The influence of soil salinity on regeneration of annual *Medicago* pastures in the Swartland area of South Africa

by

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Declaration

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Abstract

Soil is a critical aspect in food security and represents the difference between survival and extinction of all living organisms. However, most environmental reports suggest that various agricultural activities are responsible for soil degradation and thus can hinder sustainable food production. Soil salinity can be caused by agricultural activities, and it has become a major global concern. Farms in the Swartland area of the Western Cape province in South Africa have soil salinity problems which is affecting farm productivity and profitability. This study aimed at evaluating the influence of soil salinity on the regeneration of annual medic (*Medicago* spp.) pastures. The study was carried out on two farms which practice conservation agriculture in the Swartland area. The study highlights the changes in medic productivity in terms of seed production, seedling establishment and herbage production across a soil salinity gradient. The low productivity (saline) soils had the lowest ($P < 0.05$) medic seed numbers, seedling establishment and herbage yield compared to the medium and high productivity (none saline) soils. The use of gypsum was not effective in the alleviation of soil salinity, therefore, the use of salt tolerant legumes such as messina (*Melilotus siculus*), on the saline soils was recommended.

Keywords: hard seed, *M. polymorpha*, *M. truncatula,* medics, soft seed

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Abbreviations and acronyms

ARC	Agricultural Research Council
CA	Conservation Agriculture
DM	Dry Matter
ER	Electrical Resistance
ESP	Exchangeable Sodium Percentage
FSSA	Fertiliser Society of South Africa
GRM	General Regression Model
MDG	Millennium Development Goals
SAR	Sodium Adsorption Ratio
SARDI	South Australian Research and Development Institute
SE	Standard Error

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Chapter 1: General introduction

1.1 Introduction

Soil is a critical component of the earth's biosphere with various important functions such as the production of food and fibre (Doran and Zeiss 2000). Therefore, soil is a critical aspect in food security. The thin layer of soil covering the surface of the earth represents the difference between survival and extinction for both plants and animals, including meso- and microorganisms (Doran et al. 1996). However, it is only fertile or healthy soil that can be used for sustainable food production. Yet most environmental reports suggest that various agricultural activities are responsible for the degradation of the earth's productive land (Oldeman 1994). Depreciation of soil quality is a serious threat to sustainable food production (du Preez 2003; Swanepoel et al. 2015a).

Soil quality may be defined as a measure or capacity of a soil to sustain certain type of plant and animal productivity, as well as to maintain or enhance water and air quality (Karlen et al. 1997). In the last few decades, much agricultural emphasis was put on increased production and yield. This was termed “the green revolution” (Pinstrup-Andersen and Hazel 1985). Production was based on increased use of synthetic nitrogen fertilisers, superior plant seed varieties, machinery, herbicides and pesticides (Pinstrup-Andersen and Hazel 1985). However, with time, it was realised that “the green revolution” was not a sustainable form of farming. It may have contributed to the decline in soil quality, and general health of the farming community (Pinstrup-Andersen and Hazel 1985; Derpsch 2004). Instead, focus is now not only on increased production, but also on the soil and the people on or around the farm. Soil quality can therefore be regarded as the foundation of the entire agricultural system. Soil quality encompass the soil's physical, chemical and biological properties within the constraints set by climate, ecosystem as well as by the management and land use decisions. Soil quality can be used to refer to the general ability of the soil to sustain and maintain both plant and animal health (Doran and Zeiss 2000).

Even though it is well-known that leguminous plants can have a significant positive effect on soil fertility by fixing nitrogen, the growth and establishment of the legumes is also affected and limited by soil quality. Annual medics (*Medicago* spp.) pasture systems, also referred to as ley farming systems, were first developed in southern Australia. It is successfully used in the Mediterranean climate zones of North Africa, the Middle East and South Africa as the production system's forage component

(Porqueddu et al. 2016; Kotze et al. 1998). In the Mediterranean regions of South Africa, cash crops such as wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), canola (*Brassica napus*) and oats (*Avena sativa*) are cultivated in rotation with leguminous plants such as the annual medics, clovers (*Trifolium* spp.), lucerne (*Medicago sativa*) and lupins (*Lupinus* spp.) (Porqueddu et al. 2016). The incorporation of legumes in the pasture system improves the overall productivity of the system, forage quality and livestock production (Botha et al. 2008, Chatterton and Chatterton 1984). For that reason, legume pastures may improve the overall profitability of the farm (Knott 2015) if managed appropriately. However, growth and regeneration of annual medics is known to be severely limited by soil phosphorus shortage and soil salinity (Muir et al. 2001), which is a common limitation in Mediterranean zones. Therefore, more work need to be done to find possible ways of improving the regeneration of leguminous pasture systems.

Even though medic pastures play an imperative role in economic sustainability of crop rotation systems in South Africa, there is paucity of information on this aspect of the system (Swanepoel et al. 2016). Poor regeneration and poor persistence of annual medics in crop rotation systems is however one of the factors limiting production (Kotze et al. 1998). One of the reasons for poor regeneration has been attributed to the depth of tillage when medics are used in rotation with wheat, whereby a deep disc plough (50 – 250mm) drastically reduced the percentage of medic seeds that regenerate in a crop rotation system (Kotze et al. 1998).

There are other factors that may reduce the ability of medic pastures to successfully regenerate on an annual basis. Some of the factors may be related or caused by the stocking rate on the farm, amount of fertiliser applied, degree of soil erosion, soil compaction and other management practices as well as the type of livestock reared on the farm. For example, Simao Neto et al. (1987) confirmed earlier findings by Harmon and Keim (1934) that livestock ingest a great amount of seeds as they forage. Yet, cattle do not retain or completely digest small seeds such as the medic seed. Most of the ingested seeds pass though the digestive system of cattle and may be available to aid in the regeneration of the pasture (Simao Neto et al. 1987). Sheep were found to be more effective than cattle in digesting seeds hence if the pasture is foraged by sheep, then a great amount of pasture seeds may be digested and thus will not be available to aid in the regeneration process (Simao Neto et al. 1987). If the medic pastures are to be able to re-generate, then grazing must be managed in a way that a large amount of seed are produced to compensate for the others that are lost during digestion by farm animals.

1.2 Problem statement and Justification

Approximately 25% of South African soils are seriously degraded because of erosion, soil compaction, acidification, salinisation, soil pollution or a decline in soil organic matter (du Preez 2003; Swanepoel et al. 2015d). More specifically, Görgens and de Clercq (2005) showed that there has been a decline in water quality in river systems in the Western Cape over the past three decades, which can be ascribed to dryland salinity. Dryland salinity is mobilisation of salts to the soil surface through seasonal water table rise (Bennett et al. 2009). Dryland salinity is also a major problem in Western Australia (Clarke et al. 2002). Yet, in South Africa, there are no studies that assess or evaluate the impact of soil salinity on the regeneration of medic pastures. Poor regeneration and poor persistence of annual medics in crop rotation systems is currently one of the factors limiting production (Kotze et al. 1998). Medic seed production potential may have a huge impact on the ability of the annual medic pastures to successfully regenerate. Therefore, assessing the medic production potential on saline soils may in the future help to determine some appropriate cultivars or other annual species with similar characteristics, and management tools for use on farms. This, in-turn, may lead to increased livestock and crop production and improved food security in the country. Furthermore, the improved regeneration of medic pastures may eventually lead to an increase in the number of extensively farmed livestock. This is very important as modern consumers are increasingly demanding high quality and healthy meat from extensively farmed livestock with minimum use of external chemical inputs and high animal welfare standards (Labuschagne 2007).

1.3 Aim and objectives

The aim of this research is to evaluate the effect of soil salinity on the production potential of annual medic pastures and its capacity to regenerate.

The objectives are:

- To identify salinity problems in medic pastures.
- To compare medic seed production potential for regeneration on saline and non-saline soil.
- To compare the medic plant density on saline and non-saline soil.
- To compare medic herbage production on saline and non-saline soil

1.4 Hypotheses

Soil salinity:

H_0: Salinity is not a problem in medic pastures.

H_1: There is at least one saline plot in medic pastures which could limit production.

Medic seed production:

H_0: Medic seed production and potential for regeneration is similar for saline and non-saline soils.

H_1: Medic seed production and potential for regeneration on saline soil is lower than on non-saline soils.

Medic plant density:

H_0: Medic plant density on saline and non-saline soil is similar.

H_1: Medic plant density on saline soil is lower than on non-saline soil.

Medic plant biomass:

H_0: Salinity has no influence on medic plant biomass production on saline and non-saline soils.

H_1: Medic plant biomass production on saline soil is lower than non-saline soil.

Chapter 2: Literature review

2.1 Introduction

Due to increased technology and advancement in knowledge, global food production has steadily increased over the last decades (Charles et al. 2010). Nonetheless, Godfray et al. (2010) predicts that the world is faced with a major challenge of sustainably supplying food to all people. With the world population expected to increase from seven billion to approximately nine billion people by 2050 (Godfray et al. 2010). More food will need to be produced sustainably from the limited agricultural areas that are available. The increasing human and animal population increases pressure on the land (Swanepoel et al. 2015a). Africa is not spared by the population increase and Southern Africa is likewise affected.

According to Goldblatt (2010), the human population in South Africa has been steadily growing at a rate of about two percent per annum. This means that if the current trend in population growth is maintained, then the population of 49 million in the year 2009 is expected to grow to about 82 million by the year 2035 (Goldblatt 2010). However, some recent studies by Go et al. (2013) states that the population growth rate has declined. Therefore, the population in South Africa is projected to rise to about 66.4 million people up from the current 51.8 million. The population is projected to further rise to about 83.6 million people by 2050 (Go et al. 2013). Regardless of which population projection method is used, fact is the population will increase considerably. This means that the overall food production in South Africa, like the rest of the world must increase, but on the same limited land.

The increasing population pressure threatens the sustainability of rangelands and cultivated pastures. These rangelands and cultivated pastures contribute significantly to food security in the region (Swanepoel et al. 2015a).

Many cultivated pastures incorporate leguminous plants. The leguminous plants not only provide feed for the farm livestock but also provide a reliable source of nitrogen for the soil (Graziano et al. 2010). For that reason, some native rangelands in South Africa and other parts of the world have been converted to cultivated pastures as to increase productivity (Swanepoel et al. 2015c) and therefore contribute to increased food security.

In South Africa, the studies by van Heerden and Tainton (1987) revealed that the Rûens area of the southern Cape has legume based pastures that are rotated with wheat. The main dryland pastures may rotate wheat with lucerne and annual medics (*Medicago truncatula and M. polymorpha*). Lucerne was the most widely used pasture system for sheep production and in rotation with small grains and canola (van Heerden 2012). The use of such pastures with high quality forage leads to increased productivity of the livestock and may contribute to increased food security. In many ley-farming systems, annual reseeding leguminous plants such as the medics are used in rotation with cereal crops (Graziano et al. 2010). The legumes fix atmospheric nitrogen and increase the available soil nitrogen supply (Clark 2014).

Challenges arise when it comes to choosing to correct soil management practices that promote development of good soil qualities but at the same time enabling the production of more food to feed the growing global population. Practices such as deep tillage and over irrigation in intensive farming systems tend to cause soil degradation whilst reduced or minimum tillage practices improve soil quality (Karlen et al. 1994, 2013). Concerning soil nutrition, erosion and use of fertiliser, Pretty et al. (2011) came up with a list of one hundred important questions that need to be researched. Question number twelve asks how salinisation can be prevented and remedied? (Pretty et al. 2011). The question on salinity is an important one especially when considering the saline soils on some farms in the Swartland area of the Western Cape in South Africa. Soil salinity has been known to adversely affect most agricultural cereal crop growth (Podmore 2009a). Soil salinity has other detrimental effects such as reduced agricultural production and low profitability of the farming enterprise. The reduced productivity and profitability reduces the overall global food security. This further causes a shortfall on the global Millennium Development Goals set by Food and Agriculture Organisation (FAO 2015). These goals aimed at reducing the proportion of people in the world suffering from hunger by fifty percent, by 2015.

A sustainable form of agriculture is thus needed to boost the production of food to feed the world as the global population continues to rise.

2.2 Sustainable agriculture

There are many different definitions of the term 'sustainable agriculture.' According to Peterson (2011) something is sustainable if it simultaneously achieves economic feasibility, social responsibility or justice and environmental quality. Hence the term 'sustainable agriculture' is clearly described on the Sustainable Agriculture Initiative Platform (SAI Platform) website as: "the efficient production of safe, high quality agricultural products, in a way that protects and improves the natural environment, the social and economic conditions of farmers, their employees and local communities, and safeguards the health and welfare of all farmed species." This means that sustainability can only be achieved if the three named aspects, that is; planet, people and profits are satisfied.

With a view to 2050 when the global human population is expected to be about nine billion (Charles et al. 2010), there is a greater need to produce more food for human consumption. Despite the projected rise in demand of food, the agricultural industry is expected to cope with increased competition for land, water and other resources needed for production. At the same time, there is a need to reduce pollution which may lead to global climate changes. For example, the livestock industry is thought to contribute a significant amount of green-house gases such as methane, nitrous oxide and carbon dioxide (Peterson 2011) from activities such as rumination and excretion of faeces. On the other hand, land tillage practices such as the use of mould board ploughs to turn soil may cause a significant breakdown of soil organic matter through mineralisation (Swanepoel et al. 2015b). The carbon released through mineralisation, along with the nitrous oxide form part of the green-house gases that can cause global warming. The nitrous oxide from the manufacture and poor use of synthetic nitrogen fertiliser is about three hundred times as potent as carbon dioxide in its potential to cause global warming (Peterson 2011).

To produce more food, farmers may be tempted to use more of the synthetic nitrogen fertilisers, but these may eventually cause the decline in soil organic matter and soil life (Swanepoel et al. 2015b). This ultimately means that the sustainable production of food would be nearly impossible since the soil is most likely to be further depleted as farmers aim to produce more. The pollutants from the agricultural activities would also further damage the planet and that would be a direct contradiction to the definition of sustainable agriculture (Peterson 2011) provided above. Excessive use of synthetic fertilisers may also lead to imbalances of the soil nutrients and possibly lead to soil acidification and salinity.

Other activities that may further hinder the sustainability of the agricultural industry may be the reliance and use of pesticides and herbicides. Pimental and Levitan (1986) estimated that less than 0.1 percent of the pesticides that are sprayed on farms reach their intended targets. The rest of the pesticide may simply remain in the environment where it may cause death of beneficial insects such as bees and amphi-pods (Pimental and Levitan 1986). In the long run, the use of such herbicides and pesticides may also cause a massive reduction of biodiversity on the farm. The impacts may be worse if the health of farm workers or any other human near or around the farming communities are affected by some toxic or carcinogenic chemicals that are used as ingredients for the pesticides and herbicides (Zahm and Ward 1998). Some of these toxic ingredients may remain of the agricultural products such that they are consumed by humans. In which case, most humans that eat food produced from conventional farms may contain in their liver, the harmful carcinogens (Curl et al. 2003). Children are said to be more vulnerable as their livers do not have enzymes to breakdown the toxins (Curl et al. 2003).

Above all, the fertilisers, pesticides and herbicides are expensive and may in the long-term push higher the cost of production of the farm and thereby reducing the farming enterprise profitability. This only shows that the sustainability of the agricultural industry is something that need major consideration as the human population increase.

However, it is important to note that the moderate use of synthetic fertilisers, herbicides and pesticides is to an extent very necessary in modern agriculture to ensure food security. In the Western Cape Province, more than 90% of farmers are practicing conservation agriculture (CA) in a bid to make farming a sustainable business (Hardy et al. 2011).

2.3 Farm management systems - past and present

The history of farming shows that for centuries, the early farmers were nomadic (Weston et al. 2000). Farmers practiced monoculture and farmed their land until the initial fertility declined. Then they moved, opened-up new land, and in so doing maintained their productivity and profitability (Weston et al. 2000). By then the human and livestock population was relatively low hence free land or space was readily available, but the same cannot be said about now or the future (Weston et al. 2000). Space that could be taken up for agricultural purposes now should be used to construct buildings and roads. Weston et al. (2000) stated that the availability of fertile land that has not been farmed has become very scarce. Yet the continued cultivation, cropping and removal of grain products continues to reduce soil fertility (Dalal et al. 1991; Weston et al. 2000). The practice of monoculture and conventional tillage involving the turning of soil has been identified as major contributors to soil degradation (Swanepoel et al. 2015b). Such practices have led to drastic soil fertility losses on various agricultural lands. Nonetheless, most of the temperate and Mediterranean regions of the world have been practicing ley farming as a means of maintaining or restoring soil fertility (Weston et al. 2000).

2.3.1 Management systems in SA

South African farmers, like most other African farmers adopted some farming practices from the western countries such as Germany, Britain and the Dutch (Derpsch 2004). The mouldboard was successfully used to plough land that was infested by quack-grass (*Agropyron repens*) in Europe. Derpsch (2004) further explains that the mouldboard was introduced in Africa during the colonial period and it eventually replaced the so called primitive African ploughs. The introduction of tractors made tillage much simpler and farmers believed that the increased tillage led to increased yield. Instead of increased harvest, increased tillage has led to increased soil degradation by erosion, compaction, soil carbon depletion and death of soil microbes amongst others (Dalal et al. 1991; Weston et al. 2000; Derpsch 2004; Swanepoel et al. 2015c). Up to now, some farmers use such tillage practices even though recent studies have shown that reduced tillage is beneficial to the soil (Derpsch 2004; Kassam et al. 2012; Swanepoel et al. 2015b). Knowledge of the harmful impact of the mouldboard and the benefits of reduced or minimal tillage has led to a change in farm management practices with a shift to conservation farming systems. Globally the land under CA was estimated at 72 million ha in 2003 but this figure had increased to about 157 million ha in 2013 (Kassam et al. 2015).

Proper pasture management involved the controlling of grazing as to prevent over grazing (Kassam et al. 2012). Most commercial farms in South Africa make use of rotational grazing in properly set out plots to guard against overgrazing. In such cases, livestock are moved from one plot to another after a certain number of days depending on the type and number of livestock. Proper stocking rate must be followed as this will ensure that some plants or stubble are not consumed and thus are available for use as cover for the soil. Furthermore, some studies in South Africa, on ryegrass have shown that overgrazing causes a reduction in root growth (McKenzie 1996). The reduction in leaf area due to grazing may affect the physiological processes such as photosynthesis and there by lead to poor productivity. However, it is beneficial to have livestock grazing the pastures as they aid in nutrient cycling through animal manure (Swanepoel et al. 2015b). Overgrazing of regenerating pastures, for example by sheep, may lead to depletion of seed in such a measure that less will be available for pasture regeneration in the next phase (Simao Neto et al. 1987; Porqueddu 2001). Animals also play an important role in seed dispersal and scarification (Harmon and Keim 1934; Simao Neto et al. 1987). For example, the burs of the medic seed can cling on to the fur or wool of grazing livestock and may drop elsewhere. Cattle and other large livestock do not efficiently digest small seeds, hence the seed may be scarified as they pass through the digestive system (Simao Neto et al. 1987). Seeds that pass through the alimentary canal may easily undergo the softening phase and therefore may germinate when conditions become favourable.

Fertilisation is also a very important management practice, as it determines the possible establishment of the pasture. Most legume based pastures may need additional phosphorus fertilisers for proper establishment (Clark 2014). Addition of nitrogen fertilisers is rarely necessary with legume based pastures as these fix nitrogen (Dalal et al. 1991; Weston et al. 2000; Swanepoel et al. 2011). Hence care must be taken to prevent unnecessary addition as it may lead to leaching (Swanepoel et al. 2011) and contamination of water systems. There are various soil testing laboratories in South Africa that can conduct soil analysis to determine the appropriate nutrients that need to be added into the soil for best productivity. Also, there are some fertiliser and lime application guidelines that can be used by farmers in decision making regarding fertilisation (Beyers 1994; Swanepoel et al. 2015b). Other farm management practices that need to be adhered to include; pest, weed and disease control (Porqueddu 2001). The pesticides and herbicides, however, need to be used in moderation to prevent harming other useful organisms. Most commercial farms in South Africa currently employ such management practices, especially those that have adopted CA.

2.3.2 Conservation Agriculture (CA) and crop rotation systems in the Western Cape

The Food and Agriculture Organisation (FAO) of the United Nations (2006) defined CA as a compounded term that describes crop production systems in which soil tillage is kept to the minimum level possible; maintains permanent organic soil cover and employs crop rotation. The practice of no-tillage or minimum tillage enables the soil ecosystem and structure to return to a more natural state and thereby improve the soil quality (FAO 2006). Availability of organic soil cover such as green cover crops or crop stubble and residues left after harvest helps to reduce soil erosion (FAO 2011). Erosion is reduced because of reduced direct impact of raindrops and runoff. Soil cover also maintains ideal temperatures for soil organisms and conserves moisture. On the other hand, crop rotation enables crops to use nutrients in the soil more effectively (SUSTAINET EA 2010). Crop rotation becomes much more effective if for example, cereal crops are planted in rotation with nitrogen-fixing legumes (Hobbs et al. 2008). Other benefits that are associated with CA include, reduced levels of carbon emissions, higher economic returns and improved long term productivity (ISTRO 1997; Derpsch 2005; Kassam et al. 2015). Conservation agriculture is one method of farming that has been embraced by the global agricultural community as they seek to move away from unsustainable production systems (du Toit 2007; Kassam et al. 2015).

In South Africa, CA became more common after the market deregulation at end of apartheid (Findlater 2013). Market deregulation led to withdrawal of protective price control in the agricultural sector such that farmers were forced to become more efficient. Prior to the deregulation of the market, most farmers practiced monoculture farming (Swanepoel et al. 2016). For example, commercial wheat farmers in the Western Cape only produced wheat on a monoculture system (ARC 2014). As the market was liberalised, farmers had to adopt farming practices that would improve income and prevent soil degradation (Findlater 2013). Perhaps, the passing of some acts to discourage soil degradation may have contributed to the conversion to CA. In 1946, the Soil Conservation Act of 1946 was passed and later succeeded by the Conservation of Agricultural Resources Act of 1993 (Swanepoel et al. 2015b). Nonetheless, CA is done by most winter grain farmers in the Western Cape and some summer grain producers in the Free State and a few sugar cane farmers in KwaZulu-Natal (Fowler 2000). The shift from conventional farming system to conservation system is not only hindered by the huge initial capital needed for purchase of no-till planting equipment (Knott 2015). It is also affected by the expected drop in both production and profitability in the initial transition phases (Kassam et al. 2012; Knott 2015). Conservation agriculture requires a lot of knowledge inflow to the farmers. Hence, assistance in the form of special financial arrangements, machinery and extension services can positively aid the adoption of CA (Friedrich and Kienzle 2007)

The Western Cape has seen some major development in the farming system in the past decade. The use of CA by farmers in the Western Cape has risen from about 5% in the year 2000 to about 60% in 2010 (ARC 2014). The wide adoption of CA in the Western Cape has brought about a variety of rotation systems in the area (ARC 2014). The Swartland area mostly has four year rotations, with examples such as wheat-lupin-wheat-canola. This translate to an average of 50% of farm planted to wheat, 25% lupin and 25% canola. Another rotation system would be wheat-medics-wheat-medics (ARC 2014). This means that 50% of the farm is planted to wheat and another 50% planted to pasture.

2.3.3 The Swartland

In the Swartland, agriculture is the industry that employs most people. The Swartland Municipality (2007) states that the sub-region absorbs almost 26% of the West Coast labour market, thereby making it the main employment area within this district. The agricultural industry in the Swartland is diverse. Grapes, olives, dairy, canola, legumes, sheep, beef and wheat are the main farming enterprises of the region. However, wheat is the main agricultural crop produced within the district, hence the Swartland is known as the breadbasket of the Western Cape (Swartland Municipality 2007).

However, there has been a gradual decline in wheat production in the district (Meadows 2003). From 2001 to 2006 alone, there was a twenty-two percent decline in wheat yields and farmers have been making losses (Swartland Municipality 2007). There are a variety of reason to account for the decline in wheat production. Some of the reasons could be; erratic rainfalls, international wheat market prices, the farm management practices and poor quality soil. The over use of herbicides may reduce the soil biological quality (Karlen et al. 2013), and ultimately reduce plant productivity.

Other farming practices that may adversely affect soil quality include the removal of long rooted native vegetation, replacing them with shallow rooted annuals and long fallowing of paddock (Podmore 2009a). Soil salinity may also be caused by poor irrigation practices such as too much irrigation. Zhu (2001) reports that nearly 20% of the world's irrigated lands are affected by salinity.

Some parts of the Swartland have salinity problems and this may be one of the main contributing factors to the gradual decline in wheat production. The impact of soil salinity has been known to negatively affect most agricultural crops by disrupting the process of water absorption by roots (Podmore 2009b). The impact of soil salinity in agriculture may further lead to reduced income for the farmer due to reduced productivity of the agricultural land. Increased cost to rectify the impacts of salinity and possibly animal health problems if animals continuously consume the saline water.

In the Swartland area, ley farming mostly involves use of annual legumes such as annual medics to try and improve the soil quality as well as to provide feed for livestock on the farm. The use of medics and other leguminous crops in the rotation systems are beneficial to the soil.

2.4 Use of leguminous plants to improve soil fertility

Instead of simply relying only on synthetic fertilisers for improving soil fertility, leguminous plants may be used to improve soil available nitrogen and fertility (Graziano et al. 2010; Swanepoel et al. 2015b). Legumes fix atmospheric nitrogen. Concerning some pastures in South Africa, Swanepoel et al. (2015b) states that legumes, especially clovers were added to pastures to increase production of fodder for livestock. A variety of leguminous plants have been grown in ley farming systems and in permanent pastures with the aim of improving soil fertility. A few of the leguminous plants are described below.

2.4.1 Annual medics

Medics are a group of self-pollinating and regenerating annual legumes native to the Mediterranean basin (Crawford, 1985; FAO 2007) that can grow in autumn, winter and spring. On average, they need at least 250 mm rainfall for proper establishment and growth. Medics are mostly used in ley-farming systems where they are grown in rotation with cereal crops (Nichols et al. 2007). They can grow on neutral to alkaline soils depending on the variety and species. In pastures, medics provide a good source of quality proteins for grazing farm animals. Farm animals such as sheep can utilise the small dry seed pods (Simao Neto et al. 1987) to obtain the stored proteins in summer and thus maintain wool and meat growth.

Annual medics produce hard seeds of which a small proportion do not break down every year and thus give them a chance to survive droughts and allows for good regeneration after one or two years of cropping (Frame 2005). Hard seeds have an impermeable seed coat that prevent entry of water (Taylor 2005). Without taking in water, the hard seed remain dormant and cannot germinate until a time when the seeds become soft. The seed softening process may occur over any period ranging from a few weeks to many years depending on variety of the plant (Taylor 2005). The term 'soft' refers to a pliable condition of seed after absorbing water. Soft seeds are the ones that are capable of germinating and thus are responsible for the immediate regeneration of the pastures. The hardseedness of medics is important, especially in very dry area, as it allows the seed to germinate only when conditions are favourable (Graziano et al. 2010; Del Pozo et al. 2002).

With good management, medics can regenerate year after year. Clark (2010) stated that medics establish better under permanent pastures than any rotation system that involves tillage.

There are different varieties of medics that have been grown in South Africa and other parts of the world. In this paper, we will consider only a few common species such as; *Medicago polymorpha*, *Medicago truncatula* and *Medicago littoralis* (Table 2.1).

Table 2. 1: Some common annual medic species.

Scientific name	**Medic name**	**Cultivar examples**
M. polymorpha L.	Burr	Cavalier, Scimitar
M. truncatula Gaertn	Barrel	Parabinga, Paraggio, Jester
M. littoralis Rhode	Strand	Angel

Adapted from: Frame 2005

2.4.2 Medicago *polymorpha* L

Burr medic *(Medicago polymorpha)* is a hard-seeded, self-reseeding annual legume that is native to the Mediterranean basin (Graziano et al. 2010). Like many other legume species, burr medic is widespread in regions with typical Mediterranean climate such as in Australia, Chile, the United States of America and South Africa

(Graziano et al. 2010). The nodulation phase in burr medic enables it to tolerate acidic conditions. Therefore, burr medic can grow on moderately acidic soil (Ewing and Robson 1990). Denton et al. (2007) stated that burr medic is capable of disturbing the life cycle of pests, and therefore may lead to a relatively reduced use of pesticides on the farm.

Burr medic can be used to resuscitate unproductive land as well as in pasture systems largely because it is a prolific seed producer (Clark 2014). The size and shape of the seed pods can be slightly different to each other depending on the environment (Del Pozo et al. 2002). Each pod can have about 2 -6 coils and 6 – 8 seed (Clark 2014). A well developed, mature plant can produce more than 1000 pods.

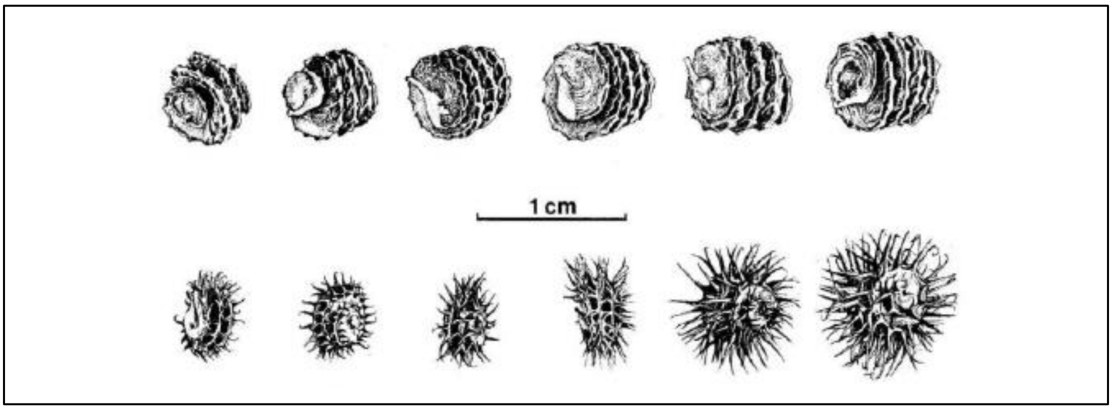

Figure 2.1: The average size and shape of burr medic seed pods.
Source: Del Pozo et al. (2002)

2.4.2.1 Scimitar

Scimitar is hybrid burr medic that was developed by the South Australian Research and Development Institute (SARDI) as a superior replacement of Santiago burr medic (Clark 2014). It has a relatively high percentage of soft seed (24%) when compared to Santiago (8.5%). The high percentage of soft seed enables the Scimitar to be more capable of regeneration when used in ley farming system.

2.4.2.2 Santiago

The Santiago burr medic originated from Chile, near the capital city, Santiago (Clark 2014). It is well adapted to a wide range of soils and can remain vegetative longer than other cultivars when water is limited. The Santiago flowers in about 84 days (Clark 2014).

2.4.2.3 Cavalier

Like the Scimitar, Cavalier was developed by SARDI (Clark 2014). Cavalier has an average of 13.8% soft seed in the first year. The amount of soft seed tends to be higher in the second year and thus allows dense regeneration in the second year of planting. This is because the hard seed of the Cavalier will soften more readily (Clark 2014). Seeds are slightly larger, kidney shaped and can weigh about 4.5 mg. In a region with an average of 350 mm rainfall, flowering occurs in about 90 to 95 days from day of seedling emergence (Clark 2014). Farm note 83 (2004), of the Western Australia Department of Agriculture states that Cavalier can tolerate moderate grazing 6 to 8 weeks after germinating, but it needs good weed control prior to seeding.

2.4.3 Medicago *truncatula* Gaertn

Most of the traits of barrel medic (*Medicago truncatula*) are similar to burr medic (Frame 2005; Nair et al. 2006). Both are regenerating annual legumes which are indigenous to the Mediterranean basin countries (Lesins and Lesins 1979). They produce barrel shaped seed pods with 2 to 6 tight coils and each pod may contain about 4 to 12 creamy white kidney shaped seeds (Frame 2005; Garcia et al. 2006). Barrel medic is adapted to a wide range of soil types but especially the well-drained neutral to alkaline soil (pH 6 to 8). Some cultivars of barrel medic are briefly described in the following paragraphs.

Figure 2.2: (a). The average size and shape of the barrel medic seed pods; **(b)**. The average size and shape of the barrel medic seeds.
Source: Garcia et al. (2006)

2.4.3.1 Jester

Jester barrel medic was developed by SARDI as a superior replacement for Jemalong barrel medic. It has a very high level of hard seeds (Nair et al. 2006). The plant takes an average of 110 days to flowering. Jester has much improved resistance to aphid such as the Blue-green aphid and Spotted Alfalfa aphid. Due to the higher level of hard seeds, it regenerates well after a cropping phase of 1 to 3 years.

2.4.3.2 Parabinga

Parabinga is early maturing barrel medic plant with an average of 88 days to flowering. It has an average of 80 to 90% levels of hard seed. The level of hard seed in the soil tend to soften slowly over a period of 5 to 10 years. This attribute allows the medic plants to survive over a long period in areas with marginal rainfall. However, the same attribute of producing a high amount of hard seed also limit the level of plant germination in the year after first sowing (Nair et al. 2006).

2.4.3.3 Paraggio

Paraggio takes an average of 98 to flowering and compared to other barrel medic varieties, it has the lowest level of hard seed (60 to 70%). The low level of hard seed allows Paraggio barrel medic to regenerate comparatively well in the year after first sowing. Nonetheless, the level of hard seed in the soil tend to soften over a period of about 5 to 10 years (Nair et al. 2006).

2.4.4 Medicago *littoralis* Rhode

Angel strand medic is an example of strand medic *(Medicago littoralis)* (Frame 2005). It is the only medic with a tolerance of sulfonylurea herbicide and therefore it can be successfully sown in areas or farms that rely on sulfonylurea weed control (Nair et al. 2006). It also has a good resistance to insects, blue-green aphid and spotted alfalfa aphid (Nair et al. 2006).

2.5 Other Cultivars

A huge variety of medics are grown in pastures in the Mediterranean region of the Western Cape such as the Swartland. The varieties include; Jemalong, Cyprus, Armadillo and Serena. As stated earlier, the medics are capable of germinating in a wide variety of soil conditions such as slightly acidic and alkaline soils. Some medics can also germinate and grow on slightly saline soils.

2.6 Soil salinity

Soil salinity is a world-wide problem and mainly occurs in arid and semi-arid regions (Mengel et al. 2001; FSSA 2007). Cases of soil salinity problems are currently increasing in agricultural soils through-out the world (Keren 2000; Qadir et al. 2000). Approximately 400 million ha throughout the world is affected by salinity (FAO 2005). Wichern et al. (2006) explained that salinity is a major threat to soil microbial communities and therefore greatly hinders the organic matter turn over processes. Increased salinity may cause microbes to suffer from osmotic stress, which ultimately leads to drying and lysis of cells. In that case, the soil tends to be less fertile and productive because the microbes play a major role in carbon and nitrogen mineralisation (Wichern et al. 2006).

From an agricultural standpoint, soil salinity is the accumulation of neutral soluble salts to a point where they adversely affect the growth of most crops (Podmore 2009a). However, saline soils can further be defined as those that have an electrical conductivity equal to or more than 4 dS/m or 400 mS/m at 25˚C in the soil saturation extract (Richards 1954; Bernstein 1975). In further defining soil salinity, the FSSA (2007) states that exchangeable sodium percentage (ESP) should be lower than 15% and the pH (H_2O) usually lower than 8.5. Saline soils contain an excess of neutral salts such as the chlorides and sulphates of Na^+, K^+, Ca^{2+} and Mg^{2+} (Bernstein 1975; Mengel et al. 2001). Rogers et al. (2005) emphasised that the predominant ions in a saline soil are usually sodium and chloride. The ESP is a measure of the percentage proportion of Na^+ of the cation exchange capacity (CEC). The term 'soluble' shows that the salts move freely in the soil solution and can be readily absorbed by plants.

In dry periods, soils that have the ESP which is less than 15% tend to show a white efflorescence of salt on the surface and are thus sometimes referred to as 'white alkali soils' (Mengel et al. 2001). Soil salinity can be classified as primary or secondary depending on the source of the salts (Podmore 2009c).

2.6.1 Primary salinity

Salt is a naturally occurring mineral and may be found in the salt marshes, salt lakes or natural salt scalds. Such naturally occurring salt in the landscape is referred to as primary salinity (Podmore 2009b). These areas are not used for agricultural production and will not be discussed in more detail.

2.6.2 Secondary salinity

Salinisation which occurs in the soil and water due to human activity is called secondary salinity (Barrett-Lennard 2002; Podmore 2009a). Human activities such as agriculture and urbanisation can cause salinization of the soil and water. Secondary salinity can be further differentiated into 3 groups, namely; dryland salinity, irrigation salinity and urban salinity (Podmore 2009b).

2.6.2.1 Dry land salinity

Dryland salinity is a major threat to agricultural production and natural resources. About 5.7 million ha of land in Australia is regarded as being at risk from salinity (Nichols et al. 2009; Bennett et al. 2009). That figure is expected to rise to about 17 million ha by the year 2050 (Nichols et al. 2009; Bennett et al. 2009). A total of 77% of the national area in Western Australia is at risk of salinity. Dryland salinity is a term that describes salinity that occurs in a land which is not under irrigation (Podmore 2009a). Land can be salinised because of rising water tables due to replacement of perennial and native vegetation that has deep roots with annual crops with shallow roots (Bennett et al. 2009). As described by Slinger and Tenison (2007), the long roots of native and perennial vegetation enable plants to absorb most of the water which seap into the ground. By so doing, less water is leaked past the plant root zone to the underground water system. Also, the absorbed water can be removed from the ground and lost to the atmosphere through evapotranspiration. But if the deep-rooted plants are replaced by shallow rooted annual plants such as done in most agricultural lands, less water will be absorbed by the plants. Also, less water is lost to the atmosphere through evapotranspiration. In such a case, more water is leaked to the underground water system. The leakage may lead to an increase in the underground water level. The rising water may bring with it some naturally dissolved salts to the ground surface and thereby increase the saltiness of the top soil (Podmore 2009a). When ground water evaporates, the salts on the soil surface become concentrated. Rainfall can leach such salts and distribute it through-out the water catchment area or region.

2.6.2.2 Irrigation salinity

On a global scale, irrigation induced salinity affects approximately 30 million ha (Bakker et al. 2010). In the near future, irrigation salinity is expected to increase by a further 80 million ha (Bakker et al. 2010). There are a variety of ways in which salinity may be caused by irrigation. For example, if saline underground water is used for irrigation, then obviously, salts will increase on the soil surface (Slinger and Tenison 2007). However, inefficient irrigation and drainage systems may contribute to soil salinity even if pure, non-saline water is used for irrigation. For example, excessive irrigation may cause too much leakage of water into the underground water system. Coupled by water added to the irrigated area by rainfall. The water table may easily rise to the plant root zone and soil surface (Podmore 2009b). On an irrigated land, leakage can be worsened if the deep rooted native and perennial plants are replaced by shallow rooted annual crops (Barrett-Lennard 2002). Poor drainage of the area also causes excess leakage. If the irrigated area is uphill on the water catchment area, it is most likely that some saline water might drain or leach down-stream and spread to other parts of the catchment.

2.6.2.3 Urban salinity

Clearing of native vegetation for urban development, excessive irrigation of sporting fields, parks and gardens may all contribute to increase in salinity in urban areas (Podmore 2009c). The compacting of surfaces during building or road construction can limit ground water flow and ultimately lead to concentration of salts on one area. Salts can further be added from other sources such as swimming pool, industrial discharges, sewage, fertilisers and food products.

2.7 Impact of soil salinity

Soil salinity is very important especially in agriculture because it significantly contributes to land degradation. As stated earlier Wichern et al. (2006) stated that soil salinity adversely affects soil microbes and thereby disturbs the soil ecosystem. Sardinha et al. (2003) argue that salinization had a stronger effect on soil microbes than heavy-metal pollution. They further argue that salinisation is probably one of the most stressing environmental conditions for soil microbes. But the impact of salinity can lead to more adverse effect. For example, Bennett et al. (2009) state that highly saline areas tend to be either bare or will only grow the most salt tolerant plants such as the samphire species. The samphire species are stem-succulent halophytes that has no commercial value. Land tend to become bare because some plants fail to grow in the saline environment. In the Mediterranean climate of Western Australia, salinity and water logging has been identified as a major hindrance to the productivity of pastures and agricultural crops (Bakker et al. 2010). Nichols et al. (2009) stated that high levels of sodium and chloride ions can be toxic and disrupts plant cell function. Salinity can disrupt the normal uptake of water by roots such that plants may have stunted growth (Zhu 2001). Stunting can also occur on plant fruits and leaves (Bernstein 1975). High salinity may cause ion imbalances which would disrupt plant growth. For example, a relatively high level of sodium ions can inhibit uptake of potassium ions (Podmore 2009b). However, plants are not all equally sensitive to salinity (FSSSA 2007). Plant root depth can influence the degree to which a plant is affected by salinity. Halophytes can tolerate high internal salts and therefore can afford to take up salts along with water. However, most agricultural plants are glycophytes (Podmore 2009a). That means that they cannot tolerate high internal salts and thus they would always try to minimise salt intake at the roots. But when growing in a highly saline area, they cannot exclude salt uptake hence they fail to survive. Also, deep-rooted plants have a better chance of surviving in a saline area than shallow rooted plants (Bennett et al. 2009). Bennett et al. (2009) also stated that salinity can be worsened by waterlogging. For example, they state that the burr medic is moderately tolerant to soil salinity but would not grow well in a water logged saline area.

In an experiment to investigate the influence of soil salinity on safflower (*Carthamus tinctorius* L.) germination, Kaya et al. (2003) realised that an increase in salinity level severely inhibited root development more than it affected the shoot. This shows that salinity is very influential in plant seedling germination and growth. Regarding the germination of *M. polymorpha,* Nichols et al. (2009) discovered that the seeds could germinate at sodium chloride (NaCl) concentrations of up to 2 400 mS/m. Mature plants proved to have better tolerance to salinity. Sometimes, the salts in the soil may not be available for uptake by the plants but can still affect plant growth. In such scenarios, different terms may be used to describe the amount or type of salts in a soil. Therefore, it is of paramount importance to note the difference between saline soil, saline-sodic soil and sodic soil. Table 2.1 summarises the impact of various salinity levels of plant growth.

Table 2.2: General plant reaction on different levels of soil salinity.

Specific conductivity		**Electrical resistance**	**Plant reaction**
mmho cm^{-1}	**mS m^{-1}**	**Ohm**	
0 – 2	0 – 200	> 1000	Salinity has no effect on plant growth
2 – 4	201 – 400	500 – 250	Growth of sensitive crops is affected
4 – 8	401 – 800	250 – 125	Yield and growth of most crops reduced
8 – 16	801 – 1600	125 – 63	Only resistant crops have reasonable growth
> 16	> 1600	< 63	Only a few very resistant crops will grow successfully

Source: FSSA 2007

2.8.1 Soil sodicity

Sodic soils can be described as soils that normally do not have excessive soluble salts but rather have a higher sodium content (Bernstein 1975; FSSA 2007). The FSSA (2007) defines a sodic soil as soil that has conductivity of a saturation extract of lower than 400 mS/m at 25°C and the ESP higher than 15%. The pH (H_2O) is almost always higher than 8.5. High sodicity is a problem because it weakens the soil aggregates, causing structural collapse as the clay particles disperse (Mengel et al. 2001). Collapsing of the soil aggregate closes soil pores and therefore restricts water and air movement. It also causes soil compaction and thus restrict root penetration and development (Mengel et al. 2001). Sodicity can lead to excessive top soil erosion as water cannot penetrates the soil but rather runs off and takes the top soil in the process.

2.8.2 Saline-sodic soil

Saline-sodic soils exhibit a combination of both saline and sodic traits (FSSA 2007). A saline-sodic soil is one that has the saturation extract with a conductivity higher than 400 mS/m. This attribute is like that of the saline soil. However, the ESP is similar to that of sodic soils in that it is higher than 15% and the pH is usually less than 8.5 (FSSA 2007). Another difference between sodic soil and saline-sodic soil is that water can infiltrate the saline-sodic soils relatively easier than in sodic soils.

The current study seeks to evaluate the impact of soil salinity on the ability of medic pastures to regenerate and establish in a ley farming system in the Swartland area.

Chapter 3: Research methodology

3.1 Locality

The Swartland is an undulating sub-region situated within the West Coast District in the Western Cape Province in South Africa and covers an area of 3,707 km^2. On the west of Swartland lies the Atlantic Ocean. The City of Cape Town is in the south whilst the Boland and Olifants River Mountains are to the east. Saldanha Bay Municipality is to the north of Swartland (Swartland Municipality 2007). The principal town of the Swartland is Malmesbury, which is situated in the south-east of the region. Malmesbury is approximately 70 km north of Cape Town, along the N7 road. Moorreesburg is a further 30 km to the north from Malmesbury along the N7 road. The pre-Cambrian metamorphosed shales and fine sandstones of marine origin known as the Malmesbury group dominate the Swartland geology (Tankard et al. 1982). The native vegetation of the Swartland is a type of shrub called the renosterveld (Meadows 2003). However, this natural vegetation has been widely removed and replaced by agricultural crops such as wheat and canola (Meadows 2003).

3.1.1 The study sites

The study was carried out on two farms in the Swartland area in South Africa. One of the farms, Pringleskraal, is located near Moorreesburg (-33.145885, 18.669062; 152 m above sea level). The second farm is Langgewens Research Farm of the Western Cape Department of Agriculture and is near Malmesbury (-33.487263, 18.693936; 187 m above sea level). Both farms follow conservation agriculture principles. These two farms may be classified as being in medium and high production potential areas in terms of rainfall, respectively. Malmesbury receives an average annual rainfall of about 460 mm whilst Moorreesburg receives about 386 mm of rainfall per year (Meadows 2003). The Koppen-Geiger climate classification system, classifies the general climatic condition of the Swartland area as Mediterranean-type climate (Peel et al. 2007). The area receives 80% of its rainfall during the cool season (May to October). The average midday temperatures range from 16^{O}C in July to about 29^{O}C in February. The map of the study site is shown on Figure 3.1.

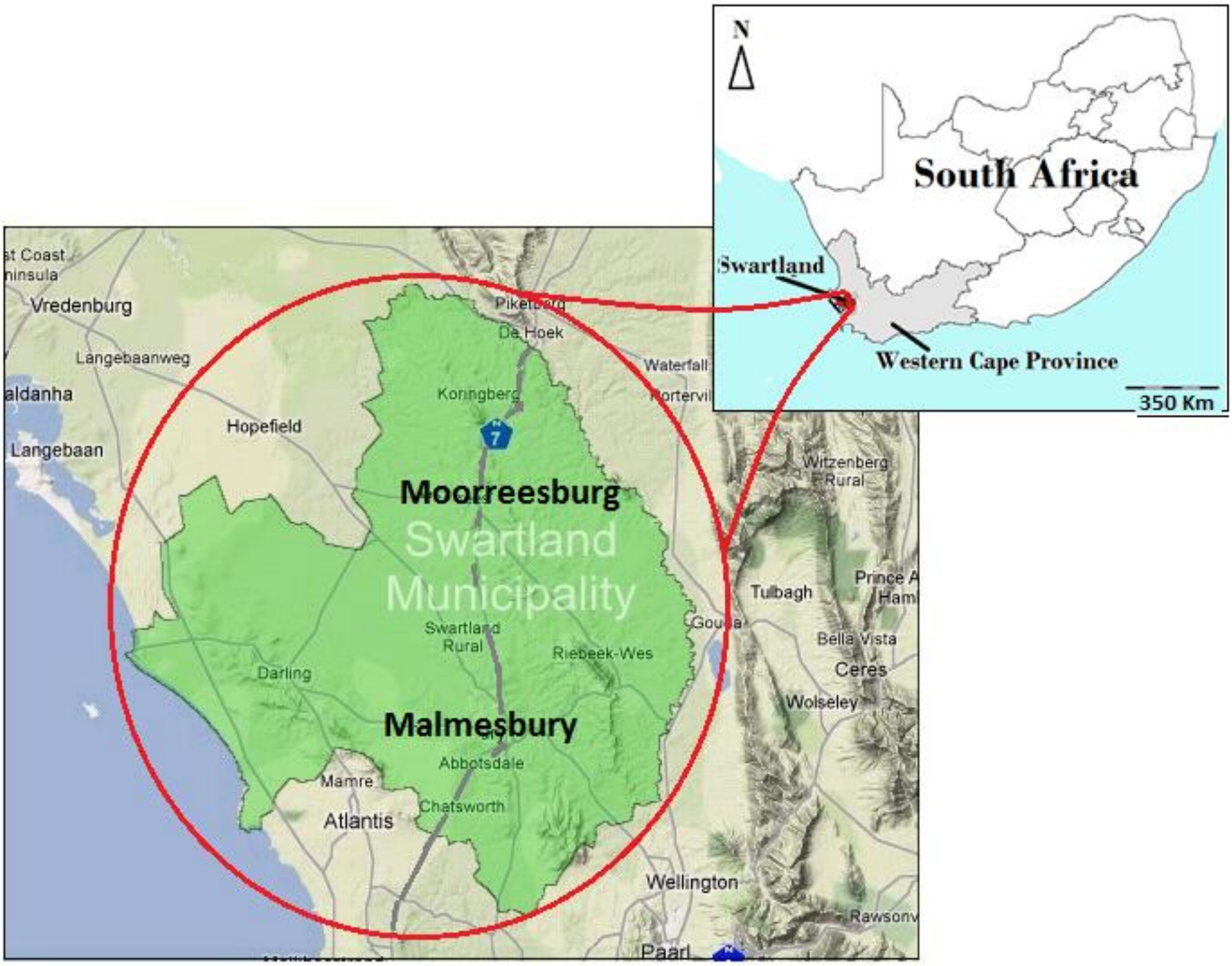

Figure 3.1: Location of the study sites (Malmesbury and Moorreesburg) in the Swartland municipality of the Western Cape Province, South Africa.

3.2 Experimental design and treatments

The experimental design for the research was a randomised block design with three treatments and three replicates on two sites. The two sites are the two farms that were used for the research (Pringleskraal and Langgewens). The treatments were the low, medium and high productivity soils, which were regarded as plots, in annual medic pastures, located in three camps on the farm, which were the blocks. The low productivity soil was suspected and considered to be the saline areas on the plots. While the high plant productivity soil was considered as non-saline. The medium plant productivity soil was the area on the margins or periphery of the low plant productivity soil. The systems involved a crop rotation of wheat and medics. The medic phase was utilised by sheep.

3.3. Sampling procedure

Two seasons were sampled, that is, the 2015 and 2016 growing seasons. For the 2015 growing season, samples were only taken at the end of the season (November 2015). For the 2016 season, samples were taken from May 2016 to October 2016 to monitor pasture productivity through time.

In the 2015 season, for each plot, two soil cores were collected to a depth of 20 cm, and composited for standard soil analysis. Furthermore, an additional three soil sub-samples per plot were collected to a depth of 5cm to determine the number of belowground medic seeds. To determine the number of aboveground medic seeds, one sample per plot was taken by collecting all aboveground plant materials within a 0.5 m^2 quadrants. In 2016, these camps were planted with wheat, and were therefore not assessed again.

Sampling in the 2016 season began in May and ended in October. Soil core samples (for standard soil analysis) and the sub-samples (for belowground medic seeds) were taken in the same way as described above. Furthermore, four exclosure cages were erected per plot to prevent grazing by sheep. Plant productivity was assessed by counting the number of seedlings in four 0.25 m^2 quadrants per plot in May 2016. Herbage was cut to ground level within the borders of the quadrants placed within the exclosure cages in July, August, September and October 2016. Thus, three representative herbage samples were collected from each camp every month (one from each of the low, medium and high productivity soils).

3.4 Analyses

3.4.1 Soil quality (0 to 200 mm soil samples)

The core soil samples (0 to 200 mm) were passed through a 2 mm sieve and sent to Elsenburg laboratory for standard soil analysis. The soil analysis included test for electrical resistance (ER), pH(KCl), potassium (K), magnesium (Mg), sodium (Na) calcium (Ca), total cations, carbon (C), total nitrogen (N), extractable phosphorous (P; citric acid method), manganese (Mn), copper (Cu), zinc (Zn), boron (B), sulphur (S) and an analysis for particle size distribution (three fractions).

3.4.2 Medic seed production

The total number of seeds in the system were determined as the sum of the aboveground and belowground (to 50 mm depth) seeds.

For aboveground seed production, the seed pods were separated from the herbage by hand. The seed pods were then crushed between two rubber boards to expose the seeds. The medic seeds were then separated from the chaff by sieving through a 1 mm sieve, followed by winnowing using a fan. In this study, seeds that passed through the 1 mm sieve were regarded as too small and were not included in the final count of the seeds.

For belowground seed numbers, the soil samples (0 to 50 mm) were sieved through a 1 mm sieve to remove the fine soil particles and any other small seed. The samples that remained in sieve was sieved again using a wet sieving method. Water was used to break the soil aggregates for it to pass through a 1 mm sieve. The wet sample that remained was oven dried at 70°C for three hours and then mixed with a solution of saturated calcium chloride according to methods described by Carter et al. (1977). The saturated solution of calcium chloride was used to separate organic matter from the soil. The specific gravity of the saturated calcium chloride is 1.41 and the organic matter consequently float on top of the solution. The floating organic matter was extracted and oven dried over night at 70˚C. The dried organic material was crushed between two rubber boards to separate the seeds from the pods and other organic matter. The seeds were separated from chaff by using a fan.

Both the aboveground and belowground seeds were counted with a Numigral-seed counter. The vibration of the machine was set at level five. The machine uses laser technology to count each single grain of seed as the seeds are moved through a sensor by the vibrations of the machine.

3.4.3 Medic herbage yield

Herbage samples were dried at 70˚C for 48 h in a convection oven. Herbage yield was subsequently determined by weighing the dry sample and converting it to kg dry matter (DM) per ha.

3.5 Statistical analyses

Statistical analyses were done by using STATISTICA version 13 (Dell Inc. 2015). A two-way Analysis of Variance (ANOVA) was used to analyse the soil and seed data at a 5% significance level. Residuals were normally distributed and had homogeneous variances. A repeated measures ANOVA was used to test for pasture herbage production through time. The fixed effects were specified as linear time, treatment and their interaction. The correlation between soil quality and medic productivity was analysed by using the General Regression Model (GRM). The relationship between variables were assessed by using the Spearman's r method of STATISTICA. A simplified regression model is as follow:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_q X_{qi} + \epsilon_i,$$

Where, Y_i is the i^{th} value of the response variable; X_{ji} is the i^{th} value of the j^{th} explanatory variable; β_0 is the intercept; β_1 is the partial slope of the j^{th} explanatory variable and ε_i is the error.

Chapter 4: Results and discussion

4.1 Soil quality analysis

Some of the soil quality indicators for the 2015 and 2016 season samples were similar ($P > 0.05$) between treatments, as shown in Table 4.1. The pH (KCl), exchangeable cations and micronutrients were within recommended soil fertility ranges for medic pastures. Extractable Zn was exceptionally high for Langgewens in 2015, and we suspect contamination of soil samples from the galvanised pipe used to take soil samples. Since there were no treatment differences, we can assume that these soil quality indicators will not cause variation on medic herbage yield.

Table 4.1: The means of soil quality indicators for samples (n = 18) to a depth of 20 cm collected during the 2015 and 2016 growing seasons on annual medic pastures on two farms in the Swartland. There were no differences ($P > 0.05$) between treatments of low, medium and high productivity soils and therefore only means are provided.

Soil quality indicator	Pringleskraal (Mean ± SE)	Langgewens (Mean ± SE)
2015 growing season		
pH (KCl)	5.81 ± 0.16	5.36 ± 0.35
Ca (mg kg^{-1})	540.44 ± 42.91	483.78 ± 81.66
Mg (mg kg^{-1})	187.47 ± 27.75	166.60 ± 94.50
K (mg kg^{-1})	160.56 ± 23.01	92.44 ± 14.71
P (mg kg^{-1})	50.56 ± 5.94	52.44 ± 8.75
Total cations ($cmol_+$ kg^{-1})	7.22 ± 0.96	5.55 ± 2.07
Cu (mg kg^{-1})	0.96 ± 0.15	0.72 ± 0.10
Zn (mg kg^{-1})	3.14 ± 0.43	51.17 ± 9.03
Mn (mg kg^{-1})	25.67 ± 3.49	67.29 ± 10.80
Organic C (%)	0.97 ± 0.05	0.45 ± 0.16
Total N (%)	0.08 ± 0.01	0.05 ± 0.01
2016 growing season		
Resistance (Ohm)	148.89 ± 43.76	532.22 ± 119.23
K (mg kg^{-1})	195.44 ± 21.01	134.33 ± 18.66
P (mg kg^{-1})	74.11 ± 11.97	90.44 ± 10.40
Cu (mg kg^{-1})	1.22 ± 0.13	0.97 ± 0.05
Zn (mg kg^{-1})	301.32 ± 66.18	150.91 ± 62.9
Mn (mg kg^{-1})	47.48 ± 8.96	103.85 ± 16.47
Total N (%)	0.12 ± 0.008	0.08 ± 0.007

4.1.1 Soil salinity determination

Tables 4.2 and 4.3 shows soil quality indicators with significant ($P < 0.05$) treatment effects. Most of these were indicators of soil salinity such as electrical resistance (ER), exchangeable Na content, Na percentage and Sodium Adsoprtion Ratio (SAR) for both 2015 and 2016 seasons, along with B and S in the 2015 season, and pH, Ca, Mg, total cations, B and S, in the 2016 season. Results further showed that soil salinity was more problematic on Pringleskraal than Langgewens, as the exchangeable Na content and percentage, and SAR was higher for Pringleskraal than for Langgewens, and ER lower ($P < 0.05$). There were no differences ($P > 0.05$) between treatments on neither the 2015 nor 2016 soil samples from Langgewens. For the 2015 samples, the ER for the low productive soils on Pringleskraal was 80.00 Ohm. Such low ER may drastically hinder the growth process of most agricultural crops (FSSA 2007). The Na and Na % of cations content for the low productive soils were 3661 and 45.11 mg kg^{-1}, respectively and was higher ($P < 0.05$) than the medium and high productive soils. Such high exchangeable Na content can contribute to the low ER and high SAR of the soil. The ideal SAR of soils is less than 1 (FSSA 2007). If the SAR value is 4 or greater, the soil can be classified as being brackish and if SAR if greater than 5, then the soil is termed permanently brack (FSSA 2007). The 2016 samples from Pringleskraal revealed that the SAR value for the high productivity soil was 0.55 but was not different ($P > 0.05$) to that of the medium productivity soil (2.08). The low productivity soil had a higher ($P < 0.05$) SAR (7.43) than the medium and high productivity soils. Therefore, the low productivity soils at Pringleskraal can be classified as permanently brack.

The areas that were mostly affected by salinity at Pringleskraal were the low-lying sections of the camps. Salts were probably leached down from higher ground to the lower ground surface. Görgens and de Clercq (2005) discovered that soil salinity problems in the Swartland and surrounding areas of the Western Cape could be caused or worsened by water flow along the Berg river catchment area down-stream to the low-lying areas. The Swartland is an undulating inland, of which Moorreesburg has a lower altitude than Malmesbury (Meadows 2003), therefore the flow of saline water from various agricultural uses up stream can easily end-up in Moorreesburg. Furthermore, the saline Malmesbury Shale type of soils could have contributed to the salinity of water as it flowed down-stream (Görgens and de Clercq 2005). The Swartland is predominantly an agricultural area that practices dry-land farming. Therefore, it is also a possibility that some salinity problems may be explained as dryland salinity. The removal of the original, indigenous and perennial renosterveld plant species for agricultural purposes could have caused the water table to rise and bring to surface the naturally occurring salts to the ground surface. The relatively higher altitude and annual rainfall received in Malmesbury (460 mm) compared to 386 mm for Moorreesburg may contribute to the reduction of salinity problems on Langgewens.

At Pringleskraal, the exchangeable S content were much higher ($P < 0.05$) on low productivity soils. This could be ascribed to gypsum (calcium sulphate) that was applied by the farmer in an effort to reclaim salt-affected soil. Gypsum is primarily used on Na-affected soils as a source of Ca^{2+} ions to displace Na^{+} ions, which is subsequently leached. The use of gypsum on saline soils could also be a reason why there was more Ca in the low productivity soils at Pringleskraal. The medium and high productivity soils were similar to one another with Ca content of 1056 and 962 mg kg^{-1}, respectively. The low productivity soils had a Ca content of 2126 mg kg^{-1} and it was significantly higher than the medium and high productivity soils.

The low and medium productivity soils at Pringleskraal, had similar ($P > 0.05$) extractable B content in 2015 (Table 4.2). The high productivity soils had less ($P < 0.05$) B than the low and medium treatments. The low and high treatments had B measuring 1.65 and 0.45 mg kg^{-1} respectively. In 2016, the B content in the low, medium and high productivity soils at Pringleskraal differed (2.50, 1.40 and 0.73 mg kg^{-1}, respectively). The B content was similar in all treatments for both the 2015 and 2016 samples collected from Langgewens. Boron is an essential micronutrient for plants and is needed for seed production and germination (Gupta 2007). Its deficiency and toxicity lie in a very narrow range (Rashid and Ryan 2004). In general, an extractable amount less than 0.1 mg kg^{-1} is regarded as inadequate, yet B may become toxic to some field crops if it is greater than 1 mg kg^{-1} (FSSA 2007). Some crops are, however able to tolerate B up to 5 mg kg^{-1} (Nable et al. 1997; Rashid and Ryan 2004-). Ozturk et al. (2009) and Howie (2012) suggested that B may become toxic to medic plants when above 15 mg kg^{-1}.

Table 4.2: The soil quality indicators for samples (n = 9) collected to a depth of 20 cm from two farms in the Swartland during the 2015 season. Different superscripts on each row indicate the treatments (low, medium and high productivity soils) with a significant difference, ($P < 0.05$). SAR = Sodium adsorption ratio.

Soil quality indicator	Pringleskraal farm (Mean ± SE)			Langgewens Research Farm (Mean ± SE)		
	Low	Medium	High	Low	Medium	High
Electrical resistance (Ohm)	80.0 ± 25.17^{b}	150.0 ± 28.87^{b}	643.33 ± 60.09^{a}	500 ± 247.59^{a}	656.67 ± 31.80^{a}	586.67 ± 31.80^{a}
Na (mg kg^{-1})	1193.67 ± 50.55^{a}	391.0 ± 68.37^{ab}	71.33 ± 4.63^{b}	686.33 ± 646.97^{ab}	43.33 ± 7.06^{b}	33.33 ± 7.84^{b}
Na % of cations	48.74 ± 4.13^{a}	26.28 ± 3.92^{b}	6.95 ± 0.46^{c}	16.59 ± 11.32^{bc}	5.74 ± 0.54^{c}	3.47 ± 0.94^{c}
SAR	3.33 ± 0.29^{a}	1.20 ± 0.22^{b}	0.23 ± 0.02^{b}	1.23 ± 1.08^{b}	0.17 ± 0.01^{b}	0.12 ± 0.03^{b}
S (mg kg^{-1})	64.0 ± 1.15^{a}	30.67 ± 10.09^{ab}	6.3 ± 0.55^{b}	49.6 ± 45.2^{ab}	6.17 ± 0.13^{ab}	4.9 ± 0.35^{b}
B (mg kg^{-1})	1.65 ± 0.49^{a}	0.81 ± 0.07^{a}	0.45 ± 0.04^{b}	0.66 ± 0.47^{b}	0.20 ± 0.04^{b}	0.17 ± 0.01^{b}

Table 4.3: The soil quality indicators for samples (n = 9) collected to a depth of 20 cm from two farms in the Swartland during the 2016 growing season. Different superscripts on each row indicate the treatments (low, medium and high productivity soils) with a significant difference ($P < 0.05$). SAR = Sodium adsorption ratio.

Soil quality indicator	Pringleskraal farm (Mean ± SE)			Langgewens farm (Mean ± SE)		
	Low	Medium	High	Low	Medium	High
Na (mg kg^{-1})	3661.0 ± 808.97^a	698.33 ± 446.12^b	153.67 ± 48.46^b	345.0 ± 237.65^b	164.0 ± 116.51^b	49.33 ± 3.18^b
Na % of cations	45.11 ± 4.21^a	22.35 ± 10.21^b	9.46 ± 3.37^b	17.95 ± 9.37^b	10.93 ± 6.78^b	4.29 ± 1.13^b
SAR	7.43 ± 1.37^a	2.08 ± 1.28^b	0.55 ± 0.2^b	1.29 ± 0.85^b	0.69 ± 0.48^b	0.21 ± 0.04^b
S (mg kg^{-1})	796.67 ± 207.39^a	129.67 ± 58.0^b	44.40 ± 23.13^b	81.67 ± 39.55^b	39.67 ± 21.40^b	14.0 ± 2.08^b
Ca (mg kg^{-1})	2126.0 ± 303.32^a	1056.0 ± 136.12^b	962 ± 128.38^b	714 ± 174.46^b	663.33 ± 78.44^b	841.33 ± 281.1^b
B (mg kg^{-1})	2.50 ± 0.31^a	1.40 ± 0.20^b	0.73 ± 0.10^c	0.37 ± 0.15^c	0.32 ± 0.06^c	0.28 ± 0.03^c
Total cations (cmol (+) kg^{-1})	34.45 ± 5.48^a	11.58 ± 2.61^b	7.31 ± 0.38^b	6.36 ± 1.97^b	5.66 ± 0.73^b	5.63 ± 1.34^b
pH (KCl)	7.00 ± 0.06^a	6.00 ± 0.1^b	5.87 ± 0.37^b	5.57 ± 0.09^{bc}	5.27 ± 0.09^c	5.43 ± 0.22^{bc}
Mg (mg kg^{-1})	882.47 ± 104.67^a	344.85 ± 107.22^b	171.61 ± 12.65^{bc}	97.6 ± 36.24^c	81.74 ± 12.22^c	91.5 ± 21.17^c

Other studies have shown that there is an interaction between B and soil salinity, with B being found in high concentrations in saline soils (Nable 1997; Gupta 2007; Martinez-Ballesta et al. 2008; Mohamed et al. 2015). The true relationship between B and salinity is still subject to debate as some contradictory results revealed that salinity can decrease or enhance the B toxicity (Mohamed et al. 2015). In sugar beet, it was found that B toxicity developed at an SAR of 0.5 at high B levels, but the effects of excess B were significantly reduced at SARs of 20 and 40 (Gupta 2007). Nonetheless, the interaction between B and salinity negatively affects germination and root development and ultimately plant growth and productivity (Martinez-Ballesta et al. 2008; Mohamed et al. 2015). Boron availability may be affected by other factors such as soil texture, cation exchange capacity (CEC) and pH (Ozturk et al. 2009; Gupta 2007). Fine textured soils are more likely to have more B than coarse textured soils (Ozturk et al. 2009). The problem of B toxicity is described as impractical to remedy through leaching or addition of gypsum and soils can thus only be used through cultivating tolerant varieties (Bogacki et al. 2013; Howie 2012; Ozturk et al. 2009; Rashid and Ryan 2004).

Other soil quality indicators that could have had a significant impact on medic productivity at Pringleskraal in 2016 were; total cations, pH (KCl) and exchangeable Mg. The total cations can be used a measure of soil fertility if it only involves exchangeable Na, Mg, Ca and K cations (Blakemore et al. 1987). Generally, a higher value equates to higher fertility, but not always. If the exchangeable cations are replaced by H^+, Al^{3+} and Mn^{2+}, the total cations content may be much higher and misleading (Blakemore et al. 1987). The low productivity soils had a very high total cations content of 34.45 $cmol_+ \ kg^{-1}$ and it was higher ($P < 0.05$) than the medium and high productivity soils which had 11.58 and 7.31 $cmol_+ \ kg^{-1}$, respectively. The medium and high treatments did not differ from each other ($P > 0.05$). Since the low productivity soils had a higher total cation content, it seemed reasonable to assume that the soils were fertile.

The range of ideal pH(KCl) for medics is 4.8 to 8 (Clark 2014). The range of pH(KCl) observed on both farms was between 5.43 to 7 hence, pH(KCl) would not be expected to be a limitation to plant growth on either of the farms. However, if the effect of pH(KCl) were to interact with other soil quality indicators such as B and extractable P, then productivity may be affected. Concerning exchangeable Mg, an excess amount may inhibit uptake of Ca or K by plants (Gupta 2007).

4.2 Medic seed production

The number of medic seeds were determined from both below- and aboveground on the low, medium and high productive soils. Samples were collected in November 2015 by the end of the growing season, and then before the start of the 2016 growing season (May 2016) and again by the end of that growing season (October 2016).

4.2.1 Belowground medic seeds: November 2015 samples

For the 2015 samples, there were no statistical differences ($P > 0.05$) in number of belowground medic seeds between low, medium and high productivity soils at Langgewens (Figure 4.1). The low, medium and high productive soils had 36, 420 and 304 seeds m^{-2}, respectively. This seem to correspond with the soil quality indicator data gathered from Langgewens. Tables 4.1 and 4.3 revealed that the soil quality indicators were similar ($P > 0.05$) across treatments, therefore we would likewise expect plant productivity to be relatively similar across treatments. If plant productivity is similar, then the number of seeds produced may be expected to be relatively similar too. However, at Pringleskraal there were treatment effects ($P < 0.05$) and the number of seeds increased drastically with increasing soil productivity. The number of belowground medic seeds for the low, medium and high productive soils at Pringleskraal were 161, 734 and 1619 seeds m^{-2}, respectively. Even though it was mostly soil salinity indicators which differed ($P < 0.05$) between treatments, S and B could have impacted the growth and productivity of the plants as well. The B content in the low and medium productivity soils were similar ($P > 0.05$), but were lower ($P < 0.05$) in the high productivity soil (Table 4.2).

The correlation between belowground seeds and soil quality indicators that had significant treatment differences for the November 2015 samples (Table 4.2) were assessed with regression analysis. The following soil quality indicators were found to have no significant correlation ($P > 0.05$) on the number of belowground seeds; ER, exchangeable Na, Na %, SAR, Mg, Ca, pH(KCl), total cations, B and S. Although these soil quality parameters may affect plant growth and productivity, they did not explain variance in belowground seed data. Rather, activities such as trampling by the hooves on animals (Winkel et al. 1991), tractors and other farming machinery driving in the pastures, rainfall (Ballare et al. 1992; Mathews et al. 2008), and wind are most likely to cause soil disturbances that may ultimately cover the seeds. Furthermore, it also forms part of the management practices of farmers in the Swartland to scarify the soil lightly so that seeds are buried to ensure proper regeneration. Soil texture also affects seed burial. Sandy soils allow for easy burial of seeds when compared to clay soils because clay can easily become compacted and prevent seed penetration into the soil (Ballare et al. 1992; Benvenuti 2007). Benvenuti (2007) also stated that seed characteristics such as seed weight can influence seed burial. Since the medic seed pods can weigh about 4.5 mg (Garcia et al. 2006), the impact of their weight on burial may be negligible.

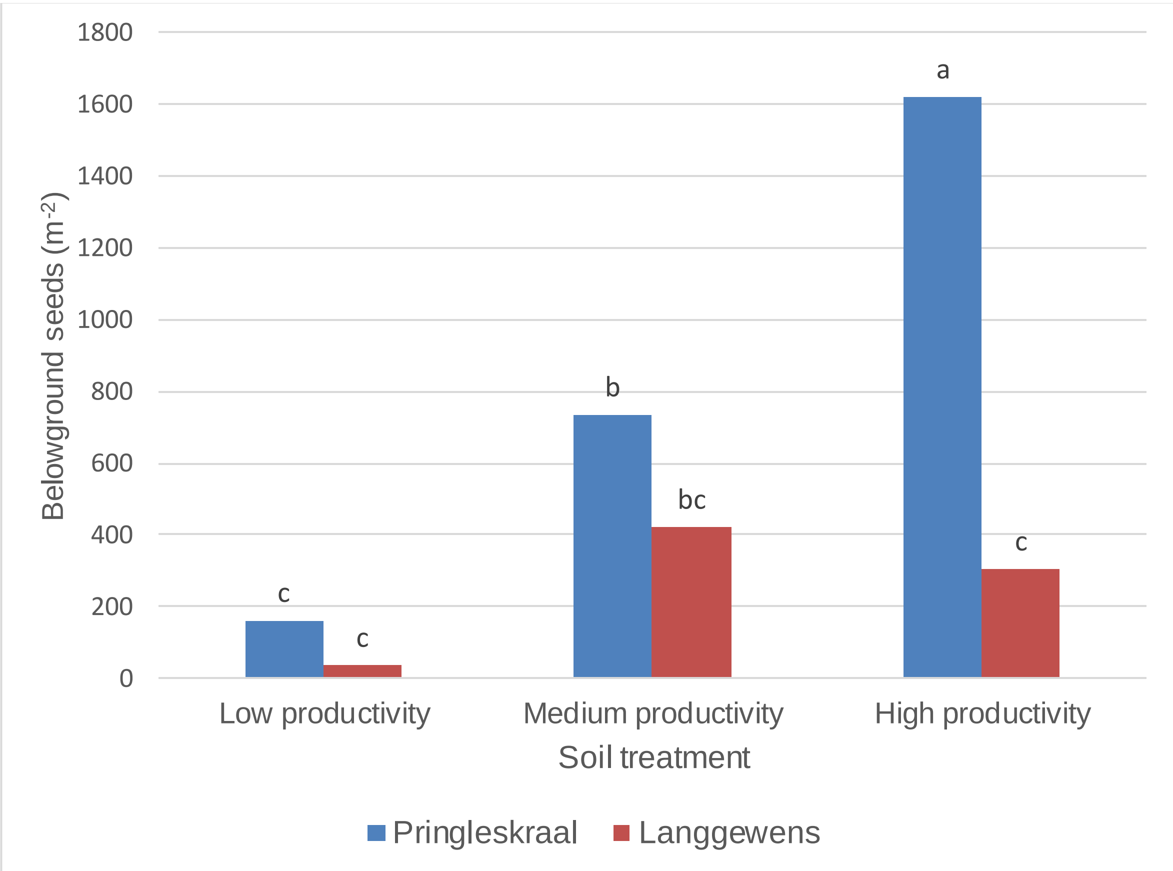

Figure 4.1: The number of belowground (5 cm) seeds for samples (n = 54) collected during the 2015 season for low, medium and high productivity soils. Different letters above the vertical bars indicate the treatments with a significant difference ($P < 0.05$).

4.2.2 Belowground medic seeds: May 2016 samples

There were no differences ($P > 0.05$) in the number of belowground medic seeds between treatments at Langgewens (Figure 4.2). The low, medium and high productive soils had 590, 1422 and 1691 seeds m^{-2}, respectively. As stated concerning the November 2015 samples for Langgewens, the similarities on number of belowground medic seeds seem to correspond with the soil quality indicator data (Tables 4.1 and 4.3). It may also be because no scarification of the soil is done at

Langgewens. However, at Pringleskraal there were 2371 and 42 seeds m^{-2} in the high and low productivity soils, respectively, which differed significantly (Figure 4.2). There was no difference ($P > 0.05$) between the high and medium productivity soil and also, for the medium and low productivity soils.

There was no correlation ($P > 0.05$) found between the number of belowground medic seeds and the following soil quality indicators; pH (KCl), Na, Na % of cation, SAR, total cations, Ca, Mg, B and S. Similar to what was found for the 2015 samples, the different soil quality indicators could have affected plant productivity and seed production, but not necessarily seed burial.

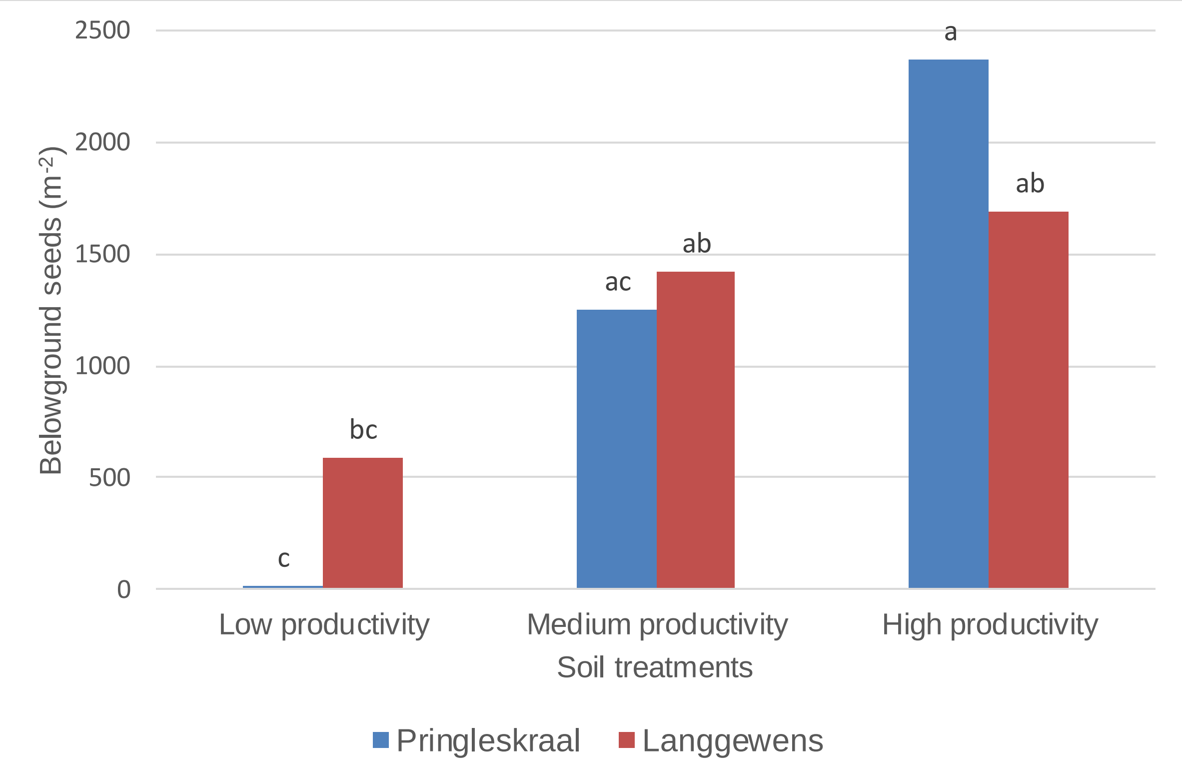

Figure 4.2: The number of belowground (5 cm) seeds for samples (n = 54) collected in May 2016 for low, medium and high productivity soils. Different letters above the vertical bars indicate the treatments with a significant difference ($P < 0.05$).

4.2.3 Belowground medic seeds: October 2016 samples

The number of belowground seeds sampled in October 2016 were similar in all the treatments ($P > 0.05$) for both the farms (Figure 4.3). For Langgewens, the results compliment the results of November 2015 and May 2016, which were discussed above, because the medic seed productivity has remained similar ($P > 0.05$) across treatments. The low, medium and high productivity soils at Langgewens had 2523, 1396 and 1744 seeds m^{-2}, respectively. However, results for Pringleskraal are slightly different from the expected as the low productivity soils now had the same number (P > 0.05) of belowground medic seeds as the highly productive soils. The November 2015 and May 2016 belowground medic seed counts for Pringleskraal had been significantly different, at least between the low and high productivity soils. In October 2016, the low, medium and high productivity soils had 349, 1664 and 1261 seeds m^{-2}, respectively (Figure 4.3). The similarities could have been caused by a couple of factors. For example, the soil seed bank was probably unevenly depleted across the treatments as the medic seeds germinated during the 2016 growing season. Depending on the sections that had more hard seeds, some soil seed bank remained relatively high such that by the time of sampling in October, the number of seeds in the soil could have become similar. The proportions of hard seeds in the soil may be expected to be different as two different burr medic varieties namely Santiago and Cavalier are sown mixed on the pastures at Pringleskraal. Cavalier was developed as a softer seed alternative to Santiago (Taylor 2005). Clark (2014) stated that Cavalier can have an average of 13.8% soft seeds in the first year and will increase in the following seasons. Time of sampling could have also impacted on seed availability as some medic plants in some plots were still green whilst others were dry.

Analysis of the correlation between soil quality indicators and belowground seeds for October 2016 showed that some soil quality indicators influenced the number of belowground medic seeds. The Na content, SAR, Mg, Ca and total cations showed a moderate negative correlation with belowground medic seeds (r = -0.43, -0.39, -0.59, -0.49 and -0.51, respectively). Extractable S showed a weak negative correlation (-0.08) with the number of belowground medic seeds (Table 4.4). Therefore, an increase in any one of the aforesaid soil quality indicators led to a reduction in number of belowground seeds. Although some correlations were found between the aforesaid soil quality indicators and number of belowground medic seeds in October 2016. The overall impact of the soil quality indicators must have been negligible because treatments had the same number (P > 0.05) of belowground medic seeds (Figure 4.3). As stated in section 4.2.1, these soil quality indicators may affect plant growth and productivity, but they did not explain the variance in belowground medic seeds well. We would expect activities such as trampling by animals, rainfall, scarification and other agents of soil disturbances to cause seed burial (Ballare et al. 1992; Mathews et al. 2008; Winkel et al. 1991).

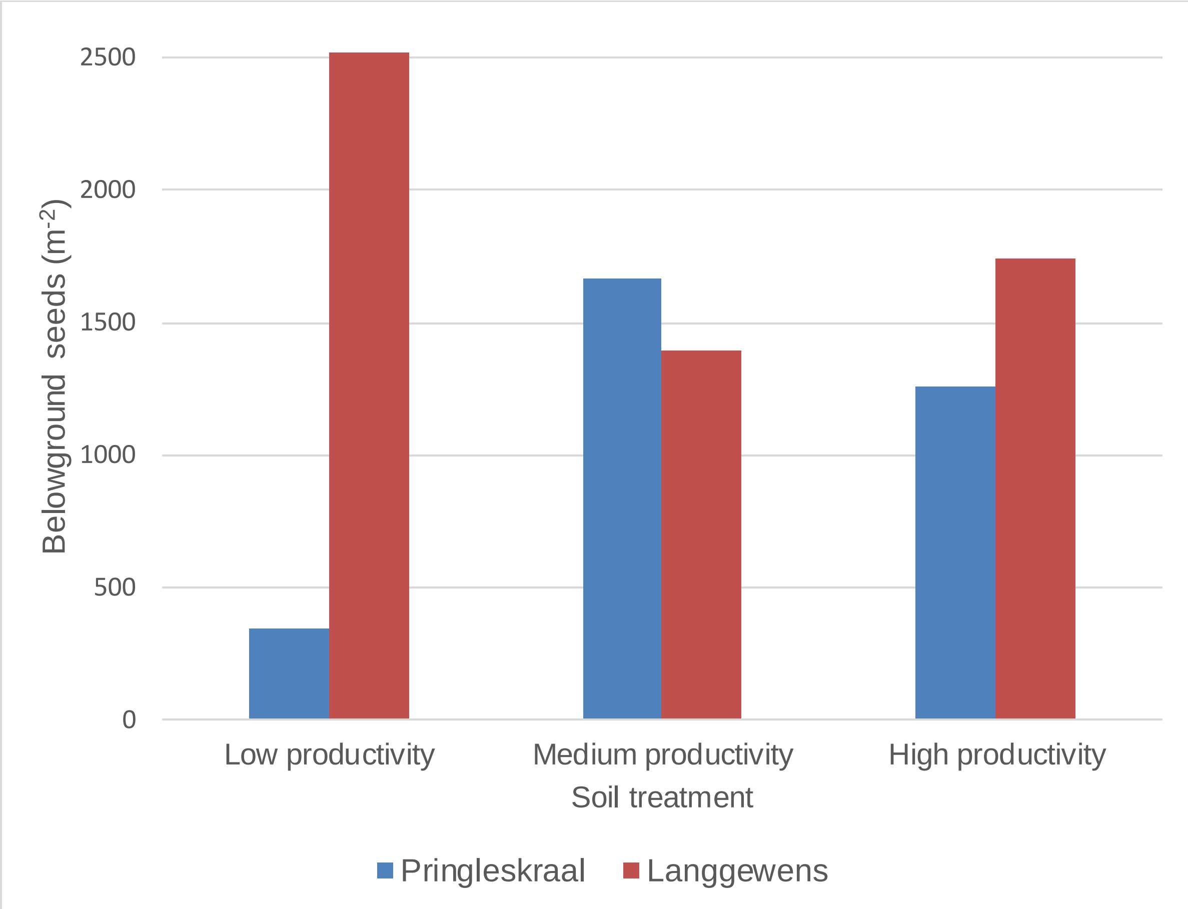

Figure 4.3: The number of belowground (5 cm) seeds for samples (n = 36) collected in October 2016 for low, medium and high productivity soils. There was no significant difference between treatments, ($P > 0.05$).

Table 4.4: Soil quality indicators that had an influence on the number of belowground medic seeds. Samples were collected in October 2016. SAR = Sodium adsorption ratio.

Soil quality indicator	Coefficient of determination (r^2)	P-value
Na (mg kg^{-1})	-0.43	0.015
SAR	-0.39	0.022
Mg (mg kg^{-1})	-0.59	0.007
Ca (mg kg^{-1})	-0.49	0.013
Total cations ($cmol_+$ kg^{-1})	-0.51	0.009
S (mg kg^{-1})	-0.08	0.031

4.2.4 Aboveground seeds: November 2015 samples

The number of aboveground medic seeds for Pringleskraal increased ($P < 0.05$) from low to high productivity soils (Figure 4.4). The low, medium and high treatments at Pringleskraal had 42, 704 and 1929 seeds m^{-2}, respectively. At Langgewens, the high and medium productive soils were similar ($P > 0.05$), but both differed from the low productive soils ($P < 0.05$). The number of aboveground medic seeds for the low, medium and high productive soils were 693, 1850 and 2993 seeds m^{-2}, respectively. Results of the below- and aboveground seeds suggest that the medic plants on the low productive soil either were very few or they produced very few seeds when compared to other plots. The number of below- and aboveground medic seeds for both the medium and high productivity soils on both farms were higher ($P < 0.05$) than on the low productivity soils and this was probably caused by a relatively high number of medic plants and seeds produced on the soils.

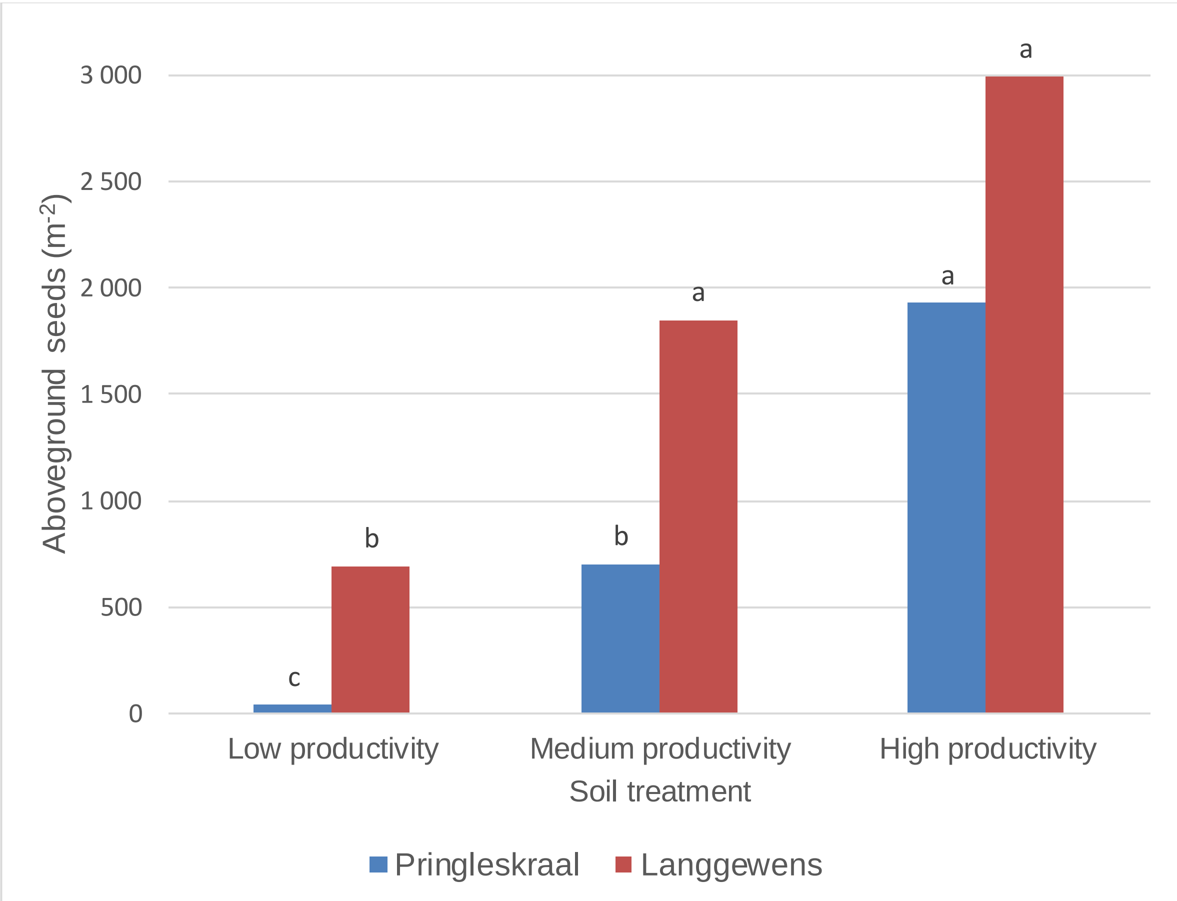

Figure 4.4: The number of aboveground seeds for samples (n = 18) collected in November 2015 for low, medium and high productivity soils. Different letters above the vertical bars indicate the treatments with a significant difference ($P < 0.05$).

The number of below- and aboveground seeds in the medium productivity soils at Pringleskraal showed a good relationship and are very similar numerically. Thus, almost an equal number of seeds is distributed both below- and aboveground. A similar trend is seen on the below- and aboveground medic seeds for the high productive soils at Pringleskraal. These have 1929 and 1619 seeds m^{-2}, respectively. This probably means that there was considerable physical movement of soil, maybe through rainfall, wind or trampling by grazing sheep which effectively buried the medic seeds. Pringleskraal keeps about four sheep per hectare on a continuous grazing system. At Langgewens, the number of belowground medic seeds was far less than the aboveground medic seeds. For example, the above and belowground seeds found in the highly productive soils were 2993 and 304 seeds m^{-2}, respectively. The above and belowground medic seeds for the medium productivity soils were 1851 and 420 seeds m^{-2}, respectively. The low number of belowground seeds at Langgewens can be attributed to the relatively low stocking rate (c. 2 to 3 ewes per ha), and no scarification of the soil.

Regressions were used to relate soil quality indicators that had significant treatment differences for the 2015 samples (ER, Na, Na % cations, SAR, B and S; Table 4.2) with the number of aboveground seeds. Electrical resistance had a moderate positive linear correlation ($r = 0.59$; $P < 0.05$) with aboveground seed (Figure 4.5). A higher ER means that the salt content in the soil is lower (FSSA 2007), and should hence promote plant growth and productivity. For that reason, the number of seeds would be expected to increase with increasing ER as plant growth will not be hindered by salinity. About 47 % of the variation on the correlation can be explained by the regression.

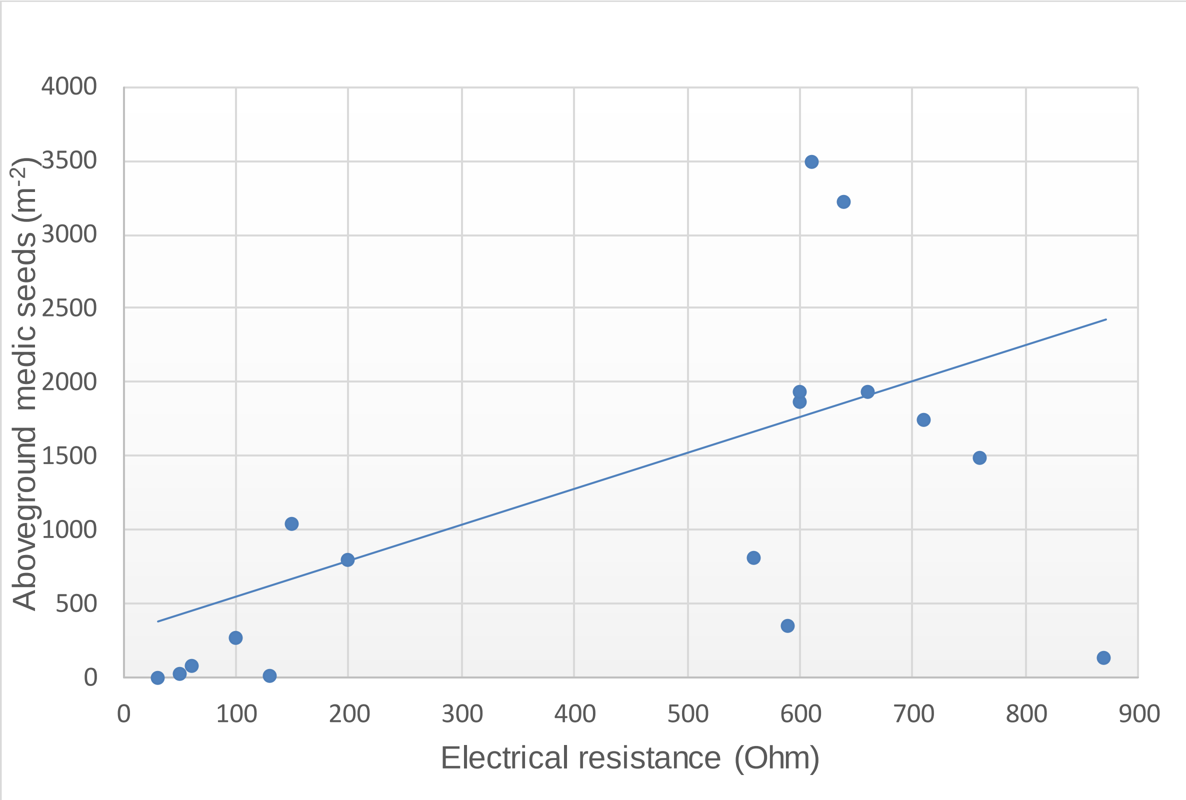

Figure 4.5: A positive linear correlation between electrical resistance and aboveground medic seeds for samples (n = 18) collected during the 2015 season. (r = 0.59; P = 0.048).

The exchangeable Na, Na % of cations and SAR had relatively strong negative linear correlation with aboveground medic seeds, i.e. r = -0.69, -0.67 and -0.67, respectively (Figures 4.6; 4.7 and 4.8). This shows that as either Na, Na % of cations or SAR increased, the number of aboveground seeds decreased. For exchangeable Na content, the decreased production of aboveground medic seeds was especially pronounced when the Na content were higher than 80 mg kg^{-1}, which could then be considered the critical threshold for optimal seed production (<1000 seeds m^{-2}). For the Na %, this critical threshold was 8% and SAR 0.3. When the indicators are lower than these thresholds, it did not limit seed production. The trend could be explained by decreased plant productivity as salinity increase. An excess amount of Na ions may disrupt plant cell functions and water intake leading to stunted plant growth (Bernstein 1975; FSSA 2007; Nichols et al. 2009; Zhu 2001). A stunted plant will tend to be less productive hence, may lead to decreased number of aboveground medic seeds. Fifty-five percent of the variation on the correlation with Na can be explained by the regression whilst for Na % of cations and SAR, 60 and 58 % of variation can be explained by the regressions, respectively.

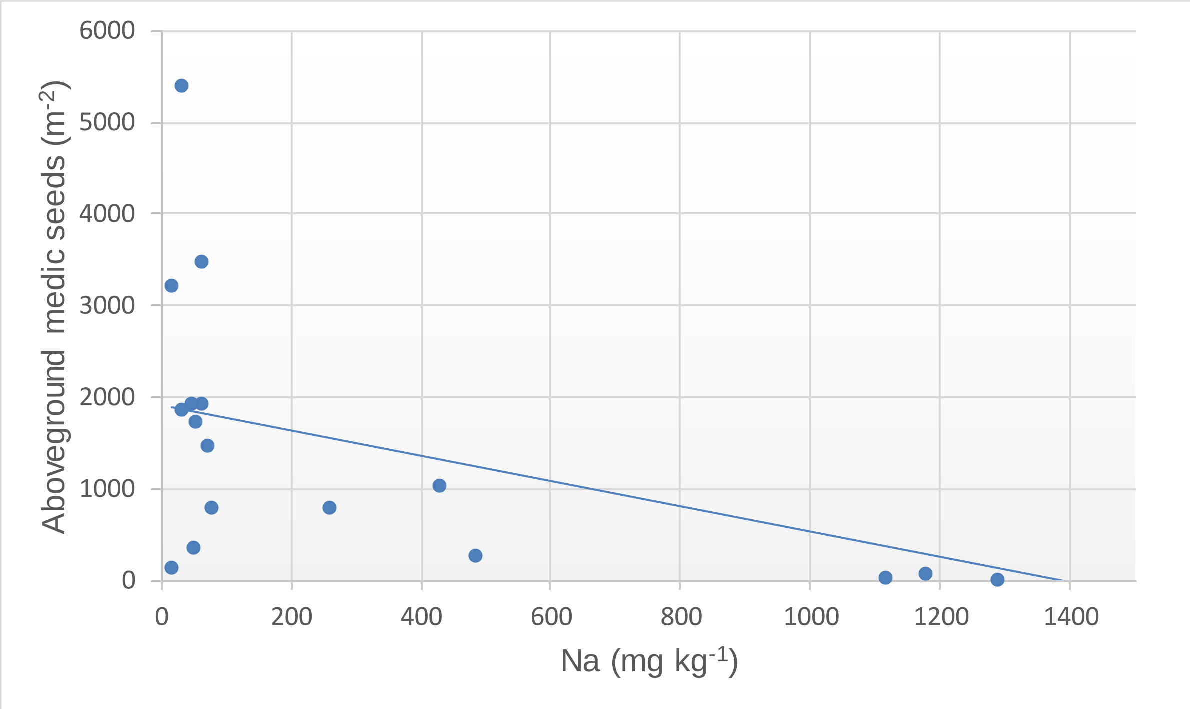

Figure 4.6: The negative linear correlation between Na and aboveground medic seeds, for samples (n = 18) collected during the 2015 season. (r = -0.69; P = 0.019).

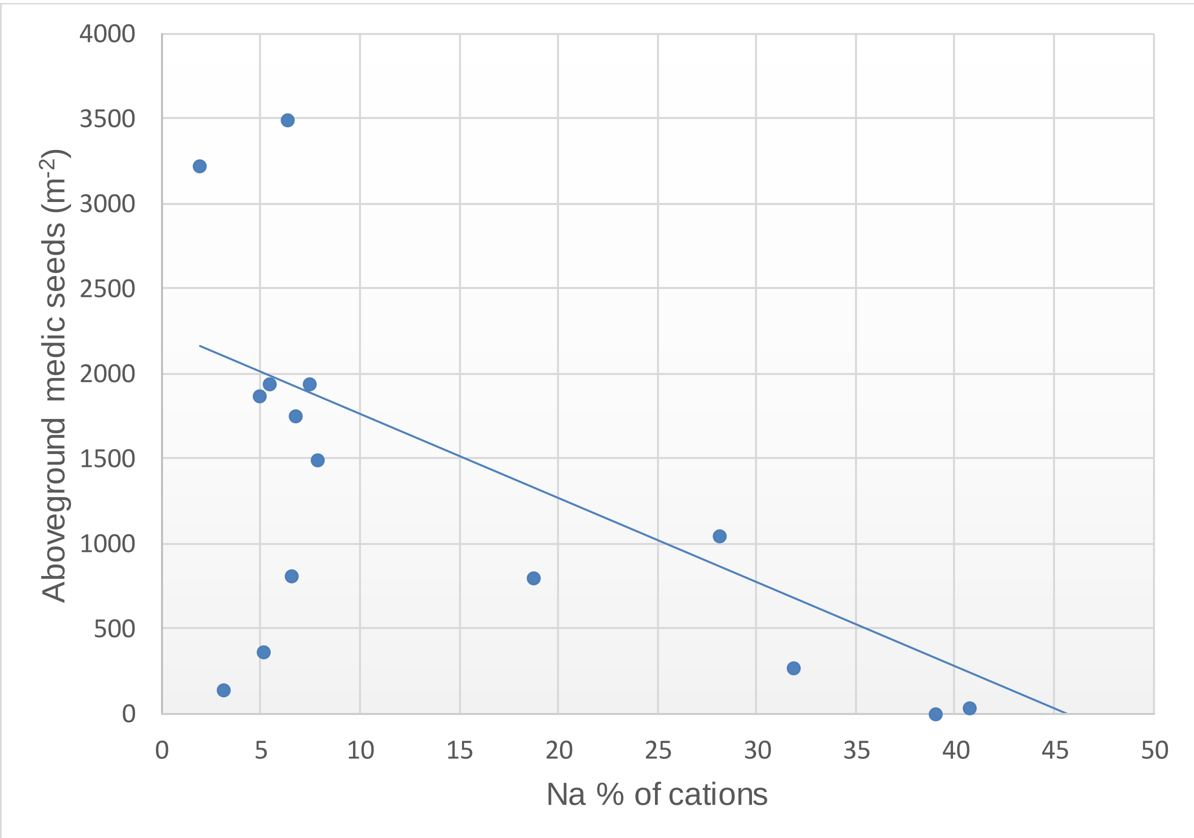

Figure 4.7: A negative linear correlation between Na % of cations and aboveground medic seeds, for samples (n = 18) collected during the 2015 season, (r = -0.67; P = 0.008).

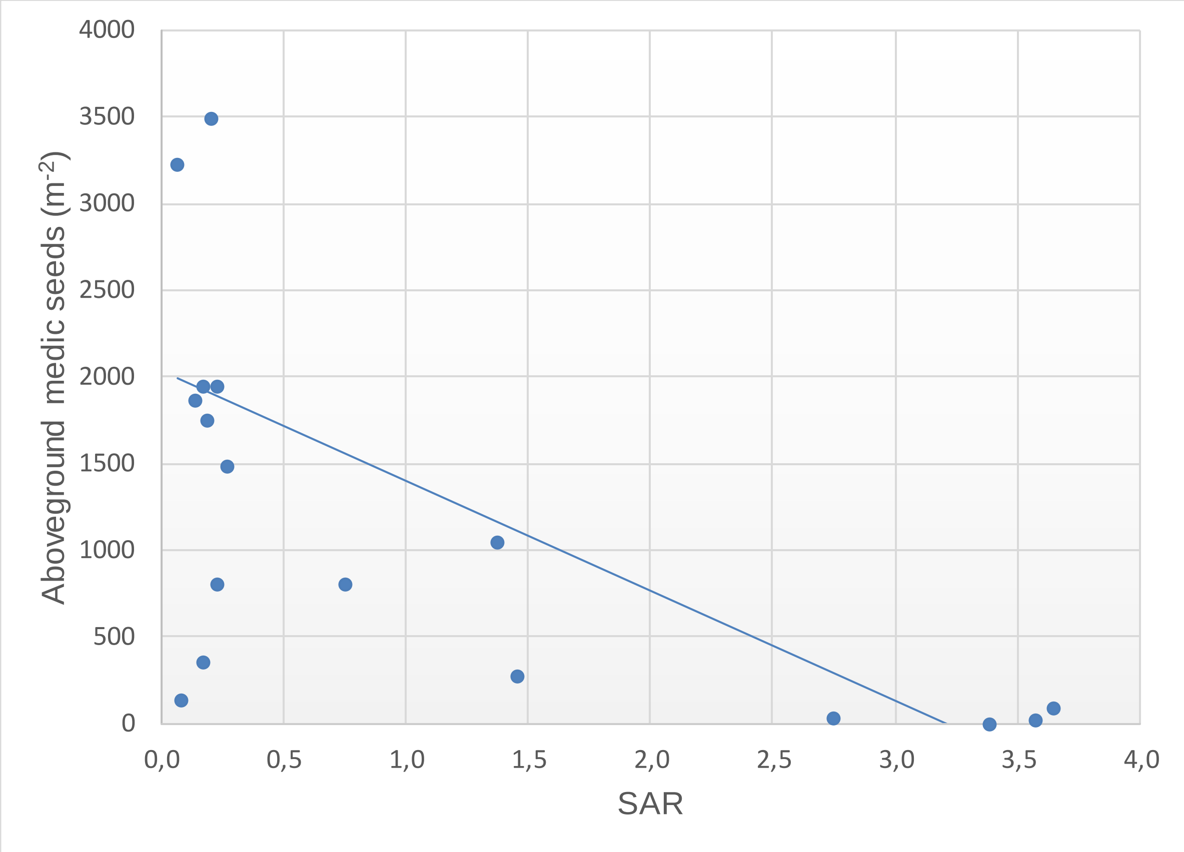

Figure 4.8: A negative linear correlation between SAR and aboveground medic seeds, for samples (n = 18) collected during the 2015 season, (r = -0.67; P = 0.012). SAR = Sodium adsorption ratio.

The B and S contents also had moderate negative linear correlation (r = -0.60 and -0.50, respectively) with the aboveground medic seeds (Figures 4.9 and 4.10). For B, 51 % of the variation can be explained by the regression whilst for S, 49 % can be explained. For most agricultural plants, B becomes toxic at a level greater than 5 mg kg^{-1} (Nable et al. 1997). The average content of extractable B, at each of the two farms was less than 5 mg kg^{-1} (Table 4.2) and we would not expect any B toxicity in the soils. The number of aboveground seeds decreased as B increased, but a critical threshold was not clear. However, when B content was higher than 1.0, there were no seeds produced.

Nonetheless, another factor that might have affected the availability of the aboveground medic seeds in 2015 is the effective grazing done by sheep in the pastures as there were no exclosure cages erected in 2015 (Harmon and Keim 1934; Simao Neto et al. 1987).

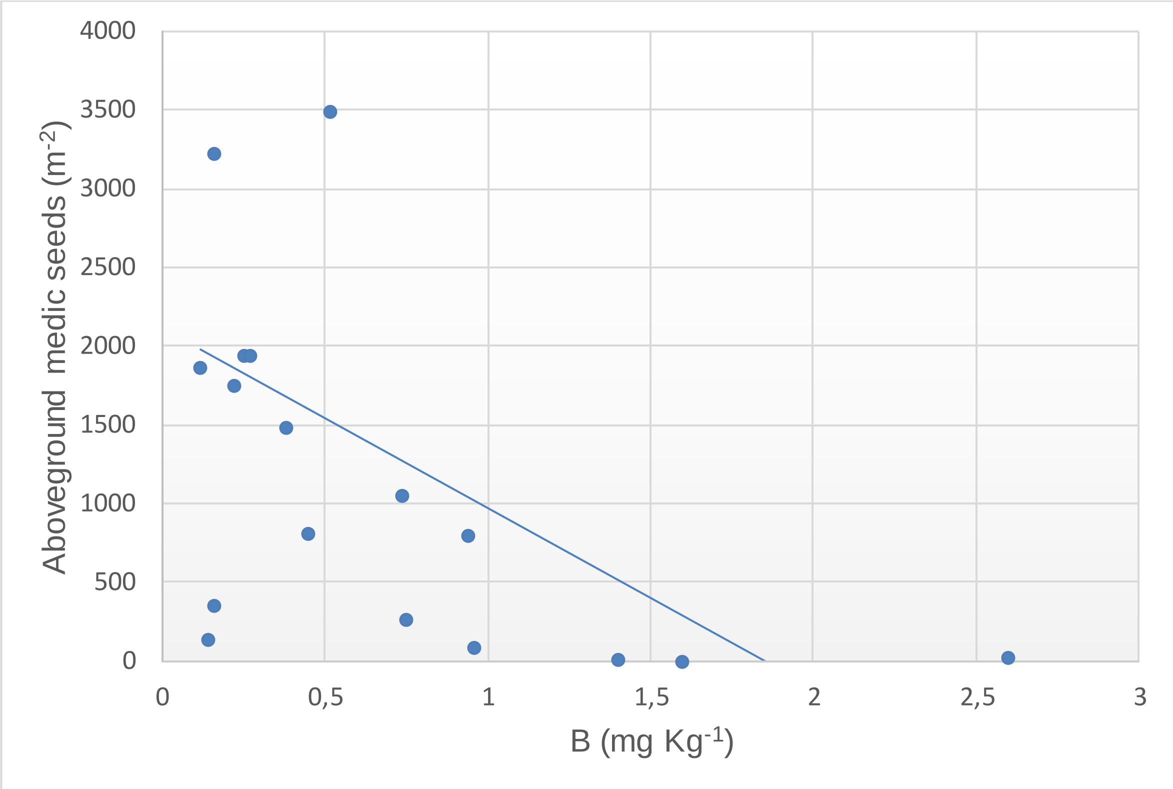

Figure 4.9: A negative linear correlation between B and aboveground medic seeds, for samples (n = 18) collected during the 2015 season, (r = -0.60; P = 0.031).

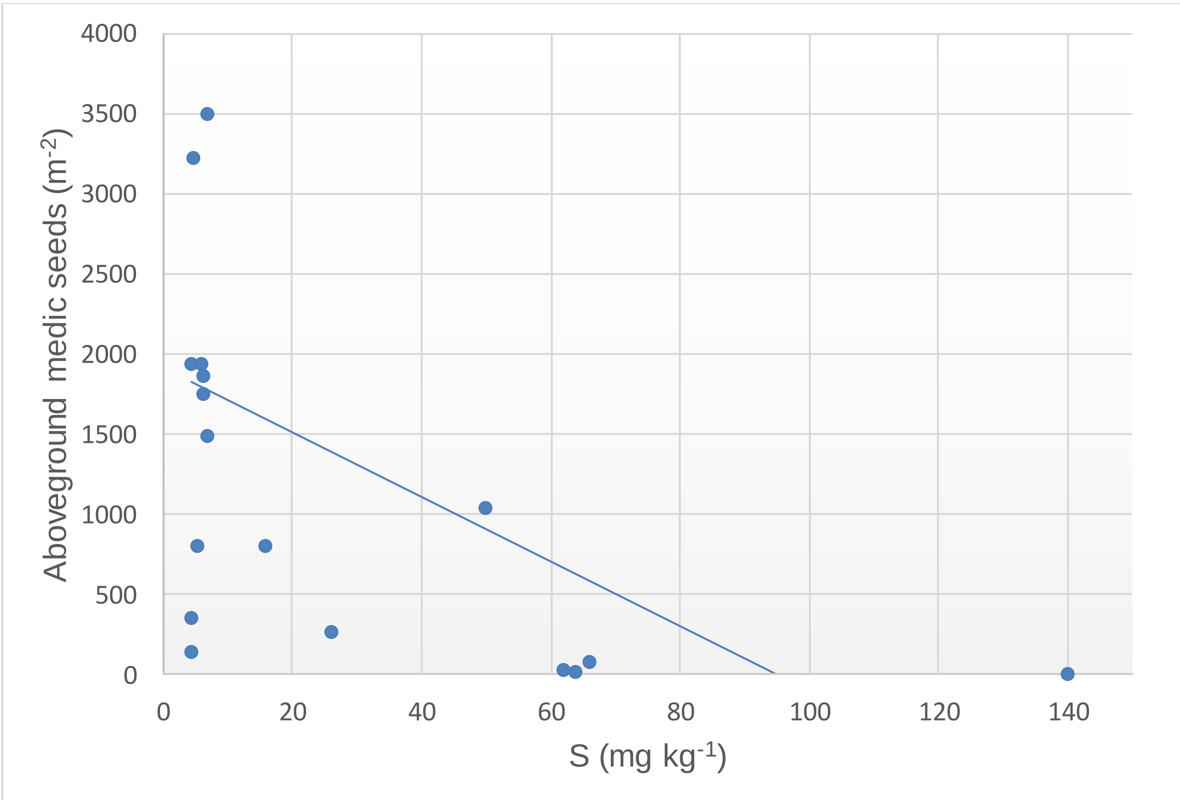

Figure 4.10: A negative linear correlation between S and aboveground medic seeds, for samples (n = 18) collected during the 2015 season, (r = -0.58; P = 0.035).

4.2.5 Total medic seeds: November 2015 samples

Correlations between the total number of medic seeds (below- and aboveground) per treatment and soil quality indicated that ER, Na, Na % of cations, SAR, B and S had an influence on the total number of seeds. A trend similar to that found on the aboveground medic seeds (section 4.2.4) was also obtained for the total number of medic seeds. Only ER had a moderate positive linear correlation with total medic seeds (r = 0.54; Figure 4.11). The other soil quality indicators (Na, Na % of cations, SAR, B and S) had moderate negative linear correlations with total medic seeds, that is, r = -0.59, -0.61, -0.61, -0.50 and -0.45 respectively (Figures 4.13 to 4.17). Therefore, an increase in ER led to an increase in the total number of seeds whilst an increase in any one of the; Na, Na % of cations, SAR, B and S, led to a decrease in the total number of medic seeds. The critical thresholds for total seed production is similar to what was found on below- and aboveground seed production individually.

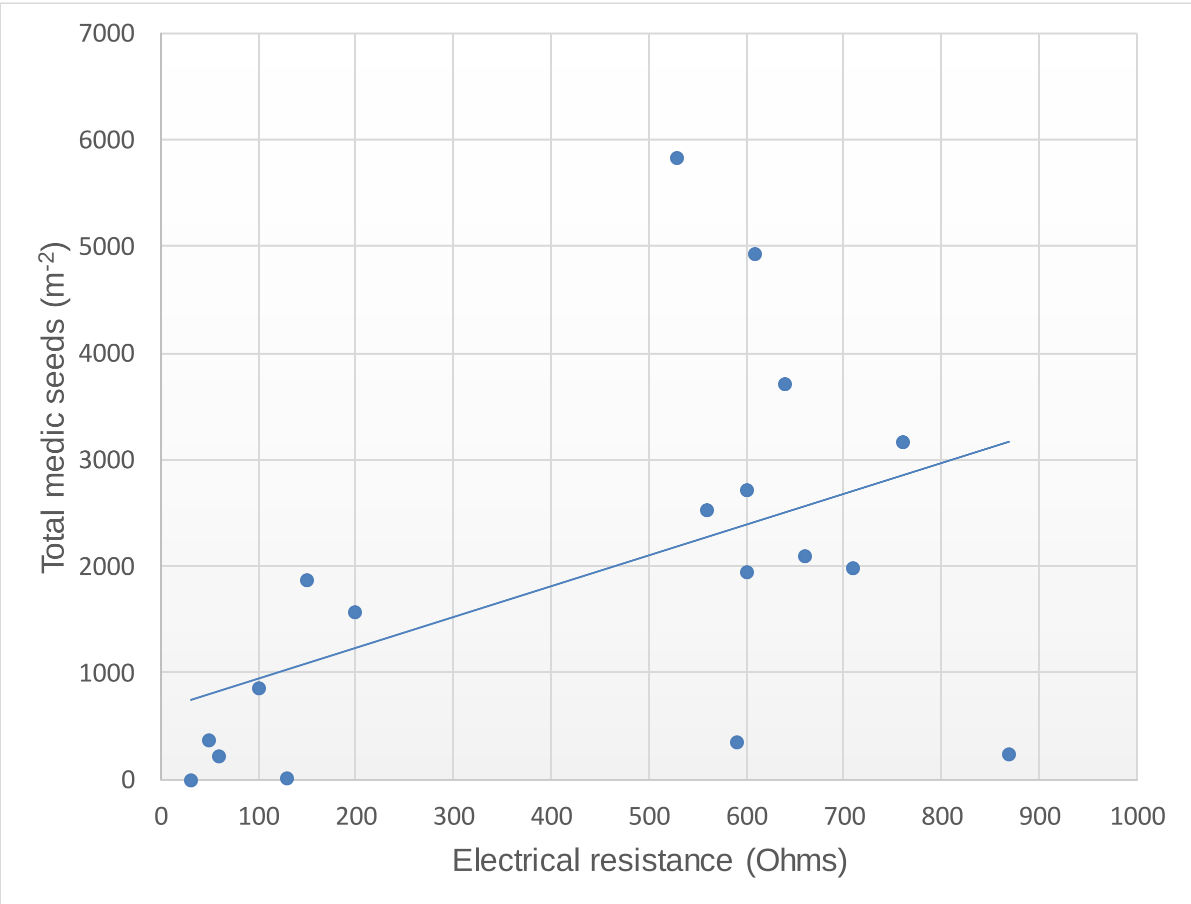

Figure 4.11: A positive linear correlation between electrical resistance and total number of medic seeds (below- and aboveground), for samples (n = 72) collected in November 2015, (r = 0.54; P = 0.042). Belowground = 5 cm depth.

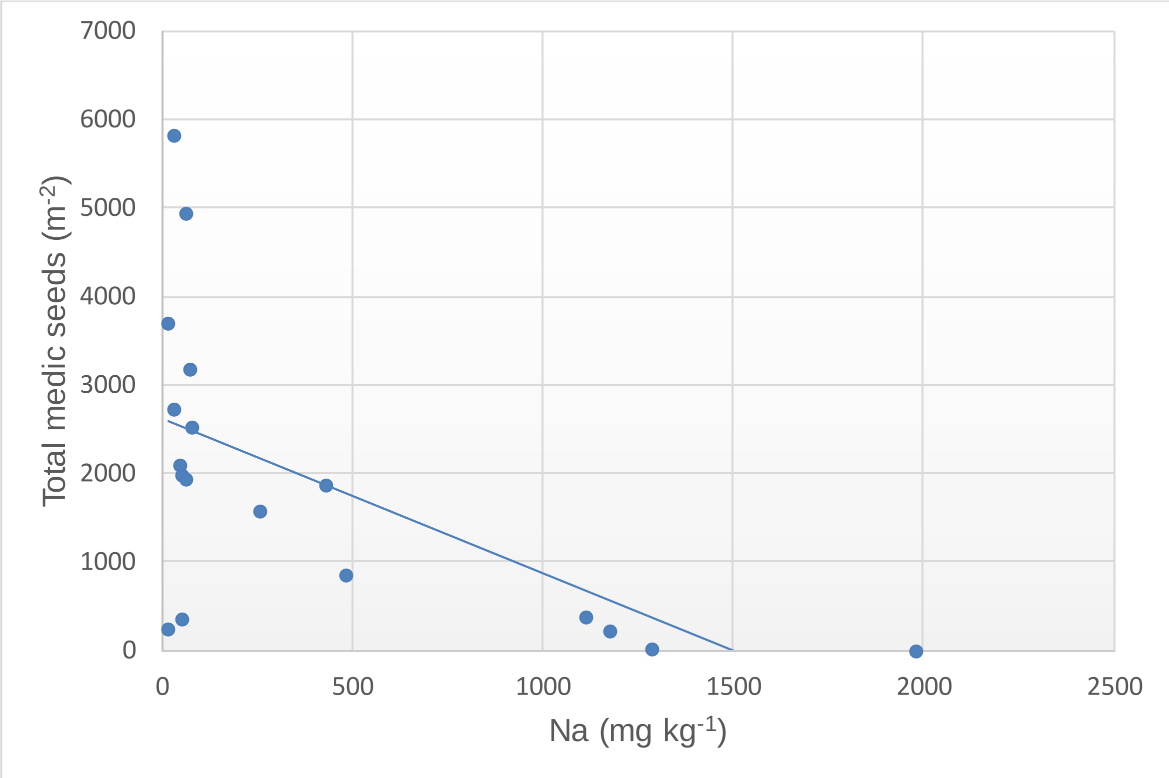

Figure 4.12: A negative linear correlation between Na and total number of medic seeds (below- and aboveground), for samples (n = 72) collected in November 2015, (r = -0.59; P = 0.009). Belowground = 5 cm depth.

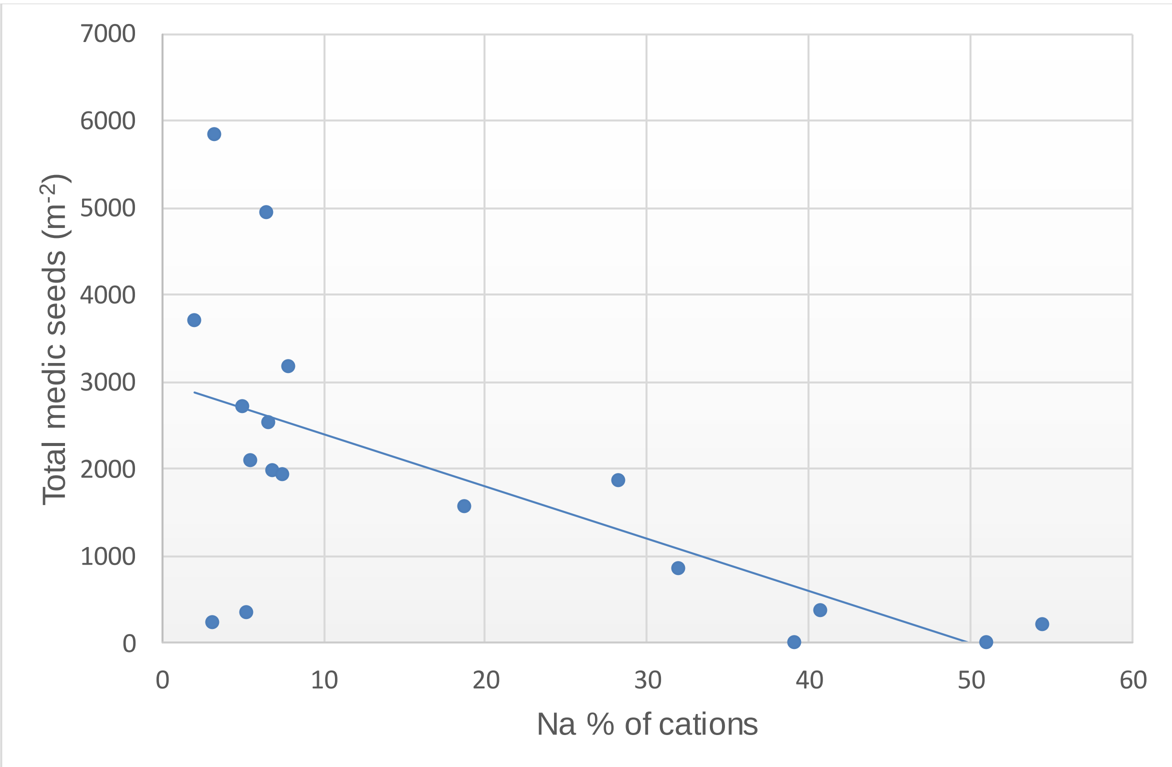

Figure 4.13: A negative linear correlation between Na % of cations and total number of medic seeds (below- and aboveground), for samples (n = 72) collected in November 2015, (r = -0.61; P = 0.005). Belowground = 5 cm depth.

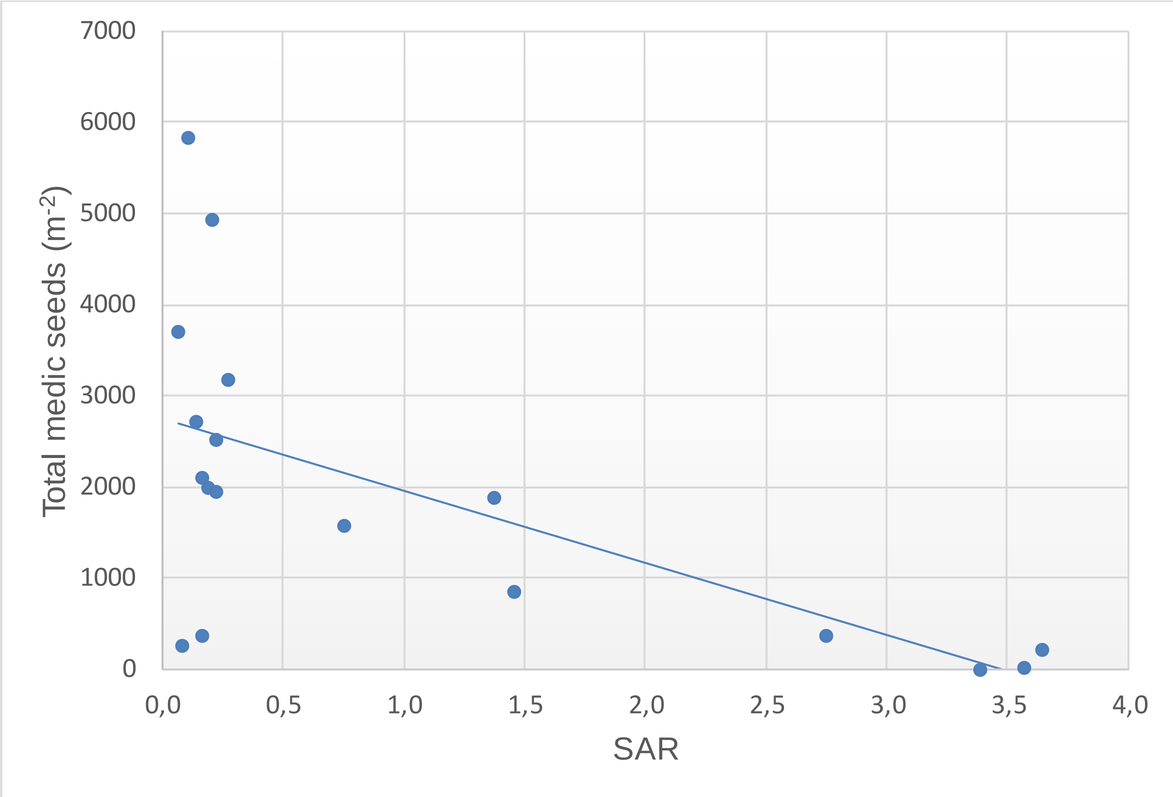

Figure 4.14: A negative linear correlation between SAR and total number of medic seeds (below- and aboveground), for samples (n = 72) collected in November 2015, (r = -0.61; P = 0.006). Belowground = 5 cm depth.

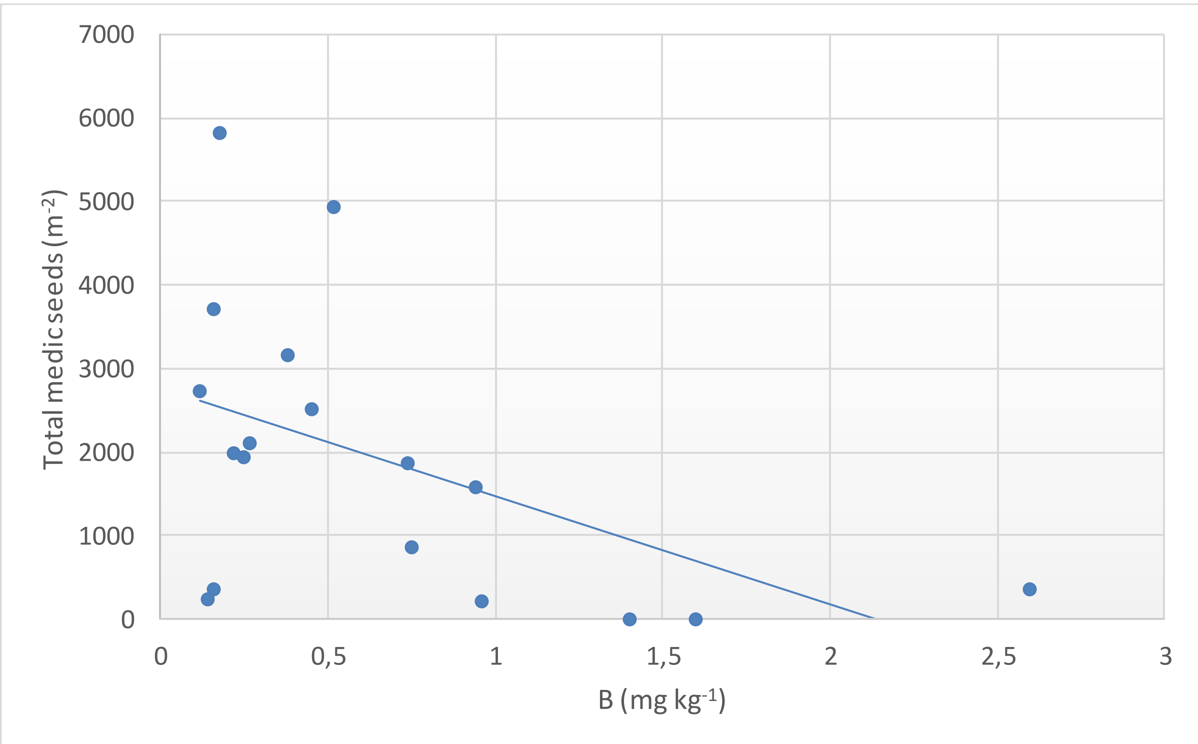

Figure 4.15: A negative linear correlation between B and total number of medic seeds (below- and aboveground), for samples (n = 72) collected in November 2015, (r = -0.50; P = 0.035). Belowground = 5 cm depth.

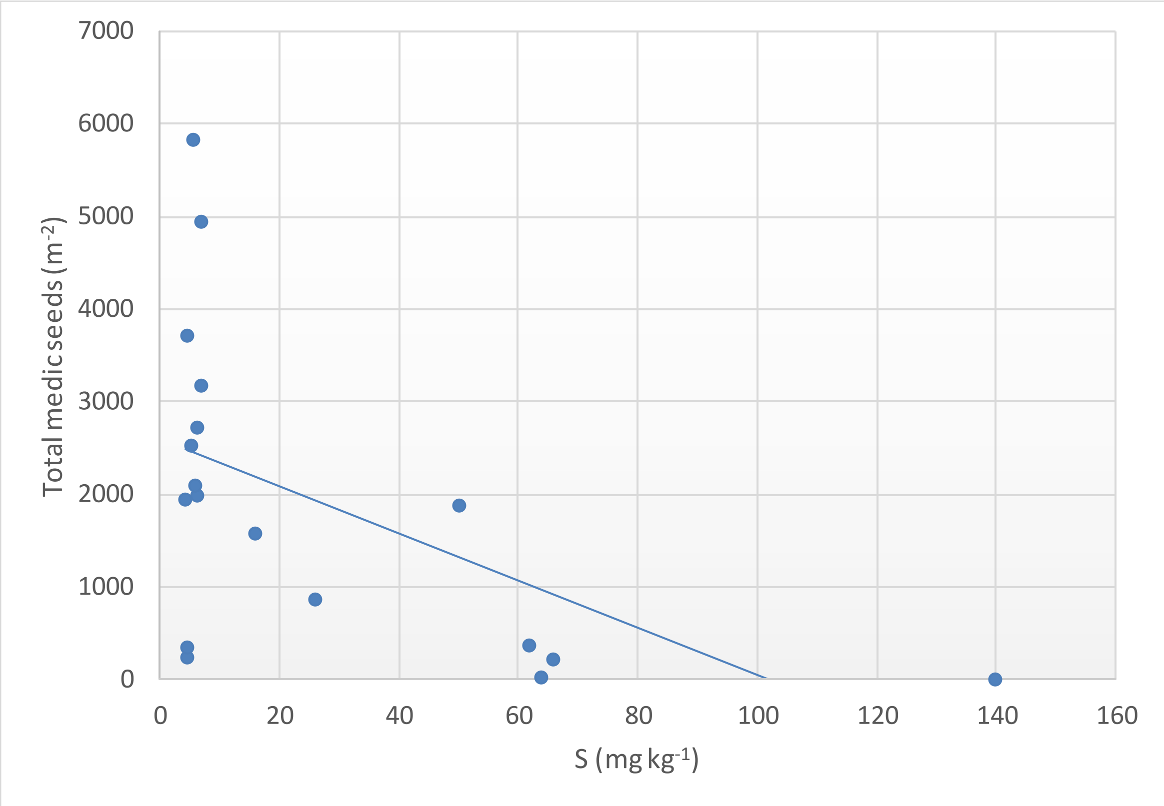

Figure 4.16: A negative linear correlation between S and total number of medic seeds (below- and aboveground), for samples (n = 72) collected in November 2015, (r = -0.45; P = 0.019). Belowground = 5 cm depth.

4.3 Medic seedling establishment

There was no difference (P > 0.05) in the number of medic seedlings that established between the low, medium and high productivity soils at Langgewens (Figure 4.17). The low, medium and high productivity soils had 147, 353 and 420 seedlings m^{-2}, respectively. The number of medic seedlings was similar across all treatments (low, medium and high productivity soils) probably because all the soil quality parameters at Langgewens were also similar (P > 0.05) in all treatments. The number of medic seedlings in the low, medium and high productivity soils at Pringleskraal were 4, 311 and 589 seeds m^{-2}, respectively. The high and medium treatments were similar (P > 0.05) and also, the medium and low treatments (P > 0.05), but the high and low treatments differed (P < 0.05). The differences in number of medic seedlings seem to be indicative of a difference in medic seedling establishments between the saline and non-saline soils. As the low productive soils at Pringleskraal were saline, this is likely be the primary reason for decreased medic seedling establishment. However, other factors such as total cations and S could have also affected the establishment of the medic seedlings.

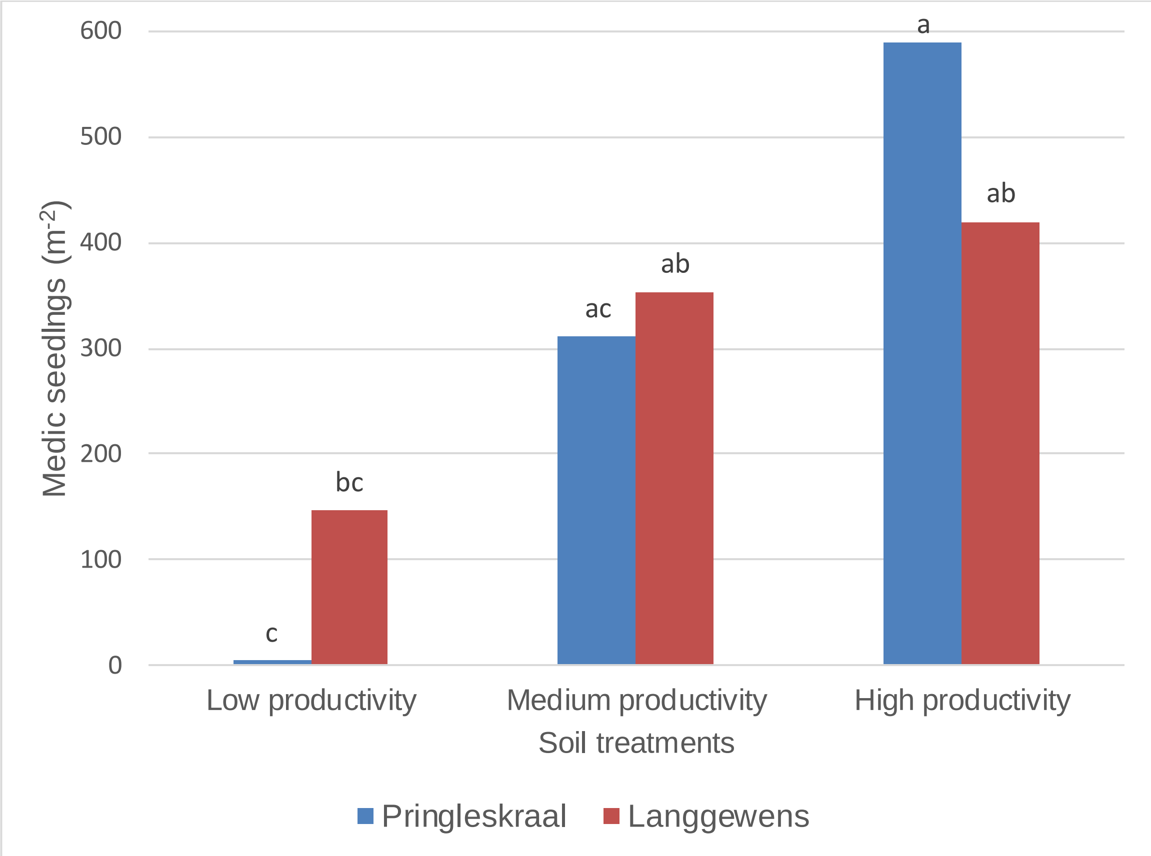

Figure 4.17: The number of medic seedlings for samples (n = 54) sampled in May 2016. Different letters above the vertical bars indicate the treatments (low, medium and high productivity soils) with a significant difference ($P < 0.05$).

Analysis of the correlation between the total number of medic seedlings per treatment and soil quality indicated that Na, SAR, total cations and S had an influence on the number of medic seedlings. The correlations between the soil quality indicators and medic seedlings were weak negative relationships (Figures 4.18, 4.19, 4.20 and 4.21). Thus, an increase in any one of the soil quality indicators (Na, SAR, total cations and S) led to a decrease in number of medic seedlings per treatment. Even though the correlation was not as strong as for aboveground seed production, there was a similar tendency as what was observed with medic seed production. This indicates that the plants are more sensitive to salinity during seed production compared to establishment.

For medic seedling establishment, the threshold for soil salinity indicators were not as clear as for seed production. The Na content in the low and high productivity soils were 3661 and 153.63 mg kg^{-1} respectively (Table 4.3). The Na content in the low productivity soils was higher than what would be recommended for optimal plant production. Conversely, the Na content in the high productivity soils was low and that may be one of the reasons why the medic seedling establishment was higher. The SAR was also high in the low productivity soil (7.43) compared to the high productivity soils (0.55).

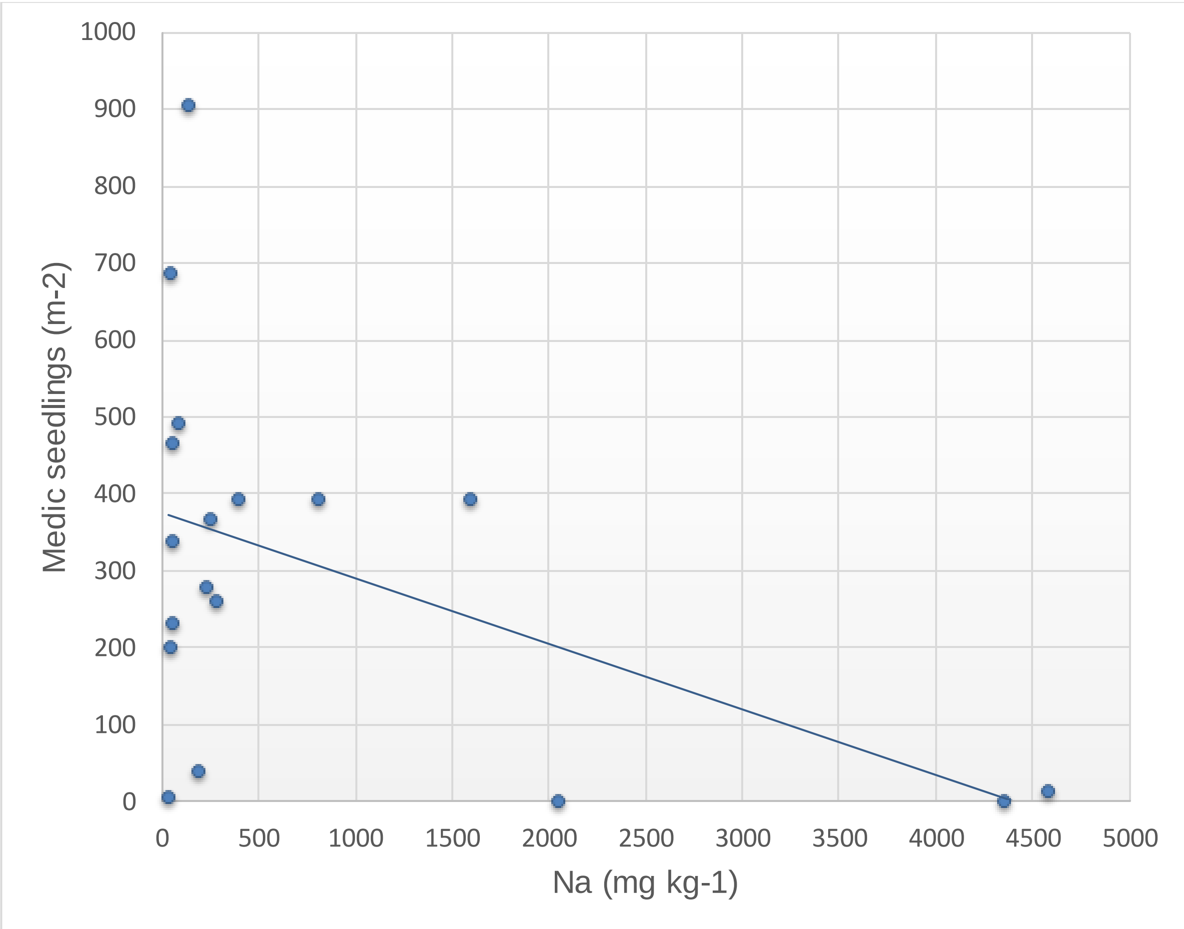

Figure 4.18: A negative linear correlation between Na and number of medic seedlings, for samples (n = 72) analysed during the 2016 growing season, (r = -0.29; P = 0.038).

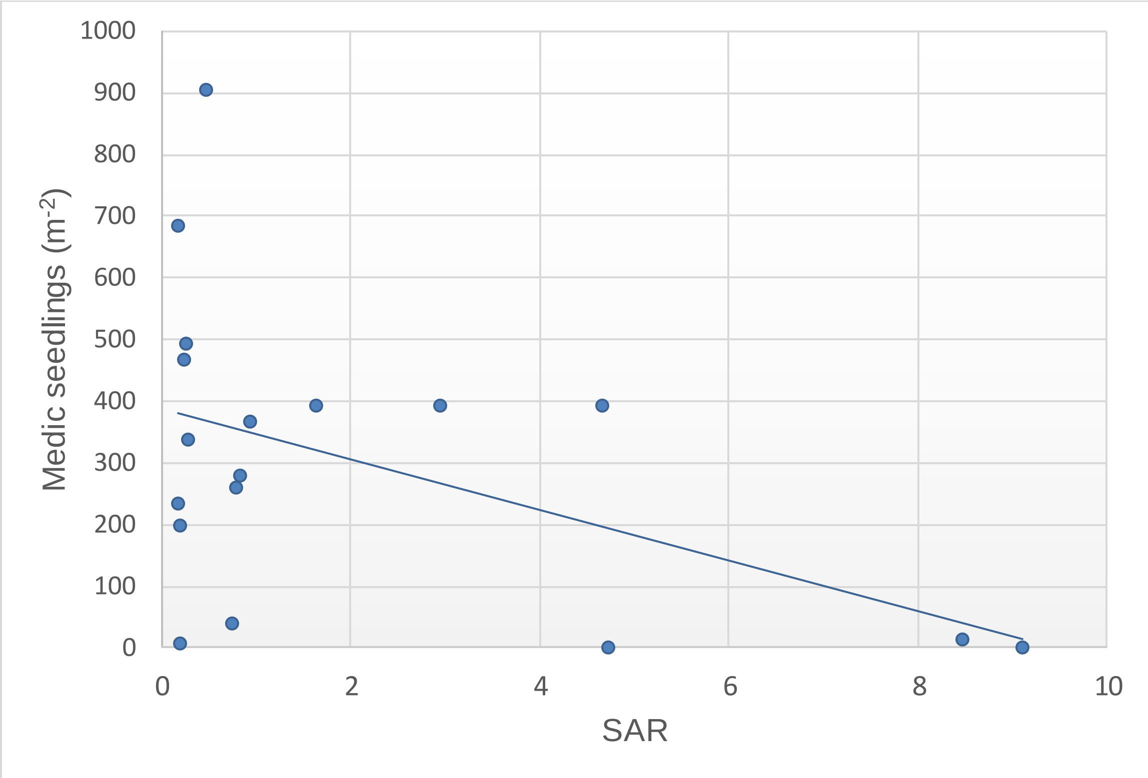

Figure 4.19: A negative linear correlation between SAR and number of medic seedlings, for samples (n = 72) analysed during the 2016 growing season, (r = -0.30; P = 0.048). SAR = Sodium adsorption ratio.

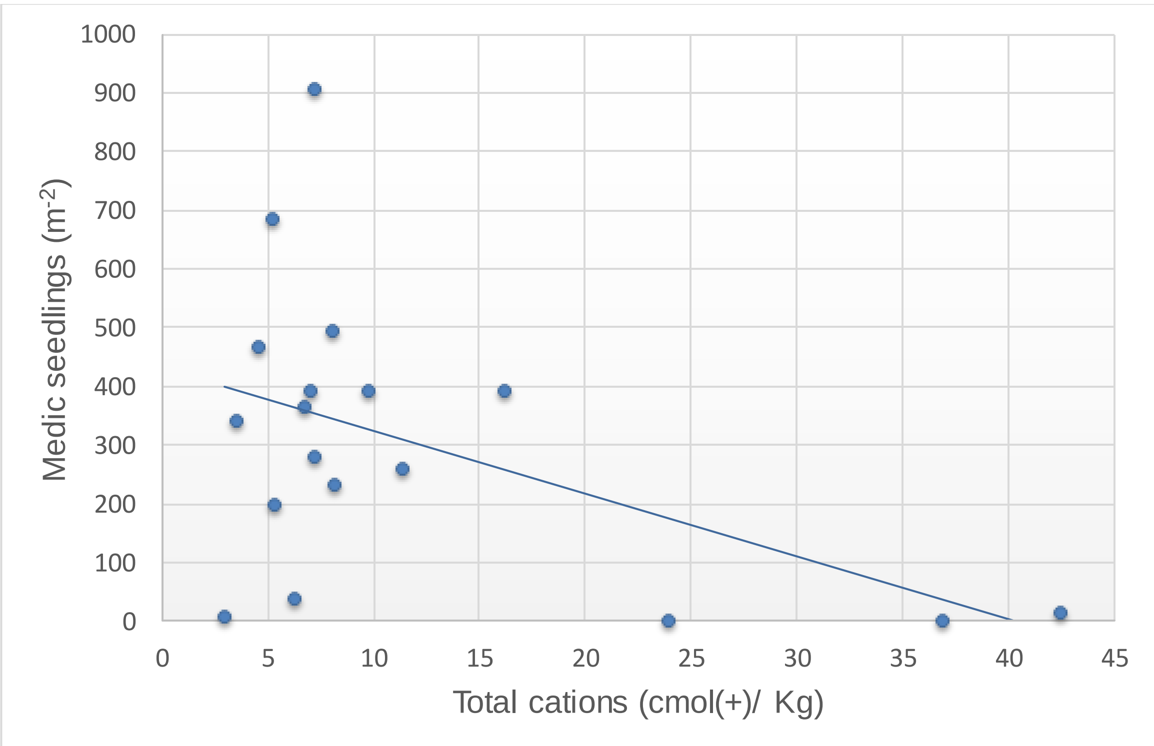

Figure 4.20: A negative linear correlation between total cations and number of medic seedlings, for samples (n = 72) analysed during the 2016 growing season, (r = -0.28; P = 0.041).

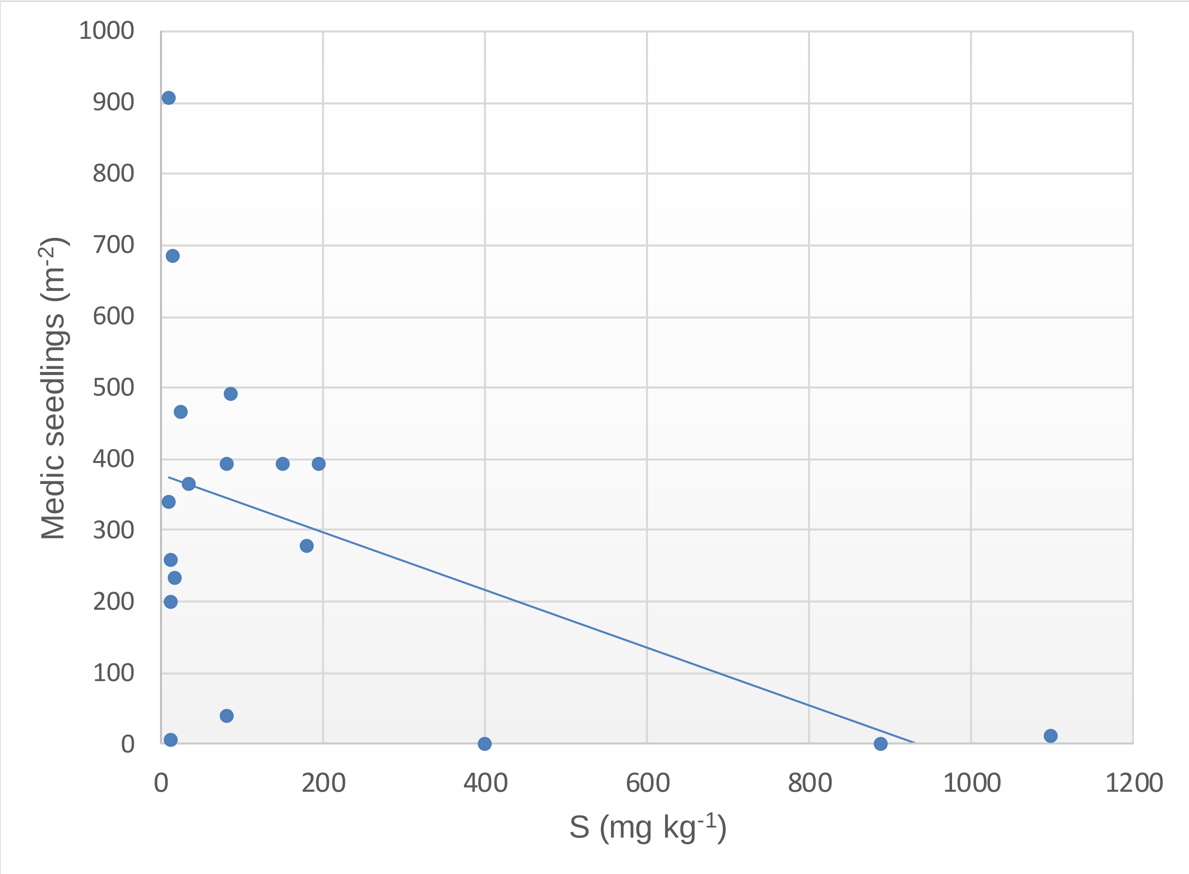

Figure 4.21: A negative linear correlation between S and number of medic seedlings, for samples (n = 72) analysed during the 2016 growing season, ($r = -0.32$; $P = 0.031$).

4.4 Medic herbage production

4.4.1 Pringleskraal

In July 2016, the medic herbage yield did not differ ($P > 0.05$) between the low, medium and high productivity soils ($P > 0.05$), and these had 0, 651 and 1033 kg DM ha^{-1}, respectively (Figure 4.22). Medic herbage yield remained low and similar ($P > 0.05$) in the low productivity soils from July to October 2016. The amount of herbage produced on these soils are therefore negligible and do not contribute to farm productivity. This highlights the problem with these soils. Either mitigation strategies to alleviate soil salinity should be found, or crops that are tolerant to soil salinity should be introduced. In August 2016, the medium and high productivity soils were similar ($P > 0.05$) to each other with yields of 1392 and 1713 kg DM ha^{-1}, respectively. These two treatments differed from the low productivity soils which had 215 kg DM ha^{-1}. A similar trend was observed in September and October 2016 as the medium and high treatments were similar ($P > 0.05$) to each other, but both differed ($P < 0.05$) from the low productivity soils. In September, the yields for the low, medium and high treatments were; 49, 1639 and 1597 kg DM ha^{-1}, respectively. In October, the yields for the low, medium and high productivity soils were; 264, 1495 and 1471 kg DM ha^{-1}, respectively. The low productivity soils mostly had some, salt tolerant weeds such as Lindley's saltbush (*Atriplex lindleyi* subsp. *inflata*) and the succulent slenderleaf iceplant (*Mesembryanthemum nodiflorum*). The presence of such weeds confirmed the salinity status of the soils and only the very tolerant plants managed to survive on the soils. Therefore, these characteristics of salt tolerance should be exploited so that these soils could also be used for agricultural production. However, plants should be palatable. Recently in Australia, a new salt and waterlogging tolerant annual pasture legume, messina (*Melilotus siculus*) was released (Nichols et al. 2012). It is grazing crops such as messina or other salt-tolerant, but palatable crops, which should be evaluated under these conditions. Messina is the most salt tolerant legume when compared to any other (Nichols et al. 2012) and would regenerate in highly saline environment. It will therefore fit well into the production systems in the Swartland.

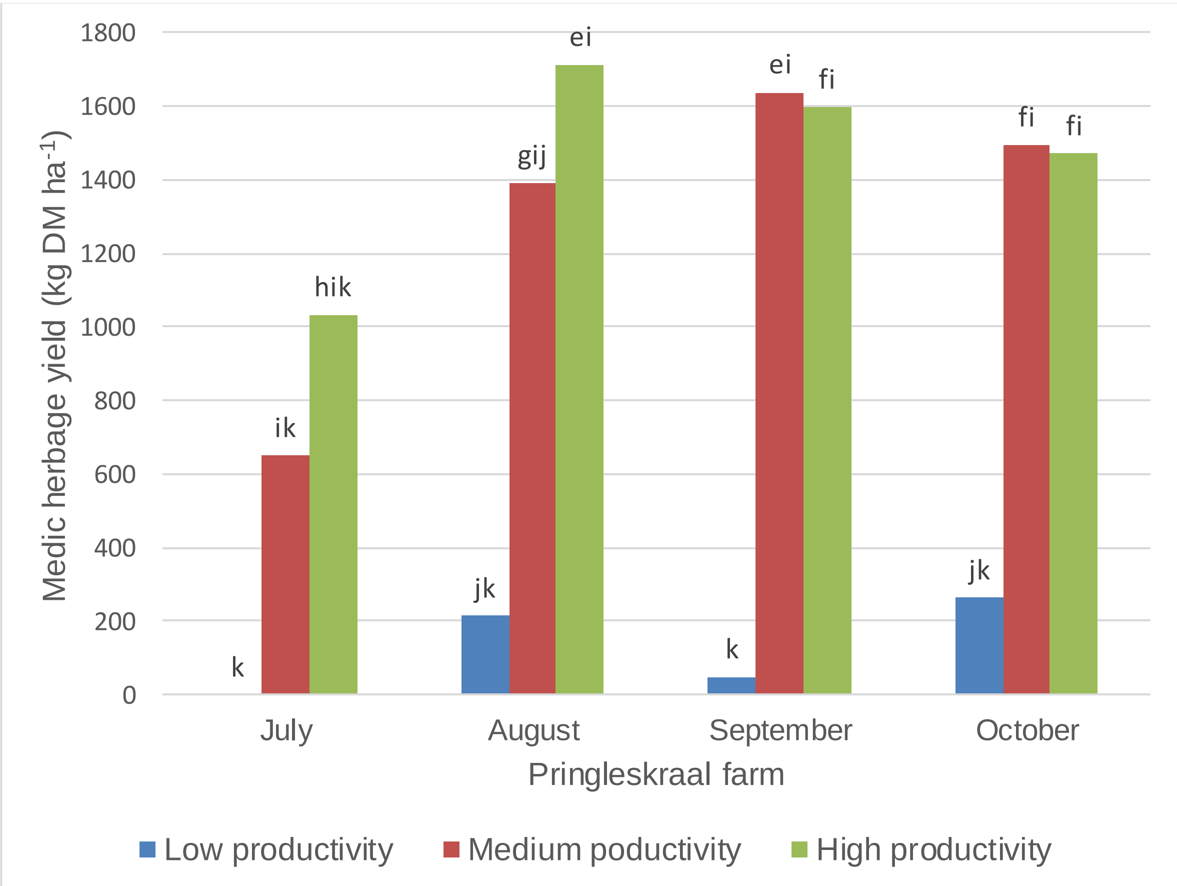

Figure 4.22: Medic herbage yield (kg DM ha^{-1}) on low, medium and high productivity soils at Pringleskraal sampled in July, August, September and October 2016 (n = 36). Different letters above the vertical bars indicate the treatments with a significant difference ($P < 0.05$).

A negative linear correlation existed between soil quality indicators (Na, Na % of cations, SAR, pH, Mg, Ca, total cations, B and S) and medic herbage yield for all four months (July to October 2016). The soil salinity indicators; exchangeable Na, Na % of cations and SAR had a coefficient of determination ranging between -0.60 and -0.82. This shows that there was a moderately strong negative linear correlation between these soil salinity indicators and medic herbage yield (Figures 4.23, 4.24 and 4.25). As the salt content increased, the medic herbage yield decreased. Table 4.3 has shown that the Na content in the low productivity soils (3661 mg kg^{-1}) is higher ($P < 0.05$) than the 345 mg kg^{-1} in the high productivity soils. The Na content in the low productivity soils was greater than the critical threshold for Na (>800 mg kg^{-1}), above which herbage yield was severely affected (<1000 kg ha^{-1} by October). The huge deviation from the critical threshold could have contributed to the low medic herbage yield in the low productivity soils. The SAR of the low productivity soils was 7.43 while the high and medium productivity soils have SARs of 0.55 and 2.08, respectively. The critical threshold for SAR was 3.0 above which productivity was compromised. The permanently brack soils (SAR > 5) of the low productivity soils (FSSA 2007), with a high Na content is detrimental to crops as salts disrupt normal functioning of cells and water movement in plants (FSSA 2007; Nichols et al. 2009; Podmore 2009a; Zhu 2001). Plant productivity in the brack soils would be negatively affected such that the herbage yield and seed production will be supressed. The medium and high productivity soils had a relatively low Na content and SAR, therefore they had a higher medic herbage yield than the low productivity soil. In such a case, an elevated amount of Na would be expected to reduce plant growth, hence, a negative correlation with herbage yield.

Soil quality data (Table 4.3) has shown that the medium and high productivity were, in most cases similar ($P > 0.05$), but both were different ($P < 0.05$) from the low productivity soils. The low productivity soils had soil quality indicators pH (KCl), Mg, total cations and B that had clear critical thresholds. These thresholds for the aforesaid soil quality indicators were; 6.6 for pH(KCl), 512.4 mg kg^{-1} for Mg, 11.38 $cmol_{+}$ kg^{-1} for total cations and 1.6 mg kg^{-1} for B.

Herbage production in the high productive soils did not gradually increase in September and October as expected. The poor medic productivity in the high productivity soils may have been caused by some factors other than soil quality. One of the factors may be the high infestation of the soils by weeds such as ryegrass

(*Lolium rigidum*) and Stinkkruid or Calomba daisy (*Oncosiphon suffruticosum*). The weeds seemed to outcompete the medic plant such that the herbicide, Rondup, was administered on some sections of the farm in mid-September of 2016 to control the weeds. The herbicide was not sprayed on the experimental areas, therefore the weeds continued to compete with medic plants such that the medic herbage yield did not increase in October.

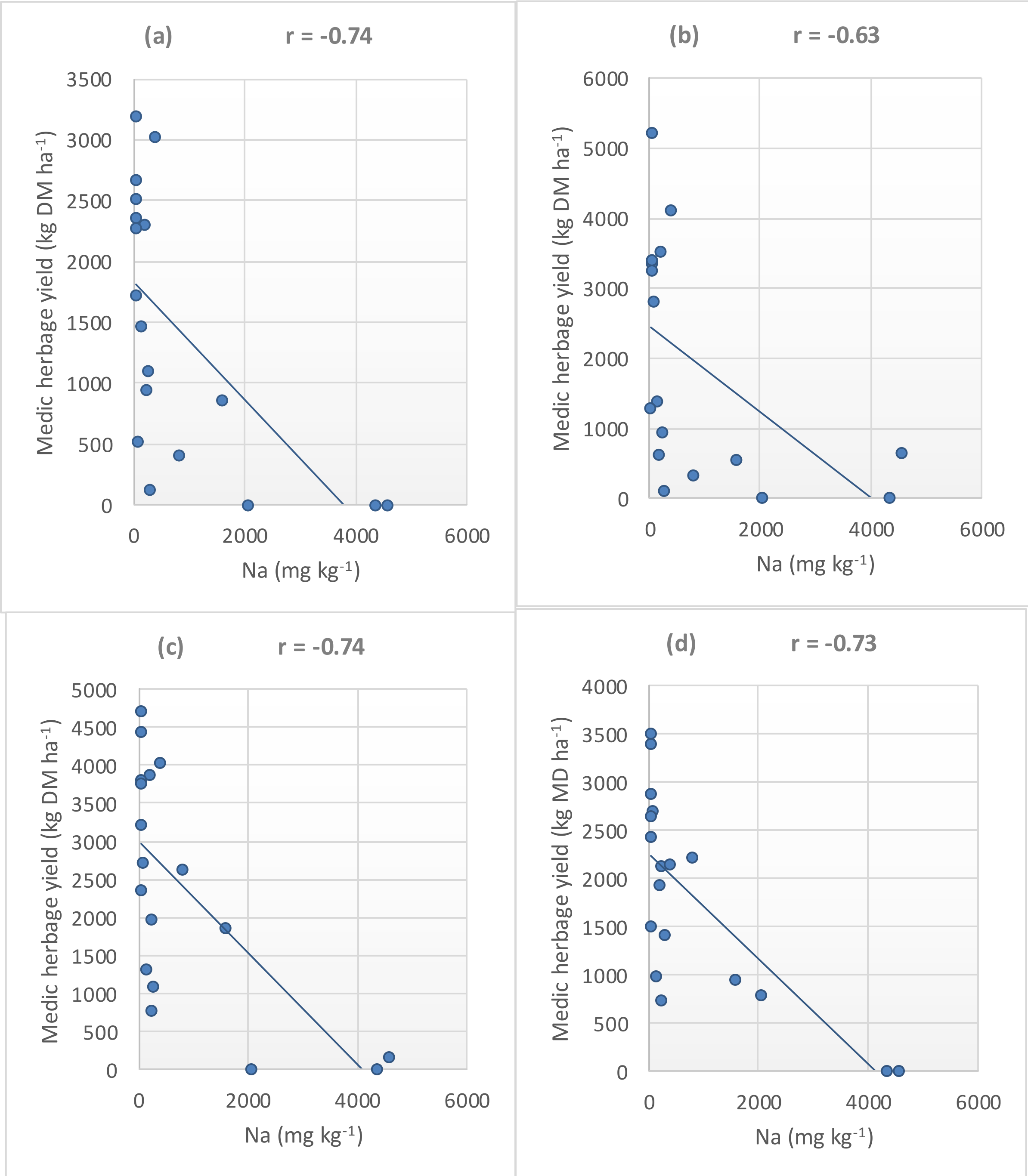

Figure 4.23: The negative linear correlations between Na and medic herbage yield, for samples (n = 32) collected during the months (a) July, (b) August, (c) September and (d) October 2016, ($P < 0.05$).

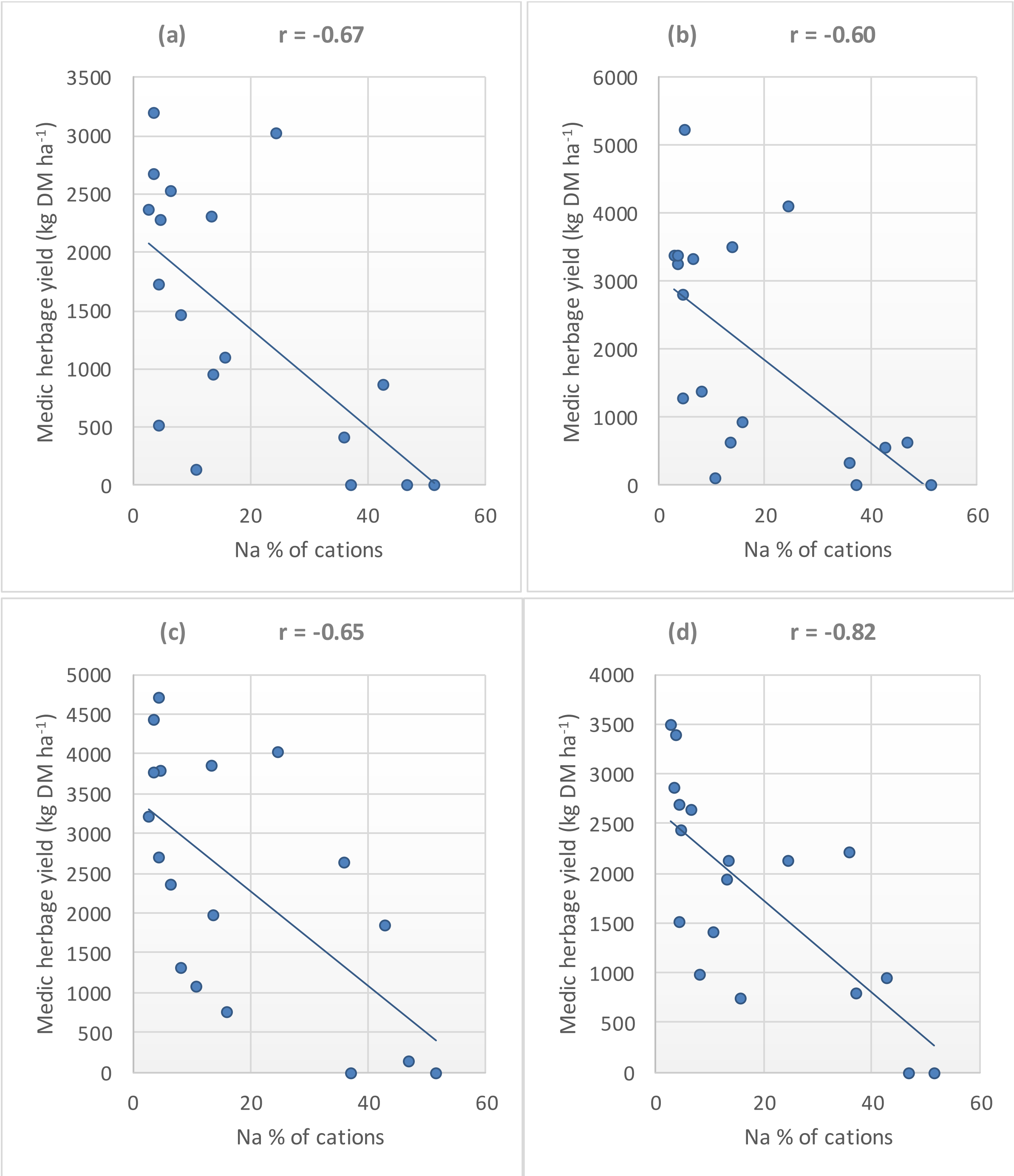

Figure 4.24: The negative linear correlations between Na % of cations and medic herbage yield, for samples (n = 32) collected during the months (a) July, (b) August, (c) September and (d) October 2016, ($P < 0.05$).

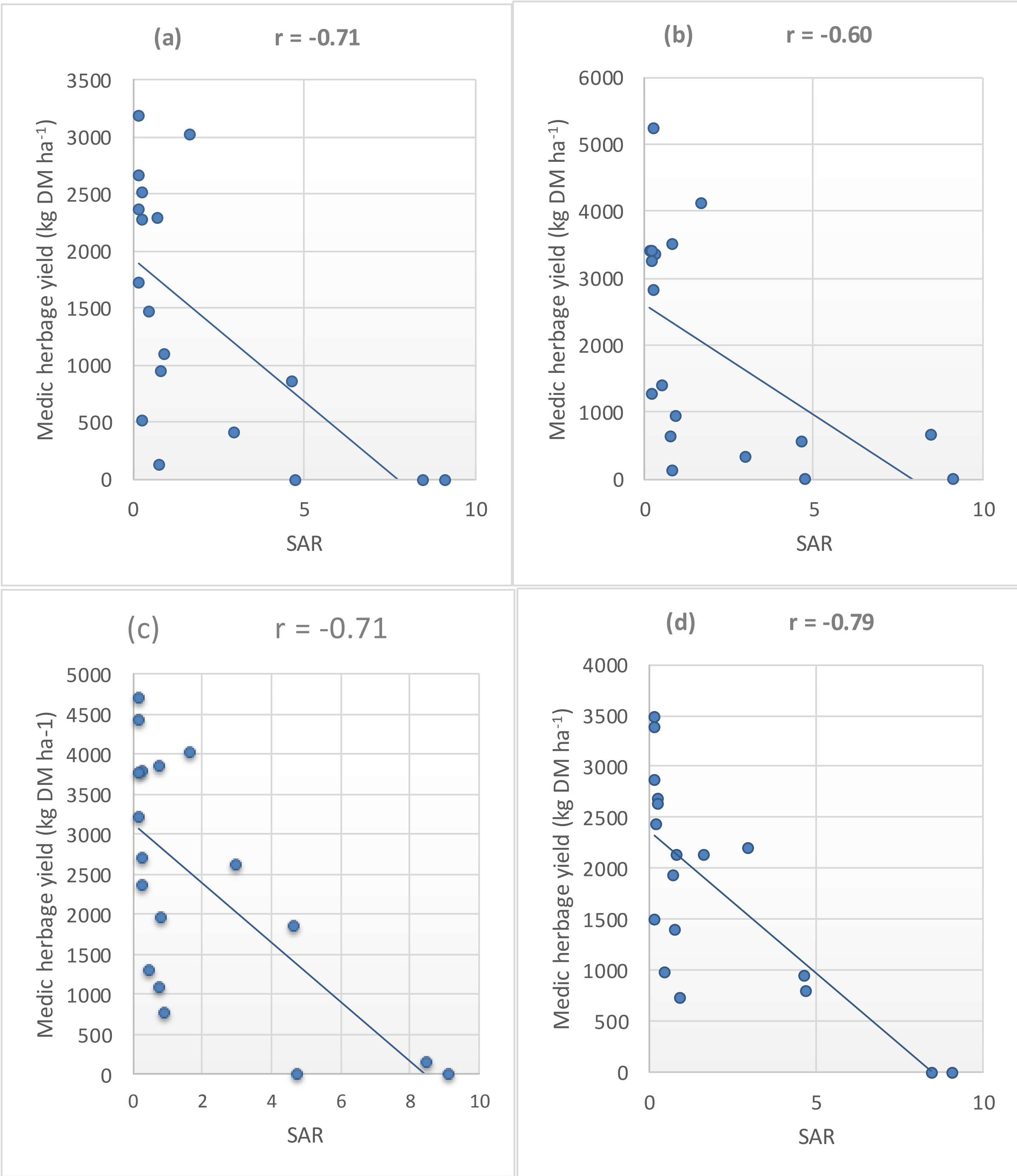

Figure 4.25: The negative linear correlations between SAR and medic herbage yield, for samples (n = 32) collected during the months (a) July, (b) August, (c) September and (d) October 2016, ($P < 0.05$).

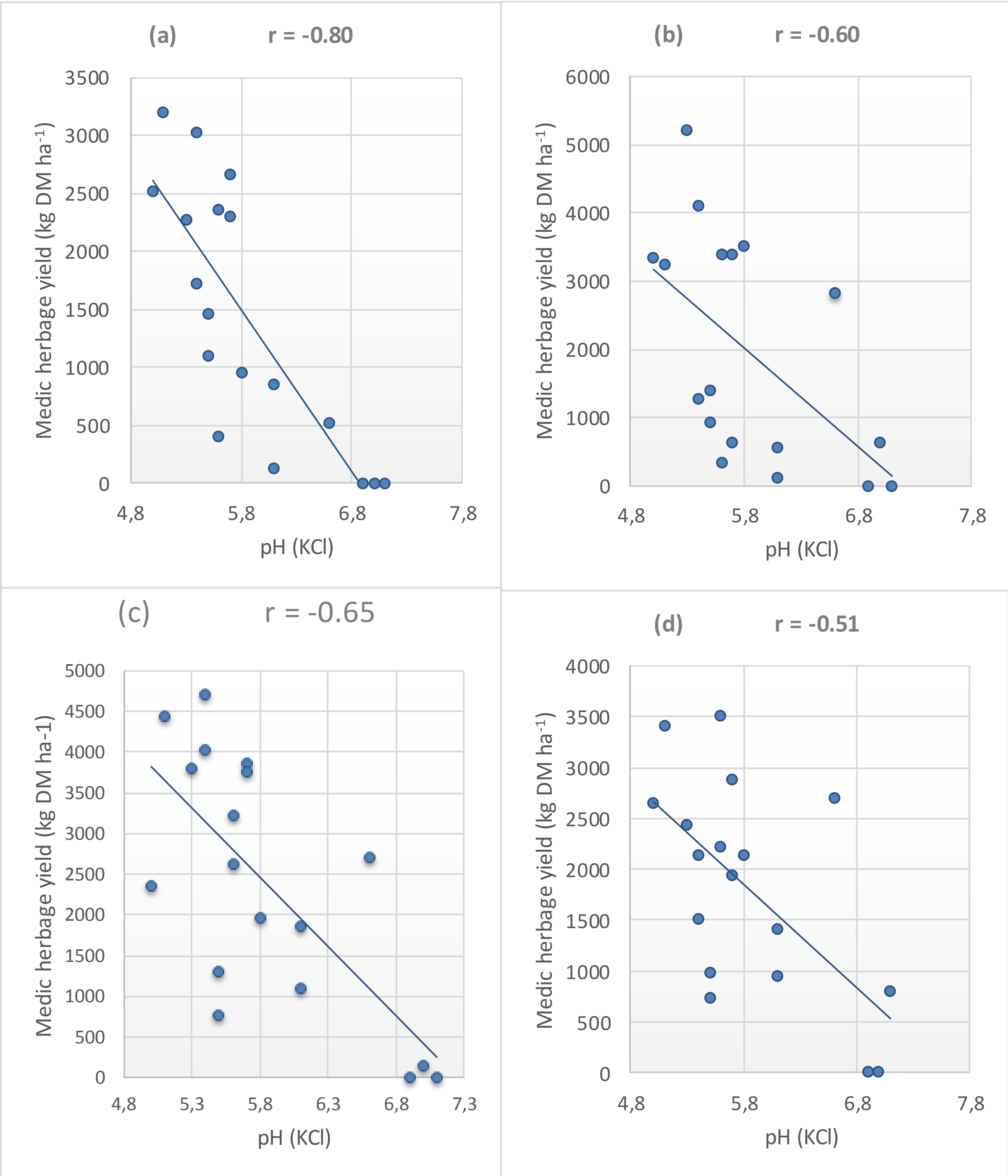

Figure 4.26: The negative linear correlations between pH (KCl) and medic herbage yield, for samples (n = 32) collected during the months (a) July, (b) August, (c) September and (d) October 2016, (P<0.05).

The coefficient of determination (r) for pH (KCl) and medic herbage yield ranged between -0.51 and -0.80 and thus had a moderately strong negative correlation. This means that an increase in pH led to a reduction in herbage yield. The pH(KCl) values for the low, medium and high productivity soils were; 7.0, 6.0 and 5.87, respectively. The ideal pH(KCl) range for medics is generally 4.8 to 8 (Bogacki et al. 2013; Clark

2014). For that reason, we would assume that the medics should not be affected by pH(KCl). Rather an interaction of pH(KCl) and other soil parameters such as B (Gupta 2007) could have contributed to poor medic herbage productivity.

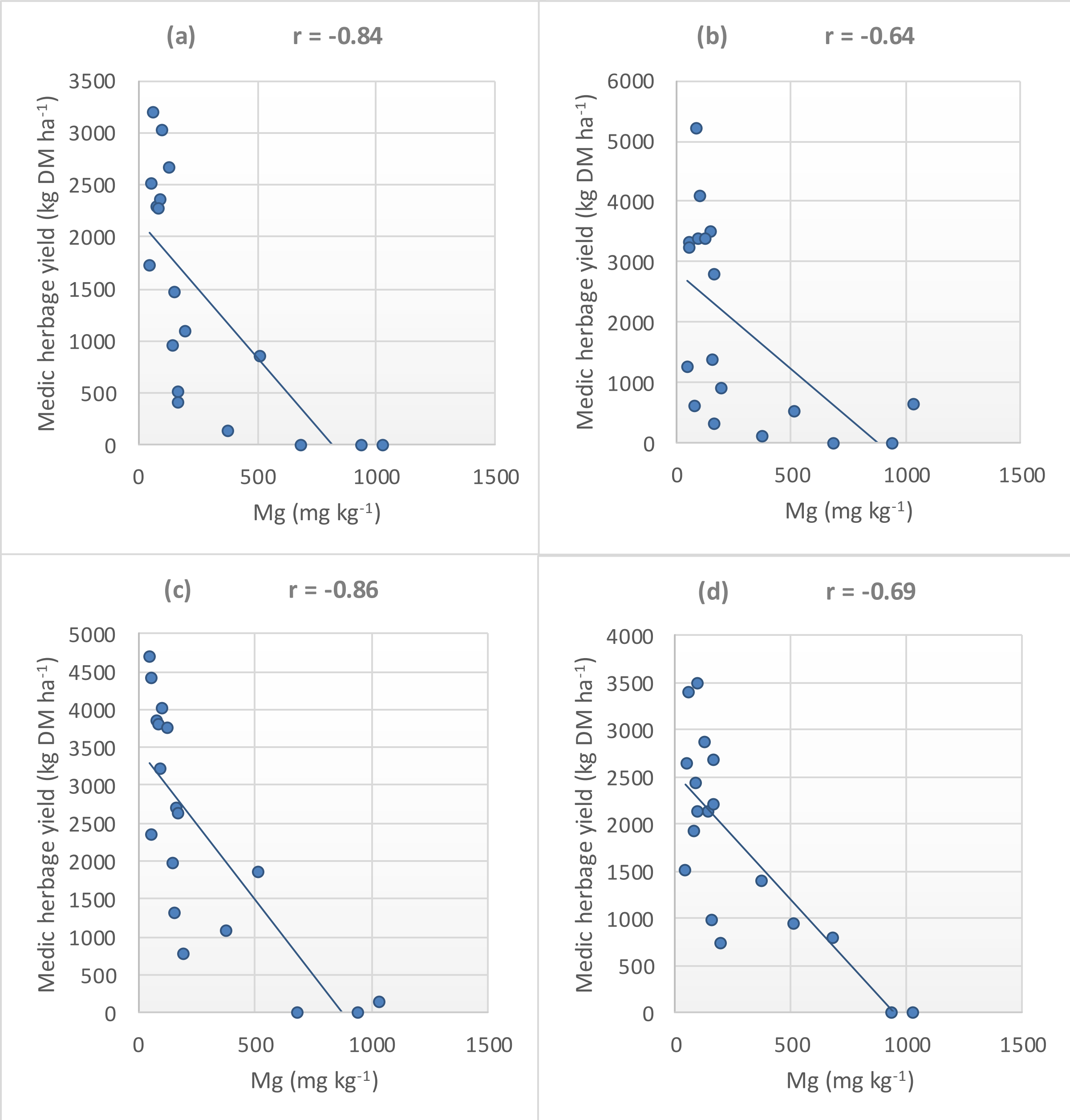

Figure 4.27: The negative linear correlations between Mg and medic herbage yield, for samples (n = 32) collected during the months (a) July, (b) August, (c) September and (d) October 2016, ($P < 0.05$).

The exchangeable Mg content was higher ($P < 0.05$) in the low productivity soils with a value of 882.47 mg kg^{-1}. The medium and high productivity soils did not differ and had 344.85 and 171.61 mg kg^{-1} respectively. The correlation between Mg and medic herbage yield has showed that there was a strong negative relationship between the two. This could be because an excess amount of Mg may lead to deficiency of other essential cations (Gupta 2007). Uptake of Ca, K and occasionally Fe can be limited by relatively high concentrations of Mg (Gupta 2007). Blakemore et al. (1987) stated that Mg should generally be twice the amount of K. However, the Mg content of the low productivity soils at Pringleskraal was at least eleven times higher than K. The Mg content was 882.47 mg kg^{-1} whilst K content was only 195.44 mg kg^{-1}. Perhaps such large differences in the ratio of the nutrients could have also contributed to the low medic productivity at Pringleskraal.

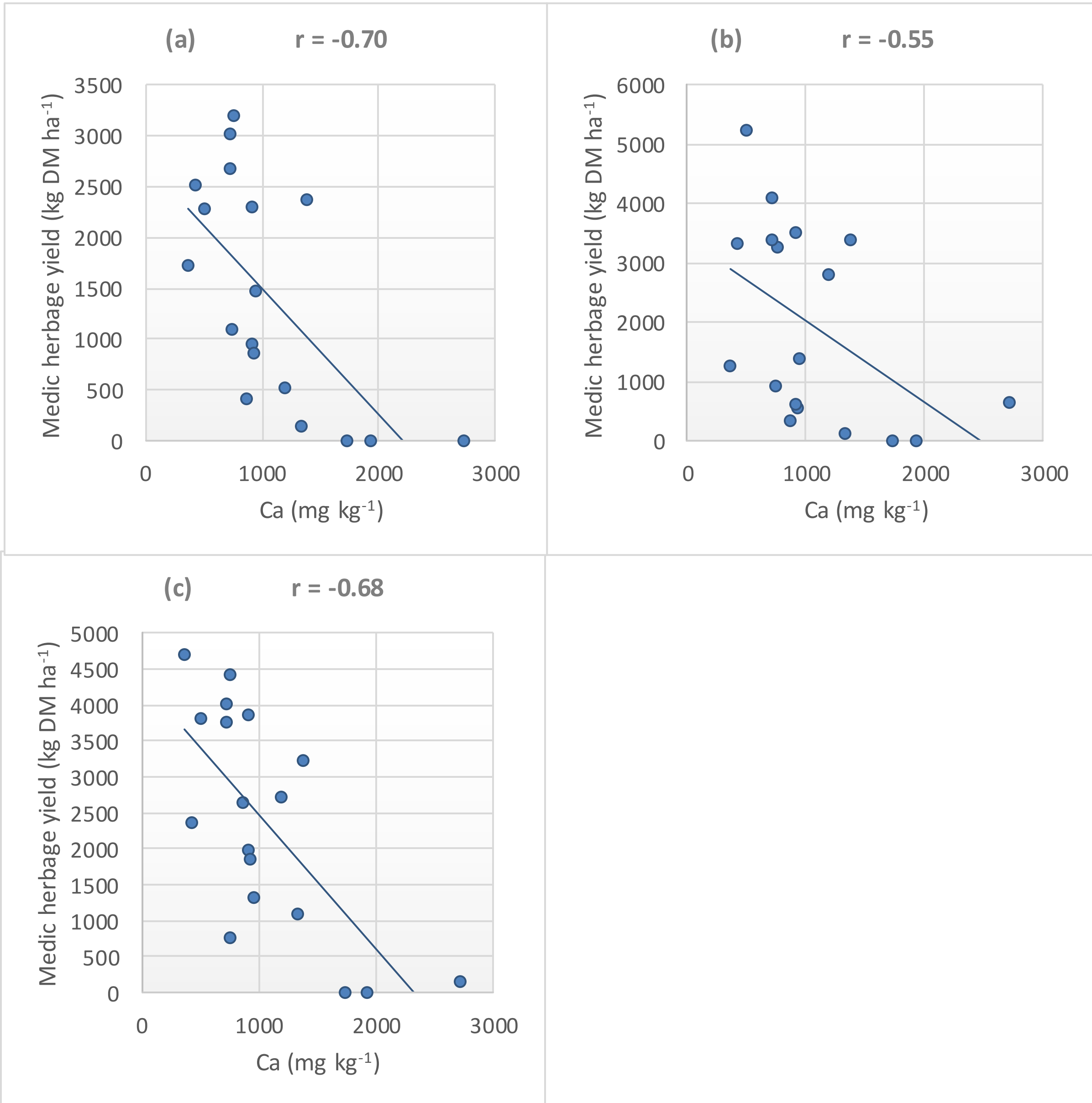

Figure 4.28: The negative linear correlations between Ca and medic herbage yield, for samples (n = 32) collected during the months (a) July, (b) August and (c) September 2016, ($P < 0.05$). There was no relationship between Ca and medic herbage yield for the October 2016 samples.

The coefficient of determination (r) for Ca and medic herbage yield ranged between -0.55 and -0.70 (Figure 4.28) and this means that there was a moderate negative linear relationship between the two variables. An increase in Ca led to a reduction in medic herbage yield. The low productivity soils had the highest Ca content (Table 4.3) and lowest herbage yield. The use of gypsum on saline soils could be reason why there was more Ca in the low productivity soils at Pringleskraal. In most cases, Ca can become limiting if the amount of Mg is very high.

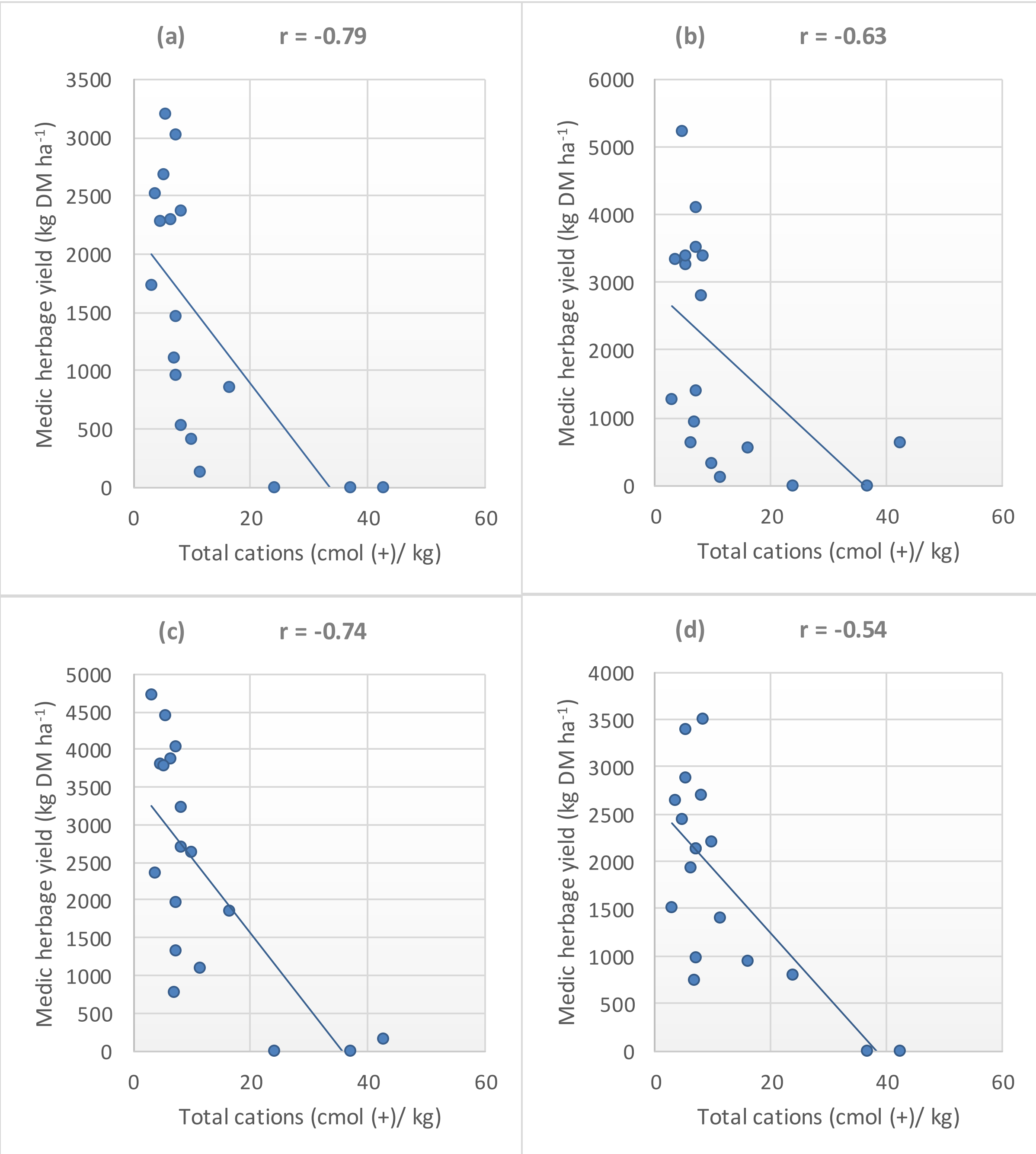

Figure 4.29: The negative linear correlations between total cations and medic herbage yield, for samples (n = 32) collected during the months (a) July, (b) August, (c) September and (d) October 2016, ($P < 0.05$).

The negative correlation between total cation and medic herbage yield contradicts our expected outcome, in which a higher total cation value is indicative of the high fertility status of the soil (Figure 4.22). This shows the limitation of using total cations to interpret soil fertility, especially when Na content becomes high. Furthermore, instead of the exchangeable Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}, the high total cation values may be due to any one of combination of the H^{+}, Al^{3+} or Mn^{2+} cations, hence the low productivity of the soils (Blakemore et al. 1987).

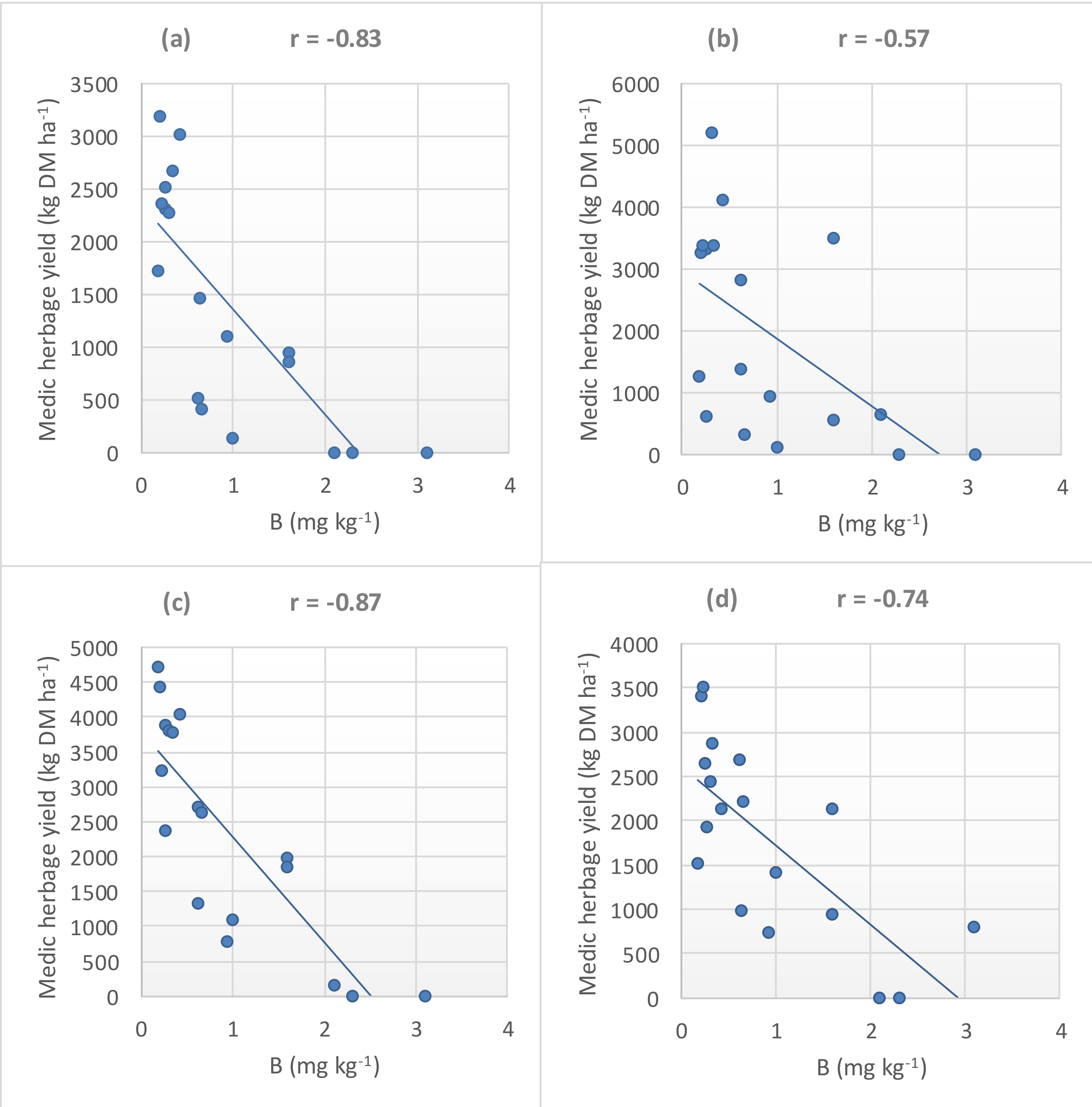

Figure 4.30: The negative linear correlations between B and medic herbage yield, for samples (n = 32) collected during the months (a) July, (b) August, (c) September and (d) October 2016, ($P < 0.05$).

There was a moderately strong negative linear correlation (-0.57 to -0.83) between B and medic herbage yield. Thus, an increase in B content led to a decrease in medic herbage yield, of which the low productivity soils had a high ($P < 0.05$) B content (Table 4.3) and low herbage yield (Figure 4.22). However, the B content was below the toxicity level of 5 mg kg^{-1} (Nable et al. 1997), therefore we would have expected that plant productivity is not limited by B toxicity or deficiency. Perhaps an interaction between B and salinity (Nable 1997; Gupta 2007; Martinez-Ballesta et al. 2008; Mohamed et al. 2015) or other soil quality indicators such as pH could have affected plant productivity. Since the true relationship between B and salinity in not yet known (Mohamed et al. 2015), it is a possibility that the interaction could have caused either a shortage or toxicity of B leading to poor plant productivity.

At Pringleskraal, the moderate negative linear relationship between S and medic herbage yield shows that a higher S content was associated with reduced herbage yield. However, we think that this is a secondary association as it was introduced through gypsum by the farmer as he tried to control soil salinity problems, which is regarded the primary problem. Clarkson et al. (1989) found that a higher S content can increase medic productivity. However, this would be true for soils with sub-optimal S content because at Pringleskraal, lower productivity was in soils that had a higher S content. Evidently gypsum was not effective in reclaiming the salt-affected soil at Pringleskraal. It is also a possibility that the low productivity soils are poorly drained such that the salts and B keep accumulating.

In addition to use of gypsum on the farm to try and alleviate the salinity problems on the low productivity soils. Mulching is also being practiced on some of the low productivity soils with the hope of keeping soil cool to reduce evapotranspiration from the soil. This may lead to reduced rates of translocation of salts from belowground to the plat root zone. With good rainfall, the salts may then be leached away before they surface on top of the soil. The process is very slow and currently, very few or no medic plants grew on the low productivity soils.

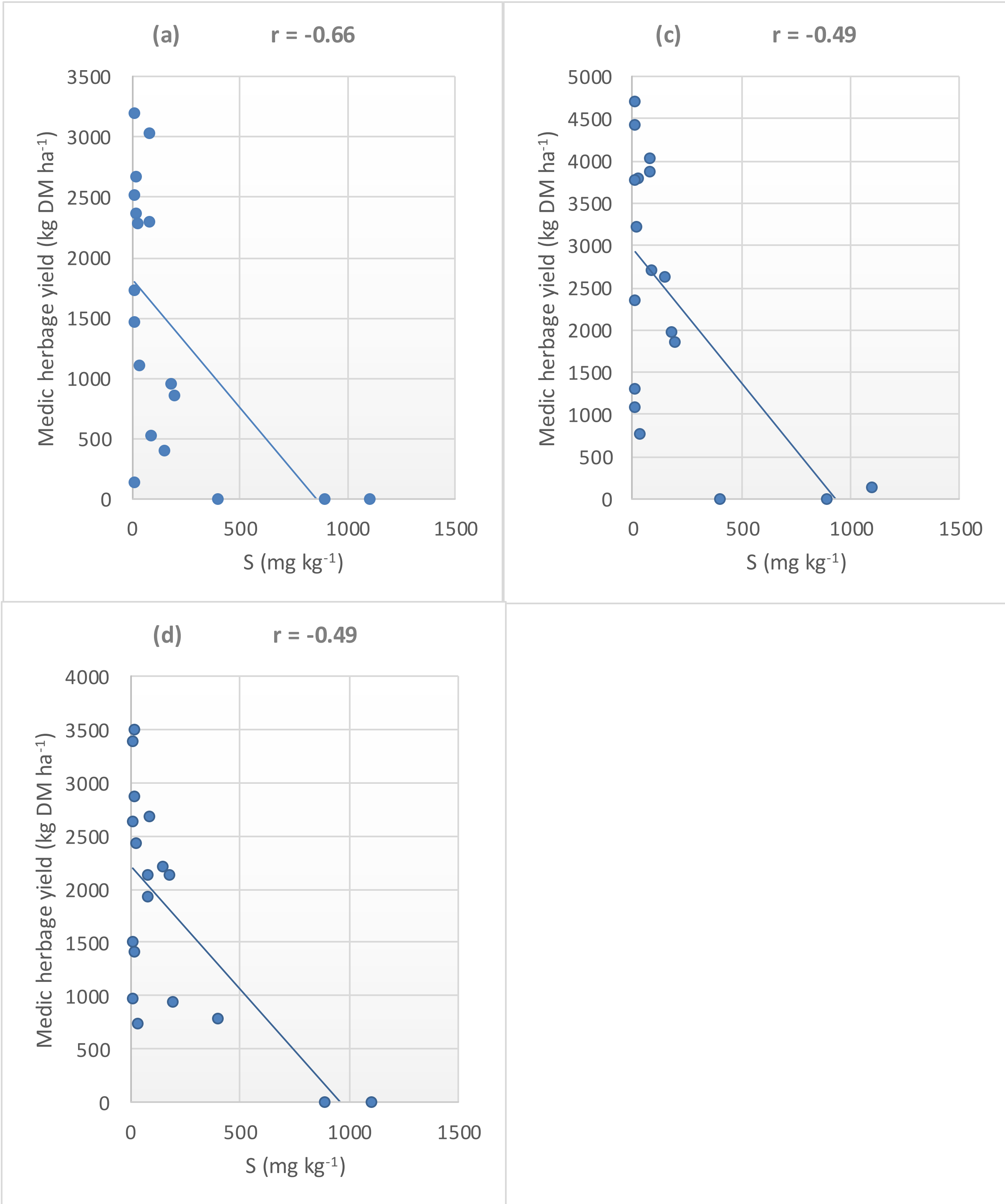

Figure 4.31: The negative linear correlations between S and medic herbage yield, for samples (n = 32) collected during the months (a) July, (c) September and (d) October 2016, ($P < 0.05$). There was no relationship between S and medic herbage yield for the August 2016 samples.

4.4.2 Langgewens

The soil quality indicators at Langgewens was generally higher for the medium and high productivity soils than low productivity soils, but did not differ (P > 0.05) within treatments between months (Figure 4.32). However, the tendencies were not as prominent as for Pringleskraal. In which case, we would expect the medic herbage yield to generally have lower variation between treatments. In July 2016, the low and high productivity soil had similar medic herbage yields (P > 0.05) of 1481 and 2523 kg DM ha^{-1}. The low and medium productivity treatments were different (P < 0.05), but the medium and high treatments were similar. The medium productivity soils had a medic herbage yield of 2837 kg DM ha^{-1}. In August, the medium and high productivity soils had similar medic herbage yields (P > 0.05) of 4197 and 3375 kg DM ha^{-1}. However, these two treatments had higher medic herbage yield (P < 0.05) than the low productivity soils. The medic herbage yield for the low productivity soils was 747 kg DM ha^{-1}. In September, there was no difference (P > 0.05) in medic herbage yield on the low, medium and high productivity soils. The medic herbage yields from low, medium and high productivity soils were 3736, 4088 and 3115 kg DM ha^{-1}, respectively. In October, the medic herbage yield did not differ (P > 0.05) in all the low, medium and high treatments and the yields were 1885, 2655 and 3004 kg DM ha^{-1}, respectively. The medic herbage yield was, however, slightly lower in October than it was in September.

Even though there were yield differences between the medium and low productivity soils in September, the low and high productivity soils were similar. This difference could be explained in terms of stage of sampling time. Some medic seeds only germinated late on some farm sections. August was therefore the only month that had a clear difference in medic herbage yields. The low productivity soils had the lowest (P < 0.05) medic herbage yield and was different (P > 0.05) from the medium and high productivity yields which were similar (P < 0.05) to one another.

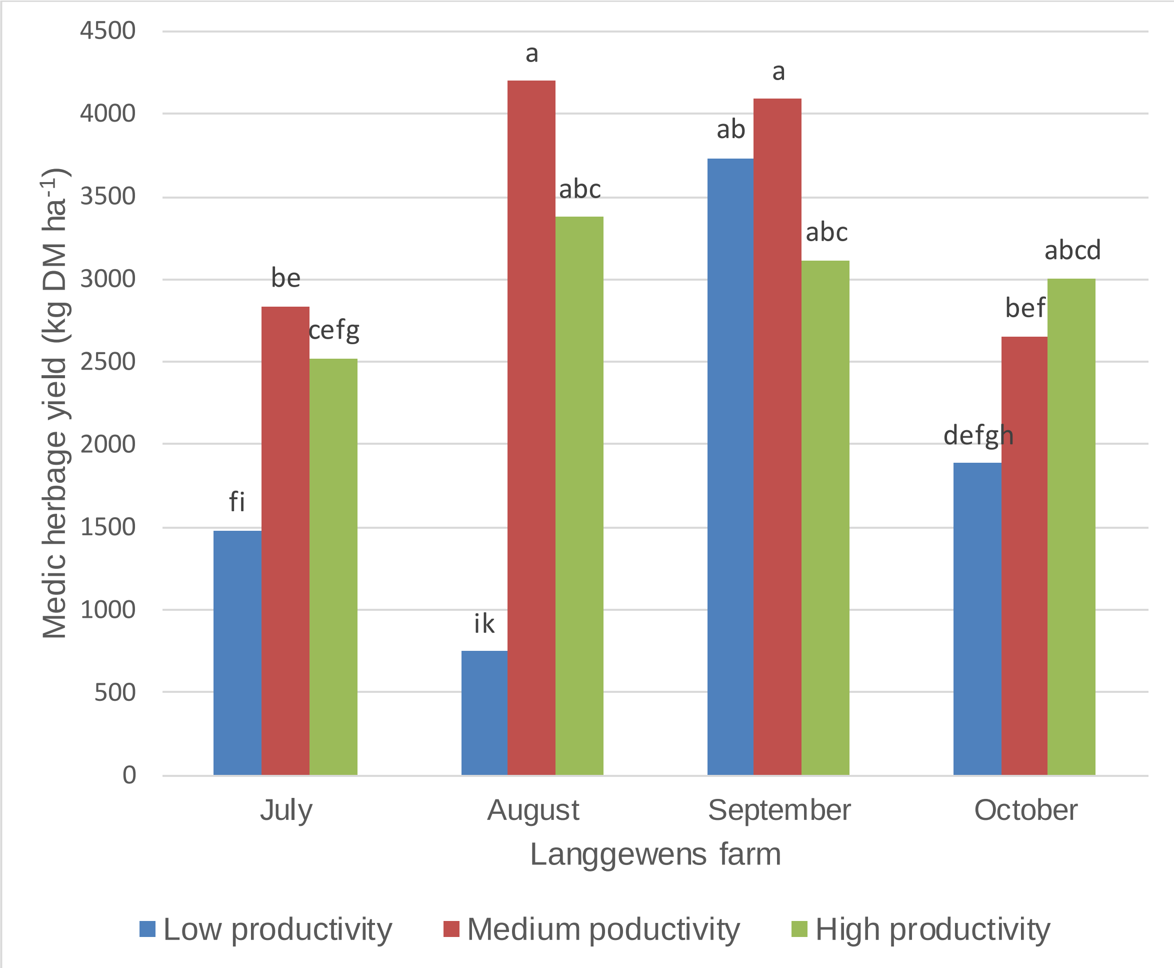

Figure 4.32: Medic herbage yield (kg DM ha^{-1}) per treatment at Langgewens farm for samples (n = 36) sampled in July, August, September and October 2016. Different letters above the vertical bars indicate the treatments with a significant difference ($P < 0.05$).

The recommended guideline for exchangeable Na content in the soil ranges between 160 to 400 mg kg^{-1} (Hazelton and Murphy 2007; Table 4.5), but the medic herbage yield was not affected when the Na content was less than 800 mg kg^{-1}. However, medic seed productivity was much more sensitive to Na content and was negatively affected when the Na content was greater than 80 mg kg^{-1}. Medic seed production was also more sensitive to Na % of cations, SAR and B when compared to herbage yield. Medic seed productivity was negatively affected when Na % of cations, SAR, and B were greater than 8.0%, 0.3 and 1.0 mg kg^{-1} respectively. The ideal SAR should be less than 1.0 (FSSA 2007).

Table 4.5: The critical thresholds for total number of medic seeds (n = 72) and medic herbage yield (n = 72) for samples collected during the 2016 growing season on annual medic pastures on two farms in the Swartland. SAR = Sodium adsorption ratio.

Soil quality indicator	Recommended guideline	Medic herbage yield (<1000kg ha^{-1})	Total number of medic seeds (<2000 seeds m^{-2})
Na (mg kg^{-1})	<160 to 400[Ψ]	<800	<80
Na % of cations	-	<37	<8
SAR	<1.0[†]	<3.0	<0.3
pH (KCl)	5.5[#]	<6.6	*
Mg (mg kg^{-1})	>60 to 80[†]	<512.4	*
Total cations (cmol (+) kg^{-1})	-	<11.38	*
B (mg kg^{-1})	>1.0[#]	<1.6	<1.0

[#]Beyers (1994)

[†]FSSA (2007)

[Ψ]Hazelton and Murphy (2007)

* = Not significant or no clear threshold

Medic herbage yield was negatively affected when Na % of cations and SAR was greater than 37% and 3.0 mg kg^{-1}, respectively. This showed that medics are able to tolerate a Na content which is above the recommended guidelines. However, farmers should constantly monitor soil salinity for optimum productivity. Bogacki et al. (2013) and Clark (2014) stated that medics can grow well in soil with pH (KCl) range of 4.8 to 8. However, medic herbage yield was negatively affected at pH (KCl) greater than 6.6. It would seem plausible then to keep the soil pH (KCl) at the recommended 5.5 (Beyers 1994). The exchangeable Mg content in the soil should be between 60 to 80 mg kg^{-1} (FSSA 2007), but the medic herbage yield was only negatively affected by Mg when its content became greater 512 mg kg^{-1}. The total cation content and B of less than 11.38 $cmol_+$ kg^{-1} and 1.6 mg kg^{-1} did not affect the medic herbage yield.

Chapter 5: Conclusions and recommendations

5.1 Conclusions

This study highlights the severity of dryland salinity and its effects on pasture production. Mitigation strategies by farmers, such as application of gypsum, may also lead to secondary problems and imbalances of nutrients in soil. In this study, soil salinity was problematic at Pringleskraal farm, near Moorreesburg. The low productivity soils at Pringleskraal were permanently brack as was shown by the salinity indicators such as Na, Na % of cations, ER and SAR. The 2015 samples indicated that the low productive soils had a ER of only 80.00 ohm whilst the high productivity soils were 643.33 ohm. Such a low ER in the low productivity soils is indicative of high salt content. The 2016 samples revealed that the low productivity soils were permanently brack as the SAR value was 7.43 which is greater than the suggested SAR value of 1. The high productivity soils had an ideal SAR value of 0.55.

The productivity in the (saline) low productivity soils was very poor ($P < 0.05$) when compared to the medium and high productivity soils. The low productivity soils had the lowest amount ($P < 0.05$) of below and aboveground medic seeds, medic seedlings establishment and medic herbage yield at Pringleskraal. The medium and the high productivity soils had similar ($P > 0.05$) medic herbage yield. The contents of soil salinity indicators (Na, Na % of cations, ER and SAR) were indicative of low soil salinity. The results, thus showed that soil salinity does negatively affect the establishment and regeneration of medic pastures.

Belowground medic seed productivity in 2016 did not differ between treatments, probably due to the fact that at the time of sampling in October, some plants were still green and had not yet dropped their seeds onto the soil. Also, there was minimal soil disturbance to bury the seeds as exclosure cages were erected to prevent grazing or trampling by sheep.

At Langgewens, the soil quality indicators were similar ($P > 0.05$) in the low, medium and high productivity soils treatments (Table 4.3). However, there were some differences ($P < 0.05$) on the medic herbage yield between the low productivity soil and the medium and high productivity soils. This difference was only visible in August 2016 when the low productivity soil had the lowest ($P < 0.05$) herbage yield. There was no difference ($P > 0.05$) on the number of medic seedlings that established or number of belowground medic seeds between low, medium and high productivity soils in May 2016. The number of medic seeds below- and above ground were therefore not directly attributed to soil quality indicators. The results showed that soil salinity was not a major problem at Langgewens.

5.2 Recommendations

Results from the current study suggest that the two different burr medic varieties (Santiago and Cavalier) that are grown mixed on the pastures at Pringleskraal, could not cope with the salinity problems on the low productivity soils. Therefore, the use of salt tolerant grazing crops, particularly legumes such as messina (*Melilotus siculus*), on the saline soils is highly recommended. Messina, is a recently domesticated annual pasture legume with a higher salt tolerance than other legumes and is also highly tolerant to waterlogging. It was recently developed and introduced in Australia and fits well into their crop rotation systems, which are similar to those of the Swartland. Alternatively, it is advisable to plant any palatable salt tolerant forage crops such as the slender wheatgrass (*Elymus trachycaulus*) or the not so palatable tall wheatgrass (*Thinopyrum ponticum*) to control to spreading of salinity.

Most plots at Pringleskraal were infested with weeds which competed with the medics in the highly productive soils. Weed management should be carried out before the weeds become fully established to minimise competition for nutrients between the medics and weeds.

Even though the elevated Ca and S contents of the low productivity soil were negatively correlated to medic herbage yield, they were regarded as secondary effects because they were introduced through gypsum by the farmer as he tried to control salinity problems. Soil salinity was the main problem that affected medic productivity. The use of gypsum to control salinity was not effective. Future research on alternative solutions of controlling salinity should be found as the use of gypsum probably led to increased Ca and S content in the low productivity soils. Evaluation of other practices, such as mulches, to alleviate stress from salinity should also be done. Mulching may keep the soil cool and thus, reduce evapotranspiration from the soil. This may lead to reduced rates of translocation of salts from belowground to the plat root zone. It is therefore assumed that with good rainfall, the salts may be leached away before they surface on top of the soil. The process is very slow but might be a better alternative to use of gypsum, hence need to be evaluated.

The low productivity soils also had high B content. The mechanisms of increased B under saline conditions and its interaction with Na is still poorly understood. Further research need to be done to determine the impact of interaction between salinity and B on medic productivity.

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