plants growing is by creeping on the soil surface and independently expand the coverage. Meanwhile *Helichrysum aureum* with high productivity is able to growth from the rootstocks in a second year and consistent in producing biomass in any community types.

In a low canopy group, slow growing monocots like *Merwillia plumbea* , in a second year the plants size was small and more or less the same size between for all seedling across communities. It also give a small number of biomass production and no significant differences between communities. This study also found that *Gazania linearis* produce a lot of seedling in a plots by re-germination process of seeds from seed production in 2011. Re-germination was made the species remain the productivity in producing high total biomass in all the communities it represented. Apart from that, this species has a high growth rate compared to other species (Chapter 3).

Another species with low productivity is *Gladiolus saundersii*. This species was experiencing a slow growth rate and still small in size in a second year. A possible explanation for this might be that because the competition for light with the rapid and productive species such as *Berkheya purpurea* and *Themeda triandra*. Size of the individual species were affected the mean biomass on each species across the communities. The results obtained from the analysis shows that although there was a little differences in total biomass across communities in several species but it will not shows any significant differences for species such as *Diascia rigescens*, *Dierama mossii*, *Crinum macowanii*, *Dierama pulcherrimum* and *Gladiolus papillio* (Table 5.8). *Diascia rigescens* is a fast growing species and producing a mat of branching stem and evergreen *Dierama mossii* and *Dierama pulcherrimum* had no problems on producing biomass against the competition for light in mix canopy layer across community. *Crinum macowanii* was almost entirely occur in the same condition due to slug and snail attack, while *Gladiolus papilio* with a small numbers of seedling survive as percentage of mortality is quite high (45.83%) make both species in a low productive in a second year of experiment.

As expected productivity of species is vary by a number of plant per quadrate in each community is differ. Many of the species different in species total biomass with significant and highly significant difference (P <0.05; P0.01) were in the sequence between low and high the number of species present in the community. There are also species that can produce high amounts of biomass despite being a few numbers in the community.

Productivity of mean biomass for most individual species across community were not shows a significantly different between communities. Only three of all species tested show a significant and highly significant different between communities. Table 5.10 shows that *Diascia integerrima* had a significant difference on mean biomass. Its might be due to the late harvesting on aboveground biomass of this species where it has been at the stage of dieback and some have decayed. This is hard to get a true picture of individual species mean biomass for this species. *Tritonia drakensbergensis* show different mean biomass may be due to competition for light. It showed in Table 5.10 that *T.drakensbergensis* produces high mean biomass when grow in low canopy group and also at a more open community such as community 4. The results also found that *Kniphofia uvaria* mean biomass was reduced when were sown with extra canopy layer in the community. A possible explanation for this is that due to competition underground. Underground competition occurs when these species are placed in combination with 20 and 30 species in the community (Table 5.10).

Most of the species do not show any significant differences of mean biomass across the community in second years. Low canopy species was not affected with the different combination of canopy height and number of species in community although it was expected will be eliminated in the second year through competition with species from a medium and tall canopy. However, this situation does not occur. It might be due to spring cutting in the early season at 50mm from surface was made an open competition for light especially for low canopy group. Most of the forbs species with rapid growth rate like *Gazania* and *Diascia* take this opportunities for establishment and productive. The spring cutting also reduces shading effect and competition for light on this species.

5.4.4 Emergence and cover value of the species across community

As a whole, mean percentage emergence was satisfactory for all species in different canopy layers except *Haplocarpha scaposa* with low percentage of germination about 4.6% (Table 5.5). This situation is most likely due to seed cleaning of this difficult to clean seed leading to low viability in the seed used in the experiment. The dispersal parachute of seeds of this species also restrict getting good contact with the surface of sharp sand when compacted during sowing process. The optimum contact between seed and medium for good germination is quite difficult to control when seed is sown on an extensive scale.. Some of the species in the low, medium and tall canopy layer achieved high percentage of seed emergence (> 30%) at 60 days after sowing.

There were a significant differences ($P<0.05$) on the cover value for all communities in until mid-May (Table 5.7). After this forbs species grew and the cover value in communities 2-9 becomes very similar and no significant differences occurred. Broadleaf dicot species play a big role in influencing the cover value of a community. The community with more geophytes and particularly in the tall canopy layer was more open. Results from the observation of 150 day found that the cover did not reach 50% until end of the observation period for the community with a high proportion of geophytes as compared with the other communities. The effect can be seen on the community 1, 4 and 8 in a first year. However, it did not happen to community 4 and 8 in the second year because of most forbs species in the community is bigger. Community 1 with 100% geophytes is still difficult to reach 50% cover in a second year after 150 days of observation.

5.5 Conclusion

Montane South African grassland species growth performance for the first two seasons, 2011 and the second in 2012 are encouraging. The first year saw a growth phase where many species were not mature enough to flower and compete and produce rapid growth rates. The community was dominated by forbs species that produce high biomass compared most geophytes.

The increase in the number of species in a community does not affect productivity of low canopy layer species. Combination of species with different canopy height was not a significant effect by competition within or between communities. Although there are significant differences in the number of species at the second year like *Diascia integerrima* but it is too early to conclude that the mix of canopy layer in community was affected and reduces the survival rate of the low canopy layer species. This explanation is due to the results in the second year where most of low canopy species survived with the exception *of Diascia integerrima*. Low canopy species have the ability to compete in the second year is probably due to the method of spring cutting reduced the competition between canopy layers and give temporary advantage to the low canopy in the early stages. It is also gave advantage to forbs species like *Berkheya purpurea* that have rapid growth. Ability to produce high biomass makes this species dominant in the coverage of communities at the beginning of the season.

Species that were very small during the second year, for example; *Merwillia plumbea*, *Eucomis bicolour*, *Gladiolus saundersii*, *Kniphofia ritualis*, *Agapanthus inapertus*, *Crinum macowanii*, *Gladiolus oppositiflorus* and *Moraea spathulata* need further monitoring for the next 2 or 3 years will give a truer indication of impact of species competition within and between communities with the different canopy layer.

CHAPTER 6: DESIGN ASPECTS OF MONTANE SOUTH AFRICAN GRASSLAND COMMUNITIES UNDER UK CLIMATE CONDITION.

6.1 Introduction

The research undertaken to review the growth and competitiveness of the species in this community has also led to the creation of a plant community with previously unknown visual characteristics. Formal assessment of the attractiveness of the community was never part of the research objectives; however this chapter does present a review of some of the key factors that are likely to influence how this vegetation might be perceived. Attractiveness of naturalistic vegetation tends to come from three factors:

i) repeating patterns of species in the mix;
ii) vegetation structure
iii) flowering colour, impact and duration.

Of these entire flower colour has been shown (Todorova et al., 2004; Kendal et al., 2008) as a key attraction to visitors and publics. Montane South African grassland species are a group of plants that have a diversity of sizes and shapes of attractive flowers, offering much to new naturalistic planting design.

The hypotheses for this part of the study was that the duration of flowering of Montane South African grassland species increases as the number of species present in the community increases.

6.1.1 Objectives

The specific objectives of this study were:

- To monitor the growth, flowering and seed set phenology of the species over two seasons.
- To determine the flowering period of all species within the designed community across two growing seasons.

- To make some observations in the impact of flowering of different species
- To make some preliminary observations on the range of insect groups visiting the flowers of these species

6.2 Material and methods

6.2.1 Data collection

Images of overall growth and flowering in the first two growing seasons of the competition experiment (2011 and 2012) have been shown in Chapter 5. Flowering phenology observations have been undertaken on the same experiment over the same time period. The number of species in flower was recorded throughout the season and the digital images of the plant community were captured in every month from the same position-angle using a Canon digital compact camera (G11). Plant growth and flowering phenology is presented as a Gantt-type chart, and the flowering period of each species expressed as days of flowering for further analysis. The methodology of recording flowering is based on the research of Dunne et al. (2003).

The number of days flowering across the number of species in community is calculated from the day species in community start to flower until the last day of flowering species in that year. While the numbers of plants flowering are counted from the plants flowering in a quadrat throughout the observations made in 2012.

6.3 Results

6.3.1 Phenology of flowering species in 2011 and 2012.

Figure 6.1 and 6.2 shows the growth and flowering of 30 South African grassland species in plots throughout the experiment. Assessment of phenology commenced after the work of planting or removals to adjust the communities to achieve target plants per plot, was completed. The flowering period of each species recorded from a minimum of 5 plants. In the first year approximately 30% of the 30 species flowered. Most of the species from the low canopy group flowered in year 1. Most of the species in the medium and tall canopy groups were not large enough to flower in 2011.

As can be seen from figure 6.1, in the low canopy group, *Gazania linearis* was the first species to flower in the second week of July 2011. It was followed by *Diascia integerrima* and *Diascia tugelensis* in the third week of July, *Haplocarpha scaposa* in the first week of August, *Helichrysum aureum* in fourth week of August and *Kniphofia hirsuta* in the third week of September. The *Diascia* and *Gazania* flowered for approximately 16 weeks, *Haplocarpha scaposa*, *Helichrysum aureum* and *Kniphofia hirsuta* flowering for 5 to 8 weeks.

In a medium canopy group, only two species flowered. *Diascia rigescens* and *Berkheya purpurea.* These species flowered from mid July to the end of October. In the tall canopy group, only *Gladiolus dalenii*, *Gladiolus papilio* and *Kniphofia uvaria* flowered. *Gladiolus dalenii* flowered from mid August to the end of October while *Gladiolus papilio* and *Kniphofia uvaria* flowered from mid October until mid November.

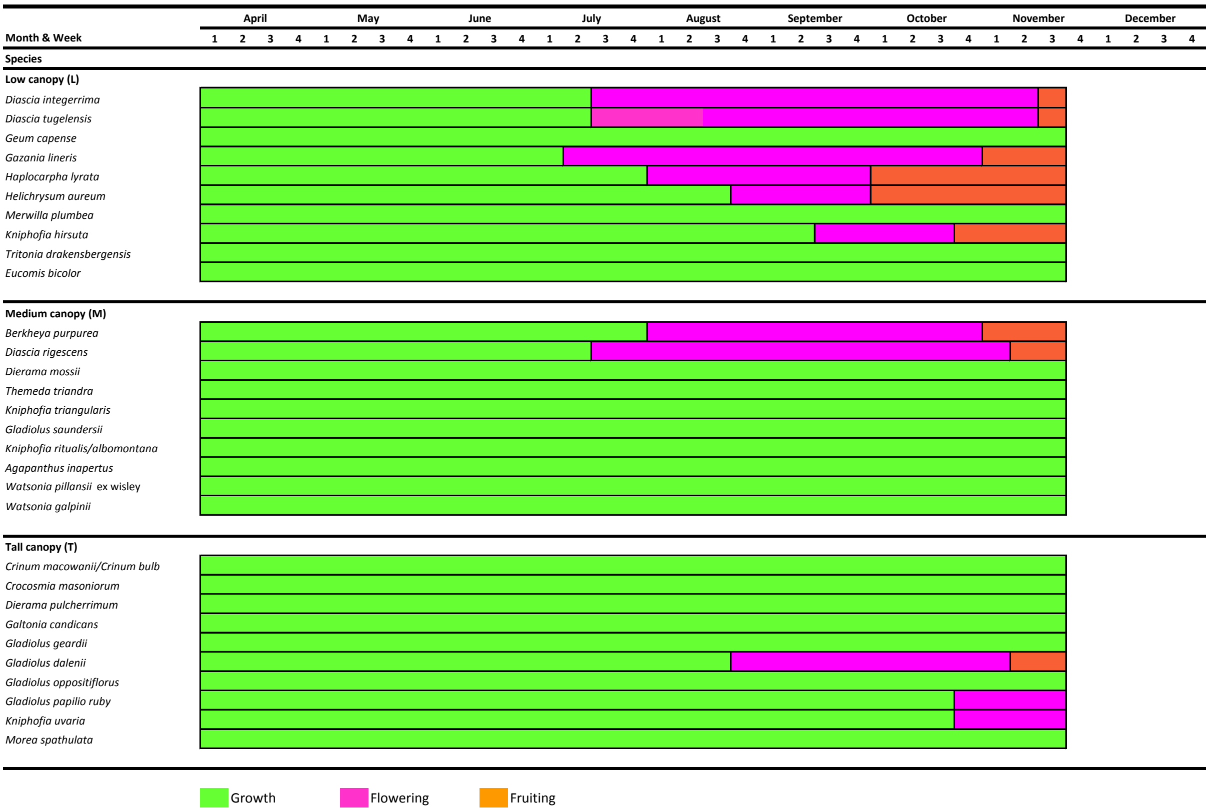


Figure 6.1 Phenology Chart for growth and flowering in 2011.

The second year monitoring commenced after spring cutting all the species back to 50 mm from the ground in early April 2012. This was undertaken to equalise initial competitive potential with the community. Growth and flowering was monitored and recorded throughout the season until the beginning of October. Twenty two of the 30 species sown flowered during this period. The first two months were dominated by the low and medium canopy with July, and August the peak flowering season across the three groups of canopy heights. The last two months of flowering were dominated by tall canopy species as shown in figure 6.2.

In the second year, 8 of the 10 species from the low canopy group flowered. However, most of the species had a shorter flowering period compared with 2011, when the flowering season was extended by different individuals of a species flowering at different times due to their different physical size. Flowering started in early May with *Geum capense* and *Gazania linearis* ending in early September by *Tritonia drakensbergensis*. Increasing numbers of species flowered in the second years. Species flowering within the medium canopy group of species also increased in year 2. *Diascia integerrima* was still as the longest flowering species in a year 2, while *Dierama mossii* had the shortest flowering period at approximately a month. Species such as *Kniphofia triangularis*, *Watsonia pilliansi* and *Watsonia galpinii* exceeded one month in flower.

Seven species from the tall canopy layer flowered in year 2. Most of the species flowered in summer and had finished by mid of September except for *Kniphofia uvaria*. *Kniphofia uvaria* flowered for much longer (about 13 weeks) compared with the other six species which flowered for 4 to 7 weeks in a year 2.

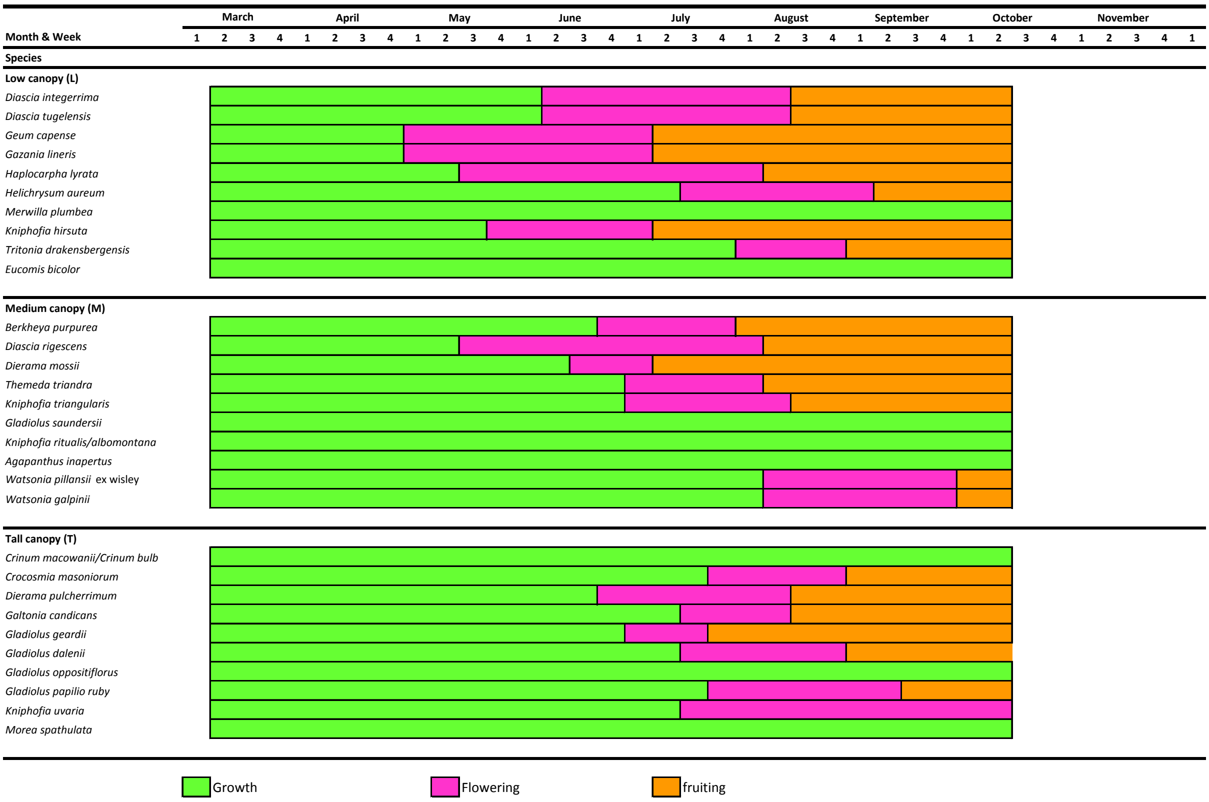
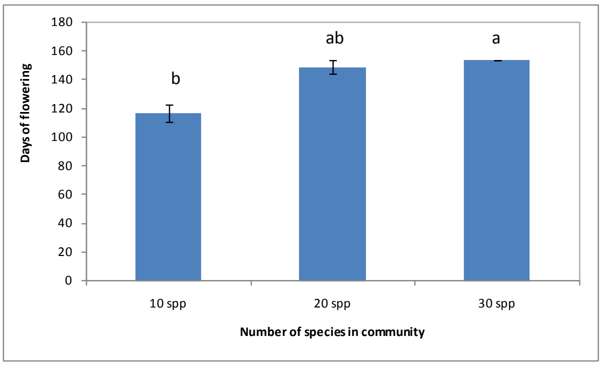


Figure 6.2 Phenology Chart period of growth and flowering season monitored in 2012.

6.3.2 Effect of number of species present on the total days of flowering

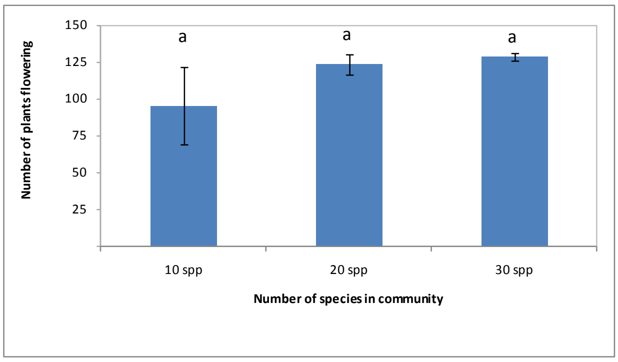
The total duration of the flowering period and the number of plants flowering within each of the 54 experimental treatment plots were recorded during the second growing season. The results showed significant differences between the numbers of days in which plants were flowering where different numbers of species of plants were used in the community (Figure 6.3a). The community with 30 species showed the longest flowering period (approximately 154 days), significantly more (P <0.05) compared with communities that have the lowest number of species (10). The latter community with 10 species produced the fewest days of flowering (approximately 117 days).

As shown in (Figure 6.3b), there is no significant difference between number of species in community on the number of plants flowering across the course of the second year.



F=20.73; df= 2; P=0.002

(a)



F=1.322; df=2;P=0.334

(b)

Figure 6.3 (a) Effect of canopy height grouping and number of species present on the total number of days of flowering in 2012. Bars labelled with different letters are significantly different at P=0.01(One Way Anova). Error bars represent 1 S.E.M.

(b)Effect of canopy height grouping and number of species on number of individual plants in flower in 2012. Bars labelled with the same letters are not significantly different at P=0.05. Error bars represent 1 S.E.

6.3.3 Effect of canopy height grouping on the number of plants flowering within the different communities.

There were highly significant differences in terms of the number of plants flowering within community ($P<0.0001$), as might be expected given the different numbers of plants of each species across the different communities (Table 6.1).

6.3.3.1 Communities based on one canopy height only

Almost all the species in low canopy group flowered (*Diascia tugelensis*, *Diascia integerrima*, *Helichrysum aureum*, *Tritonia drakensbergensis*, and *Haplocarpha lyrata)*. Only *Merwilla plumbea* and *Eucomis bicolor* did not.

In the medium canopy group, *Berkheya purpurea* and *Diascia rigescens* were the two main contributors of flowering density. Both species give the high mean number of plants flowering at 5.17 and 4.33 respectively (Table 6.1). *Gladiolus saundersii*, *Kniphofia ritualis* and *Agapanthus inapertus* did not flower.

A total of seven species from the tall canopy group flowered. *Kniphofia uvaria* had the highest number of plant flowering (3.00) followed by *Galtonia candicans*, *Gladiolus dalenii*, *Crocosmia masoniorum*. Species showed the lowest number of plants in flower were *Dierama pulcherrimum*, *Gladiolus papilio* and *Gladiolus geardii*. The remaining species did not flower at all.

The total mean number of plants flowering in Table 6.1 shows that low canopy species has a high total number of plants in flower.

6.3.3.2 Communities based on two canopy layers

In terms of adding more species, ie going from 10 to 20 plants, the total number of plants in flower was rather similar to the situation in the low and medium canopy only communities (Table 6.1).

As expected, given that by year two the main contributors to flowering were forbs present in the low and medium canopy groups, the higher total number of species in flower were found in community 9 (22.87).

6.3.3.3 Communities based on three canopy layers

The additional of tall canopied species to other canopy layers did not materially affect the number of plants in flower due to the low levels of flowering in this canopy layer in year two (Table 6.1).

Table 6.1 Mean number of plants flowering on each species within community

Species	Community								
	1	2	3	4	5	6	7	8	9
Low									
Diascia integerrima			3.67^{ab}	0.50^{bcd}	1.33^{bcd}	1.50^{cde}	0.67^{cd}		0.67^{de}
Diascia tugelensis			4.83^{a}	2.00^{ab}	2.33^{ab}	4.00^{a}	4.33^{a}		4.33^{a}
Geum capense			1.50^{bc}	0.83^{bcd}	0.17^{d}	1.17^{def}	1.00^{bcd}		0.83^{de}
Gazania linearis			1.00^{bc}	0.50^{bcd}	1.17^{bcd}	1.83^{bcd}	2.50^{abc}		2.16^{bcd}
Haplocarpha scaposa			3.00^{abc}	0.50^{bcd}	2.00^{abc}	2.83^{abc}	1.83^{abc}		1.50^{cde}
Helichrysum aureum			3.67^{ab}	2.00^{ab}	2.00^{abc}	3.17^{ab}	3.00^{ab}		3.50^{ab}
Merwilla plumbea			0.00^{c}	0.00^{d}	0.00^{d}	0.00^{f}	0.00^{d}		0.00^{e}
Kniphofia hirsuta			2.50^{abc}	0.50^{bcd}	0.33^{cd}	1.50^{cde}	1.83^{bcd}		0.50^{de}
Tritonia drakensbergensis			3.33^{ab}	1.17^{abcd}	0.50^{cd}	1.17^{def}	2.16^{abcd}		0.50^{de}
Eucomis bicolor			0.00^{c}	0.00^{d}	0.00^{d}	0.00^{f}	0.00^{d}		0.00^{e}
Medium									
Berkheya purpurea		5.17^{a}		2.50^{a}	3.50^{a}	2.00^{bcd}		4.33^{a}	3.00^{abc}
Diascia rigescens		4.33^{ab}		1.50^{abcd}	1.17^{bcd}	0.67^{def}		3.17^{abc}	1.33^{cde}
Dierama mossii		2.00^{bcd}		1.83^{abc}	2.00^{abc}	0.33^{ef}		2.17^{bcd}	1.00^{de}
Themeda triandra		3.67^{abc}		2.50^{a}	2.50^{ab}	0.33^{ef}		3.66^{ab}	2.16^{bcd}
Kniphofia triangularis		0.67^{d}		1.83^{abc}	0.50^{cd}	0.83^{def}		2.67^{abc}	1.33^{cde}
Gladiolus saundersii		0.00^{d}		0.00^{d}	0.00^{d}	0.00^{f}		0.00^{e}	0.00^{e}
Kniphofia ritualis		0.00^{d}		0.00^{d}	0.00^{d}	0.00^{f}		0.00^{e}	0.00^{e}
Agapanthus inapertus		0.00^{d}		0.00^{d}	0.00^{d}	0.00^{f}		0.00^{e}	0.00^{e}
Watsonia spp (W.pilliansii & W.galpinii)		1.33^{cd}		0.33^{cd}	0.17^{d}	0.16^{ef}		0.00^{e}	0.00^{e}
Tall									
Crinum macowanii	0.00^{c}			0.00^{d}	0.00^{d}	0.00^{f}	0.00^{d}	0.00^{e}	
Crocosmia masonoirum	1.17^{abc}			0.00^{d}	0.00^{d}	0.17^{ef}	0.00^{d}	0.00^{e}	
Dierama pulcherrimum	0.17^{bc}			0.17^{d}	0.00^{d}	0.00^{f}	0.17^{d}	0.00^{e}	
Galtonia candicans	2.33^{ab}			0.67^{bcd}	0.17^{d}	0.00^{f}	0.17^{d}	0.83^{de}	
Gladiolus geardii	0.33^{bc}			0.17^{d}	0.00^{d}	0.17^{ef}	0.00^{d}	0.33^{e}	
Gladiolus dalenii	1.33^{abc}			0.67^{bcd}	0.50^{cd}	0.00^{f}	0.50^{cd}	0.50^{de}	
Gladiolus oppositiflorus	0.00^{c}			0.00^{d}	0.00^{d}	0.00^{f}	0.00^{d}	0.00^{e}	
Gladiolus papilio ruby	0.17^{bc}			0.17^{d}	0.00^{d}	0.00^{f}	0.33^{cd}	0.00^{e}	
Kniphofia uvaria	3.00^{a}			0.00^{d}	0.17^{d}	0.33^{ef}	1.33^{bcd}	1.50^{cde}	
Morea spathulata	0.00^{c}			0.00^{d}	0.00^{d}	0.00^{f}	0.00^{d}	0.00^{e}	
Total mean no. of plants flowering	**8.5**	**17.17**	**23.47**	**20.51**	**20.51**	**20.66**	**19.82**	**19.16**	**22.87**
Mean	**0.85**	**1.71**	**2.35**	**0.70**	**0.70**	**0.71**	**0.99**	**1.01**	**1.20**
***P*-value**	0.0001**	0.0001**	0.0001**	0.0001**	0.0001**	0.0001**	0.0001**	0.0001**	0.0001**

6.3.4 Effect of canopy height grouping on mean number of plants flowering per plot across the communities in 2012.

The mean number of flowering plants was divided by the mean number of plant per plot for each species to correct the value of plants flowering per plot. The results found that the average number of flowering plant by species per plot is almost at the same numbers across the communities. Range of flowering plant per plot for each species is between 1-3 plants (Table 6.2). However, some species experienced a significant decline when were sown in a community that has a lot number of species (30 species) as compare to be sown in a small number of species, e.g.; *Kniphofia uvaria*.

Table 6.2 Mean number of plants flowering per plot across the communities 2012

Species	Community									Total	Mean
	1	2	3	4	5	6	7	8	9		
Low											
Diascia integerrima			1.11	1.00	1.98	1.15	1.00		1.34	7.58	1.26
Diascia tugelensis			0.93	0.80	0.83	0.93	1.03		0.92	5.44	0.91
Geum capense			0.38	0.49	0.10	0.37	0.36		0.25	1.94	0.32
Gazania linearis			0.50	0.71	0.65	1.02	0.83		0.86	4.58	0.76
Haplocarpha scaposa			0.79	1.00	0.71	0.81	1.08		1.00	5.39	0.90
Helichrysum aureum			0.76	1.00	0.91	0.79	0.75		0.88	5.09	0.85
Merwilla plumbea			0.00	0.00	0.00	0.00	0.00		0.00	-	-
Kniphofia hirsuta			0.34	0.18	0.10	0.25	0.35		0.13	1.36	0.23
Tritonia drakensbergensis			0.46	0.59	0.14	0.33	0.46		0.17	2.14	0.36
Eucomis bicolor			0.00	0.00	0.00	0.00	0.00		0.00	-	-
Medium											
Berkheya purpurea		0.89		0.93	0.92	1.11		1.03	1.00	5.88	0.98
Diascia rigescens		0.87		0.88	0.90	1.12		0.75	1.02	5.54	0.92
Dierama mossii		0.33		0.32	0.32	0.12		0.36	0.24	1.69	0.28
Themeda triandra		0.78		0.83	0.60	0.19		0.78	0.68	3.86	0.64
Kniphofia triangularis		0.14		0.48	0.17	0.55		0.47	0.42	2.23	0.37
Gladiolus saundersii		0.00		0.00	0.00	0.00		0.00	0.00	-	-
Kniphofia ritualis		0.00		0.00	0.00	0.00		0.00	0.00	-	-
Agapanthus inapertus		0.00		0.00	0.00	0.00		0.00	0.00	-	-
Watsonia spp (W.pilliansii & W.galpinii)		0.14		0.05	0.02	0.03		0.00	0.00	0.23	0.04
Tall											
Crinum macowanii	0.00			0.00	0.00	0.00	0.00	0.00		-	-
Crocosmia masonoirum	0.19			0.00	0.00	0.08	0.00	0.00		0.22	0.04
Dierama pulcherrimum	0.05			0.03	0.00	0.00	0.04	0.00		0.08	0.01
Galtonia candicans	0.83			0.56	0.57	0.00	0.57	0.83		0.69	0.12
Gladiolus geardii	0.08			0.10	0.00	0.57	0.00	0.15		0.17	0.03
Gladiolus dalenii	0.26			0.21	0.22	0.00	0.20	0.25		0.58	0.10
Gladiolus oppositiflorus	0.00			0.00	0.00	0.00	0.00	0.00		-	-
Gladiolus papilio ruby	0.07			0.24	0.00	0.00	0.28	0.00		0.11	0.02
Kniphofia uvaria	0.36			**0.00**	**0.06**	**0.08**	0.28	0.30		1.06	0.18
Morea spathulata	0.00			0.00	0.00	0.00	0.00	0.00		-	-

6.3.5 Monthly image of South Africa grassland community in 2011

Given that one of the goals of this research is to inform landscape practice as how to construct South African montane grassland vegetation in public landscapes, a sense of the physical and visual dynamics is an important element in this. Figure 6.4a shows seedlings sown species during emergence. Wire mesh was used to prevent plots dug by foxes at night. In practice this role is undertaken by the heavy duty jute erosion mat that is generally laid on the surface post sowing. In the experiment in question, this was not used as it complicates some aspects of maintenance. In this particular experiment the sand used appeared to contain many weed seeds, and weeding manually was needed to avoid competition in the early stages of seedling experiment. The history of the sand used has a major effect on weed loadings, but also in this site, there were many weeds such as *Epilobiium* spp. present around the plots and many of the weeds colonised from this source of blown in seeds.

Figure 6.4a Emerging seedlings in June 2011 (50 days post sowing).

Growth of the forbs seedlings is rapid with *Gazania linearis* starting to flower by July (figure 6.4b). Forbs species dominated cover in all the plots except for community 1 (Tall 100%) where forbs species were not present. As the seedling grew bigger the use of wire mesh over the plots became impractical and was replaced with a fence made by fruit netting around the experimental plots.

Figure 6.4b Forb species (namely *Gazania linearis*) starting to flowering, July 2011 (80 days).

Forbs species such as *Diascia integerrima*, *Diascia tugelensis*, *Diascia rigescens*, and *Gazania linearis* from the low and medium canopy group dominate in this image (Figure 6 4c). *Berkheya purpurea* from a medium canopy group is starting to flower in some plots. The forb species are important in providing visual interest and vegetative cover in the first growing season, however they are potentially excessively dominant, and sowing rates in practice need to be reduced to reflect this. Geophytes only communities would be problematic in terms of cover in the first and even second year.

Figure 6.4c Low and medium canopy flowering in August 2011 (130 days)

Many species flowers much later in the first year than in subsequent years because the plants are not large enough to flower until late in the first year. By September 2011, *Berkheya purpurea* and *Diascia rigescens* from the medium canopy group dominated flowering (Figure 6.4d). Flowering in most of the low canopy species like *Diascia integerrima*, *Diascia tugelensis*, *Geum capense* and *Gazania linearis* started to decline by September. However, *Haplocarpha scaposa* was at the peak of flowering. *Gladiolus dalenii*, one of only two geophytes to flower in the first growing season, began to flower in September.

Figure 6.4d Flowering in September 2011 (155 days).

By October, some of the low canopy species like *Gazania* and *Haplocarpha* are still flowering, or in the case of *Gazania* have initiated a new tranche of flower buds after flowering declining in late summer. Most of the plants of *Gladiolus dalenii* and *Kniphofia uvaria* are starting to produce flower buds (Figure 6.4e).

Figure 6.4e Tall canopy species such as *Kniphofia uvaria* starting to flower, October 2011.

Most of the low and medium canopy species were nearly to the end of their flowering period, although *Diascia rigescens* was still flowering well. *Kniphofia uvaria* was at the beginning of flowering stage, and many of the flowering stems had to be cut down before all experimental plots were covered by fleece to protect young seedlings from damage by frost during winter (Figure 6.4f).

Figure 6.4f Species from tall canopy group *Kniphofia uvaria* flowering profusely in November 2011.

6.3.6 Monthly images of the South Africa grassland community in 2012

All of the plots were cut down to 50 mm with a petrol hedge trimmer on 3rd April 2012 (Figure 6.5a) to allow all species access to light and reset the "competition clock". In the future burning post cutting down is also likely to be used to remove or suppress winter and spring flowering weeds, but this was not undertaken in 2012 to avoid the risk of damage to species whose response to fire is not well understood. Flowering in the second year was assumed likely to give a more accurate image flowering phenology-performance. With the exception of *Agapanthus inapertus, Crinum macowanii, Eucomis bicolor*, *Gladiolus oppositiflorus, G. saundersii, Merwilla plumbea* and *Moraea spathulata* all the species are large enough to flower in 2013.

Figure 6.5a Species starting to regrow after spring cutting in April 2012. Notice the greater foliage cover values.

Forbs species again drove the early flowering in the second year of the study. *Geum capense* and *Gazania linearis* were flowering in the first week of May 2012 (Figure 6.5b). The different canopy heights and leaf textures of the non flowering species provided an attractive background to the two early flowering species.

Figure 6.5b *Gazania linearis* and *Geum capense* start to flower in May 2012.

In June, the low canopy layer species reached their peak flowering period. Almost all the species in this group except *Merwillia plumbea* and *Eucomis bicolor* flowered (Figure 6.5c). In the second year, *Diascia integerrima* visual presence was reduced due to the mortality. However, species from the medium canopy layer, *Berkheya purpurea* and *Diascia rigescens* began to bloom.

Figure 6.5c The impact of species composition on community structure and flowering is now really apparent (June 2012).

By July the yellow colour produced mainly by *Gazania linearis* and *Haplocarpha scaposa* is reduced and replaced with *Helichrysum aureum*. Figure 6.5d shows that, *Berkheya purpurea* dominates flowering in this month, but is supported by other medium canopy layer species such as *Dierama mossii*, *Kniphofia triangularis* and *Diascia rigescens*. Some of the tall canopy layer species like *Galtonia candicans* and *Gladiolus dalenii* are also started to flower.

Figure 6.5d The medium species started to dominate colour impact (especially *Berkheya purpurea)* by July 2012

Many *Moraea spathulata* were present in the experimental plots but only few plants flowered (Figure 6.5e). Quite a few of the monocots were just not large enough to flower in 2012. In the 2013 the monocots are expected to increasingly dominate flowering, with the forbs becoming less visually and functionally important.

Figure 6.5e The tall canopy group start to flowering at the end of August 2012

Many species from the low and medium canopy layer are now in seed, with only a few species from the low canopy still flowering, such as *Helichrysum aureum* (Figure 6.5f). Tall canopy layer species and in particular *Kniphofia uvaria* dominate colour impact in this month. Colour late into autumn is particularly important for herbaceous vegetation in urban landscapes and the experimental communities have shown this is a design component that needs more thought. In the third year (2013), species like *Agapanthus inapertus* and *Gladiolus oppositiflorus* are expected to be flower in autumn. It is also possible to add more autumn flowering species in future designed South African plant communities. *Eucomis comosa*, autumn *Kniphofia such as K. laxiflora*, *Hesperantha coccinea*, *H. pulchra*, *Gladiolus mortonianus*, *Gladiolus ochroleucus*, *Nerine angustifolia and N. bowdenii* are all potentially valuable additional autumn flowering.

6.5f *Kniphofia uvaria* flowers dominate at the end of flowering season in September 2012.

6.4 Discussion

6.4.1 Flowering phenology and design

A flowering periods of species in the communities differed greatly between the first and second year of the evaluation. The first year saw many species produce only vegetative growth, and was too small to flower. Figure 6.1 show less than 50% of species flowered in the first year compared with approximately 70% (22 out of 30) in the second year (Figure 6.2). This pattern is likely to continue into the third year, although species such as *Eucomis* may not flower till their fifth year. The first year also saw most of the species delay their flowering until July leading to a longer period of flowering. This situation happened because of variation in size and state of development within plants in a species sown like *Diascia integerrima* and *Diascia tugelensis*.

With more species flowering, the communities were more interesting visually in the second year. Different combination of canopy height in communities created more vibrant images in the second years. In the first year, the most significant visual impact was produced by low canopy species such as *D. Integerrima*, *D. tugelensis*, *G. linearis*, *H. scaposa* and *H. aureum*. The peak flowering impact in a first year was in September 2011. In a second year, a significant change in the colour images was produced. Species from all different canopy height were flowering in this season, and even though the forbs species from the low canopy group remain dominant in the early until middle of year but at the end of the season most of the species flowering are geophytes. The different height of the canopy layer creates a more spatially complex multi-layer flower impact with peak flowering time in July 2012 (Figure 6.5d). The combination of different species flowering potentially creates a new form of design impact.

There were only three species still flowering by mid-September 2012, *Watsonia pilliansii*, *Watsonia galpinii* and *Kniphofia uvaria*. This situation suggests there is a need to add more autumn flowering species to these plant communities.

Several species of monocots and geophytes did not flower during the two seasons of the study (Table 6.1). *Eucomis bicolor* and *Merwilla plumbea* are still too small to produce flowers. *Eucomis bicolor* also was affected by slug grazing and this damaged most of the leaves. This also happened to *Crinum macowanii,* although it is not clear whether this species was killed outright by this, or whether it will re-sprout from the large bulb in spring 2013. A few species from the medium height canopy, for example, *Agapanthus inapertus, Kniphofia ritualis* and *Gladiolus saundersii* are expected to flower in 2013. Other species from tall canopy group such as *Gladiolus oppositiflorus*, *Morea spathulata* is expected achieve the size and maturity in this year to flowering. A third growing season will further change the flowering characteristics and general appearance of the plant communities created when all of the forbs, geophytes and grass are large enough to flower. *Themeda triandra* will increasingly play a bigger role in creating images of grassland, as the individual tussocks increase in size and close down the spaces, further contributing to the development of clearer layer structures.

6.4.2 Number of plants flowering in community

The number of plants flowering is important to develop colour impact of a community. The second year saw about only 10-25% of the 100 plants/ m^2 flowering in the community

(Table 6.1). This suggests that the communities will be more floral in the future as plants that were too small to flower in 2012 get large enough to do so, although this will be tempered by the increased vegetative biomass. Visual floral impact can be achieved by either species with small flowers but high densities of these, as in the case of *Diascia integerrima*, *Diascia tugelensis*, *Diascia rigescens*, *Helichrysum aureum* and *Galtonia candicans*, or conversely by species with larger flowers but lower flowering density like *Berkheya purpurea*, *Kniphofia uvaria*, *Gladiolus dalenii* and *Crocosmia masoniorum*. In the future, flowering is likely to be more dominated by the latter as the geophytes begin to dominate the vegetation.

Mean number of plant flowering in the community are subject to percentage canopy ratio for each species represented. The estimation of mean number of plant flowering per plot for each species shows that almost all of the species have an average of one plant in flowering for each plot in community (Table 6.2). *Kniphofia uvaria* found decline slightly on number of plant flowering when sown in a group with more species in community (30 species). This condition may be due to competition, particularly light either through competition with forbs species such as *Berkheya purpurea* (dominant species) or other factors of competition that exists below ground.

The process of recording flowering allowed the author to make many observations on insects visiting the flowers to harvest pollen or nectar. Despite having no evolutionary bio geographical relationships with the native insects of the UK, it was obvious that the flowers of many species were highly attractive to generalist pollinators such as bees and hoverflies (Figure 6.6)

Kniphofia hirsuta (White-tail bumblebee) *Berkheya purpurea* (Honey bee)

Dierama mossii (Honey bee) *Haplocarpha lyrata* (Hoverflies)

Gazania linearis (Honey bee) *Diascia tugelensis* (White-tail bumblebee)

Figure 6.6 Some common British bees visiting the flower in experimental plots.

6.5 Conclusion

This study has shown that it is possible to produce a long flowering and highly attractive community by sowing seed in situ. In first growing season, some of the forbs are remarkably quick to flower, commencing approximately 80 days after sowing in April 2011. Relatively few of the geophytic species flowered in the first year, but were better represented in the second year, and will increasely contribute to flowering display in the future.

As the numbers of species present in communities increased, so did the duration of flowering display, although this did not increase the number of plants in flower at any point in time. Many species are more attractive before flowering than after, and in practice increasingly the percentage of species that flower in late summer or autumn is desirable.

CHAPTER 7: CONCLUSION

The studies in this research have investigated and evaluated montane South African grassland plant communities as a new planting design form in urban greenspace. Most of the species used in this new naturalistic design form are attractive and potentially can provide strong visual impact through flowering in spring, summer and autumn. This final chapter discuss overall findings of the experiments such as; appropriate time of sowing, pre-germination treatment of slow germination species, hardiness to winter cold and wetness in response to different mulch depths and media, and the effect of different ratios of three different canopy layers in communities containing 10, 20 and 30 species. The chapter is structured around the research questions and objectives specified in **Chapter 1** of this thesis and potential areas for future research suggested.

7.1 Is it possible to develop South African grassland species as new planting design under UK climate?

Preliminary studies were initiated by Hitchmough since 2005 until 2008, with respect to using South African montane grassland species. Whilst there is some literature and practice information on species that can live and flower well in Britain (*Agapanthus, Crocosmia, Dierama, Kniphofia* (Whitehouse, 2013), more than 150 species have been sown and grown on in the preliminary phases to evaluate species that justify future study. Species have varied hugely in their adaptability to the UK environment, some otherwise desirable species have proved ungerminable (for example *Pentanasia prunellioides* and *Hypoxis* spp.) or ungrowable (*Watsonia strubeniae* (Goldblatt, 1989) plus other winter dormant species), others extremely robust and easy. This preliminary work was designed to make it possible to focus on species that were well fitted in this PhD study.

A key finding from the preliminary research was that plants are much more sensitive to winter cold grown in large pots than in the ground (Hitchmough, Unpublished). In the preliminary phases all “stock” plants were grown in 15L pots to allow them to be moved to prevent hybridisation with related species. Overwintering these plants is very difficult however as the temperature of the compost soon reaches that of the air and once -6 °C is reached the root systems of many species are damaged. The canopies of same species in the ground where roots are kept much warmer are undamaged by these temperatures (Desjardins and Chong, 1980).

Hardiness of many of the species used in the PhD to extreme cold conditions has been shown through their use at the London Olympic Park in 2011/2012 one of the coldest winters for 20 years, with air temperatures in Stratford dropping to -6/-7 °C. The relationship with soil moisture and cold is discussed later in this chapter. Suitability of species in the environment of the UK does not pose a huge problem to the 30-40 species used in the PhD study as the original habitats of the selected species experience similar temperature range in the UK (Mucina and Rutherland, 2006), except for the fact that the amount of moisture received by the winter in much higher in the UK.

Although most South African species show high levels of emergence in the UK, many of the geophytic species have much slower germination and growth rates, than for example North American or Eurasian species (Ahmad and Hitchmough, 2007). Nearly all of the geophyte species shows a slow growth rate even assisted with pre-germination treatment before sowing (Chapter 3). The slow growth rate means that the sown community is more open for a longer compared with sown communities of other species of seeds from elsewhere in the world. This situation can be mitigated by using more forbs species in a community. These species typically have low to medium canopies, and their broad leaves are capable of covering the ground faster than the geophytes species, making the management of weeds in the first year much easier. It can be seen from the results of competition experiment (Chapter 5) where the lower and middle canopy species such as *Diascia integerrima*, *Diascia tugelensis*, *Geum capense*, *Haplocarpha lyrata*, *Helichrysum aureum* and *Berkheya purpurea* able to cover 80% of the medium surface in the first year and then do this more rapidly (in approximately 50 days) in the second year. By comparison the species in the 100% geophyte Community 1 did not achieve 80% cover even after 150 days of evaluation. Besides being able to provide a quick cover the forbs are also able to give powerful colour impact in the early growing stages of the plant community. Most of the forbs species provided colour from early June to November in 2011.

However, the use of forbs should not be too dominant in a community to avoid these species from eliminating slower growing geophyte species from the community. This is especially important with species like *Berkheya purpurea, which* as revealed in Chapter 3 and 5, has particularly rapid growth rate and soon forms a competitive dominant. Using of this species in a high ratio will disrupt the growth of the slow-growing species even though it gives a very beautiful colour impact in the first and second growing season (Chapter 6).

Use of the forbs in the appropriate ratio will facilitate geophyte adequate geophyte presence in the community in the long run whilst avoiding excess. In a field sowing practice, one of the key seed mix design challenges is to control the ratio between forbs and geophytes to create an ideal sowing mix formula (Hitchmough and Wagne, 2013). In the competition research in Chapter 5, for scientific reasons all of the species were sown at the same target density within a give community. In many cases it was obvious that this would have negative effects on the slower growing species.

Information on the growth and development of South African species has been applied to the development of a South African plant community of 1000 m^2 that was sown at RHS Wisley garden in April 2013. The target for seedling emergence of dominants such as *Berkheya purpurea* was only 2 plants/m^2, with the highest densities of 10 plants per m^2 for very small species such as *Delosperma basuticum*. Geophyte species are typically sown at rates to achieve target densities of between 0.5 and 1 plant/m^2.

The flower colour, size and leaf texture of many South African species produced very interesting visual impact even in the first two years, and this gives a great potential in the new design for greenspace. The unfamiliarity of the South African species is also very useful as communities of these species are distinctively different in appearance to existing prairie or meadow species. The aesthetic impact of the species was demonstrated on site at the London Olympic Park. The response from the public on the design meadows was very encouraging (Figure 7.1). Naturalistic repeating pattern design combined with a diversity of plant forms and texture creates very high visual impact.

Figure 7.1 The colourful South African montane grassland species attract public in London Olympic Park. Picture was taken by James Hitchmough July 30th 2012.

7.2 What criteria should be considered when selecting SA plants for naturalistic planting?

Through a series of studies conducted a few species can be categorized based on the species response to treatment and the climate during the study. In the hardiness experiment (Chapter 4), there are 7 species resistant to extreme winter cold and wetness in 2010 and which survived and bloomed in 2011. Species such as *Berkheya multijuga*, *Senecio macrospermus*, *Haplocarpha lyrata*, *Gladiolus saundersii*, *Bulbine narcissifolia*, *Dierama robustum*, *Dierama reynoldsii* were the species most tolerant to extreme cold weather and wetness in 2010. Species with very slow-growth characteristic should be avoided to prevent the species being eliminated due to competition from fast-growing species. The most important thing in designed communities is that the visual impact of the slow-growing species takes a long time to develop, and it will reduce the aesthetic value of a developed community. Species such as *Agapanthus inapertus, Eucomis bicolor, Merwilla plumbea* and *Crinum macowanii* that are slow to develop can also be planted as fillers in designed community by planting seedlings randomly to fasten the growth to achieve maturity stage and flowering. Some of the species are evergreens and are able to maintain the greenery in the community for much of the year, for example, G*eum capense, Berkheya multijuga, Senecio macrospermus* and *Dierama robustum*. *Kniphofia hirsuta, Diascea tugelensis*, and *Kniphofia uvaria* are also largely evergreen.

The important factor in designing naturalistic planting in urban greenspace is long flowering season and attractiveness. This characteristic is very significant in enhancing the aesthetic impact of the community. Species that have a long flowering period (> 6 weeks) and give a long colour impact in community are species like *Diascia integerrima*, *D.tugelensis*, *D. rigescens*, *Geum capense*, *Gazania linearis*, *Haplocarpha lyrata* and *Kniphofia uvaria*. However, the critical need is species which flower late to give more colour impact in the autumn. As shown in chapter 6, *Kniphofia uvaria*, is the species that is capable of flowering until November, in the first year and October in the second year.

There are also species that have high aesthetic value and resistant to cold stress but in which germination and growth rate was very slow when sown directly to the field. In this study, species like *Merwilla plumbea*, *Eucomis bicolor*, *Agapanthus inapertus*, *Dierama pulcherrimum* and *Crinum macowanii* are species with a very slow growth rate. These characteristics typically result in , sown surfaces being too open and allowing weedy species to grow in the community (Perrow and Davy, 2002). Where, as in the case of *Agapanthus inapertus*, the seedlings seem to be highly shade tolerant and survive under the canopy of the faster species, combining these species with faster growing species gets around these problems. In this case species like *Crinum* spp. which ultimately form very large plants and have very attractive flower and tolerance to cold temperatures (Lehmiller, 1996), these can be added to the community by planting seedlings to provide exciting visual effects in the designed plant community.

7.3 Can communities of SA species be established by field sowing?

Although seedlings of South African geophytes are typically slow to emerge and grow, they have high overall emergence values. With the forbs they are typically fast growing and emergence comparable with European and North American forbs (Sayuti and Hitchmough, 2013). As such overall, when mixtures of forbs and geophytes are employed biology is no real barrier to creating successful communities.

Direct sowing is best undertaken in March and April to provide a longer time for species to grow, particularly species with slow growth. Although sowing seed in May showed high percentage of emergence and growth rates at the early growing stage but the new seedlings were exposed to the drought in that period. March and April sowing was also the best time to get a high emergence percentage and a high number of seedlings establish. Although pre-germination treatment can help speed up the germination-emergence rates of the slow species, but it does not make a significance difference scientifically. Pre-germinated seed from pre-treatment is more difficult to handle when sown directly, as the radicals may have started to emerge and when sown directly in the field in large quantities these may be damaged, reducing the emergence rate. The tolerance to desiccation during sowing practice is also an unanswered question. The species identified in this study have high potential to be used as a new planting design in plant communities, but this requires a lot of seed supply.

Only about 10 to 12 species supplied by the supplier Jelitto Seeds are commercially available at present in volume. There are also other providers such as Silverhill Seeds and Lifestyle Seeds, however, they supply seed in small quantity around 100 seeds or a few grams of seed derived from small scale ex situ plants or small collections from wild populations. The seeds used in this study were collected from production by the existing plants that survived from previous experiments and Hitchmough's germplasm collections that began around 2005. There was some evidence of the species are becoming more resistant to extreme winter in the UK across the course of the research, for example *Helichrysum aureum* seed used in this experiment is from the sixth generation that has survived in Sheffield, and is much more reliable than the seedlings from the first wild collection.

Most of the species across the communities in experiment 3 showed good growth performance and flowering during a second year of this experiment was carried out. This shows that SA grassland species communities can be established in urban park and greenspace under the UK climate. Within two growing seasons the cover values for all nine communities reached 80% cover after 150 days, with the exception of the geophyte only community. Geophytes species with slower growing rates reached maturity and flowered in summer and autumn 2012. However, there were species in this group that did not reach the size required for flowering. In a third growing season, the expectation is for an the increase in the number of individuals flowering within species such as *Gladiolus oppositiflorus*, *Dierama pulcherrimum*, and *Crocosmia masoniorum.* Planting container grown plants of these types of species would be another way to get around the long pre flowering period (Hitchmough, 2004).

The risks associated with the use of *Berkheya purpurea* in communities have previously been mentioned. Management in the early stages of community establishment are essential to reduce the density of species that have fast growth rates in order for them not to be too dominant. Maintenance of the communities through spring cutting in the second year gave temporary advantages for the forbs species with the low canopy height as the tall canopy species lost a greater share of their photosynthetic productivity as a result of the cut.. Species with the low canopies are expected to be eliminated in the competition for resources and space with the tall canopy species such as *Kniphofia uvaria*, *Agapanthus inapertus*, *Crinum macowanii*, *Berkheya purpurea* in the longer term. The experiments have however thrown up two species of low species that appear to have reasonable shade tolerance, *Diascia tugelensis* and *Geum capense* (Pooley, 2005) ; and which may persist as the taller species develop in the future.

The method to maintain stability of the plant community after winter also has to be given emphasis. In the natural habitat, lightning and human pastoralist initiated burning of the grassland and strongly influences community development and the persistence of individual species (Mucina and Rutherford, 2006; Cowling et al., 2004). Maintenance through burning using propane fuelled flame gun after the winter has a dramatic effect on reducing winter weed colonisation (Hitchmough and De La Fleur 2006) but may also. harm or kill forbs species such as *Diascia integerrima* and *Diascia rigescens,* which are typically more associated with more open grassy vegetation which is less subject to regular fire. As of yet however we do not know what the effect of burning will be on these species. If burning does kill these species it will reduce species diversity in communities and will interfere with the structural design of canopy multilayer composition. Therefore, the competition experiment (Chapter 5) should be monitored for a longer period of 2 or 3 years to assess the stability of the established community and also competition between species before it is subject to management burning. Data from the competition experiment over a five year period will be required to determine accurate information on the most appropriate species and there survivorship, the most dominant species in the long run, the most productive species in generating new seedlings and proper maintenance and management methods after winter on community stability and establishment.

7.4 What effect do sowing mulch characteristics have on emergence, establishment and longer term survival?

Sand serves as an effective mulch to control weeds from the underlying soil weed seed bank to prevent competition with species in the community. In addition, given irrigation during the germination window it is also a valuable medium for seed sowing to create the plant community. A sand depth of 50 mm to 70 mm is necessary to prevent weeds from growing and competing with the species in the community. In the absence of a sowing mulch to control competition from highly competitive weeds, the slow growing species used in this research would rapidly be eliminated through competition.

The addition of mulching depth will reduce weed competition and increase moisture reduction, especially near to the medium surface and root zone. Coarse sand is most effective in terms of reducing weed seed establishment from windblown seed, however a percentage mall fine particles, which are improves contact with the moisture films and improves the role of the sowing mulch in germination of the sown species. Thus moisture retention is a major issue in sand selection.

The soil like material (John Innes No. 1) used in Experiment 2 gave the highest percentage of emergence in the experiments; due to the higher capacity than sand to supply moisture to germinating seeds (Chapter 4). Besides always providing suitable moisture content for seeds to germinate better it additionally can keep a higher surface temperature than sand at night. However, excessively high moisture retention will damage some species that do not tolerate extremely wet substrates. Many more substrate need to be tested on South African montane grassland species, such as were studied by Hitchmough et al., (2001) in relation to emergence and growth of eleven forbs and grasses native to the Britain and Central / Southern Europe grow on sand, sand/brick rubble, sand/subsoil and top-soil. In experiment 2 (Chapter 4), a greater depth of sand was very detrimental to overwintering survival of many sown species (see 7.1.5 below).

7.5 Are South African plant communities able to survive winter cold and wetness?

Many species of SA grassland species are cultivated in the UK and reliably survive typical winter cold and wetness. As previously discussed in Sheffield we have 5 to 6 years of experience of these species in winter but mostly in large pots in which plants are more likely to exhibit root system death at temperatures at which they are unlikely to be damaged if planted in the ground due to the very high thermal insertion of soil.

Winter wetness found not to have significant effects on species that are classified as species that are sensitive to wetness; especially those come from dry habitat (Table 4.1). Species such as *Bulbine narcissifolia* originally grow in conditions of low soil moisture in their habitat showed a high survival percentage (68.75%). Although in November, and February received more rainfall and increase soil moisture in a plot, but 15 of the 22 species are able to survive in the soil. It can be suggested that the moisture is not a major factor causing the death of species in winter 2010/2011, but species will benefit from the ability of the soil to maintain a higher temperature at night. A lot of rains in November before freezing in December give soil more advantage of keeping temperature in high moisture content.

It is apparent that some species are more cold and wet sensitive than others even when making comparisons between the species occurring the same areas with South Africa. *Watsonia* species are for example far more subject to winter kill of their foliage than are for example other Iridaceae such as *Dierama* or *Moraea* from the same habitat, There are similar variations within genera. In the competition experiment all of the species with the exception of *Gladiolus geardii, Watsonia* species and *Merwilla plumbea* have all survived close to the lowest recorded screen temperatures on record in Sheffield (-8^{o}C). *Helichrysum aureum* is one example of a forbs species whose cold and winter wet tolerance has increased across the six generations in the Sheffield climate.

Some species during the course of the research *Bulbine abysinnica,* for example, showed they are sensitive to wetness in the summer, particularly when growing in pots in which the lower part is typically subject to anaerobic condition. The anaerobic conditions will stop roots respiration and eventually cause the plants to die. The early symptoms of water logging damage is often premature senescence of the lower leaves caused by the direct effects of inadequate oxygen supply to the roots (Trought and Drew, 1980).

7.6 How long to communities of SA species typically look attractive?

In this study, the phenological aspects of SA grassland were recorded from the first and second year of the growing season. Plant communities will remain for a further 2 or 3 years for further evaluation. Results from the experiment 3 (Chapter 6) on phenological data show that flowering phenology on SA grassland species was differs greatly in the first two years. The first year saw a lot of forbs species flowering and only a few species of geophytes. Seven forbs species in the low and medium canopy height categories started flowering at the beginning of July and continued until November 2011. The flowering of SA species in the first year was delayed until species were large enough to flower, hence in the first year, the community had maximum aesthetic impact in September 2011 (Figure 6.4d).

In the second year, most of the species flowered earlier starting in May approximately about two months different from the first year. The total number of species flowering also increased about 50% (22 species) compared to the first year (Figure 6.2). Many of the geophytes species were flowering in the second year, but later in the year than the forbs. The peak attractive flowering impact was in July 2012 (Figure 6.5d). During the growing phase, although few plants were in flower, the texture of the leaf, canopy structure and colour of the fresh leaves also help contribute to maintain aesthetic impact. However, when the density of a flower decreases at the end of summer, the aesthetic impact was affected.

Not only did the colour decrease, but the senescence of leaves and stems due to aging or changes by winter temperatures also resulted in a less attractive view.

To compensate for the less attractive views requires more late flowering species to add colour and aesthetic values to the community, especially at the end of the flowering phase. Several species are suggested to be used in increasing the flowering period in the community *Hesperantha cocinea*, *Gladiolus oppositiflorus*, *Gladiolus ochroleucus*, *Nerine bowdenii*, *Kniphofia multiflora*), and *Phygelius* species.

8.0 Recommendation for future research

This study provided the understanding of how to establish South African montane grassland plant communities as a new naturalistic planting design in urban green space. The combination of multi-layer canopy height and types of species, simulate a South African grassland plant community structure in the UK climate. Many forbs, geophytes and grasses have been evaluated to record growth performance, hardiness and biomass production in two growing seasons.

Further investigation is required to explore the species productivity for survival, monitor below and aboveground competition, substrate types for mulching and sowing medium and over winter maintenance in the long term. Plant communities in competition experiment (Chapter 5) have been maintained and will be monitored over the next 3 to 4 years. Exposure to different climate condition across an extended evaluation period will provide much better understanding of the dynamics of South African montane grassland communities in urban parks and greenspace in the UK.

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APPENDICES

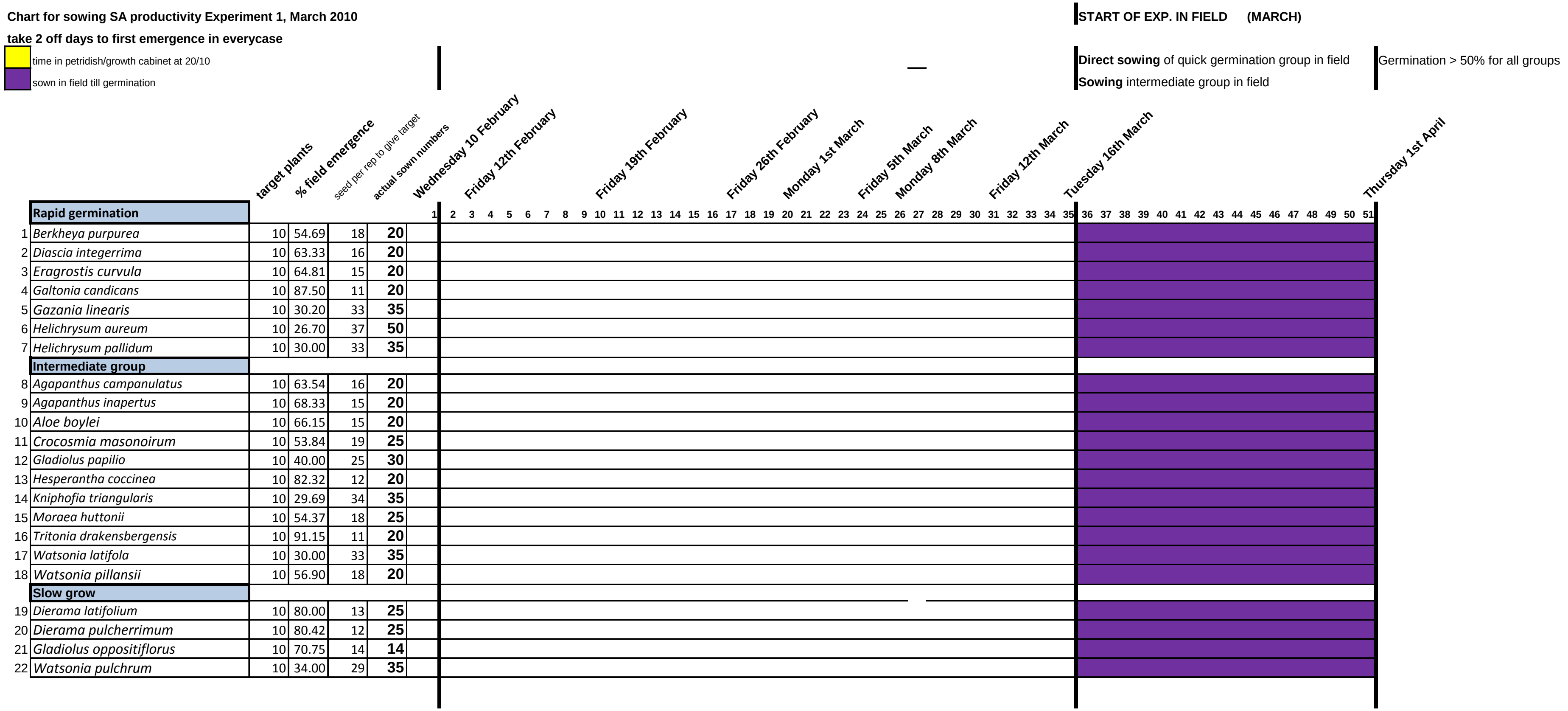

Chart for sowing SA productivity Experiment 1, March 2010

take 2 off days to first emergence in everycase

🟨 time in petridish/growth cabinet at 20/10

🟪 sown in field till germination

START OF EXP. IN FIELD (MARCH)

Direct sowing of quick germination group in field

Sowing intermediate group in field

Germination > 50% for all groups

		target plants	% field emergence	seed per rep to give target	actual sown numbers
	Rapid germination				
1	*Berkheya purpurea*	10	54.69	18	**20**
2	*Diascia integerrima*	10	63.33	16	**20**
3	*Eragrostis curvula*	10	64.81	15	**20**
4	*Galtonia candicans*	10	87.50	11	**20**
5	*Gazania linearis*	10	30.20	33	**35**
6	*Helichrysum aureum*	10	26.70	37	**50**
7	*Helichrysum pallidum*	10	30.00	33	**35**
	Intermediate group				
8	*Agapanthus campanulatus*	10	63.54	16	**20**
9	*Agapanthus inapertus*	10	68.33	15	**20**
10	*Aloe boylei*	10	66.15	15	**20**
11	*Crocosmia masonoirum*	10	53.84	19	**25**
12	*Gladiolus papilio*	10	40.00	25	**30**
13	*Hesperantha coccinea*	10	82.32	12	**20**
14	*Kniphofia triangularis*	10	29.69	34	**35**
15	*Moraea huttonii*	10	54.37	18	**25**
16	*Tritonia drakensbergensis*	10	91.15	11	**20**
17	*Watsonia latifola*	10	30.00	33	**35**
18	*Watsonia pillansii*	10	56.90	18	**20**
	Slow grow				
19	*Dierama latifolium*	10	80.00	13	**25**
20	*Dierama pulcherrimum*	10	80.42	12	**25**
21	*Gladiolus oppositiflorus*	10	70.75	14	**14**
22	*Watsonia pulchrum*	10	34.00	29	**35**

Figure A3.1 Chart for sowing South African grassland species on the same day. Species was sown base on actual seed numbers for each replicate. All species was directly sown in field on 16th March 2010.

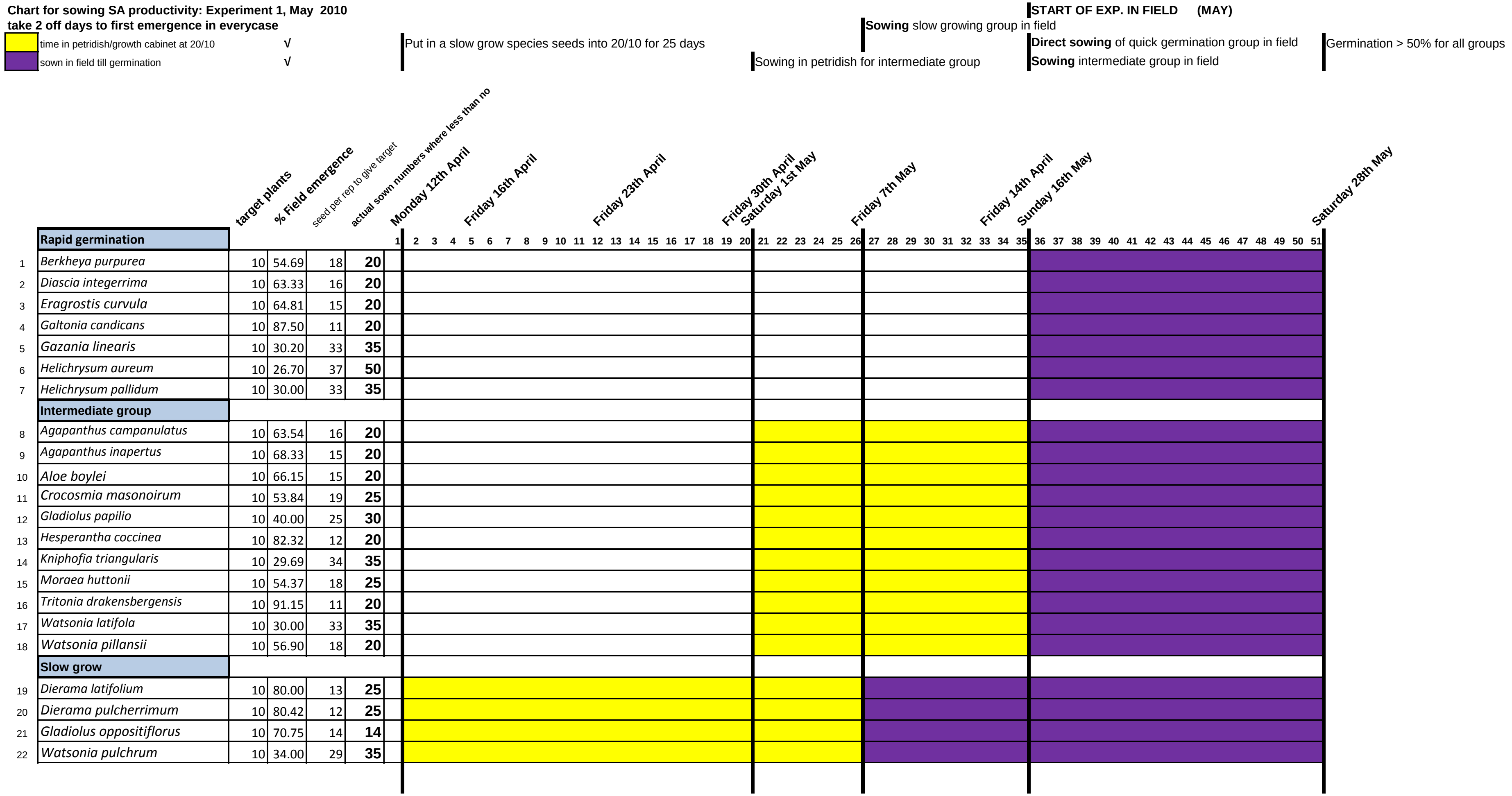

Chart for sowing SA productivity: Experiment 1, May 2010
take 2 off days to first emergence in everycase

🟨 time in petridish/growth cabinet at 20/10 √
🟪 sown in field till germination √

Put in a slow grow species seeds into 20/10 for 25 days

Sowing in petridish for intermediate group

Sowing slow growing group in field

START OF EXP. IN FIELD (MAY)

Direct sowing of quick germination group in field

Sowing intermediate group in field

Germination > 50% for all groups

		target plants	% Field emergence	seed per rep to give target	actual sown numbers where less than no
	Rapid germination				
1	*Berkheya purpurea*	10	54.69	18	**20**
2	*Diascia integerrima*	10	63.33	16	**20**
3	*Eragrostis curvula*	10	64.81	15	**20**
4	*Galtonia candicans*	10	87.50	11	**20**
5	*Gazania linearis*	10	30.20	33	**35**
6	*Helichrysum aureum*	10	26.70	37	**50**
7	*Helichrysum pallidum*	10	30.00	33	**35**
	Intermediate group				
8	*Agapanthus campanulatus*	10	63.54	16	**20**
9	*Agapanthus inapertus*	10	68.33	15	**20**
10	*Aloe boylei*	10	66.15	15	**20**
11	*Crocosmia masonoirum*	10	53.84	19	**25**
12	*Gladiolus papilio*	10	40.00	25	**30**
13	*Hesperantha coccinea*	10	82.32	12	**20**
14	*Kniphofia triangularis*	10	29.69	34	**35**
15	*Moraea huttonii*	10	54.37	18	**25**
16	*Tritonia drakensbergensis*	10	91.15	11	**20**
17	*Watsonia latifola*	10	30.00	33	**35**
18	*Watsonia pillansii*	10	56.90	18	**20**
	Slow grow				
19	*Dierama latifolium*	10	80.00	13	**25**
20	*Dierama pulcherrimum*	10	80.42	12	**25**
21	*Gladiolus oppositiflorus*	10	70.75	14	**14**
22	*Watsonia pulchrum*	10	34.00	29	**35**

Figure A3.2 Chart for sowing South African grassland species on the same day and across a staggered time period. Species was sown base on actual seed numbers for each replicate. Slow growing species was sown on 7th May while rapid and intermediate species was directly sown in field on 16th May 2010.

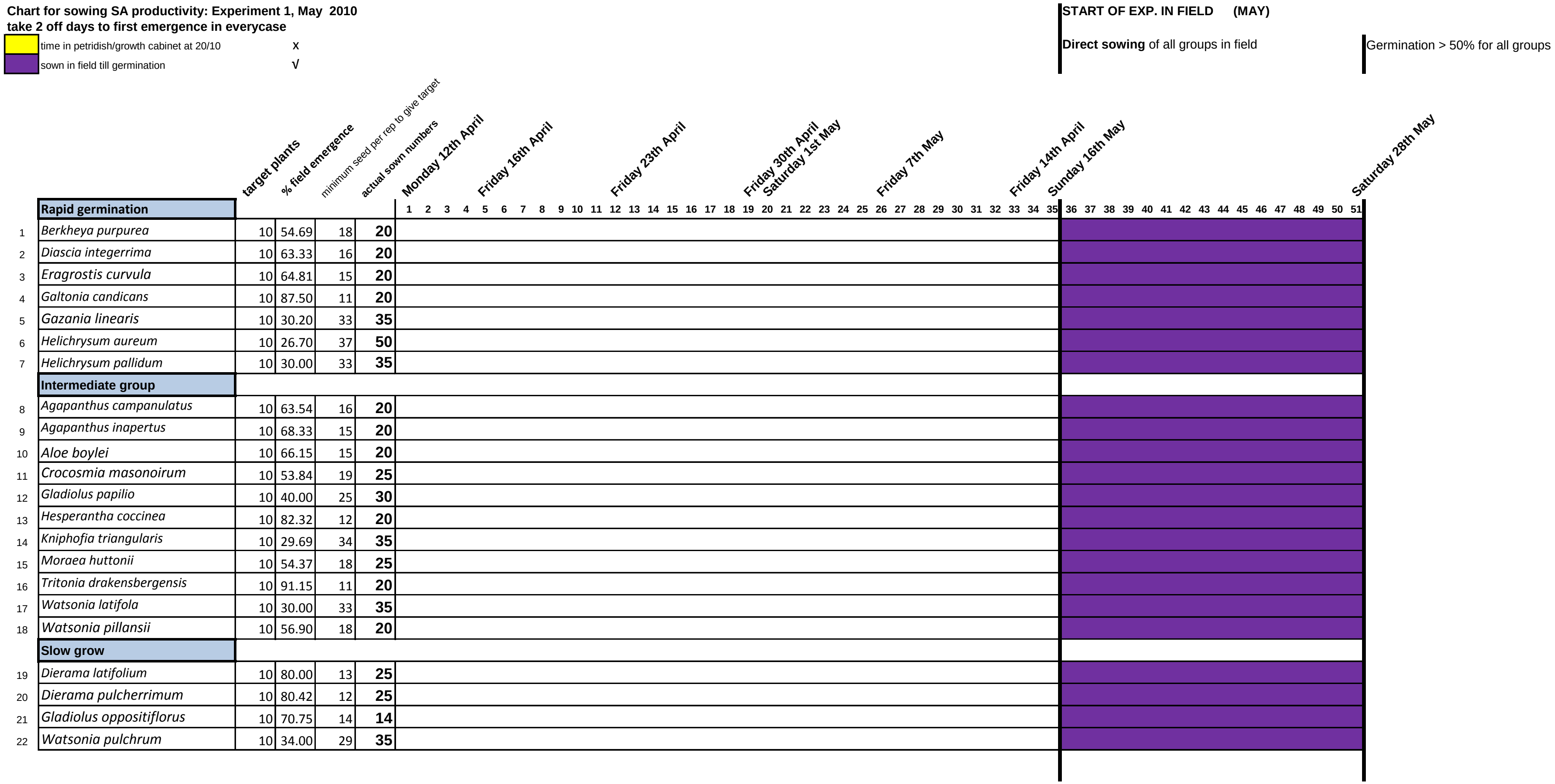

Chart for sowing SA productivity: Experiment 1, May 2010
take 2 off days to first emergence in everycase

🟨 time in petridish/growth cabinet at 20/10 x
🟪 sown in field till germination √

START OF EXP. IN FIELD **(MAY)**

Direct sowing of all groups in field

Germination > 50% for all groups

		target plants	% field emergence	minimum seed per rep to give target	actual sown numbers
	Rapid germination				
1	*Berkheya purpurea*	10	54.69	18	**20**
2	*Diascia integerrima*	10	63.33	16	**20**
3	*Eragrostis curvula*	10	64.81	15	**20**
4	*Galtonia candicans*	10	87.50	11	**20**
5	*Gazania linearis*	10	30.20	33	**35**
6	*Helichrysum aureum*	10	26.70	37	**50**
7	*Helichrysum pallidum*	10	30.00	33	**35**
	Intermediate group				
8	*Agapanthus campanulatus*	10	63.54	16	**20**
9	*Agapanthus inapertus*	10	68.33	15	**20**
10	*Aloe boylei*	10	66.15	15	**20**
11	*Crocosmia masonoirum*	10	53.84	19	**25**
12	*Gladiolus papilio*	10	40.00	25	**30**
13	*Hesperantha coccinea*	10	82.32	12	**20**
14	*Kniphofia triangularis*	10	29.69	34	**35**
15	*Moraea huttonii*	10	54.37	18	**25**
16	*Tritonia drakensbergensis*	10	91.15	11	**20**
17	*Watsonia latifola*	10	30.00	33	**35**
18	*Watsonia pillansii*	10	56.90	18	**20**
	Slow grow				
19	*Dierama latifolium*	10	80.00	13	**25**
20	*Dierama pulcherrimum*	10	80.42	12	**25**
21	*Gladiolus oppositiflorus*	10	70.75	14	**14**
22	*Watsonia pulchrum*	10	34.00	29	**35**

Figure A3.3 Chart for sowing South African grassland species on the same day. Species was sown base on actual seed numbers for each replicate. All species was directly sown in field on 16th May 2010.

Figure A5.1 Tips for landscape practitioner/ gardener to setting up the landscape plant community in urban greenspace

- The soil surface was cultivated to a depth of 150 mm to 300 mm using a Kubota mechanical soil cultivator. The soil surface then levelled manually using garden rakes.

- Weeds and other vegetation in the plots were sprayed prior to cultivation using a glyphosate herbicide and in some cases removed manually.

- Sharp sand was used as a 75 mm deep sowing mulch to prevent weed seed germination from within the underlying soil from competing with sown seedlings.

- The overall target density of seedlings 1 m^2 was 100 plants. This is the total of all seedlings present and was chosen as a compromise between not requiring too much seed and not having very small numbers of individuals of individual species when a species is present at a very low ratio overall.

- The seeds for each treatment sub-plot was mixed with a compost sowing carrier to obtain uniform seed distribution and to easily identify that the distribution was indeed uniform from the different colour of compost and sand sowing mulch.

- Raking was used to distribute the seeds evenly into the sowing mulch. Wire mesh was placed on the top of each plot to avoid seedbed surface digging by foxes at night.

- Slug and snail poison with active ingredient metaldehyde was used with the rate is about 40 pellets/m^2 every two weeks until the end of May to reduce the risk of seedling loss from this source prior to the first seedling count. Further monitoring was done around the plots once a month to prevent slug and snail damage in humid weather conditions.

- Where no significant rain (>8 mm) occurred within a 4 day period, plots were irrigated at 2 days intervals to return the sand to field capacity.

- Weeding in each plots was done manually especially at the early stage of seed emergence as sand sometimes contains weeds.

- As the number of seedlings actually present post sowing is dependent on what germinates and emerges, a sufficient number of seedlings for each treatment combination to meet the individual species target needed to be identified. Species that had more seedlings than target were thinned post count and species that had insufficient had seedlings added to the plots.

Figure A 5.2 List of species robustness and comments from the author on performance of species base on two years growing period in competition experiment.

Species	Robustness*	Comments
Agapanthus inapertus	2	A slow-growing species, take a long time to develop. It is suitable as fillers. High shade tolerance.
Berkheya purpurea	1	Have a rapid growth rate and dominant in producing biomass, capable of covering the ground faster.
Crinum macowanii	2	Slow growing and take a long time to develop but suitable as fillers. The leaf is highly favoured by slugs grazing.
Crocosmia masonoirum	1	Robust and hardy species in winter cold and wetness, faster recover after winter and flowering well in a second year from August to September (5 weeks).
Diascia integerrima	2	Fast-growing and capable of covering the ground faster, sensitive to wetness and fungal organisms, have long flowering period (>6 weeks).
Diascia rigescens	2	Fast growing and faster recover after winter but not too sensitive to wetness and fungal organisms, have a long flowering period (> 6 weeks).
Diascia tugelensis	1	Largely evergreen, capable of covering the ground faster, have reasonable shade tolerance and long flowering period (> 6 weeks).

** 1 - High robustness; 2 - Medium robustness; 3 - Low robustness*

Species	Robustness*	Comments
Dierama mossii	1	Dieback in winter and recover in spring. Flowering well in the late spring in the second year (3-4 weeks).
Dierama pulcherrimum	1	Dieback in winter and recovery in spring. Flowering well in the late spring and early summer at the second year.
Eucomis bicolor	3	Slow growing and take a long time to develop, suitable as fillers and the leaves always attacked by slugs /insect
Galtonia candicans	2	A medium growth rate and flowering in the middle of July to early August in the second years (within 4 weeks)
Gazania linearis	2	Fast growing and capable of covering the ground faster, have a long flowering period (> 6 weeks)
Geum capense	1	Largely evergreen species, capable of covering the ground faster, shade tolerance and have a long flowering period (> 6 weeks)
Gladiolus dalenii	1	Have rapid growth, flowering in August know first and resistant to extreme cold temperatures.
Gladiolus geardii	2	Less hardy species, fast recover in early spring and flowering in mid and late spring.
Gladiolus oppositiflorus	2	Have a slow growth rate but is able to compete with species that have grown up, Tolerance to shade.

** 1 - High robustness; 2 - Medium robustness; 3 - Low robustness*

Species	Robustness*	Comments
Gladiolus papilio ruby	2	Fast growing and flowering in the first and second years, tolerance to extreme cold temperatures.
Gladiolus saundersii	2	Nursery using spawn for this species provide a low percent survival. This situation is not due to species resistant to shading and killed competing with larger species.
Haplocarpha scaposa	1	fast growing and flowering well in the first and second. Have seeds that are light and easy to carry water when doing too much watering.
Helichrysum aureum	1	This species has undergone a long climate adaptation. The seeds used were from the 6th generation. It is very tolerance to extreme cold weather. Not favoured by slugs and insects. It grew and flowered well.
Kniphofia hirsuta	1	Dieback in winter and recovery in spring. Flowering well in the late spring at the first year.
Kniphofia ritualis	1	Dieback by winter and fast recovery in early spring. Spring flowering well in the first and second year.
Kniphofia triangularis	1	Dieback by winter and fast recovery in early spring. Spring flowering well in the first and second year.

** 1 - High robustness; 2 - Medium robustness; 3 - Low robustness*

Species	Robustness*	Comments
Merwilla plumbea	3	Very slow growing species and still small after 2 years growing windows.
Morea spathulata	1	Slow growing in a first year and good recover after winter, this species also tolerance to extreme cold weather, not flowering at all during the observation years.
Tritonia drakensbergensis	1	Fast growing, have a high germination rate and low mortality rate, flowering above 4 weeks in the first and second years.
Themeda triandra	1	This species has a rapid growth rate and high survival rate but there are some species that die due to cutting too low canopy and cause the loss of high-biomass before winter.
Watsonia galpinii	2	Have a high survival rate and faster recovery rate in the second year. This species also show a good flowering performance.
Watsonia pillansii ex wisley	2	Have a high survival rate and faster recovery rate in the second year. This species also show a good flowering performance.

** 1 - High robustness; 2 - Medium robustness; 3 - Low robustness*